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The effect of extracted corn germ from a fractionation process on pig growth performance and carcass characteristics

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Effect of extracted corn germ from a fractionation process on pig growth performance and carcass characteristics

by

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in partial fulfillment of the requirements for the degree of

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Chapter 1. Introduction

Using current federal ethanol policy, U. S. ethanol production from corn is projected to climb to 14.8 billion gallons by 2011 and corn will be at an equilibrium price of $4.43 (Tokgoz et al., 2007). At this price, production costs for pork production will increase by 18.4 percent. For every $1/bushel increase in price of corn, there is a $4.50 increase in cost of production per 45 kg of live weight gain. In general, every $0.10/bushel increase in corn price equates to a $0.50 increase in cost of pork production (Lawrence, 2006). Since the cost of feeding swine represents 50-60% of total production cost and corn is approximately 80% of the cost for the grow-finish diet, an increase in ethanol production could be very detrimental to pork producers. Under this federal mandate, crop farmers and pork producers have become competitors for corn instead of partners in the production process. This has forced pork producers to re-evaluate the ingredients they use as the major protein and energy sources in the diets.

Under traditional dry-grind ethanol production, distillers dried grains with solubles (DDGS) is the co-product that can be utilized for pig diets. Not only does DDGS have large variation from plant to plant for amino acid (Stein et al., 2006) and energy content (Pederson et al., 2007), but a range in suggested inclusion level of 10 to 30% in the pig diet also exists. Also, the addition of DDGS in swine diets did not affect meat quality, but had a detrimental effect on fat quality as it produces a softer, more unsaturated fat which is not ideal for the abbatoir (Whitney et al., 2001; Whitney et al., 2006; Xu et al., 2007; and Weimer et al., 2008).

Due to shrinking margins for ethanol plants and pork producers resulting from high corn prices, ethanol plants need co-products to generate more revenue and pork producers
needs a consistent co-product to incorporate into their diets as a protein or energy source. This has given rise to a new generation of ethanol plants with technology to fractionate corn before it enters the fermentation process, allowing ethanol plants and pork producers to utilize different parts of the corn kernel. Ethanol plants would utilize the endosperm, which contains the starch, and the pork producer would use the germ, which contains more protein.

Widmer et al. (2008) utilized 2 co-products in swine diets from a fractionation process, with the co-products having a varying degree of success in improving pig performance and carcass quality. The current study utilized extracted corn germ (ECG) from a different fractionation process for use in swine diets. Unlike the Widmer et al. (2008) fractionation process examined, ECG from this process does not go through the fermentation and drying process. This is also different from the traditional DDGS of dry-grind ethanol plants utilized today by most producers. Therefore, ECG has the potential to have less variability in energy content and amino acids compared to traditional DDGS utilized today. The objective of this study was to determine the effect of ECG from a fractionation process on growth performance, carcass characteristics, meat quality, and fat quality on grow-finish pigs.

**Thesis Organization**

This dissertation is organized as a literature review followed by a paper which is in the style and form of Livestock Production Science, followed by a general summary of the complete dissertation. This review of literature examines the impact of ethanol production on pork production, plus the different ethanol processes. The review also focuses on the role that corn and other co-products play in the manipulation of growth performance, meat quality, and fat quality, as well as carcass composition effects on meat quality. The research
reported in the paper was conducted by Ben W. Isaacson under the direction of Dr. Tom J. Baas, Dr. Mark S. Honeyman, and Dr. James B. Kliebenstein, and with financial support from Cargill Animal Nutrition, and Farmers Cooperative (Ames, IA).
Chapter 2. Literature Review

**Economic Impact of Ethanol Production on Pork Production**

Elobeid et al. (2006) examined the long-term impact of ethanol production on the grain and livestock sector. They calculated ethanol plant revenue of $5.67 for each gallon of ethanol per bushel of corn, and a value of $0.66 for DDGS per bushel of ethanol (including the tax credit). Thus, the ethanol plant gross revenue is $6.33. To produce the ethanol from one bushel of corn it costs $2.28 (variable plus fixed costs), which does not include the cost to buy the corn. Therefore, an ethanol plant’s breakeven price it can pay for corn is $4.05 ($6.33 - $2.28) per bushel.

With these estimates, Elobeid et al. (2006) believed ethanol expansion will continue until corn price exceeds $4.05. Plus, United States (U.S.) exports will decrease with expansion of ethanol production; once ethanol production reaches 22 billion gallons a year there will be no surplus of corn. As ethanol production increases so will world corn prices, and therefore the cost of production for pork producers at $4.05 per bushel for corn, the cost per pig will be approximately $58.00 per hundred pounds on a live weight basis. With this price increase, the pork industry will have to decline 10 to 15%, or increase demand by the same amount, to remain profitable.

Tokgoz et al. (2007) demonstrated that the value of DDGS is tied to corn prices. Since DDGS has a higher feeding value replacing corn in ruminant diets it is a competitor of corn, not a complement of corn. This logic comes from the fact for every 17 lbs of DDGS produced, 56 lbs of corn is taken off the market a ruminant producer only gets 17 lbs in their diet versus 56 lbs of equivalent energy, therefore the price of DDGS needs to be much less than corn for it to be cost competitive. For these reasons, other non-ruminant species will not
include the maximum level of DDGS in their diets simply because it is not economical, and eventually turn back to corn-soybean meal diets.

Tokgoz et al. (2007) also described the impact ethanol production could have on world food prices and the cost of production for livestock producers. At the time of their study (May 2007), with an increase of $1.50 per bushel of corn from July 2006, food prices in the U. S. had increased by approximately $47 per person. Multiplying this cost by 300 million American consumers resulted in a total cost of ethanol of about $14 billion. In addition, taxpayers have contributed $0.51 per gallon of ethanol. Because the world follows U. S. food prices, world food prices have also increased.

In their model, corn will end up at an equilibrium price of $4.43 per bushel. At this price, production costs for pork production will increase by 18.4%. With an increase of 18.4% in live hog prices, a 4.2% increase in retail pork prices would result. However, passing this price increase to the retail pork prices does not happen without increasing demand either domestically or overseas. Therefore, the more likely scenario instead of 18.4% increase in live hog prices is a reduction in total pork production to account for the increase in cost of production.

Lawrence (2006) evaluated the impact of corn price on pig feed cost. Feed cost is 50-60% of the total production cost, and corn is 80% of the cost for the grow-finish diet. For every $1 per bushel increase in corn, which equals a $10 increase in cost of corn and soybean meal per ton, there is a $4.50 increase in cost of production per hundred pounds of gain. In general, every $0.10 per bushel increase in corn price equates to a $0.50 increase in cost of pork production. In addition, Lawrence (2008) reported, a cost of production of approximately $70 per hundred weight on a carcass basis.
Plain (2007) evaluated corn and pig prices for the coming months and years. He predicted corn prices will be about $4/bushel or higher for the coming months until a corn user is squeezed out of the market. Even then he theorizes the price of corn for the next 35 years will be between $3-4.00/bushel. For 2008, Plain expects the pig price to be $62.00 per hundred pounds of carcass weight, and in 2009 to be in the low $60s.

**Traditional Ethanol Processes**

Bothast et al. (2004) reported the recent growth in the ethanol industry is due to political mandates. Ethanol is a viable renewable energy as it decreases U. S. dependence on foreign oil and is a new market for grain farmers. Plus, it is a biodegradable product that burns cleaner at a higher octane level than gasoline.

Traditionally, corn grain for ethanol was processed in a wet-mill refinery, which is a true bio-refinery. From one bushel of corn a wet-mill produces 2.5 gallons of ethanol, 1.6 lbs of corn oil, 2.6 lbs of gluten meal, and 13.5 lbs of gluten feed. This is possible because the wet mill separates the kernel into its components of starch, fiber, gluten, and the germ. Starch is used in ethanol production. The germ is extruded for corn oil, and its remaining product is added to the fiber to form corn gluten meal, which can be utilized by livestock. However, the wet-mill refinery requires more capital and is more energy intensive (Bothast et al., 2004). Currently, wet milling is used primarily to produce high fructose corn sweetner.

Furthermore, Bothast et al. (2004) that due to the high cost of production for the wet-mill, the dry grind ethanol plant has been incorporated in most of the Midwest for ethanol production. In this process, corn is ground and water is added to form a mash. The mash is cooked and enzymes are added to convert the starch to glucose. Next, yeast is added to the sugar and fermentation occurs, producing ethanol and solids. Then the ethanol, plus the
solids, are distilled and dehydrated to produce fuel-grade ethanol and the solids are dried to produce DDGS. Drying the DDGS is one third of the cost of production to the dry grind ethanol plant. In the end, one bushel of corn produces 2.8 gallons of ethanol, 17 lbs of DDGS, and 17 lbs of CO₂. The CO₂ can be captured and sold to the beverage industry for carbonation purposes, and the DDGS can be sold to the livestock industry as a viable feed source. All together, the recent growth in dry grind ethanol plants is due to the lower capital costs per gallon and incentives for farmer-owned ethanol plants through cooperatives.

Weldon (2003) confirmed some of the results from Bothast et al. (2004). If 100 kg of corn were converted into ethanol, during the mashing/cooking phase 70 kg of the corn would become starch and 30 kg would become DDGS. After the mashing and cooking, 70 kg of starch is hydrolyzed into 77.8 kg of glucose. Next, 77.8 kg of glucose is fermented into 38.9 kg of ethanol and 38.0 kg of CO₂.

Ferris (2006) compared the viability of a wet-mill ethanol plant versus a dry-mill ethanol plant. Even though a wet mill is the true “bio-refinery”, dry mills will be the emphasis for future expansion in ethanol production. This is due to the fact dry mills are more flexible in selecting their locations and have reduced capital investments.

**Future Ethanol Processes**

Duensing et al. (2003) described the process of dry grind corn milling. In dry grind corn milling, the corn is initially separated into the tail and the through. The tail contains large pieces of the endosperm, which is 80% starch. The tail is then ground down to brewer’s grits, flour, flaky grits, coarse grits, and meal, and the starch within the tail can be used for ethanol production. The through contains the germ, bran, and small portions of the endosperm. The endosperm is either put back into the tail for processing, or processed into
standard meal. The bran in the through is used for either human use or is combined, dried, and ground. The germ can have two alternatives; it can either be extruded for corn oil and then processed to a germ cake, or processed down to germ cake with no corn oil extrusion. The germ cake, bran (combined, dried, and ground portion), and standard meal are combined to form hominy feed. Hominy feed can be used as dairy feed mixes, swine feed mixes, cattle feed mixes, and aquatic feed mixes. The use of this process, separating the parts of the corn kernel, is another example of separating the corn kernel before processing, comparable to the wet-mill process.

Huang et al. (2008) examined the areas of corn separation for current and future bio-refineries. These new separation technologies are based on the conventional dry mill process, but processes have been added to recover the germ or both germ and fiber before fermentation. These modified dry-grind processes allow for further reduction of cost to the ethanol plant and producing more co-products for income. The corn oil and the germ meal recovered from the germ have a much higher potential price ($0.53-0.66/kg) than that of DDGS ($0.13-0.20/kg). The combination of germ recovery as a co-product and the increase in the fermentation capacity leads to ethanol cost reduction of $0.0269/L ($0.1010/gal or $0.2635/bushel), compared to the conventional dry grind process.

