

UTILIZATION OF FATTY ACIDS IN SWINE DIETS

EXECUTIVE SUMMARY

Fats and oils are a chemically diverse group of compounds. They have the highest average energy density among all macro nutrients (2.25-3.80x most cereal grains). Besides having high caloric value, some fats and oils like vegetable-based acidulated oils a.k.a. “acid oils” can be a major source of essential fatty acids (Ω -3 and Ω -6), which cannot be synthesized by pigs, as well as fat soluble vitamins (A, D, E and K) and antioxidants, such as phytosterols, tocopherols and carotenoids, which help preserve and stabilize fats. These micronutrients are important for animal health, growth and carcass quality. Moreover, the use of certain types of fats and oils in swine rations, particularly those with high levels of unsaturated fatty acids, can increase the metabolizable energy of the total ration beyond the calculated energy of the diet, boosting feed efficiencies as well as average daily gains by 1-2% for each 1% of fat added to the diet up to a ceiling of 5-6%. This “extra-caloric” effect of the fat comes from the increased utilization of other dietary components.

The main factor affecting the metabolizable energy of fats is their digestibility, which is dependent on the length of the fatty acid carbon chain, the degree of saturation of the fatty acid profile, and the quality/source of the fat. In general, oils of vegetable origin have higher metabolizable energy values than animal fats by equivalent weight, as they contain high amounts of unsaturated fatty acids (U), unlike fats of animal origin, which typically contain high amounts of saturated fatty acids (S). Fats and oils from animal and vegetable sources are often blended to attain a specific U:S ratio, which can increase the digestibility of animal fats, and thus produce a final product with superior metabolizable energy. A U:S ratio of 1.5 or above will help maximize the extra-caloric effect. Adding fats and oils during hot summertime barn conditions can increase energy intake and reduce heat stress. Soy-based oils (vs. tallow or yellow grease) are a favored fat source for improving lean growth rates in young pigs and milk output in lactating sows. While dietary Iodine Values (IV) must be monitored, adding vegetable oils at 3% or less, or at higher levels earlier in the production cycle, is generally not problematic.

The quality of the fat is an important consideration as fats with high moisture, impurities and unsaponifiables (MIU) can decrease digestibility, and thus deliver less metabolizable energy. Hence, when supplementing diets with fats and oils, it is vital to account for the source of the fat, the fatty acid profile, and MIU and extra caloric effects when calculating the metabolizable energy and evaluating the overall metabolic and financials impact of adding fat to the diet. In contrast to oils sourced from restaurants, the high free fatty acid levels found in acidulated oils are not an indication of lipid oxidation, producing rancidity. Thus, FFA specifications of 15% or below for restaurant oils and yellow grease are generally not applicable when utilizing high-quality acid oils that have been stabilized with antioxidants.

Finally, fats and oils can play an important role in creating pelleted products and in mill and barn dust control. Vegetable-based oils are often preferred over animal fats for pelleting and dust control because they have superior handling and performance characteristics. Typically, vegetable-based oils may be used at one-half to one-third of the normal usage rate as compared with animal sources, such as choice white grease. In certain feed applications, acidulated oils may be used in place of other vegetable-based oils, such as crude soy bean oil, and often at a significant price discount.

INTRODUCTION

The purpose of this whitepaper is to better understand the role of supplemental fats and oils in swine nutrition, and in doing so to answer three primary questions for the swine producer, nutritionist, ingredient buyer, production manager, or feed purchasing agent:

- Why add supplemental fats and oils to swine diets?
- How do supplemental fats and oils differ and where do vegetable-based oils and vegetable/animal blends have advantage?
- What are acidulated vegetable oils and why and in which segments of the swine market are they a superior form of supplemental fat and oil?

Rather than presenting the findings of many areas of swine research, which is not practical given the complexity and breadth of the topic, this whitepaper will present general findings and recommendations from university and extension agency researchers, industry practitioners and other leading experts.

Readers are encouraged to review the literature cited in the bibliography for additional, more detailed information on the principles and practices of balancing swine rations using conventional and alternative feed ingredients. Most of these publications are available via the Internet.

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WHY ADD SUPPLEMENTAL FATS OR OILS TO SWINE DIETS?

Diet Composition Drives Animal Health, Growth Rates, Production Costs & Financial Returns

As many who work have worked with fats and oils are undoubtedly aware, an important feature of fats and oils, known collectively as lipids¹, is their versatility. Fats and oils serve a number of important nutritional and non-nutritional functions. They have multiple benefits from optimizing pelleting products, machinery life, feed throughput and formula density; to controlling dust in feed mills and in barns; to the ability to affect nutrient and energy levels, energy density, feed efficiencies and thermo-body regulation; to impacting animal growth rates by influencing average daily growth (ADG) rates, particularly in younger pigs.

Before we get into the specifics of fat/oils as an energy source, it is often helpful to understand the primary components of feed rations, as well as the principal drivers of feed costs which normally account for 60-70% of overall costs of production. Why is this important? Feedstuff selection can often play a major role on operator profitability because most producers, unfortunately, are price takers vs. price makers, and small savings in feed costs, or a corresponding improvement in feed efficiency or average daily gain, can drop to the producer's bottom line, multiplied across each pig in production.

Swine diets must be balanced to contain the necessary nutrients to nourish the animal. Required nutrients include energy, amino acids (from proteins), minerals and vitamins. Recommended swine diets will vary depending on the nutrient requirements for pigs, which in turn will vary according to their stage of production and health, gender and genetic line, lean growth rate, whether they are gestating, producing or consuming milk, and ambient weather and barn conditions.²

When afforded ad libitum ("eat at will") access to feed, pigs in experimental settings will eat until their energy requirements have been satisfied. However, in commercial production most pigs do not enough energy to meet their energy needs for maximum protein deposition and growth. This is one of the reasons why adding fat to the diet in commercial situations can improve growth rates that surpass university study (high intake) conditions (Mike Tokach, KSU, personal communication, Apr 2012).

In addition, fat can be utilized not only to provide energy but fat-soluble vitamins, essential fatty acids, and even molecular signaling substances. Often the amino acid which is the most important limiting factor in grain-soybean meal diets is the amino acid lysine (used in the synthesis of new tissue).³ It is the cereal grains which are used as base feed ingredients because they are low in fiber and high in energy. However, all grains are deficient in protein quantity and quality, as well as minerals and vitamins, so additional ingredients are normally required to balance the ration.

Soybean meal is an excellent source of amino acids, which forms the basis for balancing diets vs. looking to soybean meal simply for its crude protein value. Diet formulation can be a bit tricky when fat is used since its impact is to reduce feed consumption. Lysine requirements need to be increased so that animals obtain the required amounts to allow maximum growth to take place.⁴ For more information on balancing swine diets, please see (van Heugten et al, 2007.)

¹ Lipids are composed of triglycerides (glycerol + fatty acids), water and protein. Fatty acids can be divided into three basic classifications: 1) saturated fatty acids (SFA) – fully hydrogenated with no double bonds; 2) mono-unsaturated (MUFA) fatty acids with one double bond; and 3) polyunsaturated fatty acids (PUFA) with two or more double bonds. The degree of saturation determines the melting point with highly saturated fats having higher melting points than highly unsaturated oils.

² For additional discussion of factors that influence nutrient requirements, please see (DeRouchev et al, 2007a.)

Dietary fats and carbohydrates are the principle sources of long-chain fatty acids for synthesis of SFA and MUFA in pigs through a process called "de novo fatty acid synthesis." Pigs cannot form polyunsaturated fatty acids, such as linoleic acid, so those "essential fatty acids" must be supplied via the diet.

As a rule of thumb, each 5 lb of fat should be combined with 2 lb of soybean meal to meet amino acid requirements. This blend can then be substituted for 7 lb of corn (Per G. Cromwell, Prof. Swine Nutrition).

Energy, Protein & Phosphorus – The Big Three Cost Drivers

With the rise of the bio-economy and ethanol production, today the three most expensive items in swine diets are, typically, in order of total cost: energy, protein (essential amino acids), and available phosphorus (Harper et al, 2004.) Energy must be supplied in the largest quantity and usually represents the lion's share of the overall cost of the ration – often more than 75%.

The energy value of ingredients is of particular importance because dietary levels must be adequate to meet growth, reproduction and milk production goals across a range of animal needs. Cereal grains, such as corn, sorghum, wheat, barley, are normally the primary energy-contributing ingredients for swine diets. The following hypothetical budget presented at the Iowa Pork Congress in January 2012 by Dr. John Patience, ISU, illustrates how much of each dollar must go to purchasing energy, protein/amino acids, and supplemental ingredients, such as vitamins and minerals.

