Swine nutrition and management systems that alter productivity and carcass traits

Mike D. Tokach, Robert D. Goodband, Joel M. DeRouchey, Steve S. Dritz, and Jim L. Nelssen*

INTRODUCTION

The swine industry has experienced tremendous change in recent years. Annual productivity continues to increase rapidly due to increased litter size and heavier market weights. The increase in litter size has potential negative ramifications on fetal muscle fiber development and subsequent meat quality. Increased feeding of ethanol by-products (ex. DDGS and other high fiber ingredients) decrease carcass yields and change the fatty acid profile of pork. The use of carcass modifiers, such as ractopamine, and the recent approval of immunological castration will provide further challenges and opportunities. Production systems are adapting their feeding regimens, marketing programs, genetics, and other management practices to fit specific end market targets (ie. different processors). Depending on market outlet, this can result in a wide disparity in cost of production. These industry changes and potential ramification on producer profitability and downstream carcass traits are the focus of this paper. As swine nutritionists and Extension Swine Specialists, most of our work is on the live production side and thus, the focus of the discussion will be from that perspective.

GENETIC CHANGES AND LITTER SIZE

Although genetic technology is the focus of another presentation in this session, any discussion on changes in the swine industry must include the rapid progress in genetic improvement. The days of three breed rotational breeding programs and simple, single trait selection for characteristics such as backfat are long gone. Almost the entire industry has moved to commercial breeding stock suppliers who use a nucleus and multiplier-based system with maternal line genetics used for the sow herd matched with specific terminal sire lines. Most sows are at least 50% Landrace with Yorkshire × Landrace being the most common sow used in commercial herds. These sows are bred to Pietran- or Duroc-based lines as the dominant terminal sires although Hampshire-based lines are still being used by some producers.

This focus on maternal and terminal line genetics has allowed the industry to increase productivity at a rapid rate. After very little change before 1997, pigs per litter has steadily climbed at the rate of 0.12 to 0.13 pigs per litter for the last 15 years. As a result, the entire U.S. industry has increased pigs weaned per litter from 8.6 in 2001 to just over 10.0 pigs at the end of 2011 (Figure 1). A recent National Pork Board study using data from 1.8 million sows in North America found that in 2005, total born and number born alive were 11.82 and 10.77 pigs per litter, respectively (Knauer and Hostetler, 2012). In 2010, total born and number of pigs born alive increased to 13.03 and 11.83, respectively. Impressively, pigs per mated female per year increased at a rate of 0.44 pigs per year from 21.5 in 2005 to 23.6 in 2010 (Table 1). This is a phenomenal rate of improvement in reproductive performance and the corresponding R^2 of 0.99 indicates the consistency of year over year improvement in these traits. The rate of improvement also suggests that litter size will continue to increase as long as genetic selection for this trait continues.

What does selection for hyper-prolific sows and the subsequent increase in litter size mean to meat scientists?

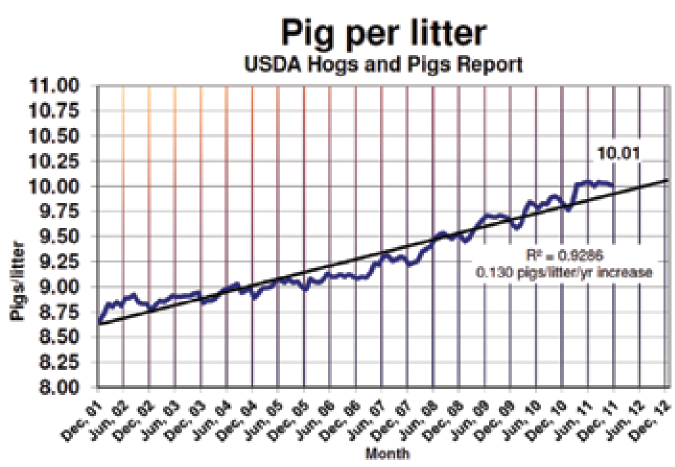

Figure 1. Pigs weaned per litter (USDA ARS, 2011)

Mike Tokach, Ph.D.
Professor/State Leader Extension
Kansas State University
246 Weber Hall, Manhattan, KS 66506
mtokach@k-state.edu

Table 1. Changes in swine productivity from 2005 to 2010 (Knauer and Hostetler, 2012)

