MANIPULATION OF PROCESSING TECHNOLOGIES TO ENHANCE GROWTH PERFORMANCE AND (OR) REDUCE PRODUCTION COSTS IN PIGS

by

CHAD BENNETT PAULK

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Major Professor
Joe D. Hancock

Abstract

Nine experiments were completed to evaluate the effects of feed manufacturing practices on milling characteristics of diets and growth performance and stomach morphology in pigs. In Exp. 1 and 2, reducing the particle size of sorghum from 800 to 400 μm improved ($P < 0.04$) efficiency of gain in finishing pigs by 5% but had negative effects on cost of milling and stomach morphology. In Exp. 3 and 4, finishing pigs fed diets with 10 mg/kg of ractopamine HCl, had improved ($P < 0.05$) ADG, G:F, HCW, dressing percentage, and percentage carcass lean. However, increasing mix time of the diet from 0 to 360 s did not affect ($P > 0.06$) the response of finishing pigs to ractopamine HCl. In Exp. 5 and 6, adding ground and cracked corn to a pelleted supplement for nursery pigs decreased ($P < 0.01$) growth performance compared to feeding a complete pellet. In Exp. 7, increasing the percentage of cracked corn in a diet for finishing pigs decreased development of stomach lesions but also had a generally negative effect on efficiency of gain. In Exp. 8, adding cracked corn to a pelleted supplement (as done for the nursery pigs) decreased milling costs and improved health of stomach tissue. But, G:F was decreased by 6% ($P < 0.05$) which will make this technology unattractive to swine producers. In our final experiment (Exp. 9), pigs fed pellets tended to have the greatest growth performance, pigs fed mash the worst, and pigs fed pellets for only part of the grow-finish phase fell in between. In conclusion, grinding sorghum-based diets for finishing pigs improved efficiency of growth but extensive mixing to maximize diet uniformity had no effect on growth performance or carcass measurements. Use of cracked corn in diets does decrease diet costs and improve stomach health in finishing pigs but feeding of complete pellets for the entire finishing period supports maximum rate and (or) efficiency of gain.

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Acknowledgements

It is not the destination that defines the person, but the journey which is endured by the individual which defines his destination, and the wisdom obtained from those who lay the path on one's journey that is used to influence the destination. It is not the destination, but the equation that derives the destination that defines the person. So, maybe the destination is just another part of the equation…

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Dedication

I dedicate my thesis to my family for everything they have done for me. This would not be possible without their love and support.

Chapter 1 - Literature Review

Introduction

There are many factors to take into consideration when feeding swine. This is a very important task when considering feed cost represents 65 to 80% of total cost of production (Jensen, 1976). Lowering feed cost while achieving maximum production has become increasingly important due to the rapid increase in grain prices. This has pushed producers to apply feed manufacturing practices to maximize utilization of feedstuffs. Processing feed ingredients can benefit both the feed manufacturer and the swine producer, but it comes with a cost. If properly managed, the increased cost required for feed processing can be accounted for by improvements in pig performance. Therefore, good feed manufacturing practices need to be developed to ensure a low cost to benefit ratio. Not only is it important to fully understand each processing method and it effects, but to also understand how they can be manipulated to enhance pig performance and (or) reduce production cost

Grinding

Grains are the main ingredient in swine feeds subject to grinding at the feedmill. Other ingredients are previously processed and arrive at the feedmill in an acceptable condition. Grinding grains produces benefits in performance of pigs, but it increases two main costs associated with milling; 1) the energy required to mill one ton of grain which is expressed in kWh/ton and 2) the production rate per horsepower hour of operation. The energy cost is considered a variable cost, and the expense added to completed diet cost is calculated by multiplying the cost of electricity by the energy required to mill the grain. Fixed costs of the feedmill are affected by the production rate. Increased production rate allows for the fixed cost to be spread out across more tons of feed, therefore, reducing the fixed cost. Understanding the factors that influence the efficiency and production rate of grinding can be very beneficial.

A variety of factors can affect the energy consumption and production rate of grinding grains. Previous research has reported that energy consumption and production rate can vary amongst different grains. Healy et al. (1994) demonstrated an increase in energy required to grind corn compared to hard endosperm and soft endosperm sorghums. Similar production data comparing the effects of grinding corn, hard endosperm, and soft endosperm sorghum was produced by Cabrera et al. (1995) and is presented in Figure 1.1. This portrays the differences in energy requirements and production rates amongst cereal grains when ground to particle sizes of 1,000, 800, 600, and 400 µm using a three-high rollermill. There were no significant differences between sorghum grains for energy consumption and production rate. However the soft endosperm sorghum required the least amount of energy and had the highest production rates. These studies agree with Baker (1960) who reported that milling sorghum grains is more efficient than milling corn. .

Cabrera et al. (1995) also demonstrated a reduction in milling efficiency as grain particle size was reduced using a three-high rollermill (Figure 1.1). As sorghum grains decreased in mean particle size from 1,000 to 400 µm, there was an increase in energy consumption and decrease in production rate. Healy et al. (1994) and Paulk et al. (2011a) also reported a decrease in milling efficiency as the particle size of sorghum was decreased. It has also been shown that reducing the particle size of corn also reduces milling efficiency (Healy et al., 1994; Cabrera et al., 1995; and Wondra et al., 1995a). However, Cabrera et al. (1995) reported only slight differences when corn particle size was reduced from 1,000 to 800 µm, but dramatic increases in energy consumption and decreases in production rate occurred as particle size of corn was further reduced to 400 µm. Wondra et al., (1995a) reported similar results when using a hammermill to mill corn to mean particle sizes of 1,000, 800, 600, and 400 µm (Figure 1.2). The authors reported an overall increase in energy required to mill corn as particle size was decreased from 1,000 to 400 µm. However, the production rate was only slightly decreased as corn particle size was reduced from 1,000 to 600 µm, and markedly decreased when further reduced to 400 µm.

From looking at the previous experiments, it is obvious that reducing the particle size of cereal grains leads to an increased energy requirement and decreased production rate. However, the rate at which these factors change can be altered by grain and mill type. With the knowledge of the negative effects particle size reduction can have on milling efficiency, it is important to further investigate if these loses can be accounted for by improvements in animal performance.

Growth Performance

The idea of reducing the particle size of grains before feeding them to pigs dates back to the early 1930's. Fraps (1932) used ground sorghum to demonstrate that reducing the particle size improved nutrient digestibility. Woodsman et al. (1932) reported similar results when feeding ground oats. This idea was expanded upon by Aubel (1945, 1955), who demonstrated improvements in efficiencies of gain when pigs were fed ground corn and sorghum grains. These experiments led the way for many animal scientists to try and develop the most beneficial way to apply this processing method to swine production.

Healy et al. (1994) applied the milling cost of McEllhiney (1986) to determine the economic value of reducing the particle size of grains in nursery pigs. The authors reported that as the particle size of grains was reduced from 900 to 500 μm, the cost of gain decreased from $36.18 to $35.63/100 kg for pigs fed the corn-based diets, from $39.49 to $37.09/100 kg for pigs fed hard endosperm sorghum-based diets, and from $39.51 to $36.82/100 kg for pigs fed soft endosperm sorghum-based diets. It was concluded that the added expense of fine grinding is usually less than the economic benefits from improved feed efficiency.

Improving the pig's rate and efficiency of gain leads to more profitable production for the producer. An 8% improvement in rate of gain of finishing pigs was demonstrated by Hedde et al. (1985) when the particle size of a corn-based diet was reduced from a coarse grind (<20% of the ground grain passing through a 1.2-mm screen) to a fine grind (>80% of the ground grain passing through a 1.2-mm screen). Lawrence et al. (1983) reported a 17% increase in rate of gain when the particle size of oats was reduced from a coarse (> 1,000 μm) to a fine (< 600 μm) particle size. There have also been previous reports of improvements in rate of gain in nursery pigs when the grain particle size is reduced. Goodband and Hines (1988) reported a 5% increase in ADG when pigs were fed diets with barley particle size reduced from 768 to 635 μm. Mavromichalis et al. (1998) demonstrated a 10% improvement in rate of gain in nursery pigs when sorghum particle size was reduced from 1300 to 600 μm.

Although reducing particle size does not always result in benefits of rate of gain, it is still a viable way to improve efficiency of gain. Grains have a hard outside protective layer that makes it hard for all of the nutrients of the grain to be accessed by digestive enzymes, therefore reducing digestion. Proper mastication can improve the digestion of the grain kernel by breaking these protective complexes and exposing more nutrients. However, pigs are poor masticators of their food, which leads to large amounts of undigested grain passing through their digestive system. Thus reducing the particle size of grains exposes the less protected areas of the kernel to digestive enzymes and allows the pig to digest a larger portion of the nutrients. Mahan et al. (1966) and Hedde et al. (1985) reported improvements in efficiency of gain in grow-finish pigs when corn particle size was reduced from coarse (> 1,000 μm) to fine (< 600 μm). Wondra et al. (1995a) concluded a 1.3% improvement in G:F for every 100 μm reduction in particle size when corn was ground from 1,000 to 400 μm. Giesmann et al. (1990) reported a 5% improvement in efficiency of gain when the particle size of sorghum was reduced from coarse (>1,000 μm) to fine (< 600 μm). Cabrera et al. (1995) demonstrated a 7 and 6% improvement in G:F when the particle size of soft and hard endosperm sorghums, respectively, was reduced from 800 to 400 μm. Paulk et al. (2011a) reported a 4% improvement in efficiency of gain when sorghum particle size was decreased from 800 to 400 μm. Combining the results of Cabrera et al. (1995) and Paulk et al. (2011a) resulted in a 1.3% improvement in efficiency of gain for every 100 μm reduction in sorghum particle size. Therefore, reducing the particle size of sorghum results in similar improvements as that of corn, with the reduction of corn particle size having a 1.2 to 1.4% improvement in gain:feed for each 100 μm reduction in corn particle size. However, data produced from grinding the complete diet and adding 5% sorghum hulls to the diet demonstrated different results. When feeding a wheat and tapioca based diet, Dirkzwager et al. (1998) reported an improvement in finishing pigs as the particle size of the complete diet was reduced. The authors also reported that adding 5% sunflower hulls to the fine diet resulted in coarse particles (> 1.4) equal to that of the medium grind, and pigs fed this treatment resulted in a 2 and 3% improvement in efficiency of gain compared to the fine and medium particle size treatments, respectively. Paulk et al. (2011b) tested the effects of replacing 10, 20, and 40% of ground corn with cracked corn. When adding 10, 20, and 40% cracked corn, the particle size was increased from 684 μm to 926, 979, 1,187 μm, respectively. There was a trend for reduction in gain:feed as the percentage of cracked corn in the diet increased. Reducing the particle size of grains improves the performance of pigs. However, there is still ample opportunity for further research in particle size reduction, especially in the area of grinding all ingredients and adding small percentages of whole or coarse ingredients to the diet.