Baker and Babcock (2008) examined the profitability of the Renew Energy plant in Jefferson, Wisconsin, which produces a high protein meal, high fat corn germ, and corn bran from fractionating the corn before it enters the fermentation process. The main reason an ethanol plant would adopt this technology is if they can generate more value than the traditional ethanol-DDGS model. The Renew Energy technology produces 7 pounds of high protein meal, 4 pounds of corn germ, and 4 pounds of bran for every bushel of corn.
processed. Using nutrient values supplied by Renew Energy, it can be determined the amount of corn and soybean meal that can be replaced in swine diets by Renew Energy co-products based on least-cost formulation. Baker and Babcock (2008) data concluded that with corn at $4.65 per bushel and soybean meal at $337.00 per ton, there is little incentive for ethanol plants to adopt the Renew Energy fractionation procedure.

Bista and Tyner (2008) evaluated the co-products from Poet LLC’s fractionation process fed to pigs on a least-cost diet formulation. Co-products from the fractionation process include fractionated DDGS and germ. These co-products were compared to Iowa DDGS from an ethanol plant in West Burlington, IA. Iowa DDGS had a lower total diet cost than fractionated DDGS and germ in all diet phases. Germ had a lower total diet cost than fractionated DDGS for grower and sow diets, and fractionated DDGS had a lower total diet cost for finisher diets. This is due to the nutrient profile of the germ and the fractionated DDGS compared to normal DDGS.

Rausch and Belyea (2006) explored the future role that co-products will play in corn processing. After examining the current situation of wet milling versus dry grinding for ethanol production, it was determined dry grinding is preferred due to less capital cost, but lacks the revenue from co-products produced by wet milling. The dry grind process only produces ethanol and DDGS, and the wet mill process fractionates the corn (the germ, fiber, and endosperm) before it enters ethanol production producing many co-products to be marketed. Thus, a combination of the dry grind and the wet mill (modified dry-grind) corn processes is needed to add co-products to current dry-grind plants.

Rausch and Belyea (2006) identified several factors that can place pressure on the value of co-products produced, including issues of supply and demand, compositional
variation, nutritional value, and environmental issues induced by the addition of co-products to the market. For a modified dry-grind plant to be profitable, their co-products must address these issues.

There are three versions of the modified dry-grind plant discussed by Rausch and Belyea (2006). The quick germ (QG) process separates the germ, and the rest of the corn ferments to ethanol. The germ can be further processed by extracting the corn oil, which is a marketable co-product. The co-products produced are corn germ, corn oil, ethanol, and DDGS. In the quick germ quick fiber (QGQF) process, germ and the pericarp fiber are recovered before the production of ethanol. The same co-products are produced with the addition of corn fiber which has a cholesterol-lowering (of interest in human nutrition) effect and high market value, and the DDGS has less fiber content. Finally, in the enzymatic dry-grind process the germ, pericarp fiber, and endosperm fiber are recovered before ethanol production. The same co-products are produced and the DDGS are higher in protein and have less fiber content. Rausch and Belyea (2006) concluded the addition of fractionating corn before ethanol production to a dry-grind ethanol plant will allow it to be sustainable and profitable in the future.

One fractionation process (Wolfe, 2008) separates the corn into two streams, a low oil fraction which contains the endosperm and a high oil fraction which contains the germ and the bran. The low oil fraction is useful for fermentation to ethanol, ruminant feed (DDGS), sweetener production, snack food, and starch production. Corn oil is extracted from the high oil fraction by use of a solvent, leaving corn germ meal. The corn oil can be utilized for food production, bio-diesel, lubricants, cosmetics, and oil-based or oil-containing chemicals. Corn germ meal can be used in swine-finishing diets, poultry feed, snack food, biodegradable
products, and a fermentation product. This fractionation process allows the modern dry-grind ethanol plants to act as a true bio-refinery, typical of a wet-mill ethanol plant.

**Yellow Dent Corn Compared to Different Corn Varieties**

Lampe et al. (2006) examined 999 pigs from 2 genetic lines and 5 dietary treatments to determine the effect of dietary energy source (yellow corn, white corn, and barley) on various compositional and quality characteristics of pork from pigs reared in a commercial environment.

There were no differences among the 5 treatments for 24 hour pH. The pH at day 25 to 27 post-slaughter displayed a difference (P < 0.05) in favor of the pigs fed 2/3 yellow corn and 1/3 white corn over pigs fed the diet containing yellow corn. Loins from the pigs fed 2/3 yellow and 1/3 white corn had a darker (P < 0.05) loin than pigs fed the diet containing barley. Plus, pigs fed the 2/3 yellow and 1/3 white corn diet had a significantly greater subjective color score (P < 0.05) than pigs fed white corn, 1/3 yellow, and 2/3 white corn, and pigs fed barley. No differences were found among diets in this study for subjective measurements of fat color, but there was a difference (P < 0.05) for objective fat color with pigs fed the barley diet having a more desireable fat color than pigs fed the white corn diet.

Swantek et al. (1996) performed a study to evaluate the effect waxy corn would have on performance and carcass composition. One hundred and sixty pigs were allocated to five treatments diets consisting of 0, 25, 50, 75, or 100% replacement of yellow dent corn with waxy corn. Results from indicated pigs fed waxy corn had significantly (P < 0.05) less 10\textsuperscript{th} rib backfat than pigs fed yellow dent corn. Plus, there was a trend (P < 0.10) for the pigs on waxy corn to have more marbling and increased percent lean. There were no differences between the treatment diets when comparing average daily gain (ADG), average daily feed
intake (ADFI), and feed to gain (F:G). Thus, they concluded waxy corn can be substituted for yellow dent corn with no detrimental effects on performance and there may be a slight improvement in carcass characteristics.

Johnston and Anderson (1996) fed 240 nursery pigs 2 treatments of corn-soybean meal diets utilizing either corn or waxy corn as the main energy source in a 28 day trial. Results indicated no difference between treatment diets for ADG or F:G.

Fent et al. (2003) studied 340 pigs, (170 gilts and 170 barrows) which were fed diets consisting of white or yellow corn from 27 kg to market weight to compare the effect of the 2 diets on growth performance and carcass composition. Growth performance measurements between the 2 diets were not different with the exception of ADG, with pigs fed the diet consisting of white corn being significantly (P < 0.05) greater than pigs fed the yellow corn. Plus, there were no differences between the 2 treatments for loin muscle area (LMA), backfat (BF), color, marbling, firmness, and pH. Furthermore, BF color was not different for the 2 treatments. Fent et al. (2003) concluded that white corn can replace yellow corn in the diet and have no detrimental effect on growth performance or carcass composition.

Forty crossbred growing-finishing gilts were allotted to 2 dietary treatments of either waxy or nonwaxy corn to evaluate the effect on growth, carcass traits, and meat quality (Camp et al., 2003). Results indicated ADG was greater for pigs fed waxy corn (P < 0.08) than pigs fed nonwaxy corn; this was attributed to waxy corn having a higher amount of available energy. Plus, pigs fed waxy corn had a greater a* value (P < 0.08) than pigs fed waxy corn; this is considered a minor change in meat color. The low number of replicates and small sample size may be the reason differences in average daily gain and meat color were significant.
Forty-eight crossbred barrows and forty-eight crossbred gilts were evaluated by Carr et al. (2005) to determine the effect of ractopamine hydrochloride and different cereal grains on performance, carcass characteristics, and fat quality in late-finishing pigs. There were no significant differences between corn, barley, or wheat-based diets for performance, carcass characteristics, meat quality, and fat quality.

Hastad et al. (2005) conducted 2 experiments to compare the growth performance of pigs and feeding value of Nutridense (ND) corn, Nutridense low-phytate (NDLP) corn, and yellow dent (YD) corn. The first study utilized 315 barrows in a research setting (Exp. 1) and the second study in a commercial research facility (Exp. 2) compared only ND corn and YD corn. Pigs from Exp. 2 were further compared for carcass characteristics.

In Exp. 1, Hastad et al. (2005) determined there were no differences in ADG among corn sources, but ADFI decreased (P < 0.02) and G:F increased (P < 0.05) for pigs fed ND and NDLP corn compared to YD corn. Also, it was determined that ND and NDLP corn had ME values of 4.5% and 2.5%, respectively higher than YD corn.

In Exp. 2, there was no difference between ADFI and G:F, but pigs fed ND corn had increased (P < 0.05) ADG compared to those fed YD corn. Plus, the ME value of ND corn is 5.3% greater than that of YD corn. Corn source had no effect on carcass criteria (BF, % lean, loin depth) except pigs fed YD corn had a greater dressing percentage (P < 0.05) than pigs fed ND corn. Thus, it was determined that the increase in ADG, ADFI, and G:F of the pigs in the 2 experiments was due to the increased amount of ME in the ND corn and NDLP corn diets compared to YD corn (Hasted et al., 2005).

Opapeju et al. (2006) evaluated twenty-four pigs (12 gilts and 12 barrows) fed 3 different diets, 1 diet barley-based and 2 diets each based on the first and second most
cultivated corn hybrids in Manitoba, Canada. They utilized these pigs and diets to compare the effect of Manitoba-grown hybrids on growth performance and carcass characteristics of growing-finishing pigs using a barley-based diet as a control. There were no differences found between any of the diets for growth performance, carcass characteristics, or fat color ($b^*$).

Muley et al. (2007) studied the ileal digestibility of corn components obtained by dry milling. Eight cannulated barrows were fed the different corn components (either the endosperm, hull, or germ) for 7 days, with collection of the ileal cannula the last 2 days. When comparing the chemical composition with corn, the germ had a greater amount of total amino acids (AA) (12.8% vs. 8.3%), was richer in neutral detergent fiber (NDF) (17.2% vs. 9.8%), and had a greater amount of phosphorus (P) (1.19% vs. 0.21%). Despite this, the germ had reduced ileal dry matter digestibility when compared to corn ($P < 0.01$), which can be explained by this fraction being high in NDF which has a strong negative effect on digestibility. Also, the germ is high in the phytate form of P which is indigestible by the pig, thus the germ had a very low ileal P digestibility (7.9%), which was lower ($P = 0.02$) than that of corn (41.6%). Furthermore, the ileal digestibility of AA was reduced on average by 10% in the germ ($P < 0.05$) when compared to corn. In conclusion, the authors determined feeding the germ when compared to corn would have detrimental effects on AA and P digestibility.

A total of 288 crossbred barrows were examined by Moore et al. (2008) using 6 different diets (treatments) consisting of a different corn hybrid for each treatment. The objective of the study was to determine the relationship between physical and chemical traits among several commercially available corn hybrids with growth performance and carcass
quality in pigs. The authors showed in this study there were no differences between the hybrids for percentage lean, BF thickness, LMA, intramuscular fat (IMF), ultimate pH, and Hunter color scores.

However, Moore et al. (2008) results indicated there were small, but statistically significant, effects between the treatments for growth performance. The hardness of the corn kernel was positively correlated with ADG during the grower 1 phase (r = 0.26, P < 0.05), ADFI during the grower 2 phase (r = 0.27, P < 0.05), and final body weight (BW) at the end of the finisher phase (r = 0.27, P < 0.05); however, it was not correlated with overall ADG and G:F. The hardness of the corn kernel correlates to the amount of amylopectin to amylase and a harder corn kernel correlates to an increased amount of amylopectin. Amylopectin has more bioavailability for the pig, thus increasing the amount of energy in the corn kernel available to the pig. Despite this, there should have been decreased ADFI and increased G:F with the correlation for ADG in the grower 1 phase. Thus, the increase in ADG is unlikely the result of more amylopectin in the corn.