Averages	2005	2006	2007	2008	2009	2010	Slope	R^2
Sow productivity								
Pigs weaned per litter	9.30	9.39	9.55	9.72	9.98	10.08	0.16	0.97
Preweaning mortality, %	13.7	14.1	14.0	14.2	14.0	14.8	0.15	0.62
Pigs per mated female	21.5	21.9	22.4	22.9	23.4	23.6	0.44	0.99
Finisher, 23 to 118 kg								
Mortality, %	6.67	6.28	7.12	5.95	5.42	5.23	-0.31	0.65
Exit weight, kg	117.7	116.9	117.8	117.9	118.8	119.9	0.5	0.74
Average daily gain, g	735	763	799	785	799	799	14	0.69
Feed efficiency	2.83	2.77	2.77	2.80	2.74	2.75	-0.01	0.56
Caloric efficiency, kcal/kg gain	9,403	9,361	9,233	9,220	9,259	9,467	0.18	0.00

Foxcroft et al. (2006) describes the negative influence of increased litter size on muscle fiber development and growth retardation in a portion of the piglets. This leads to increased variability in birth weight and postnatal growth. As litter size increases, birth weight decreases linearly. Light weight pigs at birth are slower growing and less feed efficient than heavy birth weight pigs (Gondret et al., 2004; Nissen et al., 2004; Berard et al., 2008). The lightest pigs at birth have a lower total number of myofibers, percentage of muscle tissue, total protein, total fat and semitendinosus weight while the percentages of internal organs, skin, bone, and total water are highest compared to their heavier littermates (Rehfeldt et al., 2004). The size of the myofibers is much larger in these lightweight pigs, which may be associated with greater longissimus drip loss compared with heavy birth weight pigs (Rehfeldt et al., 2004). Gondret et al., (2006) also demonstrated that the large muscle fiber area in pigs with a low birth weight was at least partly responsible for decreased tenderness of meat from these pigs. The light birth weight pigs also had greater activity of fatty acid synthase and malic enzyme in backfat and enlarged subcutaneous adipocytes compared with heavy birth weight pigs.

These studies raise concern in the industry that the continued selection for larger litter sizes will lead to slower growth and poorer feed efficiency, and could lead to meat quality issues. Most of these studies were conducted comparing the lightest and heaviest pigs within the litter. Two recent studies explored the litter size question more directly by separating the effects of birth weight and litter size (Berard et al., 2008; Beaulieu et al., 2010). These studies concluded that increasing litter size will reduce average pig birth weight, which impacts growth rate and feed efficiency; however, increasing litter size had very little effect on meat quality. The impact of selection for litter size on meat quality may vary with genotype. Foxcroft et al., (2006) suggest that hyperprolific lines with high ovulation rates and associated high in utero fetal mortality leads to higher variation in piglet birth weight as opposed to sows with more moderate ovulation rates and lower in utero fetal mortality. This is a fertile area of discussion in the swine industry.

STEADY INCREASE IN MARKET WEIGHT

Besides the increase in sow productivity, the next most consistent long-term trend in the swine industry has been the increase in carcass weights. In the short term, live pig weights have increased by 0.5 kg per year for the last six years. Figure 2 illustrates that this trend has been longer than the increase in sow productivity with carcass weights increasing steadily for over 50 years. Most swine production systems are constrained by time or weeks they have to raise a group of pigs to market weight. For example, a system may have only 24 weeks, or a fixed amount of time, to get a pig from weaning to 275 lb or heavier before the barn must be emptied to allow another group of pigs to enter the barn. In almost all cases, the days available for pig growth within a production system have not increased. Thus, the increase in market weight is mostly driven by an increase in growth rate with leaner, heavier muscled modern genotypes. Similar to the decision for processors to increase target weights to spread fixed costs of processing a pig over more total weight, producers lower their fixed costs per unit of weight gain by increasing market weights. The improved feed efficiency of lean genetics allows producers to economically increase target weights just as processors have increased their weight targets.

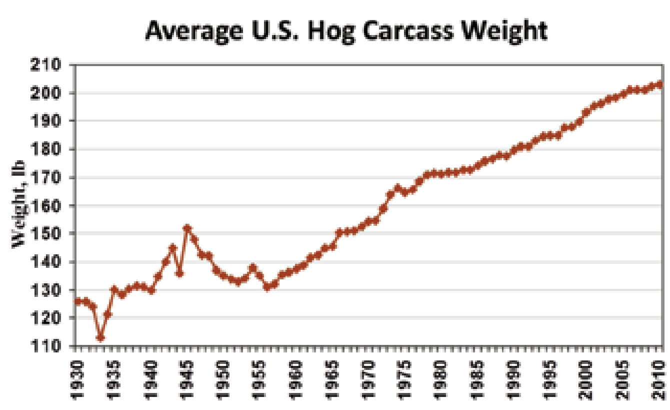

Figure 2. Average pig carcass weight in United States.