Nutrient Digestibility

Improvements in nutrient digestibility are thought to be the reason for improved performance due to particle size reduction. Continuous research has been conducted over the years on the effects of nutrient digestibility due to feed processing methods. Owsley et al. (1981) conducted an experiment to determine the apparent ileum and total track digestibility of sorghum in finishing pigs as the sorghum particle size was reduced from 1,262 to 471 μm. The authors concluded that reducing the particle size improved the apparent illeal and total track digestibility of DM, starch, N, and GE. Isoleucine, leucine, phenylalanine, threonine, and all the non-essential amino acids except glycine were also shown to improve in ileal digestibility as sorghum particle size was reduced (Owsley et al. 1981). Oh et al. 1983 had previously demonstrated improvements in nutrient digestibility when grinding sorghum grains. Passed research has also demonstrated improvements in nutrient digestibilities of corn when its particle size is reduced (Lawrence, 1967; Ohh et al., 1983; Giesemann et al., 1990).

Stomach morphology

Although decreasing the particle size of grains can cause improvements in swine performance, it can have negative effects on stomach morphology. Intensive management strategies of pigs have led to more common occurrences of ulceration of the pars esophagea region of the pig's stomach. Previous surveys from abattoirs have reported that approximately 20% of pigs have extensive lesions and 60% have pre-ulcerative parakeratosis lesions (Driesen et al., 1987; Elbers et al., 1995; O'Sullivan et al., 1996). Common feed manufacturing practices, such as fine grinding have been shown to increase the incidences of ulceration of the pars esophageal region of the stomach in finishing pigs (Mahan et al., 1966; Maxwell et al., 1970; Cabrera et al., 1995; Wondra et al., 1995a; and Ayles et al., 1996) and lactating sows (Wondra et al.,1995c). It has been hypothesized that this is due to the increased fluidity of stomach contents, which results in more mixing of stomach contents. Mixing of the fluid stomach content allows for continuous exposure of the unprotected mucosa of the esophageal region to pepsin and digestive acids (Reimann et al., 1968; Maxwell et al., 1970; Maxwell et al., 1972). The relationship between severity of ulcers and their influence on growth performance is not well defined. Hedde et al. (1985) reported that increased severity of gastric ulcers was associated with a decrease in rate of gain. It was also demonstrated by Ayles et al. (1996) that pigs with moderate to severe ulcers had depressed growth rate. However, other research has stated that gastric ulcers did not affect growth rate (Backstrom et al., 1988; Guise et al., 1997; Dirkzwager et al., 1998). Despite the effects on growth performance, once severe enough, gastric ulcers can result in sudden death of pigs. In attempts to reduce stomach ulcers while maintaining feed efficiency, we conducted an experiment to determine the effects of adding 10, 20, or 40% cracked corn to the diet. Supplementing the diet with cracked corn led to an improvement (linear, $P < 0.05$) in mean value scores for lesions of the pars esophageal region of the stomach without any significant affects ($P > 0.1$) on growth performance (Paulk et al., 2011b). Finding the balance between maximizing efficiency and minimizing stomach ulcers is a very important balance to maintain for swine producers. Compared to feeding mash diets adding a percentage of cracked corn to the diet could serve as a promising practice for achieving that balance.

Uniformity of particles

There are two common mills that are used to reduce to particle size of ingredients, hammermills and roller mills. Both mills are capable of achieving satisfactory grinds, so deciding which mill to use depends on the system to which it will be applied. Although both mills can sufficiently grind feed ingredients, they have different particle size reduction procedures. Roller mills reduce particle size by crushing, in which a comprehensive force is applied to the ingredient. This process produces a small amount of fine material resulting in a fairly uniform particle size of the grain. Hammermills reduce the particle size of ingredients by impact grinding (Pfost, 1976a). This creates a more spherical particle shape and increases the amount of fine pulverized particles, resulting in a more non uniform particle size (Koch, 2002).

Uniformity of the grind is commonly defined as the variation in particle size ($s_{gw)}$. A larger s_{gw} represents a more non uniform distribution of particle sizes and a smaller s_{gw} represents a more uniform particle size. Determining the effects uniformity of particle size has on nutrient digestibility and growth performance would help determine which type of mill to use for grinding. Wondra et al. (1995b) reported no difference in growth performance as the s_{gw} was increased. However, there was an improvement in nutrient digestibility as variation of the mean particle size was reduced. Patience et al. (2011) tested the effects of feeding ground corn with an average mean particle size of 561 μm, and s_{gw} of 1.9, 2.1, 2.3, 2.5, or 2.7. The authors reported a quadratic response (P < 0.05) to particle size variation, with DM digestibility decreasing from 85.3 to 81.1% and increasing from 81.1 to 84.5% as s_{gw} was increased from 1.9 to 2.3 and from 2.3 to 2.7, respectively. The GE digestibility had similar results with GE digestibility decreasing from 85.8 to 81.1% as s_{gw} increased from 1.9 to 2.3, and GE digestibility increasing from 81.1 to 85.0 as sgw was further increased from 2.3 to 2.7, repectively. When comparing corn ground to 800 and 400 µm using either a roller mill or hammermill, Wondra et al. (1995b) reported that uniformity of particle size affected nutrient digestibility, however, these effects were minimal at smaller particle sizes. Since the hammermilled treatment had a smaller s_{gw} at 400 µm, but the roller mill treatment still had improved digestibility, it was suggested that it was a mill type effect more so than the s_{gw} effect. Reece et al. (1985) suggested that the reduced digestibility of hammermilled grains could be due to the spherical shape of the particles. He hypothesized that digestive enzyme were less susceptible to attach to these spherical particles.

Although digestibility may be influenced by mill type there was no effect on growth performance of pigs. Therefore, it would be important to take into consideration the cost of installing and running a roller mill or hammermill to help determine which to use. Vermeer (1993) observed the difference in economics between the two over a 15 year period. A hammermills initial cost is slightly less than that of a roller mill. However, over the 15 year period, the capital and operational costs were lower for the roller mill, except for the years the rollers had to be replaced. The roller mill system resulted in a long term average cost savings of $0.12 per ton of ground product. Although, one can save $0.12 per ton of ground feed, based on Vermeer's (1993) model, the hammermill is the most commonly used piece of equipment for reducing particle size of feed ingredients in the feed industry (Pfost, 1976a).

Mixing

For a plant to be defined as a feedmill it must house a mixer (Pfost, 1976b). The job of a mixer is to blend together 2 or more ingredients until a level of homogeneity is reached. From a feed manufactures stand point, the uniformity of the diet is based on a Coefficient of variation (CV) of some marker or nutrient in the diet. For feed manufactures, it has been continuously recommended that a CV <10% defines a homogenous mixture (Beumer, 1991; Lindley, 1991; Wicker and Poole, 1991).

It is important when defining a uniform mix to develop a dependable testing procedure that is accepted by both industry (low cost, quick, and easy) and regulatory agencies (accurate). Selecting a marker (i.e. ingredient, nutrient, or chemical) that comes from a single source is recommended. It is important to understand that it is assumed that uniformity of the marker is a representative even distribution of all ingredients or nutrients. Nutrients that are common in multiple ingredients, such as protein, calcium, and phosphorus, have been shown to be poor determinants of diet uniformity, because they can achieve low CV's with minimal mixing. In a corn-soy diet salt has been considered a good marker choice, because Cl is low in other ingredients. It is also relatively cheap, quick, and easy to measure Cl concentrations using the Quantab assay (McCoy, 1994; Clark et al. 2006). McCoy (1994) and Clark et al. (2006) have reviewed various markers used to determine uniformity of feed. The authors stated that there are a variety of pros and cons for each marker tested, and not one assay has been determined as the standard for measuring diet uniformity. Although these assays may be used to monitor mixer performance, the question still remains on how accurate they may be at predicting nutritional value of finished feeds.

Animal performance

Pfost (1976b) stated that the goal of mixing a diet is to ensure that each animal receives the intended daily intake of nutrients. To achieve this level of uniformity it has been previously stated that a CV < 10% must be achieved (Pfost, 1976b; Beumer, 1991; Lindley, 1991; Wicker and Poole, 1991). Based on observations of Wicker and Poole (1991), it was reported that 50% of commercial mixers did not achieve CVs of less than 10% when using methionine and lysine as tracers. Stark et al. (1991) concluded similar results when measuring on farm mixers. Although a high percentage of these farms are not achieving a CV < 10%, the question still remains if their livestock are obtaining adequate nutrients to support maximum performance.

The species and stage of development of an animal can greatly influence the amount of diet uniformity necessary to achieve optimum performance. Holden (1988) speculated that improper mixing of one batch of feed may not be as detrimental as one may think because growing pigs will consume that batch of feed in such a short period of time. McCoy et al. (1994) completed a series of experiments determining the effects of mix uniformity on broiler chick performance. The authors reported no significant effects of on growth performance or carcass characteristics with Quantab and microtracer CV's from 42 to 50%. McCoy et al. (1994) conducted a second experiment determining the effects of mix uniformity on broiler performance when formulating the diet to 80% of the NRC (1984) recommendations. The authors reported that CVs of 12 to 23%, depending on marker, were sufficient in supporting maximum gain of broilers. Johnston and Southern (2000) demonstrated no effects on growth performance, bone ash, bone breaking strength, and calcium and phosphorus retention when phytase CVs were as high as 69%. Traylor et al. (1994) indicated that a CV of < 12% with Cr used as a marker was necessary to maximize nursery pig performance. To support maximum rate of gain in nursery pigs, Groesbeck et al. (2007) recommended salt CVs of 5 and 7%, at the mixer and at the feeder, respectively, for phase 1 diets and salt CVs of 26 and 12% at the mixer and at the feeder, respectively, for phase 2 diets. However, based on efficiency of gain for phase 1, salt CVs of 26 (mixer) and 16 (feeder) were sufficient for nursery pigs. For phase 2 there was no significant improvements in efficiency of gain as mix time was increased from 0 to 330 sec. Groesbeck et al. (2007) also reported that substantial mixing can take place during transportation of feed. This suggests that samples collected for CV determination should be taken at the feeder, when used to determine the effects on animal performance. Traylor et al. (1994) reported no significant effects on finishing pig performance when salt CVs were decreased from 54 to 10%. The previous experiments demonstrate that diet uniformity can have effects on animal performance, but a CV of 10% is not necessary to obtain maximum performance. However, the CV required is highly dependent on the species, stage of production, marker selection, and sample collection.