The amount of NDF and acid detergent fiber (ADF) content in the corn kernel also had an impact on performance. Neutral detergent fiber was negatively correlated to BW (r = -0.33, P < 0.05) and ADG (r = -0.30, P < 0.05) during the finishing phase, also positively correlated to increased number of days to market (r = 0.31, P < 0.05). Acid detergent fiber was negatively correlated to ADG (r = -0.26, P < 0.05) during the grower 1 phase and BW (r = -0.26, P < 0.05) at the end of the finisher phase (Moore et al., 2008).

It was concluded that since the r values were relatively low for the hardness of the kernel, NDF, and ADF correlated to performance, it was detrimental to single-trait select corn hybrids for swine production. If feasible, it would be optimal to select corn with a hard
kernel, plus be low in NDF and ADF. By selecting for these traits, Moore et al. (2008) determined a pig producer could account for 24% of the variation in final BW, according to r values for kernel hardness, NDF, and ADF.

**DDGS**

Cromwell et al. (1993) examined 9 sources of DDGS, 7 from a beverage alcohol plant and 2 from a fuel ethanol plant, evaluating them in the chick and the pig to assess the degree of variability in physical properties and chemical composition. The AA content, especially lysine, was extremely variable; lysine content varied between 0.43 to 0.89% among the 9 DDGS. The lysine content was the highest in the lightest colored DDGS, with a correlation between Hunter L* and lysine of 0.67 (P < 0.05). Furthermore, increased darkness of the DDGS tended to result in an increase in ADF (P < 0.10) and was significant in ADIN (P < 0.01). In conclusion, Cromwell et al. (1993) indicated darker-colored DDGS were of poorer nutritional quality, which was caused by overheating of the DDGS during the drying process. Due to differences in the drying process, there is much variability in DDGS coming from both beverage alcohol and fuel alcohol production.

Whitney et al. (2001) utilized pigs in trial to determine the effect DDGS has on growth performance and carcass composition. A total of 240 grow-finish crossbred pigs were randomly assigned to one of 4 dietary treatments consisting of 0, 10, 20, and 30% DDGS inclusion level. Their results indicated pigs fed 20 and 30% DDGS had decreased ADG (P <0.10) compared to pigs fed 0 and 10% DDGS diets, but ADFI was unaffected. Feed-to-gain increased with pigs fed the 30% DDGS inclusion level (P < 0.10) compared to pigs fed 0, 10, and 20% DDGS diets. Dressing percentage decreased linearly (P < 0.03) with increasing amounts of DDGS, but slaughter weights also decreased with pigs fed 20 and 30%
DDGS diets (P < 0.05). It was determined DDGS could be fed up to 20% in the grow-finish diet without a negative effect on growth performance when formulating on a digestible amino acid basis.

Loin depth decreased for pigs fed 30% DDGS diets (P < 0.10) compared to the other dietary treatments, but BF depth and lean percentage did not differ. It was determined DDGS could be fed up to 20% in the grow-finish diet without a negative effect on carcass composition (Whitney et al., 2001).

Whitney et al. (2006) utilized 240 crossbred pigs from grow to finish to examine the effect of increasing levels of DDGS, 0, 10, 20, and 30% in the diet (formulated on a total AA basis) on growth performance and carcass quality. Including 20 or 30% DDGS in the diet resulted in decreased ADG (P < 0.05) when compared to pigs fed diets of 0 and 10% DDGS, but ADFI was the same among treatments. Thus, pigs fed the 30% DDGS diets had a lower G:F (P < 0.05) than pigs fed 0 and 10% DDGS. Furthermore, final BW was greater (P < 0.05) for pigs fed dietary treatments of 0 and 10% DDGS than for pigs fed 20 and 30% DDGS. Therefore, when formulating on a total AA basis, the addition of DDGS above 20% has an unfavorable effect on growth performance.

Slaughter weights tended to be greater for pigs fed the 0 and 10% DDGS treatments (P < 0.10), thus as the level of DDGS percentage in the diet increased, carcass weight decreased linearly (P < 0.01). Backfat and lean percentage were unaffected by dietary treatment, but loin depth decreased linearly with the addition of DDGS in the diet (P < 0.05). Iodine value increased linearly (P < 0.05) as the dietary concentration of DDGS increased, thus belly fat became more saturated. Although significant, iodine values were not far above 70 for treatments fed 20 and 30% DDGS (70.6 and 72.0, respectively), which is adequate for
industry standards. Despite this, belly firmness scores were lower (P < 0.05) for pigs fed
30% DDGS, indicating these bellies were softer than pigs fed 0, 10, and 20% DDGS diets. 
Ultimate pH, Hunter L*, subjective color, firmness, and marbling scores were all unaffected 
by dietary treatment. Thus, Whitney et al. (2006) concluded that addition of DDGS had no 
effect on meat quality, but could affect fat quality and carcass weight. 

Stein (2008) compiled results from studies that looked at the effect of DDGS on pig 
performance and carcass characteristics: 17 experiments examined pig performance, 10 
experiments examined dressing percentage, and 13 experiments examined carcass 
characteristics. 

Stein (2008) reported that ADG and ADFI for pigs fed DDGS were improved for 1 
experiment, reduced in 6, and not affected by treatment in the remaining 9 experiments. 
Gain-to-feed was improved in 4 experiments, reduced in 3 experiments, and not affected by 
dietary treatment in 10 of the experiments. Inclusion of DDGS in diets fed to finishing pigs 
increased dressing percentage in 1 experiment, reduced dressing percentage in 6 experiments, 
and was not affected by dietary treatment in 3 of the experiments. 

Lean percentage was unaffected by dietary treatment with the exception of 1 
experiment. Plus, a reduction in belly firmness was observed and the iodine value in 3 
experiments was increased with the inclusion of DDGS. Stein (2008) concluded these 
compiled results show the variability in performance and carcass characteristics when DDGS 
is included in the pig diet. 

One-hundred and forty crossbred pigs were assigned to 5 different dietary treatments 
to evaluate the effect of increasing levels of DDGS (10, 20, and 30 %) on pig growth and 
carcass traits in a study conducted by Weimer et al. (2008). Overall ADG (P < 0.10) and G:F
(P < 0.01) decreased as DDGS levels increased to 20 and 30 %. Hot carcass weight (P < 0.10) and dressing percentage (P < 0.01) decreased linearly as DDGS inclusion levels increased. Tenth rib BF depth (P < 0.03) decreased linearly as DDGS inclusion levels increased, while LM marbling, firmness, color, and 24 hr pH were not affected. Plus, belly firmness decreased (P < 0.01) as the DDGS inclusion level increased. In conclusion, Weimer et al. (2008) determined diets formulated on a digestible lysine basis containing up to 10 % DDGS can be fed to grow-finish pigs without decreased growth performance and carcass traits, but results must be carefully examined.

Xu et al. (2007) studied 512 pigs fed 4 different dietary treatments consisting of DDGS inclusion levels of 0, 10, 20, and 30% to determine the effect of DDGS on growth performance and pork quality. Overall ADG was not different among the dietary treatments. Pigs fed 20% (P < 0.05) and 30% DDGS (P < 0.01) had lower ADFI and F:G compared with the pigs fed the control and 10% inclusion level diets. Also, pigs fed 20% (P < 0.05) and 30% (P < 0.01) DDGS had a lower dressing percentage than pigs fed the control or the 10% DDGS diets. This indicates feeding up to 30% DDGS in the diet will not have a negative effect on ADG.

Xu et al. (2007) also reported that percentage of fat-free lean, subjective color, and ultimate pH were not affected by dietary treatment. Compared to the control pigs, marbling was reduced (P < 0.05) for the pigs fed the 20% and 30% DDGS diets. Loin firmness was reduced (P < 0.05) for pigs fed 30% DDGS diets compared to the control diet. Belly firmness was reduced for pigs fed 20% (P < 0.05) and 30% (P < 0.01) DDGS compared to pigs fed the control pig fed diet. There were no differences in dressing percentage, loin marbling, loin muscle firmness, or belly firmness between the control pigs and pigs fed 10%
DDGS diets. Belly fat Minolta L*, a* and b* color values were not different for any of the dietary treatments. For BF, Minolta L* indicated a darker color for pigs fed 20% (P < 0.01) and 30% (P < 0.05) DDGS diets compared to control-fed pigs. No differences were observed for Japanese color score in the belly and in BF. Thus, Xu et al. (2007) concluded feeding diets containing 20% or higher levels of DDGS appears to have unfavorable effects on pork quality.

Hinson et al. (2007) examined 882 barrows reared in a commercial facility allotted to 3 dietary treatments with inclusion levels of 0, 10, and 20% DDGS to determine the effect DDGS had on growth performance and carcass characteristics. Overall ADG, ADFI, final BW, and carcass weight were reduced (P < 0.01) when DDGS were included in the diet, but there were no differences between the DDGS inclusion levels. Feeding of DDGS also resulted in fewest $/pig received (P < 0.01). Therefore, feeding of DDGS resulted in reduced overall growth and decreased return per pig (Hinson et al., 2007).

Fu et al. (2004) fed 256 barrows dietary treatments consisting of 0, 10, 20, and 30% inclusion levels of DDGS to determine the effect of DDGS on growth performance and carcass characteristics. The addition of DDGS resulted in a linear decrease in feed intake (P < 0.001), ADG (P < 0.001), and body weight (P < 0.01) after 92 days on test. There were no differences observed in G:F for the 92-day test, however, G:F was improved in a linear manner (P < 0.01) for the first 42 days on test with increasing DDGS. Carcass weight was reduced linearly (P < 0.002) as dietary DDGS levels increased, but there were no differences in BF, LD, and percentage lean among all treatments.

Three studies were conducted to evaluate the effect of DDGS on palatability and feed intake of growing pigs when compared to a control corn-soybean meal diet by Hasted et al.
In Exp. 1, the authors put 90 gilts in the same pen giving them the option of a corn-soybean meal diet, a diet with 30% inclusion of DDGS from an ethanol plant built before 1990, and a diet with 30% inclusion of DDGS from an ethanol plant built after 1990 (considered a modern ethanol plant). From day 7 to 13 and overall, ADFI was lower \( (P < 0.01) \) for pigs both of the DDGS diets. In Exp. 2, 187 barrows and gilts were used to examine the effect of increasing the inclusion level of DDGS (0, 10, 20, and 30%) on feed intake. Increasing DDGS decreased (linear; \( P < 0.01 \)) ADFI for the overall trail. In Exp. 3, 120 barrows and gilts were used to examine 0 and 30% inclusion levels of DDGS in the diet and the addition of Sucram, a feed flavor additive, on ADFI. The addition of Sucram had no effect on feed intake, while the pigs on the 30% inclusion level diet had a decreased ADFI \( (P < 0.01) \). Hasted et al. (2005) determined these studies show when a pig is given preference, it would prefer a diet containing corn-soybean meal with no inclusion of DDGS; regardless of which ethanol plant the DDGS came from.