INCREASED USE OF BYPRODUCTS FROM ETHANOL AND FOOD PRODUCTION IN SWINE DIETS.

One of the greatest changes impacting the cost of production of all segments of the livestock industry in the last 10 years has been the increased use of corn for ethanol production (Figure 3). On a percentage basis, corn used for feed has decreased from over 50% to approximately 35% while corn usage for ethanol production is nearing 40% of U.S. production. This change in corn supply for feed has required livestock producers to explore alternative feed ingredients for use in diets.

The main alternative ingredient used in pig diets is the byproducts of ethanol production, most notably, dried distillers grains with solubles (DDGS). Other ingredients, such as bakery byproducts and flour milling byproducts (ex. wheat middlings) also are often used as energy sources. The increased use of these byproducts in swine diets add two components to the diet, unsaturated fat and fiber, that can greatly impact the product delivered to the processor.

Stein and Shurson (2009) reviewed the effects of feeding DDGS on pig performance and carcass and fat quality. In short, increasing dietary DDGS reduces dressing percentage and belly firmness, and increases iodine value of fat stores. The influence of DDGS on other carcass measurements, such as backfat and loin depth, is dependent on whether ADG and ADFI are reduced when DDGS are added to the diet. If ADG is not reduced, backfat and loin depth and belly thickness is similar for pigs fed DDGS and those fed corn-soybean meal diets without DDGS. If ADG is reduced, their review indicated that belly thickness, backfat thickness, and loin depth are all reduced. This observation is of particular interest because many new ethanol byproducts are lower in oil and higher in fiber content than conventional DDGS.

Adding unsaturated fat to the diet, especially linoleic acid (C18:2), increases the unsaturated fatty acid content of pork fat (Benz et al., 2011). Decreasing the feeding duration of the unsaturated fat source lowers the content of fatty acids in the fat depot (Xu et al., 2010; Benz et al., 2011). However, even long term removal of the fat source from the diet results in a more unsaturated fat than if the fat source was never added to the diet. This response has been demonstrated for soybean oil (Benz et al.; 2011), DDGS (Xu et al., 2010), and a combination of DDGS and wheat middlings (Asmus et al., 2011). Although data is not available, additions of bakery byproducts or other ingredients that increase the dietary content of unsaturated fats would be expected to produce a similar response.

The changes in fat composition and belly firmness with the addition of DDGS are quite consistent; however, other quality measures are not affected as consistently. Leick et al. (2010) fed up to 60% DDGS and found that while DDGS altered belly characteristics that would influence bacon slicing, other traits like bacon shelf life and loin quality were not substantially affected. Goehring (2010) found that feeding 20% DDGS reduced belly firmness and altered the fatty acid profile as expected, but did not affect belly processing or bacon sensory characteristics. Also feeding 20% DDGS, Widmer et al. (2008) also found no effect of DDGS, high protein DDG, or corn germ on cooking loss, shear force, and bacon distortion scores or the overall palatability of bacon and pork chops.

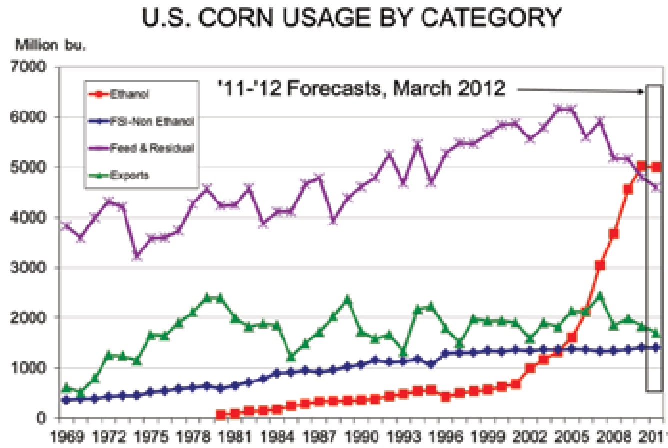

Figure 3. Corn usage by category (Source: Steve Meyer, Paragon Economics, Inc.).