Table 1. Relative Cost of Energy, Proteins/Amino Acids, and Minerals/Vitamins in Sample Swine Diet

INGREDIENT, %	PRICE \$/TON	ENERGY ONLY	ADD PROTEIN/AMINO ACIDS	ADD MINERALS/ VITAMINS
Corn	220	54.93%	47.65%	47.01%
Corn DDGS	190	30.00	25.58	27.68
Wheat midds	200	7.60	5.50	-
Soybean meal	300	-	13.50	14.19
Bakery product	230	7.50	7.50	7.50
L-Lysine HCl	2500	-	0.30	0.30
Limestone	50	-	-	1.10
Salt	90	-	-	0.45
Vitamin premix	1750	-	-	0.15
Trace mineral premix	1000	-	-	0.12
Phytase	5000	-	-	0.08
AV-blend	900	-	-	1.16
Total Cost/blended ton	-	\$210.24	\$229.58	\$244.00
Percentage of Total Diet Cost		86.2%	94.1%	100.0%

Source: Dr. John Patience, ISU

In this example, energy accounts for 86% of the cost of the diet, with added protein and amino acids adding an additional 8% to the cost, and minerals and vitamins accounting for the remaining 6% of cost. Of course, there are other ways to construct nutritionally balanced diets, but the key drivers of cost will largely remain the same unless newer lower cost sources of energy can be found. For those with interest, relative feeding values and maximum usage rates for a variety of energy sources is discussed in more detail by Reese (2000) with an emphasis on understanding the relative cost of the base energy source per unit of ME delivered.

To help further illustrate the current energy cost situation, the following data in Table 2 also presented by Dr. John Patience, ISU, at the Iowa Pork Congress (January 2012) shows the variation in unit energy costs by feedstuff. When corn was \$2.50/bushel, one mega calorie (ME) of energy cost 2.9 cents. As of February 2012, it is over 7.1 cents per ME. Notice (NE) or net available energy can influence unit costs for energy on as “as utilized” basis. As discussed later, the physical or “metabolic cost” of producing energy (i.e., generating excess body heat) may become a factor during hot summer months if animal stress from heat exhaustion and poor feed intake are worries.

Table 2. Unit Measures and Costs for Energy, by Feedstuff

INGREDIENT	COST, \$/TON	ME, MCAL/LB	NE, MCAL/LB	COST, ¢/MCAL ME	COST, ¢/MCAL NE
Corn DDGS	190	1.52	1.08	6.3	8.8
Bakery by-product	230	1.68	1.35	6.8	8.5
Corn	22	1.55	1.20	7.1	9.2
Wheat middlings	200	1.38	0.99	7.2	10.1
Soybean meal	300	1.52	0.89	9.9	16.9
AV blend	900	3.72	3.35	12.1	13.4

Source: Dr. John Patience, ISU

Supplemental Fats & Oils Increase Energy Density – Important For Certain Production Segments & Environmental Conditions

As Harper (2005) notes cereal grains vary not only in metabolizable energy (ME), but in fiber, crude protein, lysine, and available phosphorus.⁵ Feeds with higher fiber levels generally will contain less ME for swine and thus have lower relative value for diet formulation. Moreover, some feeds may be limited in their overall use because of one or more negative impacts on the animal as usage is increased.

Therefore, supplemental fats/oils can be used to provide more flexibility in preparing conventional or alternative feedstuffs that may vary in fiber, protein and energy content while meeting basic energy requirements. Fat may be added, for example, to increase the energy density in grow-finish pigs with low feed intakes (perhaps during hot weather), or high-producing lactating sows that are otherwise energy constrained. Typically, fats and oils contain about 2.25 times the energy of cereal grains.

The upper limit for supplemental fat is normally about 5-6% of the diet because higher levels can make finished feeds more difficult to handle, and in certain situations result in bridging of feeders and caking of mixers. Diets containing fats may also become rancid during prolonged storage, or when exposed to high temperatures so utilizing preservative-based fats is important to minimize these risks. See Harper (2003) for more information.

Fats and Oils – Their Role in Improving Feed Efficiency & Average Daily Gain

Fats and oils can also improve the overall feed efficiency of the ration, as well as how well (and quickly) the animal metabolizes the entire ration of DDGs, corn, soybean meal, or other cereals and grain by-products into body mass live weight gain, though more recently carcass weight and lean meat content are what increasing drive the interests of producers and packing companies.

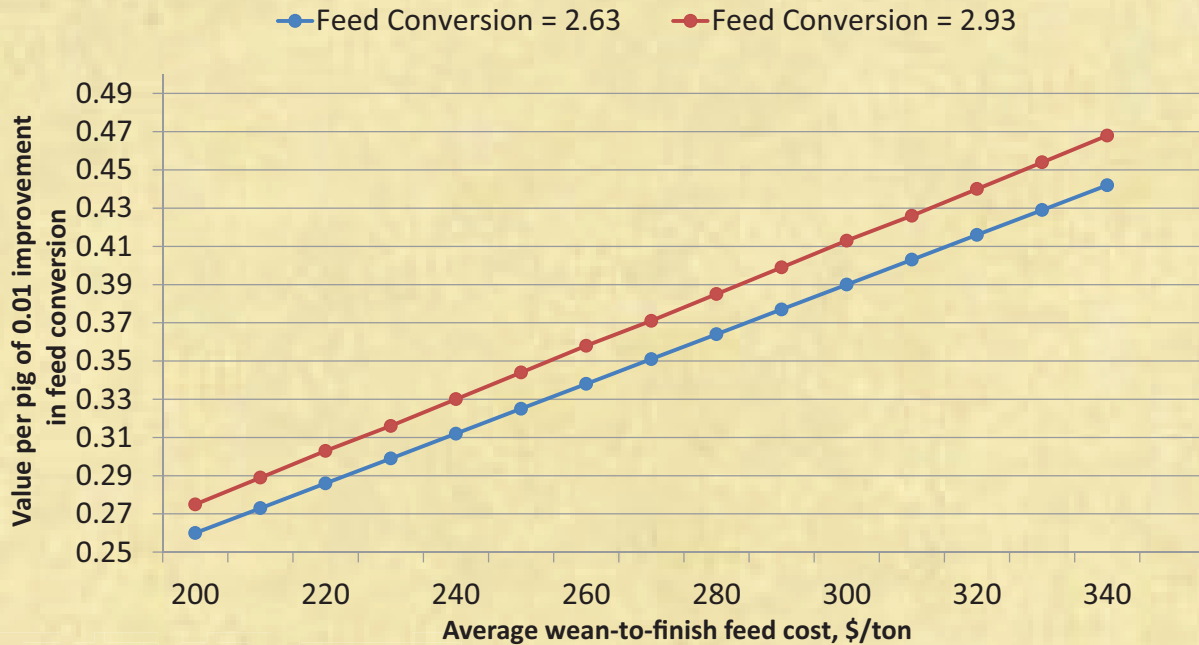
Research indicates that adding 3% to 5% fat or oil to growing-finishing swine diets will improve feed conversion and often average daily gain. According to Kansas State University, for each 1% of added fat in grower-finishing pigs, feed efficiency is usually improved 1.8%. Meanwhile, average daily gain is reported to increase approximately 2% in grower diets and 1% in late finisher diets for each 1% of added fat. See (DeRouchey, 2007a and Shannon, no date).

Therefore, diets with greater energy concentration, such as those with supplemental fat, may be fed in smaller quantities than diets with lower energy concentration. The results can be improved feed efficiencies and faster growth, assuming that other key nutrients in the ration are met.⁶ The following graph presented by Dr. John Patience, ISU, at the January 2012 Iowa Pork Congress, illustrates just how important feed conversion can be to the cost of a diet.

⁵ Metabolizable energy (ME) represents total energy minus energy lost via feces and urine. Net energy (NE) is defined as the amount of energy in the feed minus energy lost via feces, urine and the heat produced through digestive and metabolic processes (heat increment). Typically, high protein feeds have lower NE content. For example soybean meal has a similar ME as corn, but only 84% of corn on a NE basis. Thus, NE can be an important factor in constructing and evaluating feed rations. (See DeRouchey et al., 2007a.)

⁶ Unfortunately, carcass backfat is increased in pigs fed fat-supplemented diets. Typically, a 5% addition of fat to the diet will increase backfat by about 0.1 inch. While overall carcass muscling does not appear to be negatively affected, slightly more fat in the carcass means proportionately less lean carcass according to G. Cromwell, Prof. Swine Nutrition. Because many processors are decreasing their payments for lean carcass, any increase in backfat will be less of a concern.

HOW IMPORTANT IS FEED CONVERSION?



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Based on today's average wean-to-finish feed costs, each feed conversion point is worth 30 to 32 cents per pig. And with increasing input costs for feed, these costs will only continue to escalate – feed conversion will play an even more important role over time in determining operational efficiencies and overall operator profitability.

Supplemental fats and oils can play an especially important role in certain areas of swine production. As nutritionists will often caution, in higher fiber diets energy dilution is of particular concern for pigs weighing less than 80 lb and for most lactating sows. This is because the gastrointestinal capacity of these categories of animal can reach capacity before energy needs are satisfied (Reese et al., 2000). Meanwhile, Kansas State reports fats and oils can be added at 3 to 5% in lactation diets to improve milk production and nursery pig growth rates. Furthermore, fats and oils are sometimes added to gestation diets for dust control.

How does one estimate the economic benefit of using supplemental fats and oils for replacement energy? There are several approaches, but perhaps the most straightforward entails evaluating the cost of feed per unit of weight gain. When an improvement in feed efficiency is demonstrated, one can use that percentage increase to estimate the economic benefit. For example, if feed without supplemental fat/oil costs \$100/ton, the producer can afford to pay \$102/ton for feed with supplemental fat assuming it delivers at least a 2% gain in feed efficiency, and there is no attributed benefit from improved daily weight gain.