DeDecker et al. (2005) studied growth performance of 2,560 growing pigs with different inclusion levels of DDGS in the diet (0, 10, 20, and 30%). For this study there was no difference in ADG or ADFI for the pigs fed the 4 different inclusion levels, however, including DDGS at 20 or 30% resulted in a small improvement \( (P < 0.05) \) in G:F compared to the 0% treatment. Therefore, DDGS can be included at up to 30% of the diet without detrimentally affecting growth performance.

Pigs were split-sexed into 2 commercial grow-finish barns (1,040 pigs per barn) by Cook et al. (2005) to determine the effect of feeding 0, 10, 20, or 30% DDGS from a new generation ethanol plant on growth performance and carcass characteristics of grow-finish pigs. They reported there DDGS inclusion level did not affect BW, ADG, ADFI, or G:F.
This suggests that DDGS up to 30% inclusion levels can be fed without affecting growth rate of the pig. Plus, there were no differences in carcass characteristics with the exception of carcass yield decreasing linearly as dietary DDGS inclusion level increased (P < 0.01). Thus, feeding of DDGS up to 30% inclusion level is acceptable when taking into account the economic value of the decrease in carcass weight.

Widmer et al. (2007) utilized 42 barrows to measure digestibility values for energy, crude protein (CP), P, and AA in high-protein distillers dried grains (HP-DDGS) and corn germ when fed to growing pigs. The DE and ME levels did not differ between corn and corn germ, but had significantly greater values for HP-DDG (P < 0.01). This is probably due to the increased fat in HP-DDG and the increased amount of fiber in the corn germ.

Phosphorus (P) intake was greater for the corn germ compared to HP-DDG (P < 0.05), but P retention was reduced significantly for the corn germ (P < 0.05). Plus, calcium (Ca) intake was different between corn germ and HP-DDG, however, Ca retention/absorption was greater for HP-DDG (P < 0.05). Thus, corn germ may be greater in P and equivalent in Ca, but its P form is more of the phytate form which is not digestible in pigs. As a result, corn germ has less P availability and more of its Ca is bound to the phytate form of P, which makes it less available to pigs (Widmer et al., 2007).

Widmer et al. (2007) indicated the apparent ileal digestibility (AID) for CP was greater (P < 0.05) in HP-DDG than in corn germ. Plus, the AID for all indispensable AA except arginine were also greater (P < 0.05) for HP-DDG than for corn germ. Likewise, the AID values for all dispensable AA except proline were greater (P < 0.05) for HP-DDG than for corn germ. Furthermore, the standard ileal digestibility (SID) for CP in HP-DDG was greater (P < 0.05) than in corn germ. The standard ileal digestibility (SID) values for
arginine and lysine were similar for HP-DDG and corn germ. Despite this, all other indispensable AA SID values were greater (P < 0.05) for HP-DDG than corn germ. Also, SID values for all dispensable AA except glycine and proline were greater (P < 0.05) for HP-DDG than for corn germ. These results are attributed to the high fiber content of the corn germ and to the protein in the corn germ being of lower quality versus HP-DDG.

Eighty-four crossbred pigs were used by Widmer et al. (2008) allotting them 7 different treatments: control corn and soybean meal diet, 10% DDGS, 20% DDGS, HP-DDG displacing 50% of the soybean meal, HP-DDGS replacing 100% of the soybean meal, 5% corn germ, and 10% corn germ. Diets were recalculated for the grower, early finisher, and late finisher phases. Growth performance, carcass quality, and pork palatability were measured for all treatments.

There were no statistical differences between 10% DDGS, 20% DDGS, and the control diet for performance except for gain-to-feed (G:F) in the late finishing phase; the G:F at the 10% DDGS level decreased significantly and then increased at the 20% DDGS inclusion level (quadratic, P < 0.05). In the grower phase, pigs fed HP-DDG had a significant decrease in ADG, ADFI, and final BW (linear, P < 0.05) as the concentration of HP-DDG increased. There were no statistically significant differences in performance for the entire experiment between the control diets and the HP-DDG diets. However, there were trends for the HP-DDG diets compared to the control diet: decreased BW at the end of the finishing phase (linear, P = 0.07), ADFI for the entire experiment decreased (P = 0.08), and decrease in G:F in both the early and late finishing periods (quadratic, P = 0.06) as the inclusion level of HP-DDG increased (Widmer et al., 2008).
Widmer et al. (2008) showed there were no significant differences between the corn germ diets and the control diet for ADFI and G:F for the entire experiment. Despite that, final BW and ADG increased as corn germ was added to the diets (linear, P < 0.05). Furthermore, there were trends displaying increases in performance when the corn germ diets were fed: linear decrease in G:F in the grower phase (P = 0.06), linear increase in final BW in the early finishing stage (P = 0.08), and an increase in ADFI (linear, P = 0.09) in the late finishing phase as the concentration of the corn germ increased. Ultimately, corn germ displayed a trend (linear, P = 0.06) to have a higher ADG than the control diet for the entire experiment.

There were no differences in performance between the treatments fed corn germ and DDGS throughout the entire experiment. However, ADG decreased (P < 0.05) for pigs fed HP-DDG-containing diets compared with pigs fed the DDGS-containing diets in the grower phase and the entire experiment. Also, in the grower and early finisher phases, final BW was greater (P < 0.05) for pigs fed the DDGS diets compared to the HP-DDG diets. It was determined by Widmer et al. (2008) that dietary treatments including corn germ were equivalent to the control and DDGS diets, and all the dietary treatments had greater growth performance than the diets including HP-DDG.

Widmer et al. (2008) indicated carcass composition was not affected by the addition of DDGS and HP-DDG to the diet when compared to the control diet. Despite this, there was a decrease (linear, P < 0.05) in loin Muscle (LM) area and LM depth as HP-DDG was added to the diet. This was most likely because the pigs fed these diets containing HP-DDG were smaller than the control pigs at slaughter. When corn germ was added to the diet, lean
muscle percentage increased significantly (quadratic, $P < 0.01$) and there was a trend for decreased 10th rib BF ($P = 0.052$).

There were no differences between pigs fed HP-DDG and DDGS for any carcass composition measurements. Furthermore, no differences were observed between DDGS and corn germ diets with the exception that lean meat percentage and LM area were greater ($P < 0.05$) for pigs fed corn germ diets (Widmer et al., 2008).

Loin muscle marbling, color, $L^*$, and $a^*$, were unaffected by the addition of DDGS and HP-DDG with the exception of LM $b^*$ values, as there was a decrease (linear, $P < 0.05$) in the values as the concentration of both the DDGS and HP-DDG in the diets increased. Plus, there was a trend (linear, $P = 0.09$) for an increase in LM pH as the concentration of DDGS increased. Corn germ did not affect LM marbling, color, $L^*$, $a^*$, or pH. There was a trend for a decrease in LM $b^*$ value (quadratic, $P = 0.05$) when corn germ was added to the diet. There are no other reports displaying these results when comparing DDGS, HP-DDG, and corn germ diets; thus Widmer et al. (2008) concluded there were minimal differences in meat quality, and the differences would be deemed acceptable for most markets.

Fat color, belly thickness, fat $a^*$, and iodine value were not affected by the addition of DDGS, but belly firmness score and adjusted belly firmness score decreased as DDGS were added to the diet (linear, $P < 0.05$). Fat color and belly thickness were not affected by the inclusion of HP-DDG to the diet, but iodine value increased ($P < 0.05$) as HP-DDG was included in the diets. There was a trend (linear, $P = 0.06$) for a decrease in belly firmness score and adjusted belly firmness score with the addition of HP-DDG into the diet. There was no effect on fat quality with the addition of corn germ to the diets except for a decrease in iodine value (linear and quadratic, $P < 0.05$). No differences were observed in fat quality
between DDGS and HP-DDG diets. Plus, there were no differences between DDGS and corn germ with the exception of a decreased iodine value (P < 0.05) observed in the corn germ diets. One possible explanation for the decrease in iodine value with corn germ diets is the decrease in soybean oil to 0% as the corn germ was added to the diet at the 10% inclusion level; thus there was less unsaturated fat in the diet for the pig to absorb which in turn explains the reduction in iodine values for these pigs. Widmer et al. (2008) concluded corn germ had the least effect on fat quality compared to the control diet, while DDGS and HP-DDG were both detrimental to fat quality.

Field Peas

Stein et al. (2006) conducted a study to determine the effect field peas would have on growth performance, carcass quality, and pork palatability. Forty-eight pigs were fed 3 different treatment diets consisting of a control corn-soybean meal diet, a medium inclusion level of field peas, and a maximum inclusion level of field peas. There were no differences among any of the dietary treatments for ADG, ADFI, and G:F. There were no differences among any of the dietary treatments for LMA, LM depth, BF, lean percentage, loin color, fat color, pH, and marbling. Thus, it could be concluded that inclusion of field peas into the diet did not have a detrimental effect on carcass quality and growth performance.

Njoka et al. (2008) studied the effect of replacing soybean meal in the pig diet with winter, spring, and summer field peas on growth performance and carcass characteristics when compared it to a control corn-soybean meal diet. The authors indicated there were no differences in final BW, ADG, or G:F among the dietary treatments. However, ADFI was influenced by dietary treatments (P < 0.10); pigs consumed less of the corn-soybean meal and spring pea diets when compared to the winter and summer pea diets. There were no
differences between the dietary treatments when evaluating LM area and in fat-free lean. Despite this, pigs fed winter peas had more BF (P < 0.10) than pigs fed spring peas or the control diet.

Njoka et al. (2008) determined that pigs can be fed diets with Iowa-grown field peas at the 30% inclusion level, and when supplemented with synthetic amino acids, all soybean meal and a portion of corn in the grow-finish pig diet can be replaced with minimal effect on performance.

**Hominy Feed**

Stanley et al. (1982) set out to determine the digestible, metabolizable and net energy value of hominy feed utilizing 4 littermate groups of 4 crossbred pigs. The chemical analysis of hominy feed on a dry matter basis was 5.32 % ether extract, 3.12 % ash, 4.00% crude fiber, 11.67% crude protein, 22.22 % NDF, and 3.69 % ADF. The ME of hominy feed was 3.84 kcal/g of dry matter and net energy (NE) was 2.29 kcal/g. This value was about 88% of the NE value for corn reported at this time. In NRC (1998), hominy feed has 94% (2,269 kcal/kg) value of NE as yellow corn (2,395 kcal/kg). Also, the ME value for hominy feed was 3,210 kcal/kg compared to yellow corn at 3,420 kcal/kg. Hominy feed had a 10.3% crude protein, 6.7% crude fat, 28,5% NDF, 8.1% ADF, 0.05% Ca, and 0.43% P. The higher fiber content would explain the reduction in energy value. Furthermore, in NRC (1971), hominy feed with less than 5% fat, had 92.4% ME value (3,527 kcal/kg) of corn (3818 kcal/kg). Also, hominy feed with more than 5% fat had a ME value (3,460 kcal/kg) 90.7% of corn (3,818 kcal/kg).

Loy and Wright (2003) reported a ME value for hominy feed at 3,567 kcal/kg and a ME value for corn at 3,800 kcal/kg. This is 94% the value of corn. Furthermore, hominy
feed had 11.9% crude protein, 6.9% crude fat, 2.7% ash, and 21.1% NDF. This compares to corn which had 8.0% crude protein, 4.2% crude fat, 1.3% ash, and 9.5% NDF. Even though hominy feed has a fat level 2.5% higher than corn, it has a lower ME value because it has a higher fiber content with consists of more cellulose, hemicellulose, and a lower starch content than corn.