Clearly fatty acid profiles and fat firmness are changed as an unsaturated fat source is added to the diet. The influence of this change on the product value varies by customer. Thus, it is not surprising that some processors with strong Japanese export business and fresh belly customers are quite concerned with fat firmness. Other customers that predominantly market fresh pork to domestic markets or bellies for microwavable bacon are less concerned with fat firmness.

The fat content of DDGS products is changing rapidly. Ethanol processors are adopting new technologies to remove much of the oil from DDGS. While this change may alleviate a portion of the fat firmness concerns due to unsaturated fat, it will result in distiller byproducts with lower energy and, thus, less value for swine producers. Removing the fat concentrates the protein and fiber content. Increasing the fiber content in the diet increases the weight of the large intestine and lowers dressing percentage (Asmus et al., 2011). The influence of fiber on large intestine weight is the cause of decreased dressing percentage when DDGS is fed up to marketing time. Although the effect on fat firmness by adding fiber to the diet is not as great as the impact of adding unsaturated fat, increasing the fiber content will still increase iodine value and result in slightly softer fat, as demonstrated by Asmus et al. (2012) when adding wheat middlings to the diet.

RACTOPAMINE

The effect of dietary ractopamine on pig performance has been well documented. Feeding 5 to 10 ppm of ractopamine for 14 to 35 days before market increases growth rate and improves feed efficiency (Apple et al, 2007). The review of Apple et al. (2007) also found that dressing percentage, loin muscle area, and fat free lean index increased and tenth rib fat depth decreased as ractopamine level in the diet or feeding duration increased. Similarly, the feed efficiency response is dose dependent. With the recent increase in feed cost and market price, the economic benefit of ractopamine has increased due the improved value of the feed efficiency and carcass weight benefit. Thus, producers using ractopamine have increased the feeding duration and dosage compared with usage in the past.

Because feeding ractopamine increases carcass lean and decreases fat content, it also increases the degree of unsaturated fatty acids including increased linoleic acid content and total polyunsaturated fatty acids in loin muscle and backfat. However, the effect doesn't appear to be consistent across all fat depots. The iodine value of subcutaneous fat stores, such as backfat increases by approximately 2 to 3 mg/g when 10 ppm ractopamine is fed for 35 d before market (Apple et al., 2008), whereas composition of fatty acids in loin muscle only appears to be significantly influenced when high levels of ractopamine (20 ppm) are fed (Apple et al., 2007). Most experiments have found no negative effects of ractopamine on fresh pork color, firmness, or water holding capacity (Apple et al. (2007) or bacon and belly quality traits (Scramlin et al., 2008). Some have found decreased marbling when feeding ractopamine (Leick et al., 2010), but this response is not consistent (Apple et al., 2007).

Because ractopamine affects pig behavior, heart rate, catecholamine profile, and makes pigs more difficult to handle (Marchant-Forde et al., 2003), it makes pigs more susceptible to handling and transport stress. The swine industry must ensure handling practices are reviewed at the farm and processor level to minimize transport and handling related mortality and downer animals. The increased feeding duration of ractopamine highlights the need for continual focus in this area.

IMMUNOLOGICAL CASTRATION

Immunological castration is not a new technology (Dunshea et al.; 2001), but the recent approval in the United States and Canada has renewed interest in the potential use. A key advantage of immunological castration is that the male pig retains the characteristics of an intact boar until the second immunization, about 4 to 6 weeks before marketing. Thus, the increased protein deposition, lean muscle mass and reduced fat deposition of boars improves overall feed conversion compared with conventional, physically castrated pigs. A recent review of 11 studies by Dunshea (unpublished) indicated that immunized males have improved ADG (149 g/d), F/G (0.35), live weight (2.2 kg), and carcass weight (0.45 kg), and lower backfat (2.6 mm), but also had lower dressing percentage (-1.63%) than barrows. The backfat and belly thickness of immunological castrated pigs can be changed by increasing the feeding duration after the second vaccination. Feed intake increases rapidly after the second vaccination. Although feed efficiency continues to be improved at this stage compared to physically castrated pigs, fat and protein deposition are much greater for immunological castrated pigs allowing fat composition to be altered via feeding duration. Extending the feeding duration from 4 to 6 weeks after the second vaccination reduces iodine value of fresh bellies to similar iodine values as physically castrated barrows (Boler et al., 2012). Increasing dietary lysine levels fed to immunological castrated males, above those normally fed to physically castrated pigs, also increases carcass primal cutting yield (Boler et al., 2011). However, immunological castrated pigs also have thinner and less firm bellies (Boler et al., 2012) than their physically castrated counterparts.