If a faster animal growth rate is valuable to the operation, that benefit (daily weight gain) should also be quantified. A more accurate way of measuring this financial benefit – in addition to an improvement in feed efficiency – can be derived by looking at the producer's resulting revenue (and margin) over feed and holding costs for the period of time in question. In other words, does the producer increase the total return by accelerating average daily growth rates and enabling a shorter production cycle?

There are essentially two areas of additional consideration in doing this kind of cost-benefit analysis: First, is the cost of housing and maintaining that animal over a longer time period (including maintenance energy requirements of the animal) if the producer is not subject to a time constraint. And second, for operations with time constraints, valuing either the additional revenue gain resulting from the higher performance diet over the defined time period, or the lost revenues resulting from delivering an underweight animal to market.

For a helpful discussion, including sample calculations related to this topic, please see (DeRouche et al., 2007a,b). The key financial principle to keep in mind with swine production, as in other areas of business finance, is the concept of the time value of money. How quickly the animal grows may be an important factor in evaluating overall profitability of the operation that may not otherwise be recognized simply looking at the costing of feed, or evaluating feed efficiencies (ie. feed cost per unit of gain). High quality supplemental fats/oils typically improve average daily gain by 1% for each 1% of added fat up to 3-5% of the diet. Producers need to decide whether such growth benefits are useful and economical to aspects of the operation, particularly during hot summer months.⁷

Fats & Oils -- Palatability, Dust Control, Binding Agent, Lubricating Properties

Before concluding this part of the discussion, there are a number of additional benefits to fats and oils that should be noted. Fats/oils, such as soybean oil in starter pig diets, can improve diet "taste" or palatability of feed rations (Thaler et al, 1986). Plus, fats/oils serve as a natural dust control agent to reduce dust in feed mills and in animal production barns, the primary source of the dust being the feed (Curtis et al., 1975; Heber et al., 1988). Airborne dust irritates lung tissue and dust can carry microorganisms and/or serve as host sites for bacteria forming colonies that can inflame and damage lung tissue. Research has shown that the lungs of pigs fed fat in their feed have fewer lesions than lungs of control pigs (Chiba et al, 1985). Lower dust levels have positive health implications for both pigs and management personnel (Reese et al, 2000).

Kansas State reports a reduction in the amount of dust (and corresponding improvement in air quality) will be evident even with 1 to 2% (20-40lb/ton) of added fat in the diet (Gore et al., 1986; Wilson et al., 1993). Feed mills have experienced similar results. Gore found that adding 5% soybean oil to starter diets reduced dust levels by 45 to 47%. Meanwhile, (Mankel et al., 1995) determined that soybean oil is more effective as a dust control agent when added to a complete feed after grinding vs. adding to corn before grinding. Using soy oil at 1% and 3% concentrations in a corn-soybean meal ration reduced dust by 88% and 97%, respectively ($P < .001$) compared to the control. The study also determined that storage didn't negatively affect soy oil's dust suppressing effects.

Another benefit of fats and oils is that they can serve as lubricating agents for pelleted products, reducing wear and tear and increasing throughput. For example, fats and oils are often added to starting pig diets to aid in the manufacture of pelleted, milk product based-diets. If diets with high levels of milk products are pelleted without sufficient fat to lubricate the die, the diets can be burned with the result being amino acids become unavailable to the pig causing intestinal problems including diarrhea.

The physical form of feed can play a significant role in pig health and performance. Diet particle and pellet size and quality can have a measurable impact on improvements in growth rates and rates of feed conversion (Giesemann et al. 1990; Cabrera et al, 1994; Healy et al., 1994). In general, for every 100 microns in particle size above 600 microns, the feed: gain ratio is negatively increased by 1.3% (Wondra et al, 1995).

Additional Performance Benefits – Added Micronutrients, Plus Aid to Digestion and Absorption

In still another area of nutrition performance, fats and oils have been shown to play a role in nutrient uptake from other components in the diet. The fat and oil provide essential fatty acids which are required for the formation of micelles in the duodenum. Micelles not only facilitate fatty acid and amino acid uptake, but are also required to facilitate absorption of fat-soluble vitamins including A, D, E and K. Two essential fatty acids, linoleic and alpha linolenic acid, which cannot be synthesized by pigs, must instead be ingested to prevent disease responses from a deficiency.

⁷ Reese reports: "In growing-finishing pigs, fat consistently improves feed efficiency. On average, feed efficiency is improved by 2% for each 1% increment of added fat. Feed efficiency and daily gain are improved more by feeding fat to pigs during the summer than the winter. For example, daily gain may be increased by 1% for each 1% addition of fat in the summer, whereas little, if any, improvement in gain is expected in the winter. Carcass fat content is not greatly altered unless added fat levels exceed 5% of the diet and the amino acid: calorie ratio in the diet is not maintained constant. Energy intake is a major factor limiting lean growth rate in pigs weighing less than about 130lb. Fat additions to grain-soybean meal diets may increase energy intake, especially in hot weather, and improve lean growth rate in young pigs. On the other hand, added fat is less valuable in finishing pigs, because energy intake from grain-soybean diets is often sufficient to maximize lean growth rate." (Duane E. Reese et al., 2000).

Research has shown that fats and oils can improve apparent ileal digestibility of amino acids in diets containing corn, soybean meal and DDGs. For example, Albin et al. (2001) found high levels of soybean oil and palm oil (10-20%) in a purified swine diet increased the apparent ileal digestibility (AID) of certain amino acids. More recently, Kil and Stein (2011) reported that the addition of soybean oil (SBO) or choice white grease (CWG) at rates of 5% to simulated commercial swine diets improved the apparent ileal digestibility (AID) of amino acids (AA). This work built on earlier work (Li and Sauer, 1994; Cervantes-Pahm and Stein, 2008) with respect to soybean meal by studying the impacts of adding DDGs in a commercial-type situation.

The authors noted the previously reported hypotheses for the improvement in the AID of AA: This includes slower gastric emptying (Low et al., 1985), decreased passage rate of digesta (Valaja and Siljander-Rasi, 2001), and improved digestibility of DM (Kim et al. 2007). The authors noted SBO and CWG performed comparably and with the addition of plant or animal fat, reduced use of additional AA could be considered. Further research on standardized ileal digestibility (SID) of AA is warranted.

HOW DO FATS & OILS DIFFER?

Where Do Supplemental Fats & Oils have Maximum Effectiveness?

Animal fats, such as lard, choice white grease and beef tallow, and plant oils like corn, coconut, palm and soybean oil contain about 2.25 – 3.80 times as much metabolizable energy as many cereal grains. They also supply a range of fatty acids, including lineoleic and lineolenic fatty acids, found in vegetable oils like sunflower and soy that can be important to animal health, growth development, and influence carcass quality. In general, the chemical makeup of supplemental fats and oils has an important effect on their digestibility, dietary energy value, associated health benefits, and overall cost effectiveness, as will be discussed below. Some feed manufacturers use fat and oil in specialty diets as an energy source, and others more broadly for dust control and its lubricating properties in pelleting. The addition of even 1 to 2% fat in the diet will reduce dust formation, and wear and tear on machinery (Ensminger et al. 1990).

Meanwhile, research has shown that the addition of 1 to 5% fat in grow-finish swine diets can improve feed conversion and average daily gain (Coffey et al, 1982). Animal fats, such as beef tallow and lard are often less expensive than vegetable oils on a per pound basis, yet simply comparing fats and oils on a price per pound basis can be misleading. Pigs have been shown to perform better on diets containing soybean oil, choice white grease or coconut oil than on diets containing tallow (Turlington, 1989). Dietary fat absorption also depends on the fatty acid profile present in the diet (Renner and Hill, 1961). Cera et al. (1990) indicated that digestibility of tallow was improved when it was mixed with soybean oil, and suggested that the increased digestibility of tallow might result from factors including the presence of high polyunsaturated fatty acids (PUFA) and phospholipids in the soybean oil. So, the ratio of unsaturated to saturated fatty acids in the fat source and the larger diet can be an important consideration.

Research has also indicated that carcass characteristics can be affected by the type of dietary fat fed to the animal. High levels of unsaturated vegetable oils can result in soft fat pork as will be discussed in more detail below. But the severity of the softness depends on many factors including the quantity and duration of feeding of the unsaturated oils, the source and production processes used to derive the oil, the quality of the oil, the makeup of the overall diet, and whether the amino acid to calorie ratio is maintained. Producer attempts to alter fat quality or the fatty acid profile of adipose and lean tissue (for example incorporating more linoleic acid) must consider both dietary energy content and dietary fat source (Bee et al., 2002). Bee found growth performance and carcass characteristics to be impacted by dietary energy level ($P < 0.01$) but not by fat source (5% tallow or soy oil added to the diet).