With the increased use of low inclusion level ingredients, such as crystalline amino acids, growth promoters, and carcass modifiers, in the swine industry, there is an increasing concern about diet uniformity. Therefore we completed an experiment to define the level of ractopamine HCl uniformity necessary to maximize growth performance in finishing pigs. As ractopamine HCl mix time was increased from 0 (Cr CV of 67%) to 360 s (Cr CV of 12%), there were no improvements ($P > 0.15$) in finishing pig performance (Paulk et al., 2011d). A second experiment was performed to determine the combined effects of potentially non-uniform distribution of both nutrients and ractopamine HCl. Increasing the mix time from 0 to 360s or reducing the salt CV from 51 to 12% had a trend for improvement (quadratic, $P > 0.11$) in G:F with a mix time of 120 s for the complete diet and ractopamine (CV of 15) resulting in the highest numerical G:F.

Therefore, even with increased used of low inclusion level ingredients, achieving the industry standard CV of < 10% may not be necessary to maximize performance. However, there are a variety of factors that can influence the CV required.

Pelleting

After ingredients have been ground and mixed together the feed can either be fed as a mash or they can be further processed. Further processing normally involves a combination of heat, pressure, and moisture. The most common form of thermal processing in the swine industry is pelleting. Pelleting swine diets has been shown to have benefits for both the swine producer and the feed manufacture.

Pelleting proves beneficial to the feed manufacture by decreasing segregation of mixed feedstuffs, increasing bulk density, reducing dustiness, and improving handling characteristics. Swine producers are requesting the particle size of grains to be less than 600 μm, which leads to problems with flowability through storage bins and feeders. These flowability or bridging problems can be eliminated by pelleting, allowing a finer grain particle size to be targeted. Although pelleting can benefit the feed manufacturer it does not come without a cost. Pelleting is the limiting factor for production rate in a feedmill. A pellet mill also requires large amounts of energy to run.

Feeding pelleted diets to pigs has previously resulted in improvements in rate of gain (Hanke et al., 1972; Baird, 1973; Wondra et al., 1995a, Johnston et al. 1999, Potter et al. 2010). However, there have also been a number of reports suggesting no significant benefits on growth rate due to pelleting (NRC-42 Committee on Swine Nutrition, 1969, Skoch et al., 1983). Table 1.2 summarizes reports on pelleting. Based on the average of the experiments in Table 1.2, pelleting diets for growing-finishing pigs resulted in approximately a 6 and 7% improvement in rate and efficiency of gain, respectively. There are a number of theories that try and explain the mechanism behind the improvement in growth performance do to pelleting. Skoch et al. (1983) proposed the idea that pelleting increased the bulk density of diets and reduced dustiness, therefore, making the diets more palatable. However, this is not supported by the inconsistencies observed with feed intake in pelleting trials. There is also controversy on whether or not pelleting conditions are severe enough to improve starch gelatinization. Jensen and Becker (1965) argued that pelleting did indeed lead to starch gelatinization, therefore, improving digestion. Wondra et al., (1995a,b) reported improvements in DM, N, and gross energy digestibilities due to pelleting. Similarly, Le Gall et al. (2009) demonstrated improvements in OM and energy with pelleting. However, the authors did not observe improvements in fecal N digestibility with pelleting. Vande Ginste and De Schrijver (1998) and Stein and Bohlke (2007) also demonstrated no improvements in N digestibility with pelleting.

The benefits in pig performance due to pelleting can be lost if pellet quality is not maintained. Stark et al (1994) reported a 7% decrease in G:F of nursery pigs (d 7 to 21) when fed up to 25% pelleted fines. The authors also demonstrated a 5% loss in efficiency of gain when growing pigs were fed a pelleted diet that contained 40% fines. Schell and van Heugten (1998) reported a linear decrease in G:F in growing pigs as pelleting fines increased from 2.5 to 40%. Increasing the percentage of fines in the diet to 25 and 40% reduced gian:feed by 3% and 4%, respectively.

As previously stated, stomach ulcers are a common concern in swine industry. It is important to understand what factors influence gut morphology and how to maximize efficiency without inducing ulceration. It was previously determined that fine grinding can have negative effects on stomach morphology (Mahan et al., 1966, Maxwell et al., 1970, Wondra et al., 1995a, and Ayles et al., 1996), but it has also been reported that pelleting can also increase the incidences of ulceration of the pars esophageal region of the stomach (Chamberlain et al., 1967; Flatlandsmo and Slagsvold, 1971; Paulk et al., 2011b). It has been hypothesized that this is due to the increased fluidity of stomach contents, which results in more mixing of stomach contents. Mixing of the fluid stomach content allows for continuous exposure of the unprotected mucosa of the esophageal region to pepsin and digestive acids (Reimann et al., 1968; Maxwell et al., 1970; Maxwell et al., 1972). In attempts to try and reduce lesions of the pars esaphogeal region while maintaining the improvement in performance due to pelleting, we conducted an experiment in which 50% of the corn was removed from the pellet and cracked. In the current experiment, pelleting the fine ground diet led to an increase in ulceration and keratinization scores of the pars esophageal region. However, cracking 50% of the corn and adding it postpellet resulted in improved ulcer and keratinization scores. Although, feeding cracked corn and the pelleted supplement improved stomach morphology, it resulted in a 6% decrease in efficiency of gain. However, there was no negative effect on rate of gain. Adding cracked corn to the diet is thought to cause less mixing to occur in the stomach, and maintains the pH gradient in the stomach preventing the acidic stomach content from irritating the non-glandular region of the stomach. Although there may be a 6% reduction in efficiency of gain, adding cracked corn to the diet for short periods of time may be beneficial in reducing mortality in a swine herd that is prone to stomach ulcers. Future research is needed to determine if there is a correct particle size for the cracked corn fraction of the diet, if there is a certain length it should be fed, or if there is a minimum percentage that can be added to maximize efficiency of gain while improving stomach morphology.

Pulling a percentage of the grain out of the pellet and adding postpellet could potentially lead to large cost savings for the feedmill. Clark et al. (2009) evaluated the economics of removing 25% of the corn fraction from a typical broiler diet containing 64% corn. The authors applied the cost to a feedmill producing 4,400 tons/week, which calculates to approximately 45.8 tons/hr (using a 6 d work week, 2-10 hour shifts at 80% efficiency), resulting in 96 working hours per week at the feedmill. Removing 25% of the corn fraction from the pellet would result in only 3,696 tons that would need to be pelleted. With the pellet mill still operating at 45.8 tons/hr, the actual working time was reduced from 96 to 81 hours. Based on an informal survey completed by feed mill managers, it was determined that it cost an average of $300/hr to operate a feedmill. This 15 hour reduction in operating time resulted in savings of $4,500 per week. When Paulk et al. (2011b) applied the previous scenario to a finishing pig ration with 50% removal of the corn fraction from diet containing 80% corn; the targeted pellet production of 4,400 ton/week was reduced to 2,640 ton/week. For the feed mill producing 45.8 ton/hour, this would reduce the required operating time from 96 hours/week to 58 hours/week. Therefore, reducing the operating time by 38 hours will save the feed mill $11,400/week. Figuring out a way to maximize feed efficiency in finishing pigs while removing a percentage of the corn from the pellet and cracking it could save feed manufactures a large sum of money while also improving stomach morphology of the pig.

Conclusion

The various stages of feed processing play a critical role in determining the overall success of the production system. Utilizing feed processing technologies, such as grinding and pelleting, have greatly improved feed utilization in pigs. However, problems can arise from increased use of these technologies, both in the feed mill and on the farm. With pelleting being the limiting factor on production rate, an increase in demand for pelleted feeds can prevent feedmills from achieving necessary production rates. Also, increased mortality on the farm due to gastric ulcers has become a major concern in some production systems. Manipulation of feed manufacturing practices can be used to alleviate these problems. However, it is important to understand the negative impacts these changes may have on pig performance. Although feed processing has led to vast improvements in the swine industry, finding the balance between feed production cost, pig performance, and pig gut health leaves ample opportunity for research in the field of feed processing and swine nutrition.

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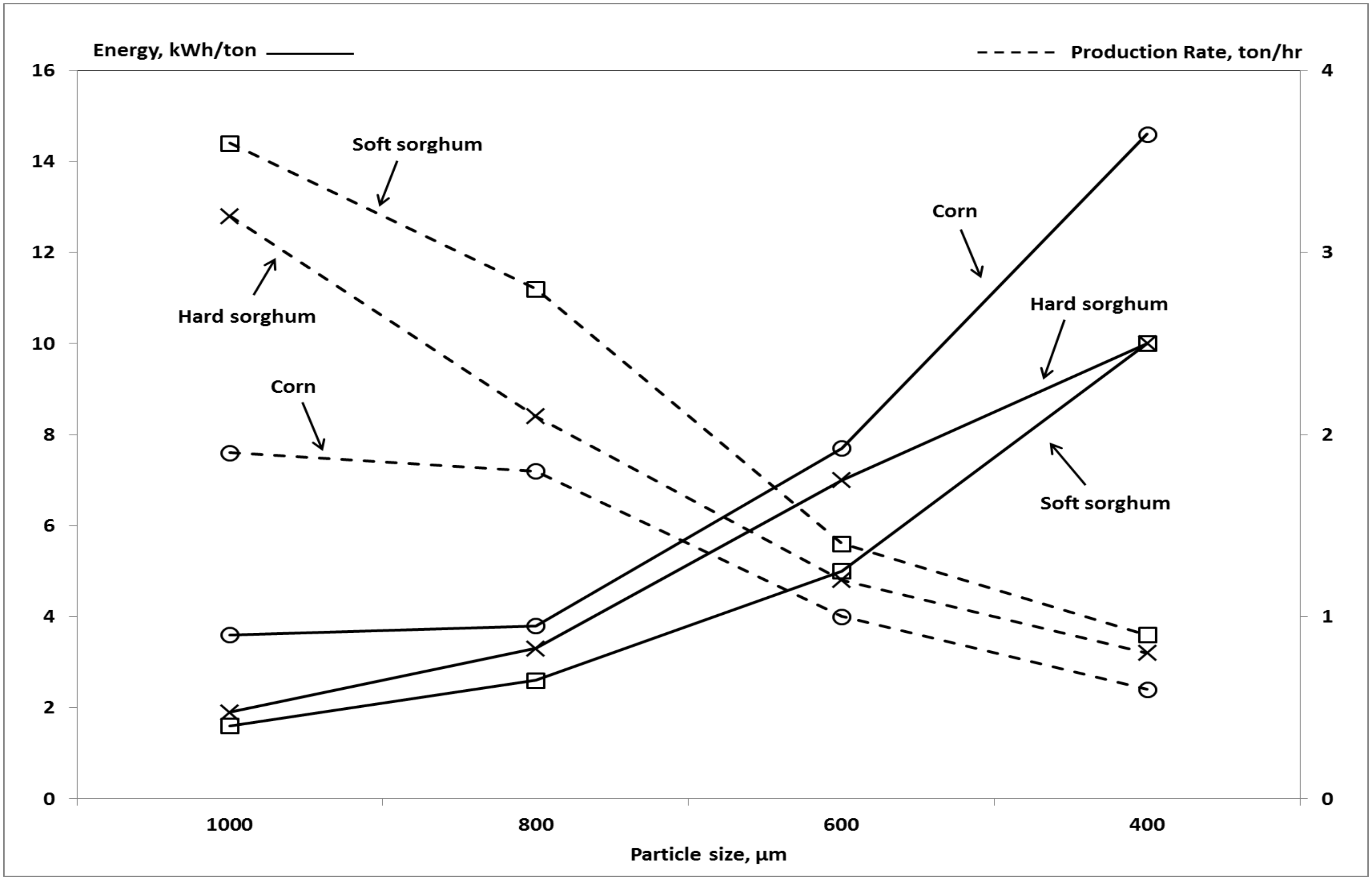