**Dietary Energy Effects on Pig Performance and Carcass Characteristics**

Pettigrew and Esnaola (2001) reviewed swine nutrition and the effects it can have on pork quality. They determined a reasonable target for energy intake is the amount needed to maximize protein accretion rate, which is energy intake exceeding maintenance energy needs determined by the pig’s nonnutritional factors (ex. genetics, sex, environment etc.). This would avoid the excessive fatness that comes from higher energy intake. Pigs would be slightly leaner at lower energy intake, but they would also grow more slowly.

NRC (1998) reported maintenance (ME<sub>m</sub>) includes the needs of all body functions and moderate activity with the ideal ME<sub>m</sub> being 106 kcal of ME/kg of BW<sup>0.75</sup>. If this is met, growth will occur which requires on average 10.6 Mcal of ME/kg for protein deposition and on average 12.5 Mcal of ME/kg for fat deposition. Even though the average energy cost is approximately the same, the energy cost for muscle tissue production is considerably less than that for fat tissue deposition.

When analyzing feedstuffs, NRC (1998) reported the addition of fiber to swine diets decreases the digestible energy (DE) concentration of the diet. The digestibility of fiber can vary due to environmental issues such as age, weight, fiber source, and individual variation among pigs. It has been reported that an increase of 1% in dietary CF depressed digestibility of gross energy by approximately 3.5%. Fibrous components are poorly digested in the small
intestine and provide substrates for microbial fermentation in the large intestine. This produces volatile fatty acids which can be used as a maintenance energy source, but is much less efficient than energy digested in the small intestine (57% versus 74%).

Ewan (2001) discussed the use of energy from carbohydrates, protein, and fats on pig growth. Most U. S. swine diets are formulated on a metabolizable energy (ME) basis, which accounts for all energy minus urinary and fecal energy. Furthermore, ME can be divided into net energy (NE). Net energy consists of ME minus heat increment, which is the heat produced by the digestion and metabolism of nutrients and by fermentation in the intestinal tract. The remaining energy is utilized first to meet the requirement for maintenance, the energy needed to sustain life and to maintain body temperature. If the supply of NE is greater than the energy required for maintenance, it is used for production.

The objective of Noblet and Perez (1993) was to calculate prediction equations for DE and ME values of mixed diets from their chemical characteristics. This was done by utilizing a series of five digestibility trials from 1983 to 1992 consisting of 114 different diets. They concluded crude protein and ether extract digestibility was negatively affected by the addition of ash and fiber (ADF for protein and NDF for ether extract) to the diet. Also, DE and ME were negatively affected by the dietary fiber content, with NDF having more of an effect. Thus, the addition of fiber, and ash to an extent, has a negative effect on energy and protein digestibility, which translates to a negative effect on growth performance for the pig.

**Slaughter Weight Effects on Meat Quality**

Cisneros et al. (1996) studied one hundred and sixty pigs consisting of equal numbers of barrows and gilts and two different genotypes. Pigs were harvested at five different
slaughter weights: 100, 115, 130, 145, and 160 kg. They used these pigs to carry out an evaluation of the influence of heavier slaughter weights on growth, carcass merit, carcass cutting and curing yields, and meat quality in modern genotypes.

They observed no difference in the effect of first rib and last lumbar fat depths and loin eye area on slaughter weight. These data suggest that the overall rate of backfat deposition did not increase with slaughter weight. However, there was a limited number of positions used on the carcass to determine backfat on the carcass, thus decreasing the significance of the backfat deposition. Furthermore, increasing slaughter weight was associated with reductions in longissimus thoracis color (P<0.05) and lower 24 hour pH (P<0.05). One possible explanation for this is the development of PSE can be temperature dependent, with elevated muscle temperatures producing the condition. Due to the increased fat deposition in the heavier carcasses, the muscle cooling may have occurred at slower rate; this increases the rate of pH decline and in turn produces a paler colored longissimus thoracis. Despite this, due to the unrealistically heavy slaughter weights (145 and 160 kg) and the lack of measurements for their linear growth model, the lack of significance of this study is in question.

Latorre et al. (2004) utilized crossbred pigs to study the influence of gender and slaughter weight on performance and carcass characteristics, and meat quality of crossbred pigs intended for the production of dry-cured hams. One hundred and ninety-two crossbred barrows and gilts were allotted to pens based on like weights and gender. These pigs were harvested at three different slaughter weights (116, 124, and 133 kg). The study consisted of four replications of each treatment. Results indicated backfat depth increased linearly as slaughter weight increased from 116 to 133 kg ($r^2 = 0.79$, $P < 0.001$). Values for L*
decreased linearly with slaughter weight ($r^2 = 0.21$, $P < 0.001$). Also, a* and myoglobin content increased linearly with slaughter weight ($r^2 = 0.28$, and 0.43; $P < 0.01$, and $P < 0.001$, respectively). They concluded as pigs increase in slaughter weight a darker colored meat results.

Gu et al. (1992) utilized 127 barrows to quantify and compare the growth and development of carcass composition in 5 genotypes of swine from 59 to 127 kg live weight. Fat percentage increased curvilinear relative to animal weight. Fat growth was accelerated in later growth phases, thus fat percentage increased with body weight and age. Adding to this, backfat depth and longissimus muscle area increased linearly, further reflecting increasing fatness and skeletal stature as the animal matured. Plus, growth of lean, backfat, bone, and skin in the carcass was nearly linearly associated with increases in live and/or carcass weight. Also, rate of increase in fat weight was curvilinear as the pig grew and accelerated in later growth periods.

Carcass characteristics and meat quality traits were measured by Shuler et al. (1970) to evaluate the effect of confinement, different floor structures, and weight on the quantitative, qualitative and chemical properties of porcine muscle. Ninety-six crossbred barrows were assigned to 6 treatments, 2 replications of 8 pigs per pen. Four pigs from each treatment were slaughtered at 45.5, 68.2, 90.9, and 113.6 kg body weight. The authors concluded as pigs increased in live weight, loin muscle area and backfat increased ($P < 0.05$). There no differences in objective color. However, the largest slaughter weight was 113.6 kg, which is not as applicable to the current industry.

Leach et al. (1996) compared negative and carrier pigs produced within the same litter for growth performance, carcass characteristics, and meat quality traits at 3 slaughter
weights that span weights currently used in the U. S. industry. Backfat showed a significant linear relationship to increases in slaughter weight (P < 0.05). However, they did not show a significant increase in longissimus pH or color with increasing slaughter weights.

One hundred twenty-six female and 132 barrow carcasses were evaluated by Martin et al. (1980) for carcass and meat quality traits. Replicates were assigned to 6 slaughter weight groups ranging from 73 to 137 kg at approximately 13 kg intervals. In a population of Lacombe swine that has been under selection for carcass leanness and rapid growth, the objective of this study was to determine the effect of slaughter weight with consideration given to both quantitative and qualitative attributes of the carcass.

Martin et al. (1980) results indicated an increase in carcass leanness for the first few slaughter groups (73 to 112 kg), and a decrease in carcass leanness at the heavier carcass weights (126 and 137 kg). However, due to the decrease in carcass leanness a linear regression failed to provide a good fit for the data as indicated by relatively low r² percentages. Despite this, there was a significant increase in loin eye area up to 137 kg (P < 0.05). Also, there was a simple linear correlation between increasing slaughter carcass weight and darker colored meat. Color reflectance with slaughter weights had a negative 0.49 correlation. There were not a significant changes in pH and slaughter weight (P < 0.05), but pH was only measured 1 hour postmortem and on the semimembranosus.

Unruh et al. (1996) utilized a 2 X 2 X 2 factorial design to analyze differences in genotype, sex, and dietary lysine level on carcass subprimal cut yields and carcass quality of finishing pigs fed to 104 or 127 kg. At 24 hours postmortem, the longissimus muscle from the high-lean genotype had lower Hunter L*, a*, and b* values (P < 0.05) when fed to 127 kg compared to being harvested at 104 kg. There were no differences in Hunter scores for
medium-lean genotypes. Thus, they concluded high-lean genotype pigs had darker, redder, and more yellow longissimus muscle at a higher weight. However, there was no difference in percentage lean between the high-lean and the medium-lean genotypes, thus decreasing the impact of this study.

Nold et al. (1997) studied 45 crossbred pigs of medium lean growth genotype. There were 6 different treatments and 3 replications and pigs were harvested at either 100 or 110 kg. They concluded pigs harvested at 100 kg had lower subjective color scores, less backfat, and a smaller loin eye area than pigs harvested at 110 kg.

The objective of the study by Bertram et al. (2007) was to use pH to investigate how a slaughter weight affected water mobility and distribution. This study included 41 crossbred pigs: 8 pigs slaughtered at an age of 90 days, 12 pigs slaughtered at 140 days, 12 pigs slaughtered at 161 days, and 9 pigs slaughtered at an age of 182 days. Results concluded that increasing weight for slaughter had no effect on pH.

A total of 116 castrated male pigs of 3 different breeds (Duroc, Landrace, and Large White), raised in a large scale production system, were used by Candek-Potokar et al. (1998) to investigate the effect of increasing slaughter weight from 100 to 130 kg on performance and meat quality. Candek-Potokar et al. (1998) observed pH 24 hours post-mortem did not differ between breeds or slaughter weights. Subjective color score increased with slaughter weight ($P < 0.05$). Plus, $a^*$ and $c^*$ increased with slaughter weight ($P < 0.001$ and $P < 0.01$, respectively). These increases support the general idea that more mature animals produce meat of more intense color.

Next, Candek-Potokar et al. (1998b) utilized 80 castrated male crossbred pigs to investigate the effects of increasing either age alone or both age and weight at slaughter on
muscle biochemical traits and pork sensory properties. Pigs were slaughtered at either 100 or 130 kg with 1 group either fed ad libitum or restricted for each slaughter weight. Meat quality measurements were conducted 24 hours postmortem. Results indicated there were no significant changes in pH, and no changes in meat color either for either objective and subjective scores.

A 2 X 2 X 3 factorial design was used for a study by Correa et al. (2006); treatments were fast growth rate versus a slow growth rate, sex, and three different slaughter weights (107, 115, and 125 kg). A total of 119 crossbred pigs were slaughtered, 10 per treatment to evaluate the effect of heavier slaughter weight on carcass and meat quality traits in slow and fast growing pigs. They concluded there were no differences for pH (24 hours), subjective color, and Hunter L*, a*, and b* for any of the treatments.

**Leanness and Meat Quality Correlations**

DeNise et al. (1983) utilized breeding animals from a closed herd of Yorkshire animals which were assigned randomly within sire and dam groups to control, lean growth, or percentage lean cuts lines. Animals were used to report the indirect effects of direct selection on carcass, reproductive efficiency and preweaning litter traits.

Subjective longissimus color score decreased slightly in both lines, as did objective muscle color reflectance. A trend toward paler longissimus muscle is indicated, although neither line was significantly different from the control. Overall, selection for leanness reduced color of the pork (DeNise et al., 1983).