The acceptability of immunological castration by U.S. pork processors will drive its application in the industry. The technology clearly works to control boar taint. Proper application within production and changes in processing plants to allow processing of immunological castrated pigs will determine whether the level of success of this technology.

PROCESSOR EXPECTATIONS AND REQUIREMENTS

Each processor in the U.S. pork industry has different expectations for products delivered to their facilities. This is based on the value of the products they produce and market. These different expectations result in signals sent to producers that determine final market weight, facility utilization, trucking cost, diet cost, genetic selection, biosecurity, and labor requirements.

Processors use weight discounts to encourage producers to market pigs closer to plant's ideal weight range. A processor that has relatively low weight discounts is more forgiving to light or heavy weight pigs. This allows the producer to market more pigs from initial loads from the barn, have fewer marketing events (the number of times groups of pigs are sold from a barn), and sell a greater percentage of their pigs to the primary market. Thus, facility utilization is increased, market weight is increased, trucking and labor cost are reduced, and biosecurity is improved. The reduction in marketing events from a facility decreases the labor and trucking costs because there are fewer partial loads from the barn. This improves biosecurity because the partially-filled truck doesn't have to go to another barn to fill the load, increasing the risk of disease transmission from one barn to another. It is difficult to easily place an economic value on some of these differences, especially for items such as biosecurity. However, it is easy to see 8% or greater differences in facility utilization between production systems marketing to a processor with a "narrow window" with higher weight discounts and production systems marketing to a packer with a wider weight window. An 8% difference in facility utilization is worth about $3/pig space per year. Decreasing the weight discounts also allows producers to market at heavier weights which lowers cost of production by spreading fixed costs over more total pounds of pork.

The biggest value difference for producers is when pigs are marketed outside the optimal weight range for the processor. Using the example in Figure 4, a semi-load of pigs marketed 15 lb above the optimal market weight would have a discount of approximately $1.50/pig for the packer with a wide weight window. For the packer with the narrow weight window, marketing pigs at 15 lb above the ideal weight would result in a discount of approximately $6.00/pig. The wide weight window is much more forgiving for loads marketed above or below the optimal market weight.

Requiring certain fat traits (ex. iodine value in belly or jowl fat) influences diet formulation and can result in increased cost of production. Because quantity of DDGS, bakery products, or other ingredients are limited by fat targets for one processor, but not for others, diet formulations and feed costs can vary greatly for producers marketing to the different processors. For example, one producer may need to limit their DDGS inclusion rate to 15% of the diet to meet low iodine value targets. Another producer without those requirements may be able to feed 30 to 40% DDGS in most of their finishing diets. At current costs, the result is a $2.50 to 4.00 per pig difference in production cost due to differences in feed cost.

Genetic source requirements are another area where one processor may differ from another. A terminal sire line may be prohibited by one processor, but allowed by another processor. The prohibited sire line may have significant advantages in live production (ex. reduced mortality

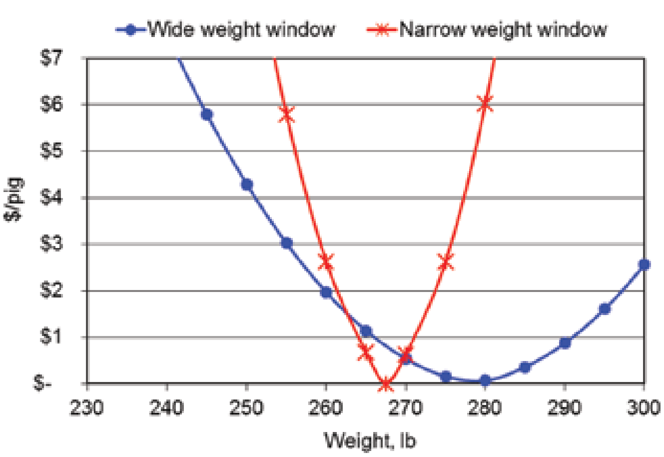

Figure 4. Average lost profitability per pig for a load of pigs marketed to two different processors with a narrow or wide weight window ($80/cwt and $250/ton final diet cost).

and number of cull pigs) that more than offsets the reduced value for the processor. As a result, a genetic source requirement can dramatically increase a producer's cost of production.