Figure 1.1 Energy consumption and production rates when roller milling corn, soft endosperm sorghum and hard endosperm sorghum

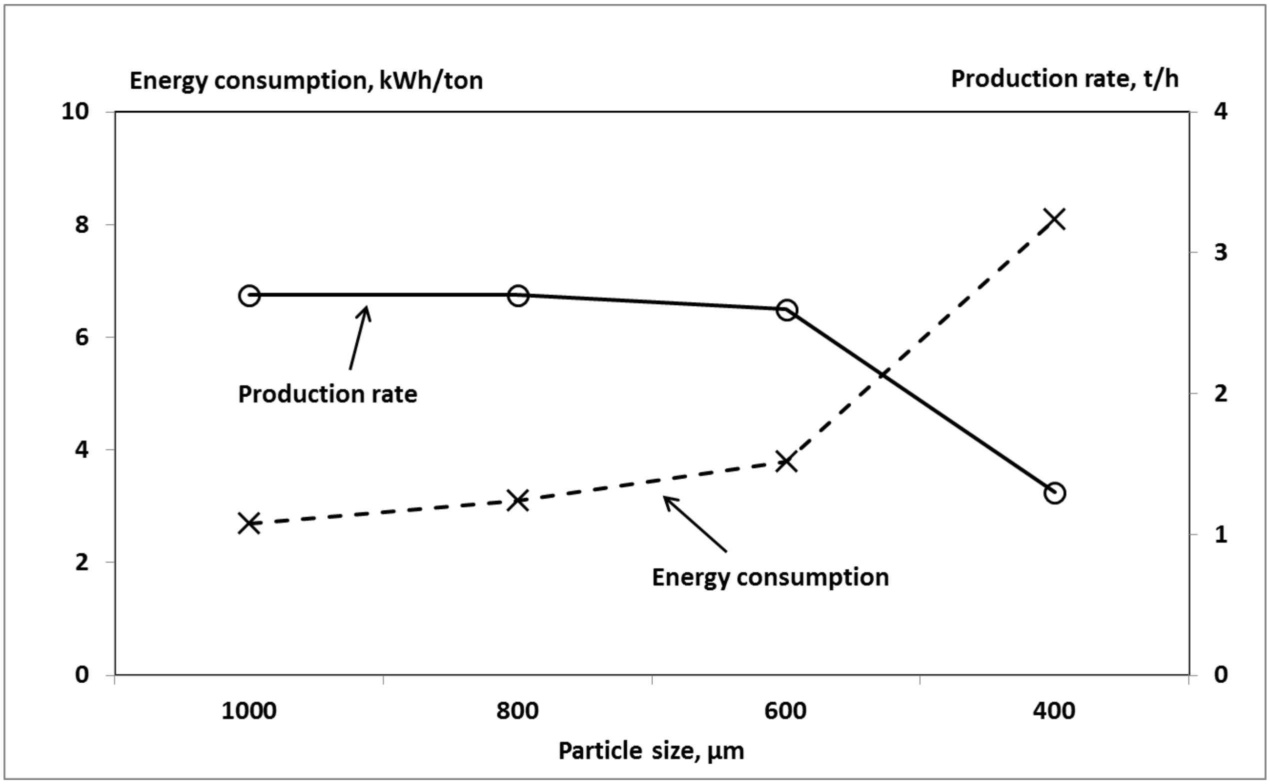

Figure 1.2 Energy consumption and production rates when hammermilling corn (Wondra et al., 1995a)

Table 1.1 Effects of particle size reduction on growth performance of grow-finish pigs

	Particle size, µm							
Item	>1,000	800	600	400	Initial and final pig wt	No. pigs	Grain	Ref.
ADG (kg)	0.68	–	0.73	–	35-97	160	Corn	Hedde et al. (1985)
Gain:feed	0.266	–	0.288	–				
ADG (kg)	–	1.00	0.98	0.99	54-120	70	Sorghum	Cabrera et al. (1994)
Gain:feed	–	0.294	0.311	0.315				
ADG (kg)	–	1.03	1.03	1.04	54-120	70	Sorghum	Cabrera et al. (1994)
Gain:feed	–	0.292	0.297	0.306				
ADG (kg)	0.98	0.98	0.99	0.99	55-115	160	Corn	Wondra et al. (1995a)
Gain:feed	0.298	0.305	0.305	0.321				
ADG (kg)	0.88	–	0.91	–	67-115	160	Wheat	Mavromichalis et al. (1998)
Gain:feed	0.285	–	0.322	–				
ADG (kg)	–	1.13	1.10	1.1	47-123	200	Sorghum	Paulk et al. (2011)
Gain:feed	–	0.365	0.369	0.379				

Table 1.2 Effects of pelleting on growth performance of grow-finish pigs[1]

Reference	Pig Wt, kg	No. of pigs	Meal			Pellet		
			ADG	ADFI	G:F	ADG	ADFI	G:F
NCR-42 Committee on Swine Nutrition (1969)	20 to 91	556	0.77	–	0.31	0.78	–	0.32
Hanke et al. (1972)	58 to 99	379	0.75	–	0.29	0.80	–	0.31
Baird (1973)	15 to 100	120	0.69	2.52	0.270	0.72	2.43	0.292
Tribble et al. (1975)	29 to 100	192	0.66	–	0.265	0.68	–	0.291
Harris et al. (1979)	70 to 100	98	0.61	2.34	0.261	0.66	2.34	0.282
Tribble et al. (1979)	59 to 98	144	0.62	2.54	0.244	0.70	2.56	0.273
Erickson et al. (1980)	10 to 97	96	0.70	–	0.33	0.79	–	0.37
Skoch et al. (1983)	49 to 98	60	0.77	2.39	0.323	0.84	2.44	0.344
Wondra et al. (1993a)	67 to 117	128	0.83	3.02	0.275	0.90	3.11	0.289
Van Heugten (1997)	Grower	346	0.722	1.556	0.467	0.746	1.508	0.496
Van Heugten (1997)	Finisher	327	0.984	2.848	0.346	0.938	2.537	0.371
Brumm (1998)	20 to 105	264	0.80	2.53	0.32	0.82	2.38	0.34
Johnston et al. (1999)	54 to 118	70	0.91	2.74	0.33	0.99	2.83	0.35
Potter et al. (2010)	28 to 129	1,072	0.87	–	0.35	0.92	–	0.37
Paulk et al. (2011)	60 to 128	200	1.134	3.13	0.363	1.195	3.09	0.392
Paulk et al. (2011)	40 to 127	252	1.046	2.66	0.40	1.108	2.72	0.417

[1]All diets were corn-soybean meal based except the diets used by Tribble et al. (1975 and 1979) and Harris et al. (1979) which were sorghum soybean meal-based.

Chapter 2 - Effects of sorghum particle size on milling characteristics, growth performance, nutrient digestibility, and stomach morphology in finishing pigs

Abstract

Two experiments were completed to determine the effects of sorghum genotype and particle size on milling characteristics, growth performance, nutrient digestibility, and stomach morphology in finishing pigs. For experiment 1, 70 barrows (average initial BW of 54.3 kg) were used in a 65-d growth assay. Pigs were sorted by ancestry and blocked by BW, with 2 pigs/pen and 5 pens/treatment. Treatments were assigned in a 2 × 3 factorial plus a control. Treatments consisted of a corn-soybean meal-based control with the corn milled to an average mean particle size of 600 µm, and either hard endosperm sorghum or soft endosperm sorghum milled to an average mean particle size of 800, 600, or 400 µm. Energy required for grinding increased and production rate decreased with the reduction in sorghum particle size. When compared to corn, the sorghums required less energy to grind, had greater production rates, and produced less noise during milling. Pigs fed the sorghum based diets had similar ($P > 0.1$) ADG, ADFI, and G:F compared to those fed the corn control. Pigs fed the hard sorghum had increased ($P < 0.04$) ADG compared to those fed soft sorghum. However, pigs fed the soft sorghum treatments had improved ($P < 0.03$) G:F compared to those fed hard sorghum treaments. Pigs fed the hard sorghum treatments resulted in increased (P < 0.02) backfat thickness. Reducing the mean particle size of sorghum from 800 to 400 µm, led to a linear improvement ($P < 0.01$) in G:F and nutrient digestibility. Excretions of DM and N were reduced ($P < 0.001$) when pigs were fed diets with reducing particle size. Severity of pars esophageal lesions were increased (P < 0.05) in pigs as particle size of sorghum was reduced. For experiment 2, 200 finishing pigs (average initial BW of 46.8 kg) were used in a 69-d growth assay. Pigs were sorted by sex and ancestry, and balanced by BW, with 5 pigs/pen and 10 pens/treatment. Treatments were a corn-soybean meal-base control with the corn milled to an average mean particle size of 600 µm, and sorghum milled to an average mean particle size of 800, 600, or 400 µm. Pigs fed diets with sorghum particle size being reduced from 800 to 400 μm had improved (linear, $P < 0.01$) G:F, and there was a tendency for decreased ($P < 0.06$) ADFI. Pigs fed the sorghum-based diets had no difference ($P > 0.12$) in growth performance or carcass characteristics compared to those fed the corn control. However, when using a regression equation, it was determined that sorghum must be ground to 515 μm to achieve a G:F equal to that of a corn-based diet, with corn ground to 550 μm. Reducing sorghum particle size from 800 to 400 μm had no effects ($P > 0.15$) on HCW, backfat thickness, loin depth, or percentage fat free lean index (FFLI), but dressing percentage was improved ($P < 0.04$). In conclusion, linear improvements in efficiency of gain and dressing percentage were demonstrated with the reduction of sorghum particle size to 319 μm. However, it is important to take into consideration the negative effects reducing particle size of sorghum can have on stomach morphology, energy usage, and milling production rates. To achieve a feeding value equal to that of corn, sorghum should be ground 35 μm finer.

Introduction

With the continuous increase in corn prices, swine producers are utilizing alternative feedstuffs to reduce diet cost. Sorghum is a cereal grain that can be an economical replacement for corn. Sorghum has attributes, such as resistance to heat stress and drought, which make it favorable to produce in certain regions of the world (Miller et al., 1964).

