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Use of crude glycerol in grower-finisher and sow diets

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Introduction

The production and use of renewable fuels such as ethanol from corn and biodiesel from soybean oil has exploded in rural America. There are many benefits generated by production and use of these fuels but there are also challenges. One important challenge is utilization of the co-products generated during biofuel production. A logical use for these co-products is in livestock feeds. Ethanol production has received the most attention recently as there are numerous groups determining the utility of dried distillers grains with solubles in swine feeds (see www.ddgs.umn.edu). Rapidly expanding biodiesel production will produce a plethora of glycerol, the co-product of biodiesel production. During biodiesel production, 100 pounds of fat or vegetable oil (usually soybean oil) is combined with 10 pounds of methanol to yield 100 pounds of biodiesel and 10 pounds of crude glycerol (National Biodiesel Board, 2006). Currently, there are 171 biodiesel plants in the US with an annual production capacity of 2.24 billion gallons of biodiesel. In fiscal year 2007 (Oct. 1 to Sept. 30), actual production of biodiesel totaled 450 million gallons (National Biodiesel Board, 2008a). For each gallon of biodiesel produced, about 0.66 pounds of crude glycerol are generated (Thompson and He, 2006). Consequently, about 148,500 tons of crude glycerol were produced in fiscal year 2007 with the potential for close to 740,000 tons of crude glycerol if all plants operated at maximum capacity.

Glycerol has many uses. Glycerol is used: to moisten, sweeten and preserve foods, as a moisturizing agent and emollient in cosmetics and toiletries, as a component of drugs and pharmaceuticals, to soften and reduce shrinkage in paper manufacturing, to produce renewable propylene glycol (antifreeze and deicing solutions), and many others (Kerr et al., 2007). Recently, there has been growing interest in the nutritive value of crude glycerol for various species and classes of livestock. The rapid expansion of biodiesel production has created a massive flux of crude glycerol into the marketplace which has driven down the price for some grades of crude glycerol. Prices can range from about \$0.06 to \$0.22 per pound (FOB). Currently the average price is about \$0.12 per pound. When glycerol prices are at the low end of the price range, crude glycerol is appealing to livestock producers as a feed ingredient; however, there is a paucity of information on feeding crude glycerol to pigs.

Glycerol is a three-carbon compound that could serve as an energy source in swine diets. However, limited research has been reported on the nutritional value of glycerol for swine. Lammers et al. (2008) reported crude glycerol (86.95% pure glycerol) contained 1,516 kcal DE/lb and 1,454 kcal ME/lb when fed to nursery and growing pigs. These estimates of energy are 95% and 94% of the DE and ME, respectively, reported for corn (NRC, 1998). Although starch and fats have been traditional sources of energy in US swine diets, glycerol could become an important energy source for pork production if the continued production of biofuels uses starch from corn to make ethanol and a variety of fats and oils are used to make biodiesel.

Glycerol also plays a role in water balance of the body. Several authors have reported that ingestion of glycerol enhances water retention in humans (Freund et al., 1995; Wagner, 1999). Consumption of glycerol-containing water increased blood volume, and decreased heart rate, rectal temperature and urinary output of human endurance athletes during exercise in heat stress conditions (Anderson et al, 2001). Rats fed glycerol exhibit increased water intake and increased urinary output (Cryer and Bartley, 1973). Glycerol's role in water balance may play a role in the quality of pork harvested from finishing pigs and help lactating sows cope with the stress of milk production during hot weather.

Use of glycerol in grower-finisher diets

Glycerol's reasonably high energy density and its potential to influence water balance and ultimately pork quality make it a logical ingredient in diets for growing-finishing pigs. German researchers (Kijora and Kupsch, 1996) reported a non-significant increase in feed intake of growing pigs fed up to 10% crude glycerol in barley-based diets. However, glycerol did not influence feed intake or growth rate in the finishing period or over the entire trial. Similarly, French researchers (Mourot et al., 1994) reported no significant effects of 5% dietary glycerol on growth performance of pigs fed wheat-soybean meal based diets. More recently, Lammers et al. (2008) fed pigs corn-soybean meal diets containing 0, 5 or 10% crude glycerol and reported no influence of dietary glycerol on growth performance of pigs during the 138-day experiment (Table 1).