In addition to the degree of saturation, other fat characteristics that may have an impact on digestibility and energy value include the chain length of the constituent fatty acids (shorter chained fatty acids are more easily digested but contain less energy), the content and type of free fatty acids, and the concentration of contaminants, such as oxidized polymers found in restaurant grease (Wiseman, J). Animal genotype may also play a critical factor in fat performance. Eggert found genotype played a more significant role in pork quality and carcass composition (ie. belly firmness) than dietary source of fat when studying grow-finish gilts response to soy oil and beef tallow at weights of 100 lb to market (Eggert et al, 1998).

In summary, the suitability of a particular fat or oil for a particular feed application may depend on a number of considerations including the other constituents in the feed, the age of the animal and the maturity of its digestive tract, whether it's gestating, lactating, entering early post-weaning, its genotype, and of course, external environmental factors, like temperature and available space. All fats and oils are not created equal. Some fats and oils work better in certain situations than others and one may want to consider factors in addition to price by weight to determine the best fat solution.

Supplemental Animal Fats and Vegetable Oils – Saturation Characteristics

Animal derived fats and soybean oil are the most common fat sources used in pig diets. Fats and oils come from a wide variety of plant and animal sources, but in the Midwest animal fats generally include tallow, choice white grease and yellow (restaurant) grease. These types of fats are rich in saturated fatty acids (SFA) and monounsaturated fatty acids (MUFA). Animal fats are often solid at room temperature and must be heated to 140-150F before blending into feed rations.

Animal fats are typically at least one-third saturated, but rarely make up more than 50% saturated fats as often believed. For example, beef tallow, the most saturated animal fat, is about 50% saturated and 50% unsaturated fat. Mutton fat, pork lard, and poultry fat are approximately, 45%, 40%, and 30% saturated fats, respectively (J. Wiseman, no date). Also, choice white grease, which is derived from pork fat, is increasing in levels of unsaturated fats as the use of DDGs in swine diets has increased. In contrast, fish oils are extremely unsaturated with long carbon chains (LC-PUFA).

More common types of plant oils here in the Midwest include soy, corn, and sunflower oils, which have high levels of polyunsaturated fats (PUFA), 84%, 86% and 89%, respectively, as well as high levels of linoleic acid (Omega 6). There is also rapeseed or canola oils, which are highly unsaturated (92%), and high in Oleic acid. Linseed oil is also highly unsaturated and high in linolenic acid. In contrast, palm oil is more characteristically high in saturated fats (SFA) with palmitic acid. Palm kernel and coconut oils are also high in SFA, including lauric and myristic acid. Vegetable oils are liquid at room temperature and can be added to the diet without heating except during cold weather conditions. In general, oils are preferred over animal fat in diets for baby pigs (weighing less than 15lb).

From a nutritional standpoint, nutritionists refer to the ratio of unsaturated to saturated fatty acids (U/S). This is an important factor because it is believed that unsaturated fats assist in the increase of micelle formation from saturated fatty acids (Carson and Bayley, 1968; Freeman et al, 1968; Jorgensen et al, 1992).⁸ Digestibility often moves from 85 to 92% when the ratio is more than 1.5 (60% U), and begins to decrease when it drops below 1.3 (56% U) (Stahly, 1984). In addition, the importance of the ratio may be more pronounced for young pigs (higher=better) than old because of the former's immature digestive systems (Powles et al, 1995).

Nutritive Value, Fatty Acid Profile, Moisture, Impurities

Depending of the type and source of the fat or oil, the lipid can vary in nutritive value (dietary, metabolic and, net energy content), fatty acid makeup, moisture, impurities and other characteristics. Waste cooking oils (yellow grease) may be utilized in swine diets but should be checked for quality. For example, high levels of free fatty acids in these types of oils, an indicator of oxidation from past heating, can impair feed intake and corrode equipment. Sulfur from cooked foods found in restaurant derived oils may also be an issue.

Fat sources should be analyzed for moisture, impurities, and unsaponifiable material (sum=MIU), plus total and free fatty acids. Kansas State recommends that moisture should not exceed 1%, impurities 0.5%, and unsaponifiable materials 1% for a total MIU < 2.5%. Total fatty acids should be at least 90% and free fatty acids [from restaurant sources] should not exceed 15%.⁹ Initial peroxide value, which provides an indication of rancidity potential, should be below 5 meq (milliequivalents).

Despite perceptions among some producers, all fats and oils are not created equal, particularly when it comes to providing energy for two of the most sensitive swine populations, lactating sows and starter pigs. Kansas State puts it succinctly: "research has shown that not all fat sources give similar improvements in pig performance, especially for baby pigs. This may be a result of the fat source's fatty acid profile or impurities from the rendering process. In general, fat sources such as soybean oil and choice white grease are considered higher quality than tallow and yellow grease." (DeRouchev et al, 2007a.)

Hence, proper diet formulation starts with an assessment of the nutritional requirements of the pigs being fed. Pig genotype and classification have a major bearing on nutritional needs. For more information on the role of supplemental fats and soy oils in particular types of swine diets, such as sow diets, gestation and lactation, breeder boar, and weanling and nursery pig-phased starter diets see: (Harper et al., 2004).

⁸ Micelles are ball-like structures, small aggregates of mixed lipids and bile acids. They are comprised of water loving "polar heads" and water hating "polar tails," with the tails of the structure, generally, pointing to the center. Bile salts formed in the liver and secreted by the gall bladder emulsify fats and break them into smaller particles. Pancreatic lipase then breaks the tri-glycerides into fatty acids and mono-glycerides. This allows for the formation of fatty acid containing micelles in the small intestine, permitting the absorption of complicated lipids (e.g., lecithin) and lipid soluble vitamins (A, D, E and K) into enterocytes in the small intestine.

⁹ While Powles (1995) concluded that digestibility of fat is linearly reduced with increasing levels of free fatty acids, DeRouchev et al (2004) found that FFA concentrations of at least 53% in oxidized CWG using lipase did not adversely impact fat utilization in nursery pigs; therefore the source of the FFA and the presence of other insoluble or unsaponifiables may play an important factor in the oil's digestibility.

Soft Fats – IV Values & Carcass/Product Quality

The degree of fat saturation has received increasing levels of scrutiny with the introduction of higher levels of distillers' dried grains (DDG) in many swine diets (>20%) and corresponding problems in the processing of pigs with "soft bellies." While most swine can be fed diets with at least 20% DDGs and sometimes greater without violating processor desired carcass firmness measures, there is an upside limitation due to higher fiber and unsaturated fat levels, though levels of digestible phosphorus are superior to corn.¹⁰

Part of the soft fat issue is due to the fact that pigs deposit carcass fat in a similar fatty acid profile to the dietary fat they consume, and consuming higher levels of unsaturated fats can inhibit endogenous synthesis of SFA and MUFA which can contribute to carcass fat firmness (Pettigrew and Esnaola, 2001). And when compared with traditional corn, DDGs with 10% corn oil deliver three times the amount of unsaturated corn oil and protein on an equal weight basis – without the starch, which is primary used for metabolic energy.¹¹ Consequently, diets which rely on a high percentage of energy in the form of unsaturated fats can influence carcass fat composition and contribute to what is known in the industry as "soft fat" pork. Dietary influences on fat composition have been studied by many in recent years (Averette Gatlin et al., 2002; Benz, 2008; Apple et al. 2009).

Soft pork causes issues because bellies become difficult to slice for bacon; it also leads to increased incidence of fat "smear" and fat separation in the cuts of meat, as well as problems with product appearance when packaged (yellowing, wet, oily appearance) and reduced shelf life (unsaturated fatty acids are more prone to lipid oxidation). Product appearance and performance is an especially important factor in Asian markets like Japan which desire rich color and hard fat composition. Iodine value is the most common test used to measure the degree of fat saturation, with higher levels indicating greater levels of unsaturated (softer) fat. It is important to keep in mind that the location of the fat depot selected for analysis can influence reported values. Iodine value can be calculated from a fatty acid analysis as described in the Official Methods and Recommended Practices of the AOCS, 1998.

As detailed in Table 3 below from NRC 1998, Nutrient Requirements for Swine, Iodine Values increase with the degree of unsaturation. In general, when delivering swine to market, packer industry guidelines may call for IV levels at the jowl typically between 72 to 74, though some set lower tolerances. Others measure iodine value on belly fat, as the strength of the correlation between IV values and pork belly attributes is still being debated in the industry and among researchers. See Guthrie and Rozeboom (2011).

Table 3. Characteristics and Energy Values of Various Sources of Fats & Oils (data on as-fed basis).

TYPE OF LIPID	TOTAL SATURATED	TOTAL UNSATURATED	IODINE VALUE	Energy Content (kcal/lb)		
				DE	ME	NE
Animal Fats						
Beef tallow	52.1	47.9	44	3,628	3,483	2,234
Choice white grease	40.8	59.2	60	3,760	3,608	2,311
Lard	41.1	58.9	64	3,757	3,605	2,313
Poultry fat	31.2	68.8	78	3,864	3,710	2,372
Fish oil, menhaden	33.3	66.7	—	3,844	3,689	2,358
Vegetable Oils						
Canola (Rapeseed)	7.4	92.6	118	3,973	3,814	2,433
Corn	13.3	86.7	125	3,971	3,812	2,426
Cotton Seed	27.1	72.9	105	3,902	3,746	2,392
Peanut	17.8	82.2	92	3,961	3,803	2,426
Soybean	15.1	84.9	130	3,968	3,810	2,431
Sunflower	10.6	89.4	133	3,973	3,814	2,433

*From NRC 1998, Nutrient Requirements for Swine

¹⁰ Cromwell et al, 2011 studied DDGs inclusion rates of 13 and 22 percent in grow-finish pigs (72-266 lb) and impacts on IV values for backfat (70 and 74, respectively). See summary in Guthrie and Rozeboom (2011) for additional DDGs study results, including withdrawal regimes. See also Stein and Shurson (2009)

¹¹ The absence of carbohydrates (starch from the corn) may also impede de novo fatty acid synthesis of SFA and MUFA, which can contribute to a firmer carcass fat.