One-hundred and sixty Duroc and halothane-negative British Landrace boars and gilts were performance tested by Cameron (1990) either on ad libitum or restricted feeding regimes, with like-sexed non-littermate groups of 1, 2, 3 or 4 pigs per pen. This study
estimated heritabilities for meat and eating quality traits and genetic correlations between these traits and between meat quality traits and carcass traits. Cameron (1990) concluded selection for increased carcass lean weight or decreased carcass fat weight would result in increased muscle moisture content, but resulted in decreased muscle pH and intramuscular fat content.

Two groups of purebred Danish Landrace pigs, one slow growing and the other fast growing, were compared by Oksbjerg et al. (2000) with respect to performance, muscle physiology, and meat quality traits under similar conditions. Results indicated fast growing pigs were significantly leaner than slow growing pigs (P < 0.01). Furthermore, they had higher L* and a* values (P < 0.01). Thus, in this study fast growing pigs were leaner and exhibited paler, less red meat.

The aim of a study by Sonesson et al. (1998) was to estimate genetic and phenotypic parameters for meat quality and performance traits and genetic trends for these traits in lines of pigs that have been single-trait selected for either low backfat thickness (L - Line) or high growth rate (F – Line).

Sonesson et al. (1998) observed the L-line showed a significant decrease in pH at 24 hours. For both lines there were genetic trends toward lighter colored meat. Furthermore, there was a more negative genetic relationship between percent lean and meat quality, especially pH. Therefore, selection for backfat, which in effect increased percent lean, was detrimental to meat quality. Also, pH had a high genetic correlation with Japanese color score (0.60) and L* values (-0.62). Thus, the increased leanness achieved by decreased backfat thickness decreased ultimate pH and ultimately decreased overall meat color. Plus,
selection for growth rate had genetic correlations that were detrimental for pH and meat color; ultimately, this also decreased meat quality.

Four hundred forty-two pigs of the Duroc, Yorkshire, Hampshire, Poland China, and Spotted Swine breeds were tested from day 65 of age to 90 kg. Jensen et al. (1967) harvested pigs to determine the extent of genetic variation in measures of meat quality and their association with backfat thickness, longissimus dorsi area, and percent lean cuts.

Phenotypic correlations indicated that backfat thickness had a positive correlation with meat quality, while correlations with increased longissimus dorsi area and percent lean cuts were negative. However, these correlations were low. There was a moderate correlation between color and pH of 0.38. Genetic correlations for backfat thickness were higher (0.53) indicating that selection for less backfat had a negative impact on color and firmness of the meat, and ultimately, on meat quality. Overall, selection for less backfat and increased percent lean correlated to a decrease in overall meat quality (Jensen et al., 1967).

A total of 1,113 animals of 2 sexes (boars and gilts) and 2 breeds, Dutch-Yorkshire and Duroc of American and Danish origin, were measured by Hovenier et al. (1992) for production and meat quality traits. The aim of this study is to estimate genetic parameters for meat quality and production traits in a Dutch pig population with low halothane susceptibility.

Hovenier et al. (1992) observed a positive correlation (0.46) between meat color and growth, indicating darker meat when animals grow fast. Plus, there was a high genetic correlation (0.71) between ultimate pH and color, indicating a higher ultimate pH results in a darker colored meat. When utilizing all of the genetic correlations between the production
and meat quality traits, data suggest a better meat quality for faster growing animals with a greater backfat thickness and lower lean muscle content.

In a study by Hermesch et al. (2000), 1,799 Large White and 1,522 Landrace boars were utilized to obtain genetic parameters for meat quality, carcass, and performance traits. Results indicated a paler color of the longissimus dorsi was associated with reduced pH (-0.83). Plus, selection for reduced backfat had a positive correlation with pH 45 minutes post-mortem (0.64); thus, this confirms that selection for reduced backfat will increase the incidence of pale, soft, and exudative pork.

Lonergan et al. (2001) conducted a study utilizing 15 animals from a Duroc line selected for improved feed conversion and decreased backfat thickness at 105 kg, compared to a control Duroc line of 24 animals from a contemporary line selected to maintain the performance traits of the original foundation herd. This study set out to determine the extent of the impact of selection for lean growth efficiency on fresh pork and to determine what factors cause this deterioration in quality. Selection for lean growth efficiency resulted in pork that was normal in color, but was softer (P < 0.05) and more exudative (P < 0.05), and that had higher Warner-Bratzler Shear force values (P < 0.01) when compared to the control line.

De Vries et al. (1994) utilized 4,055 slaughter pigs with meat quality data on 1,807 pigs from 7 Dutch Yorkshire lines. They estimated genetic parameters of pig meat quality traits and quantified relationships of meat quality with production traits in halothane free populations. Ultimate pH had a close relationship with Minolta L* and Hunter L* (-0.60 and -0.53, respectively); thus, higher ultimate pH is correlated with darker colored meat. Growth rate showed no important correlations with meat quality traits. Residual feed intake
displayed a negative genetic correlation with Minolta L* and Hunter L* (-0.58 and -0.43, respectively). This is probably due to its positive association with ultimate pH. In this study, color had no unfavorable correlations with lean percentage and growth rate.

Latorre et al. (2007) utilized 96 gilts from 3 different genotypes (32 Large White, 32 Synthetic Genex 3000, and 32 Meishan-derived dam line gilts) to investigate the existing relationship within production performance parameters, within meat quality characteristics, and between these 2 types of variables. Growth performance and meat quality variables were negatively correlated. Also, they determined that performance and meat quality correlations were very breed dependent.

Huff-Lonergan et al. (2002) examined a group of 525 F2 animals originating from 2 purebred Berkshire boars and 9 Yorkshire females. The objective of this study was to determine phenotypic associations between specific biochemical and physical-sensory characteristics to obtain a better understanding of how changes in specific traits may influence pork quality overall.

Results from Huff-Lonergan et al. (2002) indicated there were significant moderate phenotypic correlations found between subjective color score, pH, and glycogen potential (0.30, P < 0.003; 0.28, P < 0.0001; and -0.30, P < 0.0001, respectively). Furthermore, objective color measurements of Hunter L had significant moderate phenotypic correlations with pH (24 and 48 hours), glycogen, lactate, and glycolytic potential (-0.32, P < 0.0001; -0.27, P < 0.0001; 0.22, P < 0.0001; 0.26, P < 0.0001; and 0.30, P < 0.0001, respectively). There were low phenotypic correlations between subjective color and backfat, type 2 muscle fiber type, and glycogen (-0.10, P < 0.02; 0.13, P < 0.003; and -0.18, P < 0.0001, respectively). Also, Hunter L and backfat had a significant low phenotypic correlation with
type 2 muscle fiber type (0.19, P < 0.0001; -0.11, P < 0.02). Although significant, these low phenotypic correlations suggest many other characteristics could have an effect on subjective color. These results indicate that pH and glycolytic potential have a significant moderate phenotypic correlation with subjective color (-0.38 P < 0.0001 at 24 hours, and -0.39 P < 0.0001), which can have a large role in meat color with a higher pH and decreased glycolytic potential associated with darker colored meat. Of importance, 2 relatively high phenotypic correlations were identified; subjective color and Hunter L of -0.69 (P < 0.0001), and 24 hour pH and 48 hour pH of 0.71 (P < 0.001).

Duroc pigs from 7 generations of selection for average daily gain, loin muscle area, backfat, and intramuscular fat were utilized in this experiment (Suzuki et al., 2005). A total of 547 pigs were slaughtered to measure meat quality to estimate genetic parameters and assess correlated genetic trends of meat quality traits with selection. Average daily gain was correlated moderately with meat color and L* (-0.33 and 0.33, respectively), thus suggesting improve growth rate is correlated with paler colored meat. Also, backfat was positively correlated with L* (0.55), suggesting selection for decreased backfat thickness correlates to darker meat. In this study, pH had a low correlation with subjective color score and L* (0.16 and -0.10, respectively).

Van Wijk et al. (2005) studied 242 individual crossbred pigs from a commercial herd utilizing 20 sires of a synthetic Pietrain-Large White, halothane-free boar line mated to 239 sows of a single commercial line. These pigs were used to estimate genetic parameters for carcass and meat quality traits that are of practical relevance in combination with information from current or intended classification systems. There was a high correlation between pH and Hunter L* and subjective color scores (-0.60 and 0.80, respectively). However, there
was a moderate positive correlation between backfat and L* (0.43). Furthermore, in this study they concluded high performance in pigs to be negatively correlated with good pork quality (pH close to -1).

DeVol et al. (1988) utilized a random sample of 120 pork loins obtained from a Midwest packing plant with an average daily slaughter of approximately 1,200 hogs. At 48 hours, ultimate pH and objective color were measured. Utilizing regression analysis, they observed a high correlation between longissimus pH and objective color of the longissimus (r = 0.73; P<0.001).

Bidner et al. (2004) used 47 carcasses selected based on longissimus thoracis pH (LTPH) measured at 24 hours postmortem to represent a wide range in ultimate pH. They utilized these carcasses to characterize the effect of ultimate pH on fresh pork quality and sensory attributes, as well as processing characteristics. LTPH explained 79% (cubic) of the variation in subjective color and 57% (cubic) of the variation in drip loss; plus, LTPH explained 52% of the variation in the L* values (linear). Furthermore, ultimate pH explained 66% of the variation (quadratic) in glycolytic potential.

Color scores were maximized and drip loss was minimized at LTPH of 6.3 to 6.5. Purge loss and L* values decreased with increasing LTPH (R² = 0.77 quadratic, and 0.72 quadratic). The observations of ultimate pH and glycolytic potential are consistent with previous studies as increased glycolytic potential leads to decreased ultimate pH.

**Effect of Fat Content of the Diet on Fat Quality**

According to Pettigrew and Esnaola (2001), feeding of dietary fat increases the amount of polyunsaturated fats in the pig, which is indicated by an increase in iodine value
(IV). The increase in polyunsaturated fats causes the pig carcass fat to be softer. Feeding of higher diets with oil, including high-oil corn, often increases the IV of the pig’s fat.

St. John et al. (1987) examined the effect of increasing amounts of monounsaturated fat in the pig diet utilizing canola oil. Three dietary treatments consisted of a control corn-soybean meal diet, control plus 10% canola oil, and control plus 20% canola oil. They observed more unsaturated fat in pigs fed the 20% canola oil and the 10% canola oil diets ($P < 0.05$) compared to pigs fed the control diet. Furthermore, the fat became softer and more oily as the percentage of canola oil in the diet increased ($P < 0.05$). The authors concluded the fat was softer and more oily due to the lower melting point of unsaturated fat relative to saturated fat.

Engel et al. (2001) studied the effect of choice white grease compared to poultry fat on the degree of saturation in the subcutaneous fat of a finished pig, with choice white grease having more saturated fats. Pigs fed diets containing choice white grease had a lower IV than pigs fed poultry fat, indicating more saturated fats ($P < 0.05$). Despite this, no differences in belly firmness were observed between dietary treatments.

Gatlin et al. (2002) investigated the role dietary fat source has on fat quality in pigs. They utilized soy oil, animal-vegetable blend, and beef tallow in the dietary treatments, with the latter diet having the most saturation. They concluded that a decrease of soy oil in the diet and an increase in beef tallow as the dietary fat source decreased the IV of the fat ($P < 0.05$), thus decreasing the amount of unsaturated fats in the carcass.
Literature Cited


Lawrence, J. 2006. Impact on hog feed cost of corn and DDGS prices. Iowa Farm Outlook. Iowa State University, Ames, IA.