Over the years, the nutritional value of sorghum has been enhanced through genetic selection of sorghum grains and by applying feed processing strategies. Johnston et al. (1998) demonstrated that pelleting sorghum based diets improved nutrient digestibility and efficiency of gain when fed to finishing pigs. Processing sorghum based diets using an expander before pelleting can further improve nutrient digestibility in finishing pigs (Traylor et al., 1997). Extrusion processing of sorghum has been shown to improve nutrient digestibility and growth performance in pigs (Hancock et al., 1991). The most common feed manufacturing practice used to enhance swine performance is the grinding of cereal grains. However, the particle size necessary to make the feeding value of sorghum equal to that of corn is not well defined. Thus, 2 experiments were completed to determine the effects of reducing particle size on milling inputs and growth performance, nutrient digestibility, and stomach morphology and to develop a sorghum particle size necessary to achieve the same performance as corn when fed to growing and finishing pigs.

Materials and Methods

All experimental protocols used for the following experiments were approved by the Kansas State University Institutional Animal Care and Use Committee.

Experiment 1

Grains used in the experiment consisted of corn (Pioneer 3377, Pioneer Hybrids Int., Des Moines, IA), soft endosperm sorghum (Pioneer 894), and hard endosperm sorghum (Pioneer 8585). A modified version of the procedure suggested by Kirleis and Crosby (1982) was used to measure endosperm hardness of the sorghums. Grain was clean and ground through a laboratory mill (Model 1093 Cyclotech, Tecator, Sweden) equipped with a 1-mm screen. The ground meal was sifted for 10 min in a Ro-Tap® shaker (W.S. Tyler Engineering, Mentor, OH) with a Tyler screen No. 100 (149-µm screen openings). After sifting, the particles that passed through the screen were calculated as a percentage of the original sample weight. Harder endosperm was indicated by smaller values. Endosperm and pericarp color of the sorghums were determined by breaking 10 seeds of each and comparing the exposed interior to seeds previously classified for pericarp and endosperm color as described by Lauver (1988). The procedure proposed by Rooney and Miller (1982) was used to describe Endosperm texture, where 1 = corneous endosperm and 5 = floury endosperm. Starch types of sorghums, normal or waxy, where determined using iodine test (Whistler and Paschall, 1967). A bleach test was conducted to determine tannin content of sorghums, with yellow equaling low tannins and black equaling high tannins (Waniska et al., 1992). The ASAE (1983) standard method was used to determine the particle size of milled corn and sorghum. Tyler sieves, with numbers 6, 8, 10, 14, 20, 28, 35, 48, 65, 100, 150, 200, 270, and a pan, were used for particle size determination. A Ro-Tap® shaker (W. S. Tyler, Mentor, Ohio) was used to sift the 100 g samples for ten minutes. A geometric mean particle size (dgw) and the log normal standard deviation (sgw) were calculated by measuring the amount of ground grain remaining on each screen. Grain, feed, and feces were subjected to proximate and amino acid analyses (AOAC, 1990) and were analyzed for concentrations of DM (NAFTA Method 2.1.2), GE (Adiabatic bomb caloimetry; Parr Instruments, Moline, IL), and Nitrogen (AOAC 1990; Leco Corp., St. Joeseph, MO).

A total of 70 pigs (Yorkshire × Hampshire × Chester White × Duroc; average initial BW of 54.3 kg) were sorted by sex and ancestry and blocked by BW. Pigs were housed in a totally enclosed, environmentally controlled (20°C) building with slatted flooring. There were a total of 35 pens with 2 pigs/pen and 5 pens/treatment. Pigs were provided feed and water on an ad libitum basis, with each pen (1.52-m × 1.52-m) having a nipple waterer and a single-hole self-feeder. All diets were formulated to meet or exceed all nutrient recommendations by the NRC (1988; Table 2.1). The overall treatment design was a 2 × 3 factorial plus a control. The control was corn-based with the corn milled to a geometric mean particle size of 600 μm. Experimental treatments consisted of Soft endosperm sorghum (Pioneer 894) and hard endosperm sorghum (Pioneer 8585), each milled to mean particle sizes of 800, 600, and 400 μm. The corn, soft endosperm sorghum, and hard endosperm sorghum had 12.9, 13.0, and 13.0% moisture, respectively, when milled. Cereal grains were milled using a three-high roller mill (1:1, 1.5:1, 1.5:1 differential drives; 3.2, 4.7, and 6.3 corrugations per centimeter; and 0, 8.3, and 8.3 cm of spiral/meter of roller, Model K, Roskamp Manufacturing, Cedar Falls, IA). An audio dosimeter (MK-2 Model®, AMATEK, Largo, FL) was used to measure the noise level (Lavg) during grinding of each grain. All diets were pelleted in a 30 horsepower pellet mill (30 HD Master Model®, California Pellet Mill, San Francisco) with a 32 mm thick die having 4 mm openings. Steam was used before pelleting to condition the diets to 65°C. Pellets were analyzed for pellet durability index (PDI; ASAE, 1987). Average voltage and amperage during processing were calculated and used to determine electrical consumption for each batch of feed.

Pigs and feeders were weighed at the beginning and end of the experiment and daily feed additions were recorded. On d 50 of the experiment, chromic oxide (Cr_2O_3) was added to the diet as an indigestible marker. Feces were collected on d 55 to allow for calculation of apparent digestibilities of DM, GE, and N (Schurch et al., 1952). Feed and feces were analyzed for concentrations of DM, GE, and N (AOAC 1990). Atomic absorption spectroscopy (Perkin-Elmer model 3110) was used to determine concentrations of Cr in feed and feces using the procedure of Williams et al. (1962). Apparent digestibility of nutrients was then calculated using the indirect ratio method (Maynard et al., 1979).

Atomic absorption spectroscopy was used to determine chromium concentrations in feed and feces (Williams et al., 1962; Perkin-Elmer et al., 1971). Chromium's were then used to calculate apparent digestibility using the indirect ratio method. Pigs were fed to a final BW of 120.1 kg and slaughtered for collection of hot carcass weights, last rib fat thickness, and stomach tissues. The esophageal region of stomachs was scored for ulcers and keranitization. For keratinization, the non-glandular mucosa of the esophageal region that was not ulcerated was scored on the scale of 1= normal or no keratinization, 2 = keratin covering < 25% of the non-glandular mucosa, 3 = keratin covering 25 to 75% of the non-glandular mucosa, and 4 = keratin covering > 75% of the non-glandular mucosa. For ulceration, the esophageal region was scored as 1 = no ulcer, 2 = ulceration present, but affecting < 25% of non-glandular mucosa, 3 = ulceration of 25-75% of the non-glandular mucosa, and 4 = ulceration of > 75% of non-glandular mucosa. Dressing percentage was calculated with HCW as a percentage of preshipping live weights.

All data was analyzed as a randomized complete block design, with a 2 × 3 factorial arrangement of treatments using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC.). Final BW was used as a covariate for analyses of backfat thickness and dressing percentage data. Treatment comparisons were made using the orthogonal contrasts: 1) corn control vs sorghum treatments; 2) hard sorghum vs soft sorghum; 3) linear effect of particle size; 4) quadratic effect of particle size; 5) hard sorghum vs soft sorghum × linear effect of particle size; and 6) hard sorghum vs soft sorghum × quadratic effect of particle size. Stomach scores were categorical and were tested for significant main effects of grain type and particle size using the Cochran-Mantel-Haenszel procedure of SAS (i.e., a row mean scores differ test for categorical data).

Experiment 2

A total of 200 pigs (PIC line TR4 × 1050; average initial BW of 46.8 kg) were sorted by sex and ancestry and balanced by body weight assigned to treatments. There were 5 barrows/pen or 5 gilts/pen and 10 pens/treatment. Pigs were housed in an environmentally-controlled finisher with pens (2.4 m × 1.5 m) having concrete slatted floors. Each pen contained a self-feeder and 2 nipple waterers to allow ad libitum consumption of feed and water. The control was corn-based with the corn milled to a geometric mean particle size of 600 µm. Treatments were sorghum based with sorghum milled to a targeted average mean particle size of 800, 600, or 400 µm. For the control, corn was milled using a hammer mill (Jacobseen P240D) with a screen size of 6.35 mm ("tear-drop" full circle screen). For the 400 µm treatment, sorghum was milled using the same hammer mill (Jacobseen P240D) with a screen size of 1.59 mm ("tear-drop" full circle screen). For the 800 and 600 µm treatments sorghum was milled using a three-high roller mill (1:1, 1.5:1, 1.5:1 differential drives; 3.2, 4.7, and 6.3 corrugations per centimeter; and 0, 8.3, and

8.3 cm of spiral/meter of roller, Model K, Roskamp Manufacturing, Cedar Falls, IA). The ASAE (1983) standard method was used to determine the particle size of milled corn and sorghum. Tyler sieves, with numbers 6, 8, 10, 14, 20, 28, 35, 48, 65, 100, 150, 200, 270, and a pan, were used for particle size determination. A Ro-Tap® shaker (W. S. Tyler, Mentor, Ohio) was used to sift the 100 g samples for ten minutes. A geometric mean particle size (dgw) and the log normal standard deviation (sgw) were calculated by measuring the amount of ground grain remaining on each screen. All diets were pelleted in a 30 horsepower pellet mill (30 HD Master Model®, California Pellet Mill, San Francisco) with a 32 mm thick die having 4 mm openings. Pellets were analyzed for pellet durability index (PDI; ASAE, 1987) and modified PDI by altering the procedure by adding 5 13-mm hexagonal nuts prior to tumbling. An amp-volt meter (Model DM-II, Amprobe Instrument, Lynbrook, NY) was used to calculate energy used during grinding and pelleting.

The experimental treatments (Table 2.2) were fed in 3 phases, with phase 1 being fed from day 0 to 28 of the experiment, phase 2 from day 28 to 48, and phase 3 from day 48 to 69 of the experiment. All diets were formulated to meet or exceed NRC (1998) recommendations.

Pigs and feeders were weighed on d 0, 20, and 41 of the experiment to calculate ADG, ADFI, and G:F. On d 69, pigs were tattooed and shipped to a commercial abattoir (Farmland Foods, Inc.; Crete, NE) for slaughter the following morning. Measurements were acquired immediately after slaughter for hot carcass weight (HCW), 10th rib fat thickness (SFK Technology A/S model S 82; Herlev, Denmark), and loin depth. Dressing percentage was calculated with HCW as a percentage of preshipping live weights. Carcass lean percentage was calculated with fat free lean index as a percentage of HCW. Fat free lean index was calculated using the equation suggested by the National Pork Producers Council (NPPC, 2001).

The MIXED procedure (SAS Inst. Inc., Cary, NC.) was used to perform the statistical analysis. All growth data was analyzed as a completely randomized design with pen as the experimental unit. For analyses of carcass data, HCW was used as a covariate. The shape of the response to decreasing particle size was characterized using polynomial regression.