While producers should pay attention to the overall quality and quantity of unsaturated fats delivered to the animal, IV standards do not mean that unsaturated fats, whether delivered in the form of DDGs or added separately as supplemental fat and oil, can't play an important role during a significant portion of the animal's life cycle – for example, during lactation, or in starter diets. The focal point should be on the nutritional needs and impacts of the overall diet. For more information on nutritional effects on fat firmness, see Sosnicki (2010).

For example, Benz (2007) studied the effects of choice white grease or soybean oil on growth performance and carcass characteristics of grow-finish pigs. Pigs received diets containing CWG or soybean oil with the fat added for varying durations from 26 to 82 days. Pigs showed improved feed efficiencies and dressing percentages using CWG or Soybean oil at 5% levels compared to a corn-soybean control diet. Furthermore, soybean oil unlike CWG was found to improve ADG, though IV values using soy oil were also higher and found to exceed 73 at the jowl for market weight pigs (Triumph Foods, St Joseph, MO standard) even in the shortest 26-day trial application which removed soy oil 56 days before market. In contrast, CWG did not exceed this standard across study length and yield improvements were superior for CWG over soy oil. Hence, soy oil's superior ADG and average daily feed intake (ADFI) benefits may be best positioned for younger pigs (<90 lb).

More recently, Kellner (2011), as reported at the Iowa Pork Congress by Dr. John Patience, has studied finishers from 165 to 290 lb fed supplemental corn oil at rates of 3% and 6%. The study revealed IV values at the jowl of 72.6 and 80.0 at market, respectively. Hence, feeding a slightly lower rate of 3% corn oil during the finishing stage of production may be feasible without causing undue soft fat problems depending on the basal iodine value (the level when no fat is fed, which is dictated by genetics, growth rate, and the health status of the pigs).

Fats and Oils – Role in Gestation & Lactation Feeding Diets

Supplemental fats and oils can play an important role in lactation diets and improving survival rates of young pigs by up to 4% when fed just before and after farrowing (G. Cromwell, no date). Sows that are overfed during gestation will typically lose that weight during lactation. However, the risk is that heavier sows at farrowing may cause management difficulties and may be more likely to exhibit infant mortality by accidental crushing of baby pigs. These types of results can be aggravated, particularly during summer periods when sows are subject to heat stress.

In contrast, sows that are limit fed and avoid excessive weight gain during gestation can be fed higher energy lactation diets that provide the additional energy needed during lactation. Supplemental fats and oils can help increase the energy density of these diets. As noted earlier, energy in the form of fat and oil can be burned more efficiently by the animal than stored fat with less internal heat generation, a factor in heat stress.

Reese notes “feeding fat to sows during late gestation may improve pig pre-weaning survival rate by 2 to 3%. The greatest response to dietary fat is achieved in herds in which pig pre-weaning survival rate is less than 80% [though today a rate this low is uncommon]” (Reese et al., 2000. p.30). Feeding a lactation diet with 3% added fat for up to 14 days before farrowing is recommended. Much of the added fat will be available to the litter via the milk, and may increase litter weight gain as well.

Rosaro-Tapia (2011) studied the impacts of supplemental fat on sows, including during high ambient temperature conditions. In the first experiment where sows were fed supplemental fat (animal-vegetable blend) at 0, 2,4 and 6%, sows bred within 8d after weaning, showed improved rates of conception and farrowing rates ($P<0.001$), but the wean to breeding interval was not affected.

The objective of the second experiment was to determine the response to increments of two sources of dietary fat (AV and CWG) on sow and piglet performance during high ambient temperatures. Rosaro-Tapia determined feed and caloric intake increased ($P<0.05$) with addition of A-V blend and CWG. In addition, sows fed CWG diets reduced ($P<0.05$) BW lost during lactation. However, litter growth rate was not affected by the additional of either type of fat. Rosaro-Tapia noted CWG improved the gain: feed ratio ($P<0.05$) but the A-V blend did not. In summary, both the A-V blend and CWG improved ($P<0.001$) conception and farrowing rates and subsequent litter size compared to the control diet. Rosaro-Tapia hypothesized the presence of higher amounts of aldehydes (quantified by anisidine value) in the A-V blend may have compromised fat quality to an extent and impacted the response of the lactating sow with respect to feed efficiency.

Fats & Oils – Role in Weanling and Nursery/Starter Pig Diets

Restricted consumption at weaning is common and often the primary cause of post-weaning lag when the pigs are in an energy deficient state. Pigs at this stage are undergoing physiological changes that convert the digestive system from one best suited to using milk to one optimized for the digestion and absorption of complex carbohydrates and proteins found in grain and soybean meal while the immune system function and response mechanisms are still developing as well.

From the 1970s to the 1990s, the age at weaning was dramatically reduced from 6 to 3wk to increase sow productivity. However, in order to meet the nutritional needs of these younger animals, a new group of feed ingredients was needed to prevent digestive disorders including diarrhea and the negative effects of dehydration on growth.

Hence, a new opportunity arose for fats and oils to be used in combination with plasma proteins and milk by-products to wean pigs earlier, and allow them to more effectively utilize the nutrients in specialized starter diets. The basic need is to help minimize growth lags associated with the post weaning phase by improving energy delivery and uptake while warding off disease events and infections. Fish oils and oils that contain omega-3 fatty acids, such as certain vegetable oils, are also believed to have beneficial impacts to animal health.

Consequently, starter diets that have high palatability and digestibility can reduce the post-weaning lag by encouraging pigs to begin eating as soon as possible. Early-weaned pigs have unique nutritional needs both in terms of nutrient sources and concentrations in the diet. These pigs typically have low feed intake so diets must be high in nutrient density to achieve energy, protein, vitamin and mineral levels. While supplemental fat can increase caloric intake, the type of fat may affect how well the dietary energy is utilized. Soybean oil, a long chain, highly unsaturated fat source, is well utilized by pigs but is also costly. Soy oil additions of between 3 and 5% are beneficial to starter pig performance (Thaler et al, 1986). Tallow and lard, both long chain, more saturated fats, are less expensive but also more difficult to digest.¹²

Falker (1992) studied the effect of protein and fat source on the performance of early weaned pigs at 21-28 days over two study periods of 14 and 21 days. The experiment compared two diets, one using soybean meal and the other using a plasma protein, and to that added 8% soy oil or medium-chain tri-glycerides, esterified to glycerol, as the fat source. The results indicated that pigs receiving the soy oil grew 9% faster ($P < 0.5$) than pigs which consumed the medium-chain tri-glycerides. Plasma protein also improved performance over soybean meal by as much as 15% over the full study period ($P < .05$).

Meanwhile, Ching and Mahan evaluated the effects of dietary energy from lactose (rates of 0, 15, 30%) and soybean oil (0, 5, 10%) over a 35-day trial, beginning with pigs weaned at 17-days. The results indicated that both dietary lactose and soybean oil have a mutually beneficial effect on pig growth performance, body muscle and fat deposition. Urea nitrogen levels declined as well suggesting improved amino acid utilization (Ching and Mahan, 2001).

More recently, (Lauridsen et al., 2007) evaluated a series of alternative vegetable-based fat sources against animal fat due to the BSE-crisis in the European Union. The study included weaned pigs (28 days) and growing pigs from 51.7 to 82.1 kg and determined that apparent fat digestibility of four different vegetable based fats (palm oil mix, palm oil, coconut oil blend, and rapeseed oil) was superior (80%-76%) to animal fat (75%) in weaned pigs. This included a palm oil mix with a free fatty acid level of 73.2. In contrast, grower pigs showed lower levels of digestibility with both animal and vegetable fats. The rapeseed oil diet had a higher apparent digestibility (73.5%) than all the other diets (59-67%). The authors concluded that the palm oil and palm oil blend, coconut oil and rapeseed oil are viable alternatives to animal fat in pig feed.

The relationship between lean gain and energy intake is generally linear for starter pigs beginning at about 4 weeks post weaning to about 45 lb, and then for grower pigs up to 130 lb. After this stage, energy intake and lean gain are not as closely related. When adding supplemental fat, many experts recommend increasing the percentage of amino acids and minerals to maintain a constant nutrient: calorie ratio. See Reese (2000) for example starter diets that include fats and oils for pigs 8-45 lb. See also (Harper et al, 2003) for suggested use of soy oil in early weaned and segregated early weaned (SEW) pigs weighing 12lb or less. Soy oils are also used in the first phase of starter diets (10-14lb) for early weaned pigs with maturing digestive tracts. For optimal performance, diets should be crumbled or pelleted.