Lawrence, J. 2008. Losses mount and inventories grow for pork producers. Iowa Farm Outlook. Iowa State University, Ames, IA.


Chapter 3. Effect of extracted corn germ from a fractionation process on pig growth performance and carcass characteristics

A paper to be published in *Livestock Production Science*

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Abstract: The objective of this study was to determine the effect of extracted corn germ (ECG) from a fractionation process on growth performance and carcass characteristics of grow-finish pigs. Pigs were phase-fed six diets (lysine levels of 1.14%, 1.02%, 0.93%, 0.84%, 0.74%, and 0.61%, respectively) from 23 kg to 127 kg. The control diet (C) was a corn, soybean meal, and premix diet, with corn in the treatment diet replaced with ECG. Control and treatment diets were formulated to equal levels of lysine and energy in each phase. A total of 2,400 crossbred (PIC 337 x Genetiporc) pigs were split equally between treatments in a commercial wean-to-finish facility and evaluated from 5.5 kg to 127 kg. At time of entry, 200 pigs assigned to the C diet and 200 pigs assigned to the ECG diet were randomly selected for performance and carcass evaluation. Pigs were weighed on test and started on dietary treatments at 23 kg BW. Average daily gain was greater for the C-fed pigs from 23 to 85 kg, 85 kg to 127 kg, and 23 kg to 127 kg (P < 0.001). Treatment effects were not different for LMA and percent lean, and there was a trend for ECG-fed pigs to have less 10th-rib backfat (P = 0.08). Pigs fed the C diet had lower Minolta (P < 0.01) and Hunter L* values (P < 0.001) at both 24 and 48 h post-mortem. At 24 h post-mortem, pH was not affected by treatment, but there was a trend for the C-fed pigs to have a higher pH at 48 h (P = 0.06). Pigs fed the C diet had a greater subjective color score (P < 0.05), but marbling and firmness were not different. Forty-eight hour b* values evaluated on subcutaneous fat indicated a trend (P = 0.06) for the ECG-fed pigs to have a whiter fat. Fat samples from 24 pigs on each treatment were evaluated to determine iodine value; pigs fed the ECG diet had a lower iodine value (P < 0.01) than pigs fed the C diet, indicating a more saturated fat. Further research is needed to determine the optimum inclusion level of ECG in grow-finish swine diets.
Key words: corn germ, energy source, fractionation, performance, pig

Introduction

Using current federal ethanol policy, U. S. ethanol production from corn is projected to reach 14.8 billion gallons by 2011 and corn will be at an equilibrium price of $4.43 per bushel (Tokgoz et al., 2007). At this price, production costs for pork production will increase by 18.4 percent. For every $1 per bushel increase in price of corn, there is a $4.50 increase in cost of production per 45 kg of gain. In general, every $0.10/bushel increase in corn price equates to a $0.50 increase in cost of pork production (Lawrence, 2006). Since the cost of feed represents 50-60% of total pig production cost and corn is approximately 80% of the cost for the grow-finish diet, an increase in ethanol production could be very detrimental to pork producers. Under this federal mandate, crop farmers and pork producers have become competitors for corn instead partners in the production process.

Under traditional dry-grind ethanol production, distillers dried grains with solubles (DDGS) is the co-product utilized for pig diets. Not only do DDGS have large variation from plant to plant for amino acid (Stein et al., 2006) and energy content (Pederson et al., 2007), but a range in suggested inclusion level is 10 to 30% of the pig diet (Whitney et al., 2001; Whitney et al., 2006; Xu et al., 2007; and Weimer et al., 2008).

Due to shrinking margins for ethanol plants and pork producers resulting from high corn prices, ethanol plants need more co-products to generate revenue and pork producers need a consistent co-product to incorporate in their diets. This has given rise to a new generation of ethanol plants with technology to fractionate corn before it enters the fermentation process, allowing ethanol plants and pork producers to utilize different parts of the corn kernel.
Widmer et al. (2008) utilized 2 co-products in swine diets from a fractionation process, with the co-products having varying degrees of success in improving pig performance and carcass quality. The current study utilized extracted corn germ (ECG) from a different fractionation process for use in swine diets. The objective of this study was to determine the effect of ECG from a fractionation process on growth performance, carcass characteristics, meat quality, and fat quality on grow-finish pigs.

Materials and Methods

The experimental protocols for this study were approved by the Iowa State University Institutional Animal Care and Use Committee. Weaned crossbred pigs (PIC 337 x Genetiporc) were allocated in one commercial barn (n = 2,400) into 2 large pens, which allowed 1 treatment in each side of the barn. Each pen had 1,200 pigs, with approximately equal number of barrows and gilts. On arrival to the commercial unit, pigs were weighed and assigned to treatment pens. Two hundred pigs in each treatment were randomly selected and individually tagged for performance and carcass evaluation.

The control treatment (C) was a corn, soybean meal, and premix diet, with corn in the treatment diet (ECG) replaced with ECG. Diets were formulated to equal levels of lysine and energy in each phase. Pigs were phase-fed 6 grow-finish diets based on 21-day intervals for each phase, except for the last phase which was determined by final BW. Diets consisted of lysine levels of 1.14%, 1.02%, 0.93%, 0.84%, 0.74%, and 0.61%, respectively. Nutrient composition of the dietary treatments can be found in Table 1.

Individually tagged pigs were weighed at 23 kg BW, 85 kg, and at market weight (approximately 127 kg) to calculate average daily gain (ADG). One hundred eighty-three C
pigs and 159 ECG pigs were used for the calculation of ADG. Feed intake and feed efficiency were calculated for both pens in the trial.

Kilograms of lean at market weight and at test entry were estimated for the test pigs using the following fat-free lean equations (NPPC, 2000):

\[
\text{Market weight lean (kg)} = 0.3782 \times \text{sex (barrow} = 1; \text{gilt} = 2) - 2.9488 \times (\text{BF}, \text{cm}) + 0.3817 \times (\text{LMA}, \text{cm}^2) + 0.291 \times (\text{off-test weight, kg}) - 0.2424
\]

\[
\text{Trial entry lean (kg)} = 0.188 \times (\text{on-test weight, kg}) - 1.644
\]

Lean gain per day on test (LGOT) was calculated by subtracting the estimate of trial entry lean from market weight lean and dividing by days on test. Percentage lean on a carcass basis were calculated using carcass measurements attained at the commercial abbatoir.

Upon reaching market weight, 147 C and 152 ECG tagged pigs were individually tattooed and shipped to a commercial abattoir. At 24 h post-mortem, standard carcass collection procedures (NPPC, 2000), were used to obtain measurements of 10\textsuperscript{th}-rib backfat (BF10) and loin muscle area (LMA). Ultimate pH was measured on the 10\textsuperscript{th}-rib face of the LM using a pH star probe (SFK Ltd, Hvidovre, Denmark). Hunter L score and Minolta reflectance (a measure of light reflectance, where lower values indicate darker and more desirable color) were measured with a 50-mm-diameter aperture, D65 illuminant, and calibrated to the white calibration plate. A section of bone-in loin containing the 10\textsuperscript{th} to 12\textsuperscript{th} ribs was excised from the carcass and transported to the Iowa State University Meat Laboratory.

At 48 h post-mortem, the 11\textsuperscript{th} and 12\textsuperscript{th} rib sections were cut into 2.54-cm chops and set with the freshly cut side up for 10 minutes to allow the sample to bloom. Subjective measures of color (1 = pale pinkish gray to white; 6 = dark purplish red), marbling (1 = 1.0%
IMF; 10 = 10.0% IMF), and firmness (1 = soft; 3 = very firm) were evaluated on the 11th-rib face according to NPPC (2000) by a person trained in meat quality evaluation. Objective color scores and pH were evaluated. Fat color was measured on the 10th rib BF layer by using the Minolta CIELab system (b* value for yellowness). Fat iodine values were measured on 24 pigs per treatment. A 100 g fat sample from the jowl was obtained 24 h post-mortem and sent to Barrow Agee Laboratory (Memphis, TN) for analysis of iodine value.

Statistical Analysis

Data were analyzed using the PROC MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Sex, treatment, and on test weight were fixed effects in the model for growth performance traits. Sex, treatment, and slaughter date were fixed effects in the model for carcass composition, meat quality, and fat quality traits. Treatment means were calculated using the LSMEANS statement in PROC MIXED. All 2-way and 3-way interactions were tested and found to be nonsignificant (P > 0.05); thus, they were deleted from the final model. Pig was the experimental unit for these analyses, and an α level of 0.05 was used to assess significance among means.

Results and Discussion

Results for pig performance and carcass characteristics are shown in Table 2, and results for meat quality and fat quality traits are shown in Table 3.

Pig Performance and Carcass Characteristics

Pigs fed the C diet had a greater ADG from 23 kg to 85 kg, 85 kg to market, and 23 kg to market (P < 0.01). There were no differences between the C and ECG treatments for
LMA and percent lean, which resulted in a greater lean gain on test for C-fed pigs \( (P < 0.01) \). However, there was a trend for the ECG-fed pigs to have less BF \( (P = 0.075) \).

Energy content of the ECG diets was overestimated (M. Wolfe, personal communication) resulting in lower energy intake for ECG-fed pigs in this study. According to NRC (1998) and Ewan (2001), the amount of energy used for the needs of all body functions and moderate activity is maintenance energy, and if maintenance requirement are met, any additional energy will go toward protein deposition and fat accretion. Furthermore, Pettigrew and Esnaola (2001) reported a reasonable target for energy intake is the amount needed to maximize protein accretion rate, which is energy intake exceeding maintenance energy needs determined by the pig’s nonnutritional factors (ex. genetics, sex, environment). This would avoid the excessive fatness that comes from higher energy intake. Therefore, pigs would be slightly leaner at lower energy intake, but they would also grow more slowly, which agrees with the results of this study.

The ECG diets were also higher in fiber content (Table 1). NRC (1998) and Noblet and Perez (1993) reported that an increase in dietary fiber in swine diets decreases the digestible energy concentration of the diet. Moore et al. (2008) reported a negative correlation between neutral detergent fiber (NDF), and acid detergent fiber (NDF) content, and final BW \( (r = -0.30, P < 0.05, \text{ and } r = -0.26, P < 0.05, \text{ respectively}) \). Plus, Muley et al. (2007) determined corn germ had more total amino acids (AA) \( (12.8 \text{ vs. } 8.3\%) \), and was richer in neutral detergent fiber (NDF) \( (17.2\% \text{ vs. } 9.8\%) \) than corn. Despite this, the germ had reduced ileal dry matter digestibility when compared with corn \( (P < 0.01) \), which can be explained by this fraction being higher in NDF content.
Latorre et al. (2004) and Leach et al. (1996) reported an increase in BF as slaughter weight of the pig increased, which agrees with this study. Also, Gu et al. (1992), Shuler et al. (1970), and Nold (1997) reported not only an increase in BF with an increase in slaughter weight, but also an increase in LMA.