Results and Discussion

Experiment 1

Grain characteristics are shown in Table 2.3. Both soft and hard sorghum resulted in pericarp color that was red and endosperm that was normal and white. The particle size index indicated that corn had the hardest endosperm, hard sorghum was intermediate, and soft sorghum had the softest endosperm. The grains resulted in particle size index values of 40, 47, and 52 for corn, hard sorghum, and soft sorghum, respectively.

Proximate analysis and amino acid composition of cereal grains is presented in Table 2.4. Sorghum resulted in CP levels higher than that of corn, with soft sorghum having the highest CP value (10.46%). There were no tannins detected in any of the cereal grains. Corn resulted in the lowest levels of basic amino acids (i.e., arginine, histidine, and lysine). However, hard sorghum had histidine levels equal to that of corn. Branched chain amino acids (i.e., isoleucine, leucine, and valine) and nonessential amino acids were the most abundant in soft sorghum.

Particle size values achieved for cereal grains were close to targeted values (Table 2.5). Energy required for grinding was inversely related to fineness of grind. As the mean particle size of hard and soft sorghum was decreased, the geometric standard deviation (s_{gw}) decreased and energy (kWh/ton) required increased. When comparing the energy to grind the 600 μm treatments, soft sorghum required 35% less energy than corn, and hard sorghum required 8% less energy than corn. Reducing particle size of sorghum led to a reduction in production rate. However, grinding sorghum to 600 μm had a production rate 35% greater than corn ground to 600 μm. This is in agreement with previous research, which has reported that sorghum grains are easier to grind than corn (Baker, 1960; Wu, 1984; and Healy et al., 1994).

Increased exposure of feedmill workers to noise pollution can have negative impacts on their hearing. Therefore, noise level was measured based on dose and time of exposure using an audiodosimeter. There was no difference in noise generated as particle size was decreased. However, the average noise produced by all sorghum treatments was 12% less than that generated when grinding corn. Permanent, irreparable, hearing loss can be caused by long term exposures to excessive noise levels. Employees cannot be exposed to noise levels exceeding 90 dBA for 8 h a day (OSHA, 1990). Noise levels between 80 and 90 dB could cause injuries to more susceptible persons, but noise levels below 80 dB have no damage potential. However, if levels exceed 90 dBA, OSHA mandates that protection against the effects of noise exposure must be provided.

There were no differences (*P* > 0.15) in ADG, ADFI, or G:F when pigs were fed either corn- or sorghum- based diets (Table 2.6). Pigs fed the hard sorghum treatments had an increased *(P* < 0.04) ADG and ADFI compared to those fed the soft sorghum treatments. However, pigs fed the soft sorghum treatments had improved (*P* < 0.03) G:F compared to those fed the hard sorghum. Decreasing the particle size of sorghum led to an improvement (*P* < 0.001) in G:F in finishing pigs, but did not affect (P > 0.15) ADG. Previous research demonstrated similar results, concluding that the reduction of sorghum particle size led to an improvement in efficiency of gain but had no effects on rate of gain (Jensen et al., 1965; Luce et al., 1970). As particle size was decreased from 800 to 400 μm, ADFI of pigs was decreased (*P* < 0.01). It has been proposed that feed intake of pigs is determined by energy concentration of the diet (Owen and Ridgeman, 1968; Wondra et al., 1995a; and Wondra et al., 1995b). Therefore, reducing the particle size of sorghum can improve its energy value, leading to an increase in the energy concentration of the diet. The improvement in G:F due to particle size reduction is in agreement with data previously reported by Hedde et al. (1985), Giesemann et al. (1990), Healy et al. (1994), and Wondra et al. (1995a, and 1995b). There was no difference in the improvement in G:F between hard and soft sorghum when particle size was reduced, and when both genotypes were pooled together reducing the particle size from 800 to 400 μm, efficiency of gain was improved by 7%.

Pigs fed either corn- or sorghum-based diets had no difference (*P* > 0.12) in carcass measurements. This is in agreement with previous research which demonstrated no differences in carcass characteristics (Meade et al., 1966; Baird, 1973; Wondra et al., 1995a; and Wondra et al., 1995b). There was a tendency (*P* < 0.07) for pigs fed the soft sorghum treatment to have a lower dressing percentage compared to pigs fed the hard sorghum treatments. However, this 1% difference in dressing percentage was detected significantly due to low variability in the data. Pigs fed the diets containing soft sorghum had decreased (*P* < 0.02) backfat thickness compared to those fed the diets containing hard sorghum. This could be due to an increase in feed intakes and DE intakes for pigs fed hard sorghum.

Pigs fed the sorghum-based diets had greater (*P* < 0.001) apparent digiestibilities of DM and GE compared to those fed the corn-based diets. However, there was no difference (*P* > 0.15) in N digestibility between pigs fed either corn or sorghum. Giesseman et al. (1990) reported that feeding sorghum-based diets resulted in increased DM and GE digestibilities but no difference in N digestibility compared to corn of equal particle size. In contrast, Cousins et al., (1981) demonstrated similar digestibilities of nutrients in pigs fed corn and low tannin sorghum. However, differences in digestibilities of nutrients between corn and sorghum are variable in past literature (Noland et al., 1976; Subramanyam et al., 1980; and Lin et al., 1987). Soft sorghum had increased ($P < 0.001$) DM, N, and GE digestibility compared to hard sorghum. Elmalik et al. (1985) indicated that DM digestibility of soft endosperm sorghum was greater than that of hard endosperm sorghum in rats.

Reducing particle size from 800 to 400 μm, resulted in linear and quadratic effects ($P < 0.001$) on DM, N, and GE digestibilities of sorghum grains. This is in agreement with previous research, which demonstrated improvements in digestibilities of DM and N for pigs fed diets with sorghum particle size decreasing from 800 to 400 μm (Ohh et al., 1983; Wu, 1984). However, our research resulted in genotype × d_{gw} interactions ($P < 0.001$) for apparent digestibilities of DM, N, and GE, primarily because of low apparent digestibilities for hard sorghum ground to 600 μm. Healy et al. (1994) demonstrated a similar response to nutrient utilization of nursery pigs fed hard endosperm sorghum at particle sizes of 700 and 500 μm. These differences suggest that endosperm characteristics can influence the response of nutrient utilization to particle size reduction.

Environmental pollution is an area of concern for intensive animal production systems (Jongbloed et al., 1992). The effects of sorghum particle size on DM and N secretion are shown in table 3.6. In conjunction with food intakes and differences in DM digestibility, there was a treatment effect ($P < 0.001$) on DM secretion. Pigs fed sorghum-based diets had 17% lower excretion of DM than those fed the corn control diet. This resulted primarily from a reduction ($P < 0.001$) in DM and N secreted when pigs were fed diets containing soft sorghum instead of hard sorghum. Reducing the particle size of sorghum from 800 to 400 μm reduced ($P < 0.001$) the amount of DM and N excreted. However, there were sorghum genotype × particle size reduction interactions ($P < 0.001$), with soft sorghum resulting in a strong linear decrease in excretion of DM and N.

Gastric ulcers in finishing pigs are a common concern in swine production systems. Therefore, the effects of sorghum genotype and fineness of grind on stomach morphology was evaluated (Table 2.7). There was a tendency for an increase in stomach keratinization as particle size of the sorghum grains was decreased from 800 to 400 μm. Moreover, the reduction in sorghum particle size led to an increase ($P < 0.05$) in stomach ulcers. This is in agreement with previous research that reported an increase in stomach ulcers when finely ground grain was fed to finishing pigs (Mahan et al., 1966; Reimann et al., 1968; Picket et al., 1969; Maxwell et al., 1970). There were no differences ($P > 0.15$) in stomach scores when comparing sorghum grains to the corn control. However, the 400 μm sorghum treatments was numerically less than that of the 600 μm corn control. This is in agreement with research conducted by Healy et al. (1994), who reported that when nursery pigs were fed sorghum diets with particle sizes similar to that of corn, stomach lesions may be reduced.

Experiment 2

The particle size for each treatment was lower than that of the targeted value (Table 2.8). Energy required for pelleting the sorghum treatments slightly increased as particle size decreased. Healy et al. (1994) reported no major differences in energy consumption during pelleting when sorghum was ground between 900 and 300 μm. However, pelleting the corn-based diet required 5% more energy than the average of the sorghum treatments. Pelleting the 400 μm sorghum treatment resulted in the highest production rate, which were 7% higher than that of the 800 and 600 μm treatments and 4% higher than that of the corn control. As particle size was decreased from 800 to 400 μm there were minor improvements in pellet durability index (PDI), and all were higher than that of corn. In agreement with the current experiment, Healy et al. (1994) reported similar PDI's amongst sorghum treatments ground to various particle sizes.

There was no difference ($P > 0.15$) in growth performance for pigs fed the corn and sorghum-based diets (Table 2.9). However, there was improved (linear, $P < 0.01$) G:F in pigs as sorghum particle size was reduced from 800 to 400 μm. This resulted from a numerical decrease (linear, $P < 0.06$) in ADFI, as particle size of sorghum was reduced. This is in agreement with previous research that concluded that efficiency of gain of pigs can be improved by reducing the particle size of sorghum (Hedde et al., 1985; Giesemann et al., 1990, Healy et al., 1994; Wondra et al. 1995a; Wondra et al., 1995b). Based on the proposal that pig's feed intake is regulated by energy content of the diet, the decrease in ADFI supports the statement suggesting that reducing the particle size of sorghum increases the energy concentration of the diet (Owen and Ridgeman, 1968; Wondra et al., 1995a; and Wondra et al., 1995b). When comparing the feeding value of sorghum to corn ground to 555 μm, sorghum must be ground to 515 μm to achieve similar efficiencies of gain (Figure 2.1).

Pigs fed sorghum-based treatments had no difference ($P > 0.12$) in carcass measurements compared to those fed the corn-based control. This is in agreement with previous data which demonstrated no differences in carcass characteristics of pigs fed either corn- or sorghum- based diets (Meade et al., 1966; Baird, 1973; Wondra et al., 1995a; and Wondra et al., 1995b). However, as sorghum particle size was reduced from 800 to 400 μm, dressing percentage was linearly increased ($P < 0.04$). Wondra et al. (1995b) reported a similar increase in dressing percentage as particle size was decreased. These differences in dressing percentage can be caused by increases in gut fill due to a coarser particle size. This is in agreement with previous research, which has demonstrated increases in stomach weight resulting from feeding coarsely ground grains (Reimann et al., 1968; Lawrence et al., 1998).

In conclusion, feeding sorghum-based diets to grow-finish pigs resulted in no differences in growth performance or carcass characteristics compared to those fed corn-based diets. However, to achieve an efficiency of gain equal to that of corn, sorghum should be ground 35 μm finer than corn. We observed an improvement in the apparent digestibility of DM and GE and the amount of DM and N digested per day when pigs were fed sorghum-based diets. Sorghum diets also led to a decrease in N excreted into the environment.