¹² (Hancock, no date) ranks fats with greater concentrations of medium-to-short-chain fatty acids and less saturation and most readily digestible by young animals. Milk fat and coconut oil are superior in this respect. The next most favorable oils are longer chain, unsaturated fatty acid sources such as soy oil, corn oil, sunflower oil, and canola oil. The least favorable sources include beef tallow, choice white grease and poultry fat. The one exception to this ranking came from a blend of beef tallow and an emulsifier (soy lecithin) that had utilization equal to coconut and soybean oil.

"Evidence indicates that blends of soybean oil and coconut oil support excellent performance in baby pigs," (DeRouchey et al, 2007a). The K-State program further cautions in its starter pig recommendation guide (p.5) that dietary fat uptake is limited in young pigs before 35 days of age. The reason is not well understood the authors note, but may include low digestibility after weaning and limited ability to catabolize fat from body stores. However, they note it is well understood that dietary fat is extremely important from a feed manufacturing point of view because it provides lubrication for pelleting equipment, increases throughput, and improves pellet quality in starter diets that contain milk products in high concentrations.

Studies have shown that pelleting increases feed efficiency, and hence K-State recommends pelleting for SEW (segregated early weaning), transition and intensive care diets.¹³ Pellet size is important, small diameter, 3/32 or 1/8-inch pellet or crumble for these diets. Feed wastage will be "approximately 20 percent greater and daily gain slightly lower for pigs fed meal diets." According to K-State, "A high quality fat source, such as choice white grease, soy bean oil or corn oil, should serve as the main fat source... Tallow, restaurant greases, and poor quality yellow grease should not be used in the diet for early weaned pigs (DeRouchey et al, 2007c, p. 5.) As animal enzyme systems mature, fat can serve as an important energy source. By phase 3 (25lb to 50lb), "Pigs will respond with improved average daily gain and feed efficiency with increasing levels of fat in the phase 3 diets up to approximately 3%... feed efficiency will be 5 to 8% better with a pelleted diet... a larger pellet (5/32 or 3/16 inch) can be used for these older pigs." (Ibid, 2007).

Finally, other factors may play an important role in fat and oil performance at this early age. Jones (1992) studied the effects of lecithin and lysolecithin on the digestibility of fat sources in diets for weanling pigs (17d of age and 11.6lb initial wt) and found a positive effect on nutrient digestibility, including fat, nitrogen and gross energy digestibility. The effect was most pronounced for lecithin added at a 1% concentration with 9% added tallow in a corn-soybean meal diet achieving a 9% increase in fat digestibility (80.9 to 88.4%), and 9% added soy oil yielding a 3% increase (89.5 to 92.6%).

Fats & Oils – Role in Grower-Finisher, Phased Feeding Diets

The addition of fats and oils into grower pig diets has shown it clearly enhances diet acceptability and improves feed efficiency, particularly in combination with pelleting. Research has also indicated that added fat reduces feed intake and improves feed efficiency in finishers (Goodband et al, 1989). Because the demand for market hogs is based primarily on packers monitoring of carcass weight and lean meat content, the grower industry has responded by increased use of lean genotype breeding animals and terminal mating systems that optimize lean tissue growth rather than simply live weight gain. Harper (2004) notes that "high lean gain genotypes require diets formulated to contain higher nutrient and energy density."

Since gilts and barrows have different nutritional needs, particularly above 110lb of body weight, production units often formulate different diets and separate feeding programs. From 80lb until market weight, gilts normally consume about 8% less feed than barrows while depositing lean tissue at the same rate. Consequently, gilt diets require greater concentrations of amino acids to maintain optimal growth rates and lean tissue content. See (Reese et al, 2000) for sex based amino acid recommendations.

Phased feeding with customized diets for weight and age classification are recommended to optimize pig performance and control feeding costs by limiting the time that nutrients are over or underfed. In addition, phase feeding can reduce the amount of excess nitrogen or phosphorus pigs excrete in their manure. For additional details, see (DeRouchey et al, 2007b). Harper et al. constructs a variety of diet formulations for grower-finisher hogs of various weight and sex categories, including those that take advantage of supplemental soy oils for increased energy density. When higher fiber and lower energy ingredients are included in the formulation, dietary energy density can be maintained by supplementing with fats and oils (Harper et al, 2004).

Soy Oil vs. Choice White Grease, Palm, Tallow and Other Fats

Presented at a 1989 conference, Goodband et al. studied finishing pigs and the effects of various fat sources on growth performance in finishing pigs with initial weights of 124lb. In addition to the non-fat control diet, treatment diets included 4% added fat from soybean oil, coconut oil, or choice white grease. All three fat sources showed an increase in feed intake and feed efficiency in comparison with the non-fat control, resulting with soybean oil boosting F/G levels by 4% and CWG by 11%. In this study, CWG appeared to be a better fat source for finishing pigs (Goodband et al, 1989).

¹³ According to the U.S. Pork Center of Excellence, KSU research shows that pelleted diets increase available nutrients, show better feed conversions, as well as reduce feed wastage and dust while lowering the incidence of ulcer problems.

Subsequently, D.A. Nichols et al., Kansas State University (1991) studied the effects of fat source and level on finishing pig performance. Pigs from 120 to 230lb were tested on a milo-soybean control diet with treatment diets containing supplemental soybean oil (2.5, 5.0, 7.5%) or tallow fat (2.5, 5.0%). While there were no significant effects on feed intake, average daily gain or feed to gain ratio when comparing soy oil to tallow at similar levels, soybean oil additions resulted in carcasses with significantly more average backfat and 10th rib fat depth at the 5% and 7.5% levels. Carcass firmness was also reduced. However, sensory panel analysis indicated acceptable pork quality for all dietary treatments. It was also noted that fatty acid profile differences can be explained based on dietary fat source. Feed efficiency improved linearly with increasing soybean oil additions to finishing diets.

In two more recent research studies conducted at the University of Illinois (2010), as reported in National Hog Farmer (August 2010) choice white grease and soybean oil were evaluated against a control at concentrations of 3% and 6% in finishers from 150lb to market weight. The study included two phases of evaluation, 0-21 days and 21-49 days. In a second two phased study of 47-days, palm oil, an animal-vegetable blend and tallow were also added to the field and tested against soy and CWG, all at 6% levels, and a control. All of the supplemental fat diets in both trials showed improvements in average daily gain and feed efficiencies over the controls. In the first trial, SBO at the 3% and 6% level had superior ADG over CWG (2.58¹⁴ vs. 2.49) while F/G results were superior for SBO at 3% (2.80 vs. 2.87) and CWG at 6% (2.61 vs. 2.70). In the second trial, CWG at 6% was the top performing oil for ADG (2.70) and F/G (2.72). (Y. Liu et al., 2010).

In another recent research experiment, (Park et al, 2009) studied soybean oil and tallow for effects on growth performance and carcass characteristics, including fatty acid composition. Their 4-treatment study entailed supplementing with soybean oil or tallow at 5% in corn-soybean meal diets of pigs starting at average 40lb through market weight of 238 lb. Two of the groups were moved from tallow to soybean oil at 99lb and 176lb of weight. Park et al. noted tallow had better initial palatability than soybean oil in young pigs of starter age, but that after an adaption period pigs on the soybean oil ate more and grew faster.

Park concluded that soybean oil was a useful supplement and could be added to pig diets without negative effect on carcass characteristics compared to tallow, though they did report firmness and melting point of back fat increased with the length of tallow supplementation. They also noted that higher levels of polyunsaturated fatty acids (PUFA), especially [omega]-3 fatty acids, in the carcasses of the animals fed soybean oil could be of interest in addressing certain human health conditions (coronary disease, hypertension) by delivering meat with lower saturated fatty acid levels that are less likely to raise cholesterol levels. "If [omega]-3 fatty acids enriched pork is deemed to grow at niche market, soybean oil can be safely used a source of [omega]-3 fatty acids in pig diet. Same could be applied to the production of [omega]-3 fatty acids in enriched eggs."

Similarly, see (Mitchaothai, 2008) who studied sunflower oil and beef tallow in grower-finishers. Mitchaothai found that feeding pigs over 91 days with sunflower oil instead of beef tallow altered the fatty acid composition of tissue (increasing PUFA in adipose and loin) without negatively affecting various characteristics of meat quality.¹⁵ Mitchaothai concluded that there is a potential for improving pork quality by increasing polyunsaturated fatty acid concentrations in pig feeds. Influencing this meat characteristic may be of particular interest in Asian markets.

Fats & Oils – Role in Summer vs. Winter Feeding Conditions

Somewhat counter-intuitive, supplemental fat and oil will, generally, have a greater impact on feed performance during hot summer conditions vs. cold winter conditions. This is because less digestive heat is produced by the animal to convert the lipid into energy for maintenance and growth compared with the conversion of protein or starch to energy.

Susceptibility to heat stress increases with body weight. Thus fats and oils allow stress susceptible animals with high energy demands, or energy deficient situations, to continue to meet energy needs when feed intake is normally reduced. Consequently, fat is generally more cost effective when fed in summer than winter.