The potential for glycerol to influence water balance in the body suggests that pork quality may be affected by dietary glycerol. Mourot et al. (1994) reported decreased drip losses from longissimus dorsi and semimembranosus muscles and decreased cooking losses from semimembranosus muscle of pigs fed 5% glycerol. These data suggest that dietary glycerol can improve water holding capacity of pork which could improve the eating experience of consumers. However, Lammers et al. (2008) evaluated a wide range of pork quality traits in the laboratory and with a trained human taste panel and found no effect of dietary glycerol on any measure of pork quality. Because Lammers et al. (2008) supplied glycerol to pigs from weaning through to marketing, pigs may have become adapted to the elevated dietary glycerol such that there was no beneficial influence on pork quality. Hyperhydration studies in human subjects measured only short-term effects (a few hours) of glycerol ingestion on body hydration and athletic performance (Freund et al., 1995; Wagner, 1999). We theorized that long-term feeding of glycerol may mask any positive effects on pork quality because pigs adapted to the new water balance. Therefore, we conducted a study to evaluate long-term and shorter-term feeding of glycerol to growing-finishing pigs. In this experiment, we assigned pigs to one of three dietary treatments: control - a corn-soybean meal diet; long-term (LT) - a corn-soybean meal diet supplemented with 8% crude glycerol throughout the entire feeding period; short-term (ST) - the control diet fed during the initial portion of the experiment and the 8% glycerol diet fed during the last 7 weeks of the experiment. Crude glycerol contained 82.3% glycerol, 5.97% salt, and < 100 ppm methanol. Dietary treatments were offered in a 4-phase feeding program over the 14-week study. Pigs fed the 8% glycerol throughout the 14-week study grew faster as a result of increased ($P < 0.05$) daily feed intake compared with pigs assigned to the Control treatment (Table 2). However, the 3% reduction in efficiency of gain resulting from long-term feeding of glycerol tended to be significant ($P < 0.07$). Daily weight gain, daily feed intake and percent lean of pigs fed 8% glycerol in the last 7 weeks of the experiment was intermediate to and not significantly different from pigs assigned to the Control or LT treatments. The increased feed intake of pigs assigned to the LT treatment may be attributable to the sweet taste of glycerol reported by Kijora and Kupsch (1996). Effects of long and short-term feeding of glycerol on pork quality and taste panel data are currently being evaluated and will be reported in the near future.

Based on the recent work of Lammers et al. (2008) and our results at the University of Minnesota, it appears that growth performance of pigs fed up to 8% crude glycerol is similar to that of pigs fed a corn-soybean meal diet. Initial indications are that carcass traits and pork quality are not dramatically influenced by dietary glycerol but additional data from our lab will help clarify this conclusion.

Use of glycerol in sow diets

We are unaware of any published reports of feeding glycerol to breeding swine. Realizing that glycerol can play a role in water balance of human athletes, it seemed logical to investigate the utility of crude glycerol in diets for lactating sows. Dietary glycerol may increase water intake of sows and improve milk production since milk is about 80% water. Glycerol feeding increases concentration of glucose in blood of rats (Cryer and Bartley, 1973). Glucose is also a precursor for production of lactose in mammary epithelial cells. Lactose secretion by mammary cells is an important driver of milk yield (Schmidt, 1971). Under some metabolic conditions, glycerol can promote fat synthesis in rat mammary glands (Robinson and Williamson, 1977). With these thoughts in mind, we designed a study to evaluate the effects of increasing concentrations of crude glycerol in diets for lactating sows.