Reducing the particle size of sorghum from 800 to 400 μm improved efficiency of gain by 5%. These results suggest a 1.3% improvement in efficiency of gain for each 100 μm decrease in sorghum particle size. However, it is important to consider the negative effects reducing particle size can have on energy consumption, production rate, and stomach morphology.

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Table 2.1 Composition of experimental diets (Exp. 1; as-fed basis)[1]

Item, %	Control diet, %[1]	Sorghum diet, %
Corn	82.47	—
Sorghum	—	82.45
Soybean meal (46.5% CP)	14.75	14.75
L-Lys·HCl	0.04	0.06
Monocalcium phosphate	1.07	1.07
Limestone	1.02	1.02
Salt	0.30	0.30
Viamin premix[2]	0.15	0.15
Mineral premix[3]	0.10	0.10
Antibiotic[4]	0.10	0.10

[1]The control diet was formulated with corn to provide 14.16% CP, 0.7% lysine, 0.65% Ca, and 0.55% P. Hard and soft endosperm sorghums were used to replace corn on a weight/weight basis.

[2]Provided (per kilogram of diet) 5,513 IU of vitamin A, 551 IU of vitamin D, 22 IU of vitamin E, 2.2 mg of vitamin K (as menadione dimethyprimidinol bisulfite), 30.3 mg of niacin, 13.8 mg of pantothenic acid (as d-calcium pantothenate), 5.5 mg of riboflavin, 551 mg of choline, and 0.03 mg of vitamin B_{12}.

[3]Provided (per kilogram of diet) 10 mg of copper, 3.0 mg of iodine, 100 mg of iron, 100 mg of manganese, 0.3 mg of selenium, 100 mg of zinc, 1.0 mg of cobalt, and 40 mg of calcium.

[4]Provided (per kilogram of diet) 100 mg of chlortetracycline.

Table 2.2 Composition of experimental diets (Exp. 2; as-fed basis)[1]

	Phase 1		Phase 2		Phase 3	
Item, %	Corn	Sorghum	Corn	Sorghum	Corn	Sorghum
Corn	76.22	—	78.60	—	80.67	—
Sorghum	—	76.21	—	78.60	—	80.64
Soybean meal (46.5% CP)	21.5	21.5	19.5	19.5	17.5	17.5
L-Lysine HCl	0.21	0.23	0.14	0.16	0.074	0.096
DL-Methionine	0.03	0.04	—	0.002	—	—
L-Threonine	0.06	0.04	0.018	0.002	—	—
Monocalcium phosphate	0.70	0.70	0.50	0.50	0.51	0.51
Limestone	0.88	0.88	0.85	0.85	0.86	0.86
Salt	0.25	0.25	0.25	0.25	0.25	0.25
Viamin premix[2]	0.04	0.04	0.04	0.04	0.04	0.04
Mineral premix[3]	0.06	0.06	0.06	0.06	0.06	0.06
Antibiotic[4]	0.05	0.05	0.05	0.05	0.05	0.05
Calculated Analyses,%						
CP,	16.6	17.3	15.7	16.5	15.0	15.6
SID Lysine	0.88	0.88	0.78	0.78	0.68	0.68
Ca	0.55	0.55	0.50	0.50	0.50	0.50
Available P	0.21	0.22	0.17	0.18	0.17	0.18

[1]Experimental treatments were fed in pelleted form.

[2]Provided (per kilogram of diet) 3,524 IU of vitamin A, 441 IU of vitamin D, 14.1 IU of vitamin E, 1.4 mg of vitamin K (as menadione dimethyprimidinol bisulfite), 15.9 mg of niacin, 8.8 mg of pantothenic acid (as d-calcium pantothenate), 2.6 mg of riboflavin, 12.3 μg of vitamin B_{12}.

[3]Provided (per kilogram of diet) 4.4 mg of copper, 0.1 mg of iodine, 44 mg of iron, 10.6 mg of manganese, 0.1 mg of selenium, 44 mg of zinc.

[4]Provided (per kilogram of diet) 9.1 mg/kg of tylosin.

Table 2.3 Characteristics of corn, soft endosperm, and hard endosperm sorghum (Exp. 1)

Item	Corn	Soft sorghum	Hard sorghum
Physical traits			
Pericarp color[1]	–	Red	Red
Endosperm color[1]	–	White	White
Endosperm texture[2]	–	5	3
Particle size index[3]	40	52	47
Endosperm type[4]	Normal	Normal	Normal

[1]Pericarp color was scored as white, yellow, red, brown, or mixed. Endosperm color scored as: white, heteroyellow, or yellow (adapted from Lauver, 1988).

[2]Scoring scale of 1 to 5 with 1 = all corneous endosperm and 5 = all flour endosperm (Rooney and Miller, 1982).

[3]Percentage of meal passing through a Tyler Screen No. 100 with 149-µm openings after grinding (Kirleis and Crosby, 1982).

[4]Scored as normal or waxy (Whistler and Paschall, 1967).

Table 2.4 Amino acid composition of corn, soft endosperm sorghum, and hard endosperm sorghum[1] (Exp. 1)

Item	Corn	Soft sorghum	Hard sorghum
CP, %	7.7	10.5	9.5
Ether extract, %	3.7	3.7	4.0
Ash, %	1.9	1.4	1.3
GE, Mcal/kg	3.9	3.9	3.9
Moisture, %	12.9	13.0	13.0
Tannin[3]	ND[4]	ND	ND
Amino acids, %			
Essential			
Arginine	0.36	0.40	0.42
Histidine	0.23	0.25	0.23
Isoleucine	0.28	0.45	0.39
Leucine	0.99	1.57	1.23
Lysine	0.24	0.23	0.27
Methionine	0.18	0.19	0.18
Phenylalanine	0.40	0.61	0.50
Threonine	0.27	0.35	0.32
Tryptophan	0.04	0.05	0.06
Valine	0.38	0.56	0.51
Nonessential			
Alanine	0.59	1.07	0.85
Aspartic acid	0.51	0.75	0.70
Glutamic acid	1.44	2.33	1.89
Glycine	0.30	0.34	0.36
Serine	0.34	0.46	0.43
Tyrosine	0.26	0.36	0.32

[1]Dry matter basis.
[2]AOAC (1990).
[3]Sorghum grains were scored as yellow = no tannin detected black = tannins present (Waniska et al., 1992).
[4]ND = none detected.

Table 2.5 Processing characteristics of corn, soft endosperm sorghum and hard endosperm sorghums[1] (Exp. 1)

	Corn, µm	Soft sorghum, µm			Hard sorghum, µm		
Item	600	800	600	400	800	600	400
dgw, µm							
Milled grain	592	810	613	407	802	594	417
sgw, µm							
Milled grain	2.1	1.9	1.8	1.7	1.8	1.8	1.7
Surface area, cm^2/g							
Milled grain	101.8	64.4	87.7	127.4	68.9	87.4	126.4
Grinding							
Energy, kWh/t	7.65	2.64	5.00	9.97	3.28	7.00	10.01
Production rate, t/h	0.96	2.77	1.42	0.89	2.11	1.18	0.84
Lavg, dB[4]	95.4	83.6	81.2	84.7	85.1	83.7	86.1
Pelleting							
Energy, kWh/t	11.9	9.7	11.1	10.5	11.6	10.3	10.8
Production rate, t/h	1.47	1.77	1.67	1.57	1.30	1.50	1.32
Fines, %	10.4	9.4	9.5	7.8	10.7	9.0	8.3
Durability, %[5]	89.6	90.6	90.5	92.2	89.3	91.0	91.7

[1]The corn and sorghum treatments were made using a roller mill.
[2]Geometric mean particle size (ASAE, 1983).
[3]Log normal standard deviation (ASAE, 1983).
[4]Average decibel level based on dose and time of exposure.
[5]ASAE (1987).

Table 2.6 Effects of particle size of soft endosperm and hard endosperm sorghum on growth performance, carcass characteristics, apparent digestibility, intake, and excretion of nutrients (Exp. 1)[1]

	Corn, µm	Soft sorghum, µm			Hard sorghum, µm				Contrasts[2]					
Item	600	800	600	400	800	600	400	SE	1	2	3	4	5	6
ADG, g	990	1,000	980	990	1,030	1,030	1,040	12	–[3]	0.04	–	–	–	–
ADFI, kg	3.23	3.40	3.15	3.14	3.53	3.47	3.40	0.17	–	0.001	0.01	–	–	–
G:F	307	294	311	315	292	297	306	4	–	0.03	0.001	–	–	–
Last rib fat depth, mm	37.3	32.0	34.7	34.0	36.5	35.8	36.5	1.3	–	0.02	–	–	–	–
Dress, %	74.1	74.6	73.5	74.6	74.8	74.9	75.1	0.5	–	0.07	–	–	–	–
Apparent digestibility, %														
DM	86.21	87.07	89.09	94.28	88.38	86.52	89.57	0.27	0.001	0.001	0.001	0.001	0.001	–
N	79.78	75.55	80.99	90.68	79.14	75.47	83.89	0.72	NS	0.001	0.001	0.001	0.001	0.01
GE	86.93	87.07	89.23	94.56	88.82	86.87	90.83	0.33	0.001	0.001	0.001	0.001	0.001	0.03
DM digested, g/d	2,501	2,660	2,524	2,660	2,810	2,701	2,737	130	0.01	0.01	–	0.08	–	–
N digested, g/d	54.9	67.6	65.3	70.8	61.7	58.1	63.1	0.3	0.001	0.001	–	0.009	–	–
GE digested, Mcal/d	10.2	10.5	10.0	10.6	10.8	9.9	10.8	0.2	–	–	–	0.005	–	–
DM excretion, g/d	400	395	309	164	369	419	319	12	0.001	0.001	0.001	0.001	0.001	0.08
N excretion, g/d	13.62	21.79	14.98	7.26	16.34	18.61	11.80	0.7	0.07	–	0.001	0.001	0.001	0.01

A total 70 pigs (average initial BW of 54.3 kg) were used in the 65-d growth assay.

[2]Contrasts were: 1) control vs sorghums; 2) soft sorghum vs hard sorghum; 3) particle size linear; 4) particle size quadratic; 5) sorghum genotype × linear; 6) sorghum genotype × quadratic.