In severe cold, cold stressed pigs, including limit fed pigs, can utilize fats and oils to make up energy deficiencies. In contrast to summer temperatures, smaller and younger animals are more susceptible to the cold. See Reese (2000) for additional information on supplemental fats and oils.

¹⁴ Table 1 showed an incorrect calculation of ADG at 3% SBO for the life of the trial. After contact, the authors of the paper provided a corrected number.

¹⁵ Fat levels added to the diets were not provided in the summary of the research.

Fats & Oils – Synergistic Agents, Dietary L-Carnitine & Conjugated Linoleic Acid

Dietary L-Carnitine, a natural occurring amino acid, has been shown to improve nitrogen utilization in growing pigs fed low energy, fat containing diets. Heo et al, 2000, studied the effects of L-carnitine and protein intake on nitrogen (N) balance and body composition. Growing pigs of 17.8kg were placed on a 4% soy oil, corn-soybean meal basal diets containing low or high protein (136 or 180g/diet) for 10-days using 0 or 500 mg/kg of L-carnitine. Irrespective of protein level, Carnitine increased ADG (7.3%) and CP (9%). Carnitine also improved nitrogen retention and reduced urinary excretion (14%). Carcass fat was also reduced in Carnitine supplemented pigs. (Owen et al, 1996) reported similar grow enhancing and body composition results in early weaned pigs fed soybean oil at 0 to 10% and L-carnitine at 0, 500, or 1000 ppm. The authors concluded that dietary L-carnitine improves G/F and reduces carcass lipid accretion in early-weaned pigs.

Omega-3 fatty acids (e.g. linoleic acid) have been a focus of research due to their ability to modulate infection and inflammation (Blok et al., 1996). The release of pro-inflammatory cytokines resulting from immune response stimulation is reduced by dietary omega-3 fatty acids in many species. It has been theorized that conjugated linoleic acid (CLA), a category of polyunsaturated fatty acids that are positional and geometric isomers of linoleic acid (C18:2), can improve growth by inhibiting prostaglandin-E2 (PGE2) production, a protein which is a potent catabolic inflammatory mediator (Cook et al, 1993). Spurlock et al. (1997) tested pigs on conventional and high oil corn (HOC), the latter containing higher levels of linoleic acid, which is a precursor to PGE production. Spurlock found that growth depression caused by immunological challenge was not greater in pigs fed HOC diets.

In human nutrition, CLA comes primarily from dairy products and ruminant meat products since CLA is produced during bacterial fermentation in the rumen. The main isomers of CLA are cis-9, trans-11 (c9t11) and trans-10, cis-12 (t10c12). Ruminants produce c9t11 in greatest proportion. Animal research has shown CLA can have a positive impact on obesity, cancer, atherosclerosis, and diabetes. From a feed standpoint, CLA may provide a nutritional supplement to counteract carcass fat and belly firmness problems associated with feeding higher levels of unsaturated vegetable fats like corn and soy oil (Eggert et al, 2001). CLA can also improve color and marbling scores (Schinckel, 2000). Other studies in pigs have shown that CLA is able to reduce adipose tissue deposits using 50% or more t10c12. See (Richert et al, 2007).

The FDA has approved CLA in swine diets for use in growing and finishing pigs. The level of fatty acids are not to exceed 0.6% in the finished feed. The CLA source must contain a minimum of 28% cis-9, trans-11 and trans-10, cis-12 as methyl esters derived from sunflower oil (FDA Registry, Vol. 73: No. 210; pg 64197-64199). As described in more detail in (Richert et al, 2007), a number of trials have shown CLA-supplemented diets may provide a means to decrease back fat in average lean genetics while increasing the percent of lean carcass and improving (firmer) carcass fat quality. Research indicates that feeding CLA at 0.6% for 10-14 days before market may reduce carcass fatty acid IV by approximately 2-4 IV units; and when fed for 8 weeks, by 7-10 IV units.

From a marketing perspective, it is entirely possible that CLA can become a selling point for “heart healthy” pork given more evidence of its beneficial impacts with respect to cancer and heart disease prevention.

ACIDULATED OIL AND HOW IS IT DIFFERENT FROM CRUDE SOY OIL AND OTHER ANIMAL-VEGETABLE BLENDED OILS?

Acidulated Vegetable Oil vs. Crude Soy Oil

Acidulated vegetable oils or “acid oils” are a by-product of the caustic refining process of soybean and/or other vegetable oils. Soapstock is generated at a rate of about 6% of the volume of crude soybean oil refined (Hammond, 2005, p.614). That soybean soapstock is then processed using an acidification process that entails heating, processing and then separating the oil from the material and its other constituents. Acid oils have traditionally been used by fatty acid producers, soap makers, foundries and animal feed manufacturers, such as Feed Energy (Des Moines, IA). As the name suggests, acid oils are typically acid in nature with a pH of about 2.5-3.0. However, this pH level can be adjusted to 4-4.5 depending on the desired end use. Acid oil typical sells at a substantial discount to crude soy oil.

Energy Content, TFA and FFA

When one purchases feed fat, available calories are often the primary consideration. Fats and oils are the catalyst that enables animals to optimize the energy value of the other feed ingredients that are supplied. High quality acid oil – oil that has been stabilized with preservatives and/or antioxidants – is high in total fatty acids (TFA = 92%) and high in available calories depending on whether the customer desires an all-vegetable (4,000 Kcal/lb) or an animal-vegetable blended product (3,800 Kcal/lb).

How is acid oil different than regular crude soybean oil or restaurant based A-V blends? “All vegetable” and blended animal-vegetable acid oils typically have 40-55% free fatty acids (vs. 0.3-0.7% FFA for crude soy)¹⁶, which means that the concentration of glycerin is typically about half that of crude soy oil. Since glycerin has about 40% of the energy value of fatty acids, there is a larger concentration of high energy FFAs in acidulated vegetable oil than in refined soy oil on an equivalent pound for pound basis. Thus, all-vegetable acid oils, which have been properly stabilized, are “hotter” oils with more metabolizable energy than crude soy oils (3,810 Kcal/lb, 1998 NRC).

Unlike high FFA levels in feed oils sourced from restaurants (>15% FFA), which can be a “marker” for poor oil quality because they signal a) oxidation, b) higher levels of unsaponifiables and insoluble impurities, and c) the potential for rancidity, the FFAs associated with acid oil are not an indicator of poor quality; in fact, the FFAs in acid oils are more fully available for metabolism and they have been stabilized with powerful natural antioxidants described in more detail below. It is useful to keep in mind that high quality acid oils, such as those supplied by Feed Energy (Des Moines, IA), typically have average moisture (1.5%<), insoluble impurities (0.3%<) and unsaponifiable matter (2.5%<), and do not contain high levels of lipid oxidation products (<5 initial P.V.)¹⁷, oligomers and other hard to digest polymers that can be found in restaurant grease. Such lower quality restaurant derived A-V blends with these types of constituents can be harder to digest, and therefore typically receive a “discount” by nutritionists of 1% to 1.5% for each 10% of FFA content in the oil if they follow the work of Powles (1995).

In summary, acid oils are more like high-octane gas for your car, which in addition to supplying calories, enhances feed conversion rates and average daily gain, while supplying vitamins and other micro-nutrients that can improve animal health and accelerate growth.

Essential Fatty Acids, Vitamins & Natural Preservatives

Essential fatty acids are organic compounds that animals cannot synthesize on their own and must be derived from a dietary source. Crude soy oils are considered to have good nutritional value mainly because of their high concentration of essential polyunsaturates. Crude soy is high in linoleic acid (C 18:2) and linolenic (C 18:3) acids, which also, unfortunately, also contributes to its oxidative instability, along with exposure to light and contamination with copper or iron.

Crude soy bean oil typically contains approximately 3.5 times the [alpha]-linolenic acid [Omega-3] compared to tallow, 5.35% to 1.53% (Park et. al, 2009). Acid oils, such as Feed Energy’s All Veg 4000, have comparable levels of linolenic acid [Omega-6] to crude soy oil. However, with respect to linoleic acid, crude soy (51%) and all vegetable acid oils (Feed Energy All Veg, 53%) have an even greater advantage over tallow (3.1%) with as much as 17 times of this essentially fatty acid.

With respect to vitamins and nutraceuticals, Feed Energy’s acid oil All Veg 4000 contains vitamins A, D, E, K plus Phytosterols. For example, one pound of All Veg 4000 will contain 340 mg of vitamin E, an important anti-oxidant. Vitamin E is a mixture of eight stereoisomer compounds of which four tocopherol compounds are found in All Veg 4000. Tocopherols are the most important lipid-soluble antioxidant, protecting cell membranes from oxidation by reacting with lipid radicals produced in the lipid peroxidation chain reaction.

In part, because neutralization, bleaching and deodorization of crude soy oil – which has poor oxidative stability – often removes considerable amounts of sterols and tocopherols (Hammond, 2005, p. 580, 606-7), acid oil will typically contain 10-15 times the normal concentration of tocopherols found in crude soy (the main ingredient in vitamin E, and also a natural antioxidant) plus many of the color bodies (carotenes) that are also anti-oxidants that refined soy oil does not have. By acting as a preservative, tocopherols help stabilize the acid oil and ward off rancidity. Natural vitamin E is also believed to be superior to synthetic forms, with an impact approximately 25% greater on an equal weight basis. In certain animal segments with higher vitamin E needs, such as nursery pigs, this can be a valuable boost to performance (DeRouchey et al, 2007, p. 22-23).