Table 1: Performance of growing pigs fed crude glycerol[1]

	Diet			
	0	**5**	**10**	***P*-value**
Replicate pens[2]	8	8	8	
Initial wt., lb	17.4	17.6	17.2	0.60
Final wt., lb	293.0	295.4	292.8	0.92
ADG, lb	1.99	2.01	1.99	0.93
ADFI, lb	5.14	5.25	5.29	0.66
G:F	0.39	0.38	0.38	0.12

1 Lammers et al., 2008.

2 Four pigs were initially assigned to each pen, over the course of the experiment 6 pigs were removed with no pen having more than 1 pig removed.

Production II

Three hundred forty five, mixed parity sows were assigned to corn-soybean meal based diets containing 0, 3, 6, or 9% crude glycerol. Crude glycerol contained 86.1% glycerol, 6.01% salt, and < 100 ppm methanol. Dietary treatments were imposed on day 109 of gestation when sows were transferred to a confinement farrowing facility. Until farrowing, sows were restricted to 5 lb/d of their experimental diet. After farrowing, sows were allowed ad libitum access to their experimental diet. The experiment began in July and concluded in November, 2007.

Inclusion of up to 9% crude glycerol had no significant effects on sow weight or backfat losses, litter size or weight at weaning or wean-to-estrus interval for sows that displayed estrus by day 10 postweaning (Table 3). Dietary treatment tended ($P < 0.08$) to influence daily feed intake of sows mostly due to the difference in feed intake between sows fed 3 and 6% glycerol. An explanation for the lower feed intake of sows fed the 6% glycerol diet is not apparent. Results of this study suggest that lactating sows fed diets containing up to 9% crude glycerol perform similar to sows fed a standard corn-soybean meal control diet.

Table 2: Effect of long or short term feeding of crude glycerol on performance and carcass traits of finishing pigs[1]

Trait	Control	Long term	Short term	PSE
No. of pens	8	8	8	--
Initial wt., lb	69.4	69.1	68.4	0.33
Final wt., lb	279.3	284.4	284.3	1.73
ADG, lb	2.12^{ac}	2.20^{b}	$2.19b^{c}$	0.02
ADFI, lb	6.14^{x}	6.47^{y}	6.31^{xy}	0.06
G/F	0.346^{u}	0.339^{v}	0.346^{u}	0.002
Dressing %	74.48^{ab}	74.90^{a}	74.32^{b}	0.15
Fat-free lean, %[2]	53.32^{u}	52.26^{v}	52.55^{uv}	0.34

[1] Schieck, unpublished.

[2] Calculated according NPPC, 2000.

[abc] Means with unlike superscripts are different ($P < 0.05$).

[xy] Means with unlike superscripts are different ($P < 0.01$).

[uv] Means with unlike superscripts tend to differ ($P < 0.08$).

Table 3: Effect of crude glycerol in diets for lactating sows[1]

	% Dietary glycerol				
Trait	0	3	6	9	PSE
No. of sows	90	89	85	81	--
Avg. parity	4.5	4.4	4.2	4.2	0.14
Lactation length, d	19.1	18.9	18.8	18.8	0.14
Sow feed intake, lb/d	13.0	13.4^{a}	12.2^{b}	12.8	0.30
Sow wt. loss, lb[2]	2.2	4.7	6.2	4.5	2.67
Sow backfat loss, mm[2]	1.4	1.5	1.2	1.4	0.18
Litter size weaned	9.4	9.4	9.2	9.2	0.10
Litter weaning wt., lb[2]	131.9	129.4	124.7	127.8	2.02
Wean to estrus, d[2]	5.5	5.4	5.6	5.2	0.11

[1] Schieck, unpublished.

[2] Lactation length used as covariate in statistical analysis.

[ab] Means with unlike superscripts differ ($P < 0.06$).