A final difference between processors can be their acceptance of technology such as ractopamine. With current prices, feeding ractopamine can increase profitability by $2 to 4/pig. Therefore, a producer marketing to a processor that does not allow ractopamine use must be paid a higher price to compensate for the reduced profit potential.

CONCLUSION

The swine industry continues to undergo rapid changes that impact production costs and the quality of pork delivered to the processor. This paper has touched upon some of the technology implemented by pork producers to help lower their cost of production. For example, litter size is increasing at 0.13 pigs per litter each year. While this is a benefit for the pork producer, it may negatively affect muscle fiber development which could lead to decreased pork quality. The increasing use of ethanol byproducts (ex. DDGS) has resulted in fat quality concerns, especially for export markets and belly processors. Yet again, this is an opportunity for the producer to help lower cost of production by $2 to 4 per pig. Increases in feed cost also have resulted in the increased dose and feeding duration of ractopamine, which while profitable to the producer, makes pigs more susceptible to transport stress and elevates the need for proper handling techniques to minimize downer or fatigued pigs. Immunological castration provides a new challenge for producers and processors to determine whether they can capture the potential value of this technology. Finally, pork processors' purchasing programs and specifications regarding ideal carcass weight ranges have led to major differences in barn utilization, feed cost, and cost of production for different swine producers.

The objective of my paper has been to try to educate meat scientists and processors about these technologies that are economically favorable to producers but may have negative ramifications on pork quality. U.S pork producers are some of the most efficient producers in the world. We all want to produce a safe, nutritious, and desirable product to feed the worlds growing need for protein. Our hope is that we can find compromise in cost structure for producers and pork quality for packers. Obviously, there is need for enhanced communication between pork producers and packers to solve these issues.

REFERENCES

Apple, J.K.; Maxwell, C.V.; Kutz, B.R.; Rakes, L.K.; Sawyer, J.T.; Johnson, Z.B.; Armstrong, T.A.; Carr, S.N.; Matzat, P.D. 2008. Interactive effect of ractopamine and dietary fat source on pork quality characteristics of fresh pork chops during simulated retail display. *J. Anim. Sci.* 86:2711-2722.

Apple, J.K.; Rincker, P.J.; McKeith, F.K.; Carr, S.N.; Armstrong, T.A.; Matzat, P.D. 2007. REVIEW: Meta-analysis of the ractopamine response in finishing swine. *Prof. Anim. Sci.* 23:179-196.

Asmus, M.D., J. M. DeRouchey, J. L. Nelssen, M. D. Tokach, S. S. Dritz , R. D. Goodband, and T. A. Houser. 2011. Effects of Lowering Dietary Neutral Detergent Fiber Levels Prior to Marketing on Finishing Pig Growth Performance, Carcass Characteristics, Carcass Fat Quality and Intestinal Weights. KSU Swine Day Report. access via www.KSUswine.org

Asmus, M.D.; DeRouchey, J.M.; Nelssen, J.L.; Tokach, M.D.; Dritz, S.S.; Goodgand, R.D. 2012. Effects of increasing NDF from corn dried distillers grains with solubles (DDGS) or wheat middlings (Midds), individually or in combination, on growth performance, carcass characteristics, and fat quality in finishing pigs. J. Anim. Sci. 90(Suppl. 1):Abstr.

Beaulieu, A.D.; Aalhus, J.L.; Williams, N.H. Patience, J.F. 2010. Impact of piglet birth weight, birth order, and litter size on subsequent growth performance, carcass quality, muscle composition, and eating quality of pork. *J. Anim. Sci.* 88:2767-2778.

Benz, J. M.; Tokach, M.D.; Dritz, S.S.; Nelssen, J.L.; DeRouchey, J.M.; Sulabo, R.C.; Goodband, R.D. 2011. Effects of choice white grease and soybean oil on growth performance, carcass characteristics, and carcass fat quality of growing-finishing pigs. *J. Anim. Sci.* 89:404-413.

Bérard, J.; Kreuzer, M.; Bee, G. 2008. Effect of litter size and birth weight on growth, carcass and pork quality, and their relationship to postmortem proteolysis. J. Anim. Sci. 86:2357-2368.