All Veg 4000 is an excellent source of pro-vitamin A (avg. 113 mg/lb) or carotenoids. Carotenoids include alpha-carotene, beta-carotene, lycopene, zeaxanthin and lutein. Carotenoids are efficient free-radical scavengers and serve as powerful antioxidants and have high stability in animals. Like tocopherols, they also assist with preservation and stability and lengthen the shelf life of the product. Since animals are incapable of synthesizing carotenoids, they must be obtained through the diet. Finally, All Veg 4000 is a rich source of phytosterols (900 mg/lb). Phytosterols perform the same basic function in plants as cholesterol does in animals, serving a key role in cell membrane function. Clinical trials have shown that plant phytosterols can lower plasma cholesterol levels safely and efficiently.

¹⁶ Typical composition of Crude Soybean Oil: TFA 94.4%; unsaponifiable matter 1.3-1.6%; Tocopherols 0.123%; FFA 0.3-0.7% (Hammond, 2005, p. 579).

¹⁷ Peroxide value is an index to the oxidative state of an oil. Crude soy oil is considered to be “fresh” when it has a peroxide value <1.0 mEq/kg; to have low oxidation with 1.0-5.0 mEq/kg; to have moderate oxidation at 5.0-10.0 mEq/kg, and to have high oxidation at >10.0 mEq/kg (Hammond, 2005, p. 635).

U:S Ratio, IV Value, Acid vs. Restaurant A-V Blends

Depending on the fatty acid profile, typically the U:S ratio for acid based vegetable oils will lie between 5.5-6 (typical crude soy oil has U:S ratio of 5.6, according to 1998 NRC). Meanwhile for A-V Blends, such as Feed Energy's Hypercal 3800 (tallow; vegetable blend), the U:S ratio will typically fall between 2.3-3. With respect to IV values, all vegetable acid oils will receive IV ratings of 125-135 depending on the actual fatty acid profile (crude soy has an IV value of 130 according to the 1998 NRC); because of the presence of saturated fats, A-V blends will have lower IV values.

In comparison with restaurant based A-V blends, IV values for acid oil A-V blends may not be reflective of two important distinctions. First, many restaurant frying oils have been hydrogenated to enhance stability to oxidation, which results in the conversion of relatively unstable unsaturated to more stable saturated fatty acids. This may yield lower IV values (90-115) but at a loss of some nutrient quality including linolenate, lineoleate and oleate, the extent to which depends on the process used and the desired use for the oil e.g. frying, salad oil, etc. (Hammond, 2005, p.608, 611).

Second, used restaurant oils may lose unsaturated fatty acids and other nutrients, including essential fatty acids, because of fat oxidation and degradation during frying. In addition, when frying fats are heated in the presence of moisture, such as in food preparation, fatty acids (including trans-fatty acids) are released via hydrolysis of the ester linkages. These FFAs can accelerate the oxidation of the oil, including the production of di- and tri-oxygenated esters, and dimeric and polymers, negatively affecting the physical, nutritional and toxicological properties of the oil (Hammond, 2005, p.620, 631). More recently, the presence of trans-fatty acids in frying fats and fried food have raised health concerns in human food consumption.

Physical Properties – Viscosity, Density, Molecular Mass

When it comes to pelleting and dust control, acid oils like other vegetable oils may have a number of important advantages in handling, dispersion, and overall cost effectiveness versus other choices of fats. Soy based oils are known for having excellent lubricity, and the marketplace has recognized the feed efficiency benefits of feeding pelleted products over mash.

Melting points, viscosity/lubricity, density, and other physical characteristics may positively or negatively impact pellet quality, machinery wear and tear, and energy consumption/operating costs. Some anecdotal evidence suggests that the inclusion of more dried distiller's grains (DDGs) in modern swine diets is harder on pelleting equipment and energy consumption (Leland McKinney, personal communication, April 17, 2012). This trend may increase in severity as more corn oil is "spun" from the DDGs. More research in this area is required to better understand the potential viscosity and/or "lubricity related" benefits of adding supplemental fats and oils in modern feed rations, including high and low fat DDG rations.

All vegetable acid oils, like Feed Energy's All Veg 4000, have an approximate viscosity of 30-40cP @ 20 degrees celcius versus 58.5-62.2cP for crude soy @ 20 degrees celcius (Hammond, 2005, p.585). Feed Energy's All vegetable acid oil has an approximate density is 0.9kg/m³ versus 0.9165 to 0.9261 g/mL for crude soy (Hammond, 2005, p.585). Acid oil A-V Blends, such as Feed Energy's Hypercal 3800, have similar viscosity and density ratings to Feed Energy's All Veg 4000 product.

In addition to pelleting related questions, with the trend toward using more and lower fat DDGs in swine diets of all ages, more research is warranted to better understand the role of adding supplemental fats and oils for dust control in modern commercial diets. Much of the research in this area is more than 20 years, and was focused on traditional corn-soybean diets using ground particle sizes of 650-700 microns versus 300-400 microns today. Are oils with smaller molecular mass components, such acid oils with their higher free fatty acid content, more efficacious in controlling fines and dust than other fats and oils at similar concentrations?

Similarly, are there specific market niches e.g. mineral mixes, grow-finish diets, starter diets, that would benefit in particular from fats and oils with specific physical viscosity and other physical requirements, not unlike matching motor oils to engine performance? Acidulated oils may offer a performance and a cost advantage that is worth a closer look.

SUMMARY

Supplemental fats and oil play a number of important roles in swine diets, but it is important to keep in mind all fats are not created equal. Vegetable-based fats and oils, including animal-vegetable blends, which contain a substantial proportion of unsaturated fatty acids have a number of performance advantages over typical saturated animal fats, like choice white grease, yellow grease, lard or tallow. The benefits of adding fat and oil to swine diets include the following:

1. Increases the energy density of the diet, providing high levels of metabolizable energy which can be important during energy deficit situations (lactation, starter pigs, hot weather conditions, or when pigs would otherwise go to market underweight)
2. The addition of fat to swine diets provides an “extra caloric effect” by improving the absorption of energy from other portions of the ration via micelle formation and activation. In general, this effect is improved when the fat or fat blend has a U/S ratio above 1.5.
3. Supplemental fats can deliver fat-soluble vitamins (A, D, E and K), and increase their uptake; in addition, certain vegetable-based unsaturated fats, like soy-based vegetable oils are an important source of the essential fatty acids, linoleic and linolenic acid, which cannot be produced by swine.
4. Acidulated vegetable oils are a good source of anti-oxidants, such as phytosterols, tocopherols and carotenoids, which also help preserve and stabilize the oil. Other vegetable based fats, such as restaurant grease, may be more prone to rancidity and breakdown.
5. Because fat is metabolized more efficiently than other sources of dietary energy, adding fat to the diet can lower the heat increment and reduce the likelihood of heat stress and reduced growth during periods of high ambient temperature barn conditions. Vegetable oils are a favored fat source for improving lean growth rates in young pigs and milk output in lactating sows. They have higher digestibility than tallow or yellow grease, and typically are considered higher in quality and safer to use.
6. When evaluating fat and oil choices, all the quality parameters, including the extra caloric effect, should be accounted for as per the Garrett model, not just the U/S ratio and free fatty acid content which can deliver an incomplete and/or misleading picture.
7. High Free Fatty Acid (FFA) levels found in restaurant grease (a.k.a. yellow grease) are a result of heating and oxidation, often in the presence of moisture. Normally, there is a loss or degradation in the quality of the fat when this happens. This degradation is typically more pronounced with unsaturated fatty acids. Plus, oxidation leads to the formation of by-products like polymers and oligomers, aldehydes, ketones, and other secondary products which are hard to digest or undigestible. In contrast, high FFA levels found in acidulated vegetable oils (are not an indication of rancidity) and do not result in concomitant deterioration in unsaturated fatty acids or the formation of polymers and oligomers as long as the oil has been stabilized with antioxidants. Therefore, standard FFA limits of 15% designed for restaurant greases or other highly saturated fats should not necessarily be applied to higher FFA levels found in acidulated vegetable oils, or blends made therewith.
8. While dietary Iodine Values (IV) should be monitored by producers, particularly those using high levels of DDGs, adding supplemental vegetable oils or animal-vegetable blends at 3% or less of the diet, or at higher levels earlier in the production cycle (starter diets/lactation/periods of heat stress) may be feasible without causing excessive soft fat issues, depending on packer standards.
9. Fats and oils can play an important role in creating pelleted products by increasing machinery throughput and reducing dust in the mill and in the barn. Because of its superior handling and lower melting point, high quality, vegetable-based oils may often be used at one-half to one-third of the rate compared to many animal fat sources. Moreover, acidulated vegetable oils can often be purchased at a significant discount to other vegetable oils, such as crude soy bean oil.

In order to evaluate the true efficacy and economic return of fats and oils, producers should look beyond just the metabolizable energy value for the fat in question and consider the various roles that supplemental fats and oil play during the production cycle.

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