**Meat quality**

There were no differences between treatments for 24 h pH, 48 h subjective marbling score, and 48 h subjective firmness score. There was a difference in Minolta Y and Hunter L* score (P < 0.002) at both 24 and 48 h post-mortem in favor of pigs fed the C diet. Also, pigs fed the C diet had a greater subjective color score (P < 0.05). At 48 h, pigs fed the C diet tended to have a higher pH (P = 0.062). These results indicate a darker colored meat for pigs fed the C diet. Although treatment differences were significant, both treatment diets would be deemed acceptable for most consumer markets.

One possible explanation for differences in meat quality in the current study is a higher slaughter weight at the time of harvest for pigs fed the C diet. Latorre et al. (2004), Martin et al. (1980), Unruh et al. (1996), Nold et al. (1997), and Candek-Potokar et al. (1998) found pigs at a higher slaughter weight had a darker colored meat, in agreement with the current study. However, Cisneros et al. (1996) showed a decrease in subjective color scores with increasing slaughter weight. Shuler et al. (1970), Leach et al. (1996), Candek-Potokar et al. (1998b), and Correa et al. (2006) showed no effect of slaughter weight on meat color. Leach et al. (1996), Bertran et al. (2007), Candek-Potokar et al. (1998b), Candek-Potokar et al. (1998), and Correa et al. (2006) found that slaughter weight did not effect pH.

Another possible explanation for differences in meat color and pH is that the ECG-fed pigs had decreased BF thickness and lower pH. Studies conducted by Cameron et al.
(1990), Sonesson et al. (1998), Suzuki et al. (2005), and Jensen et al. (1967) indicated that selection for thinner BF had a negative impact on color. Hovenier et al. (1992), Hermesch et al. (2000), DeVries et al. (1994), Huff-Lonergan et al. (2002), and Van Wijk et al. (2005) reported moderate to strong positive correlations between pH and color, indicating a higher pH value is correlated to a darker colored meat.

**Fat quality**

Importers of U. S. meat products desire a loin that has a bright white fat color to complement superior meat and eating quality characteristics (Lampe et al., 2006). Forty-eight hour b* scores on subcutaneous fat displayed a trend (P = 0.06) for the ECG-fed pigs to have a whiter fat, which would be desirable for U. S. meat importers.

Pigs fed the ECG diet had a lower iodine value (IV) (P < 0.01) than pigs fed C diets (70.2 and 72.9). Analysis of the added dietary fat (choice white grease) indicated a higher saturated to unsaturated fat content. The ECG diet had a higher inclusion level of added dietary fat than the C diet, which was higher in corn-oil. Studies by St. John et al. (1987), Engel et al. (2001), and Gatlin et al. (2002) determined that diets with a higher unsaturated to saturated fat ratio had a higher iodine value. Pettigrew and Esnaola (2001) determined an increase in polyunsaturated fats causes the pig’s carcass fat to be softer, which is indicated by an increase in IV. High energy diets, including high-oil corn, often increase the IV of the pig’s fat.

Complete replacement of corn by ECG in this study was detrimental to a pig’s growth performance and meat quality, but was beneficial to fat quality. Further research is needed to determine if partial replacement of corn with ECG in grow-finish swine diets will maintain improvements in fat quality and reduce the negative effect on performance and quality traits.
Literature Cited


   Iowa State University, Ames, IA.

   performance, carcass characteristics, and meat quality of halothane carrier and


   2008. The correlation of chemical and physical corn kernel traits with growth

   2007. Nutritional value for swine of extruded corn and corn fractions obtained after

Noblet, J., and J. M. Perez. 1993. Prediction of digestibility of nutrients and energy values of

   characteristics and carcass traits of boars, barrows, and gilts fed high- or adequate-
   protein diets and slaughtered at 100 or 110 kilograms. J. Anim. Sci. 75:2641-2651.

   Press, Washington, DC.

   Pork. Prod. Counc., Des Moines, IA.


Table 1. Nutrient composition of dietary treatments in a study to evaluate the effect of extracted corn germ (ECG) on pigs growth performance, carcass characteristics, and fat quality.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Diet C</th>
<th>Diet ECG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Protein %</td>
<td>8.97</td>
<td>13.69</td>
</tr>
<tr>
<td>Fat %</td>
<td>3.25</td>
<td>1.05</td>
</tr>
<tr>
<td>NDF %</td>
<td>6.84</td>
<td>13.41</td>
</tr>
<tr>
<td>ADF %</td>
<td>1.63</td>
<td>3.00</td>
</tr>
<tr>
<td>Ash %</td>
<td>1.16</td>
<td>2.91</td>
</tr>
<tr>
<td>Gross Energy, kcal/kg</td>
<td>4,479</td>
<td>4,437</td>
</tr>
</tbody>
</table>

C = Pigs fed control diet  ECG = Pigs fed extracted corn germ
Table 2. Least squares means (±SE) of growth performance and carcass characteristics of pigs in a study to evaluate the effect of extracted corn germ (ECG) on pigs growth performance, carcass characteristics, and fat quality.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Diet</th>
<th>Difference between C and ECG</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADG Ontest-Midtest, kg</td>
<td>0.90 ± 0.006</td>
<td>0.84 ± 0.007</td>
<td>0.064 ± 0.008</td>
</tr>
<tr>
<td>ADG Midtest-Offtest, kg</td>
<td>0.91 ± 0.011</td>
<td>0.83 ± 0.012</td>
<td>0.079 ± 0.016</td>
</tr>
<tr>
<td>ADG Ontest-Offtest, kg</td>
<td>0.92 ± 0.006</td>
<td>0.84 ± 0.007</td>
<td>0.079 ± 0.009</td>
</tr>
<tr>
<td>Lean gain on test, kg/d</td>
<td>0.39 ± 0.003</td>
<td>0.38 ± 0.003</td>
<td>0.021 ± 0.007</td>
</tr>
<tr>
<td>10th-rib backfat, cm</td>
<td>2.07 ± 0.047</td>
<td>1.94 ± 0.046</td>
<td>0.129 ± 0.073</td>
</tr>
<tr>
<td>Loin Muscle Area, cm²</td>
<td>50.7 ± 0.515</td>
<td>51.1 ± 0.497</td>
<td>-0.305 ± 0.801</td>
</tr>
<tr>
<td>Percent lean</td>
<td>54.9 ± 0.325</td>
<td>55.4 ± 0.315</td>
<td>-0.656 ± 0.505</td>
</tr>
</tbody>
</table>

NS = not significant \((P > 0.05)\); * = \(P < 0.10\); ** = \(P < 0.05\); *** = \(P < 0.01\).

C = Pigs fed control diet ECG = Pigs fed extracted corn germ
Table 3. Least squares means (±SE) of meat quality traits and fat color of pigs in a study to evaluate the effect of extracted corn germ (ECG) on pigs growth performance, carcass characteristics, and fat quality.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Diet</th>
<th>Difference between C and ECG</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>ECG</td>
<td></td>
</tr>
<tr>
<td>24 h pH</td>
<td>5.689 ± 0.015</td>
<td>5.655 ± 0.015</td>
<td>0.034 ± 0.023</td>
</tr>
<tr>
<td>48 h pH</td>
<td>5.653 ± 0.010</td>
<td>5.625 ± 0.010</td>
<td>0.028 ± 0.015</td>
</tr>
<tr>
<td>48 h subjective color</td>
<td>2.368 ± 0.055</td>
<td>2.148 ± 0.054</td>
<td>0.220 ± 0.086</td>
</tr>
<tr>
<td>48 h marbling score</td>
<td>1.281 ± 0.046</td>
<td>1.257 ± 0.045</td>
<td>0.024 ± 0.072</td>
</tr>
<tr>
<td>48 h firmness score</td>
<td>1.739 ± 0.062</td>
<td>1.808 ± 0.060</td>
<td>-0.069 ± 0.096</td>
</tr>
<tr>
<td>24 h Minolta Y</td>
<td>21.999 ± 0.266</td>
<td>23.284 ± 0.257</td>
<td>-1.285 ± 0.413</td>
</tr>
<tr>
<td>24 h Hunter L*</td>
<td>46.772 ± 0.275</td>
<td>48.159 ± 0.266</td>
<td>-1.387 ± 0.427</td>
</tr>
<tr>
<td>48 h Minolta Y</td>
<td>20.991 ± 0.205</td>
<td>22.089 ± 0.199</td>
<td>-1.098 ± 0.319</td>
</tr>
<tr>
<td>48 h Hunter L*</td>
<td>45.697 ± 0.229</td>
<td>47.017 ± 0.222</td>
<td>-1.320 ± 0.357</td>
</tr>
<tr>
<td>48 h hunter b* on fat</td>
<td>6.500 ± 0.101</td>
<td>6.210 ± 0.097</td>
<td>0.290 ± 0.157</td>
</tr>
</tbody>
</table>

NS = not significant ($P > 0.05$); * = $P < 0.10$; ** = $P < 0.05$; *** = $P < 0.01$.
C = Pigs fed control diet ECG = Pigs fed extracted corn germ
Chapter 4. Summary

The federal ethanol mandate has opened up a new market for corn, thus increasing the price of corn. Since feed is 50 to 60 percent of the cost of production for pork producers, the increase in corn price per bushel has been detrimental to their profitability. This mandate has forced U. S. pork producers to re-evaluate the main energy and protein sources they are providing the pig in their diet. Co-products from ethanol plants have been seen as a logical feedstuff to evaluate as Midwest ethanol plants are located close to where pigs are produced. The first generation of co-products (DDGS) from a dry-grind plant is variable in amino acid and energy content due to the fermentation and drying process. Ethanol plants, in an attempt to increase revenue, are exploring the addition of a fractionation process on the front end of the plant which is giving rise to new co-products. Extracted corn germ (ECG) is one of the co-products from a fractionation process that has the potential to replace corn in the diet. In this study, ECG was fed to grow-finish pigs to evaluate growth performance and carcass characteristics.

Pigs fed ECG had decreased ADG, and LGOT compared to control pigs. There was a trend for ECG-fed pigs to have decreased backfat thickness, but percent lean and LMA were not different. Pigs fed ECG were also different in 24 and 48-h minolta Y, 24 and 48-h Hunter L*, and 48-h subjective color score, with ECG-fed pigs having a paler colored meat. Plus, there was a trend in favor of control fed pigs for 48-h pH. Twenty-four hour pH and 48-h subjective marbling and firmness scores were unaffected by treatment. There was a trend for the ECG-fed pigs to have a whiter fat color. Also, the iodine value was significantly different with the ECG-fed pigs have a lower value.
The decrease in growth performance for ECG-fed pigs is likely due to an overestimation of energy content of ECG and increased fiber content of the diet. Color differences between the two dietary treatments is possibly due to decreased backfat thickness for ECG-fed pigs and lower pH value at 48 hours, which both are correlated to a paler colored meat. The more saturated fat content of the ECG dietary treatment explains the lower iodine value for the ECG-fed pigs. Also, less yellow pigmentation in the ECG dietary treatment and increased saturated fat content explains the whiter fat content of ECG-fed pigs.

Results of this experiment suggest full replacement of corn by ECG may not be viable in the grow-finish pig diet. Future research is needed to determine the optimal inclusion level of ECG. Even though meat quality differences were significant in this experiment, it is important to note that from a practical standpoint, values for the ECG-fed pigs would be acceptable in most markets, but this is also an area for more research. There is promise for this co-product to improve fat quality without the negative effects other co-products from ethanol plants have reported.
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