Boler, D.D.; Kutzler, L.W.; Meeuwse, D.M.; King, V.L.; Campion, D.R.; McKeith, F.K.; Killefer, J. 2011. Effects of increasing lysine on carcass composition and cutting yields of immunologically castrated male pigs. *J. Anim. Sci.* 89:2189-2199.

Boler, D.D.; Killefer, J.; Meeuwse, D.M.; King, V.L.; McKeith, F.K.;.Dilger, A.C. 2012. Effects of slaughter time post-second injection on carcass cutting yields and bacon characteristics of immunologically castrated male pigs. *J. Anim. Sci.* 90:334-344.

Dunshea, F.R., Colantoni, C., Howard, K.; McCauley, I.; Jackson, P.; Long, K.A.; Lopaticki, S.; Nugent, E.A.; Simons, J.A.; Walker, J.; Hennessy, D.P. 2001. Vaccination of boars with a GnRH vaccine (Improvac) eliminates boar taint and increases growth performance. *J. Anim. Sci.* 79:2524-2535.

Foxcroft, G.R.; Dixon, W.T.; Novak, S.; Putman, C.T.; Town, S.C. Vinsky, M.D.A. 2006. The biological basis for prenatal programming of postnatal performance in pigs. J. Anim. Sci. 84:E105-E112.

Gondret, F., L. Lefaucheur, H. Juin, I. Louveau and B. Lebret. (2006) Low birth weight is associated with enlarged muscle fibre area and impaired meat tenderness of the longissimus muscle in pigs. *J. Anim. Sci.* 84:93-103.

Goehring, B.L. 2008. Influence of dietary dried distillers grains and glycerol on bacon quality. M.S. Thesis. Kansas State University. Available at: http://krex.k-state.edu/dspace/bitstream/2097/4136/7/BrandonGoehring2010.pdf

Leick, C.M.; Puls, C.L.; Ellis, M.; Killefer, J.; Carr, T. R.; Scramlin, S. M.; England, M. B.; Gaines, A. M.; Wolter, B. F.; Carr S. N.; McKeith F. K. 2010. Effect of distillers dried grains with solubles and ractopamine (Paylean) on quality and shelf-life of fresh pork and bacon. *J. Anim. Sci.* 88:2751-2766.

Knauer, M.T.; Hostetler, C.E. 2012. Industry productivity analysis – Sow farm traits. *J. Anim. Sci.* 90 (Suppl. 1):Abstract.

Marchant-Forde, J. N.; Lay, Jr., D.C.; Pajor, E.A.; Richert, B.T.; Schinckel, A.P. 2003. The effects of ractopamine on the behavior and physiology of finishing pigs. *J. Anim. Sci.* 81-416-422.

Nissen, P.M.; Jorgensen P.F.; Oksbjerg, N. 2004. Within-litter variation in muscle fiber characteristics, pig performance, and meat quality traits. *J. Anim. Sci.* 82: 414-421.

Rehfeldt, C.; Kuhn, G.; Fiedler, I.; K. Ender, K. 2004. Muscle fibre characteristics are important in the relationship between birth weight and carcass quality. *J. Anim. Sci.* 82(Suppl. 1):250.

Scramlin, S.M.; Carr, S.N.; Parks, C.W.; Fernandez-Duenas, D.M.; Leick, C.M.; McKeith, F.K.; Killefer, J. 2008. Effect of ractopamine level, gender, and duration of ractopamine on belly and bacon quality traits. *Meat Sci.* 80:1218-1221.

Stein, H.H.; Shurson, G.C. 2009. BOARD-INVITED REVIEW: The use and application of distillers dried grains with solubles in swine diets. *J. Anim. Sci.* 87:1292-1303.

Widmer, M.R.; McGinnis, L.M.; Wulf, D.M.; Stein, H.H. 2008. Effects of feeding distillers dried grains with solubles, high-protein distillers dried grains, and corn germ to growing-finishing pigs on pig performance, carcass quality, and the palatability of pork. *J. Anim. Sci.* 86:1819-1831.

Xu, G.; Baidoo, S.K.; Johnston, L.J.; Bibus, D; Cannon, J.E.; Shurson, G.C. 2010. The effects of feeding diets containing corn distillers dried grains with solubles, and withdrawal period of distillers dried grains with solubles, on growth performance and pork quality in grower-finisher pigs. *J. Anim. Sci.* 88:1388-1397.