Other considerations for feeding crude glycerol

Recent studies suggest that crude glycerol is a potentially viable feed ingredient for growing-finishing pigs and lactating sows. However, there are some concerns with feeding crude glycerol that must be considered when selecting a source and formulating diets.

Salt concentrations. Sodium hydroxide or potassium hydroxide typically is used as a catalyst in the conversion of fats or oils to biodiesel and glycerol. The crude glycerol contains unused catalyst that is neutralized with acid creating sodium chloride or potassium chloride that remains in the crude glycerol (National Biodiesel Board, 2008b). Kerr (2007) reported that salt concentration of crude glycerol ranges from 2 to 10%. These high salt levels must be considered when formulating diets for swine. The NRC (1980) sets the maximum tolerable level of salt in swine diets at 8% *provided* pigs have an abundant supply of drinking water. It appears that salt content of crude glycerol will not be a problem in typical swine diets particularly if supplemental salt is reduced or removed to account for the salt content of glycerol.

Methanol. In the production of biodiesel, 100 pounds of fat or oil (usually soybean oil) are reacted with 10 pounds of a short chain alcohol (usually methanol) in the presence of a catalyst to produce 100 pounds of biodiesel and 10 pounds of crude glycerol (National Biodiesel Board, 2008b). The methanol is usually recovered by flash evaporation or distillation. However, the recovery is not complete. The degree to which the methanol is removed from crude glycerol depends on economic conditions, the intended market for the glycerol, and the efficiency of methanol recovery from biodiesel. Crude glycerol available for livestock feeding can range from less than 100 ppm up to 3,200 ppm methanol. Methanol can be toxic if consumed at high concentrations but the toxicity of methanol in pigs has not been well established. Lammers et al. (2008) fed pigs diets containing glycerol with 3,200 ppm methanol for 138 days such that final diet concentrations of methanol potentially reached 640 ppm. They reported no effect of diet on kidney, liver, and eye tissues collected to determine the presence of toxicity lesions. Schieck (unpublished) fed finishing pigs a diet with glycerol that contained 1,000 ppm methanol for 12 days and detected no reduction in pig performance or evidence of ill health in the pigs.

Legality of feeding crude glycerol with high levels of methanol is not clear. Pure glycerol can be feed to livestock as a GRAS (Generally Recognized As Safe) substance. However, crude glycerol does not have GRAS status nor does it have an AAFCO (American Association of Feed Control Officials) definition. In the absence of these typical definitions used in the feed industry, the FDA applies United States Pharmacopeia (USP) and Food and Chemical Codex (FCC) standards for pure glycerol to crude glycerol. USP and FCC standards limit methanol concentration in glycerol to less than 150 ppm. A statement from FDA officials suggests some latitude in this regulation for crude glycerol if elevated concentrations of methanol in glycerol "were shown to be safe for use in animal diets". Recently, the Texas State Chemist ruled that crude glycerol used in livestock feeds may not exceed 1% methanol (10,000 ppm) with inclusion rates of glycerol not to exceed 10% of the diet.

Handling crude glycerol. Crude glycerol is a liquid with a viscosity slightly thicker than cooking oil. Glycerol weighs 10.4 lbs per gallon compared with vegetable oil that weighs about 7.7 lbs per gallon. Mixing high concentrations (8 to 10%) in swine diets may require careful consideration of flowability of the final feed. In our research, diets containing 8 to 9% crude glycerol exhibited some initial problems with bridging in bulk storage bins but flow was easily established. Once the feed began flowing out of the bin, flow was easily maintained. During winter, crude glycerol does not freeze but does become thicker making pumping of glycerol into feed mixers more difficult.

Summary

Our initial assessments suggest that crude glycerol is a viable feed ingredient to supply energy to diets for growing-finishing pigs and lactating sows. Special considerations of salt concentrations, methanol content and handling characteristics are necessary to make crude glycerol a practical feed ingredient in commercial pork production systems.

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