[3]Not significant (*P* > 0.12)

Table 2.7 Effects of particle size of soft endosperm and hard endosperm sorghum on stomach morphology in finishing pigs[1] (Exp. 1)

	Corn, µm	Soft sorghum, µm			Hard sorghum, µm				Contrasts[2]					
Item	600	800	600	400	800	600	400	SE	1	2	3	4	5	6
Stomach keratinization[3]														
No. observations	10	10	10	9	9	10	10							
Normal	0	2	0	0	2	1	0							
Mild	4	7	6	5	3	4	7							
Moderate	4	1	3	3	4	5	1							
Severe	2	0	1	1	0	0	2							
Mean	2.80	1.90	2.50	2.50	2.30	2.40	2.50	–	–	–	–	–	–	–
Stomach ulceration[4]														
No. observations	10	10	10	9	9	10	10							
Normal	6	9	10	5	9	7	6							
Erosions	3	0	0	4	0	3	2							
Ulcers	0	1	0	0	0	0	2							
Severe ulcers	1	0	0	0	0	0	0							
Mean	1.60	1.20	1.00	1.40	1.00	1.30	1.60	–	–	–	–	–	–	–

[1] A total 70 pigs (average initial BW of 54.3 kg) were used in the 65-d growth assay.

[2]Contrasts were: 1) control vs sorghums; 2) soft sorghum vs hard sorghum; 3) particle size linear; 4) particle size quadratic; 5) sorghum genotype × linear; 6) sorghum genotype × quadratic

[3]Scoring system was: 1 = normal; 2 = mild; 3 = moderate: and 4 = severe (Cochran-Mantel-Haenszel statistic, row mean scores differ test).

[4]Scoring system was: 1 = normal: 2 = erosions; 3 = ulcers; 4 = severe ulcers (particle size effect, $P < 0.05$; Cochran-Mantel-Haenszel statistic, row mean scores differ test).

Table 2.8 Processing characteristics of corn, soft endosperm sorghum and hard endosperm sorghums (Exp. 2)

	Corn, µm	Sorghum, µm		
Item	600[1]	800[2]	600[2]	400[3]
dgw, µm[4]				
Milled grain	555	724	573	319
sgw, µm[5]				
Milled grain	3.14	2.46	2.31	2.52
Grinding				
Energy, kWh/t	6.0	2.62	6.1	11.4
Production rate, t/h	2.7	1.9	2.7	2.1
Pelleting				
Energy, kWh/t	10.31	9.67	9.84	9.96
Production rate, t/h	1.43	1.39	1.39	1.49
Durability, %[6]	88.4	89.0	89.7	90.4
Modified durability, %[7]	85.0	85.2	86.8	86.9

[1]Corn was milled using a hammer mill (Jacobseen P240D) with a screen size of 6.35 mm ("tear-drop" full circle screen).

[2] Sorghum was milled using a three-high roller mill (Model K, Roskamp Manufacturing, Cedar Falls, IA).

[3]Sorghum was milled using the same hammer mill (Jacobseen P240D) with a screen size of 1.59 mm ("tear-drop" full circle screen).

[4]Geometric mean particle size (ASAE, 1983).

[5]Log normal standard deviation (ASAE, 1983).

[6]ASAE (1987).

[7]Modified the ASAE (1987) by adding 5 13-mm hexagonal nuts prior to tumbling.

Table 2.9 Effects of sorghum particle size in finishing pig diets (Exp. 2)[1]

	Corn, μm	Sorghum, μm				*P*-value		
Item	600	800	600	400	SE	Corn vs Sorghum	Linear	Quadratic
ADG, g	1,078	1,128	1,103	1,100	23	0.22	0.39	0.68
ADFI, kg	2.90	3.10	2.99	2.91	0.07	0.24	0.06	0.91
G:F, g/kg	372	365	369	379	4	0.84	0.01	0.50
Final BW, kg	121.1	124.7	122.9	122.8	2.4	0.40	0.57	0.78
HCW, kg	88.1	90.6	89.7	90.0	1.8	0.33	0.78	0.80
Dressing, %[2]	72.6	72.7	73.0	73.2	0.19	0.12	0.04	0.93
Backfat thickness, mm[2]	22.7	22.1	22.1	22.4	0.9	0.68	0.85	0.91
Loin depth, mm[2]	59.7	60.9	59.9	59.4	0.9	0.76	0.24	0.83
FFLI, %[2,3]	49.2	49.7	49.5	49.3	0.6	0.69	0.67	0.97

[1]A total 200 pigs (average initial BW of 46.8 kg) were used in the 69-d growth assay.
[2]HCW used as a covariate.
[3]Fat-free lean index (NPPC, 2001).

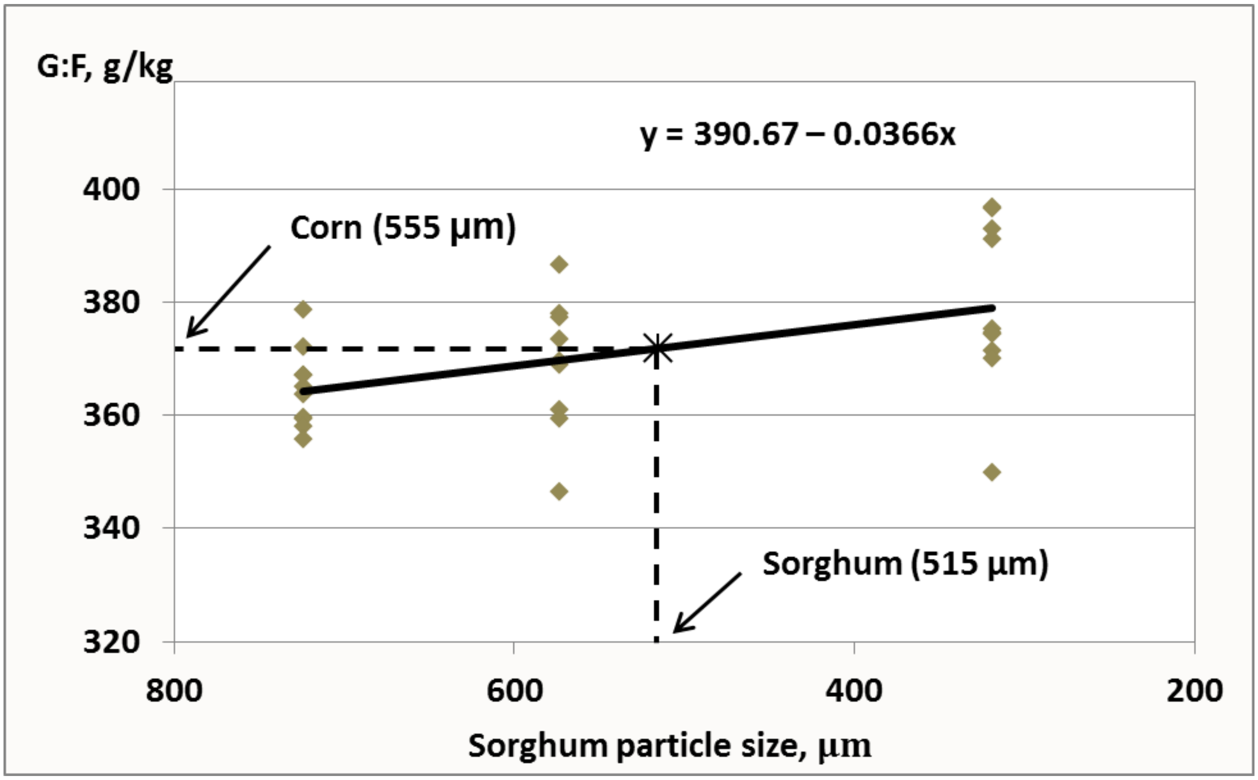

Figure 2.1 Particle size of sorghum required to obtain an efficiency of gain equal to that of corn.

Chapter 3 - Effects of mix time for diets with ractopamine when fed to finishing pigs

Abstract

Two experiments were completed to determine the effects of mix uniformity for diets with ractopamine HCl when fed to finishing pigs. In Exp. 1, a total of 200 pigs (average BW of 90 kg) were used in a 33-d growth assay arranged in a randomized complete-block design with 5 pigs/pen and 8 pens/treatment. Treatments were a corn-soybean meal-based control diet mixed for 360 s and the mixed control diet with 10 mg/kg ractopamine added before additional mixing for 0, 30, 120, and 360 s. Thus, this experiment was designed to determine the effects of nutrient utilization from a thoroughly mixed diet with a potential non-uniform distribution of ractopamine. Pigs fed diets with ractopamine had greater ($P < 0.01$) ADG, G:F, final BW, HCW, dressing percentage, loin depth, and percentage carcass lean with lower ($P < 0.005$) backfat thickness. Increasing mix time from 0 to 360 s decreased CVs for Cr from 67 to 12%, but had no effect ($P > 0.15$) on the response to ractopamine for any growth or carcass measurement. In Exp. 2, a total of 160 pigs (average BW of 93 kg) were used in a 27-d growth assay arranged in a completely randomized design with 2 pigs/pen and 16 pens/treatment. Treatments were a corn-soybean meal-based control mixed for 360 s and control diets with 10 mg/kg ractopamine mixed for 0, 30, 120, and 360 s. Thus, this experiment was designed to determine the combined effects of potentially non-uniform distribution of both nutrients and ractopamine. The use of ractopamine increased ($P < 0.01$) ADG, G:F, final BW, HCW, dressing percent, percentage lean, and loin depth. Increasing mix times from 0 to 360 s decreased CVs for salt from 51 to 12% with no effect ($P > 0.11$) on ADG, G:F, HCW, dressing percentage, backfat thickness, loin depth, or percentage carcass lean. In conclusion, increasing mix time of diets from 0 to 360 s did not affect the response of finishing pigs to ractopamine.

Introduction

The goal of mixing a diet is to ensure that each animal receives the intended daily intake of nutrients (Pfost 1976). Furthermore, he proposed that a diet should be mixed long enough to ensure a CV of 10% for the concentration of salt in 10 random samples taken from the batch of fed. However, McCoy et al. (1994) reported no significant effects of mix time on growth performance, carcass characteristics, or bone breaking strength with Quantab CV's of 43% for salt, 50% for red iron particles, 48% for blue iron particles, and 50% for chromiums. When formulating the diet to 80% of the NRC (1984) recommendations, the authors reported that CVs of 12% for salt, 17% for iron particles, and 23% for sodium were sufficient in supporting maximum performance of broilers. Furthermore, Traylor et al. (1994) reported no effects on growth performance, carcass characteristics, or bone strength in finishing pigs fed diets with CV's for salt of 40 to 50% and reported only a minor decrease in growth performance of nursery pigs fed diets with CV's for Cr of up to 28%. However, (Groesbeck et al., 2007) suggested that the importance of mixing was increased when ingredients having low inclusions were added to the diet

Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN) is added to diets for finishing pig to improve growth performance and carcass leanness. A quite low inclusion of only 5 to 10 mg/kg of ractopamine for the last 20 to 40 kg of gain is recommended by the manufacturer. For maximum performance in pigs consuming diets with ractopamine, much attention is given to dietary factors such as increasing the concentration of protein and amino acids. However, a factor that has not been addressed is the importance of mixing time for diets with ractopamine. Therefore, our objective was to determine the effects of dietary mix uniformity on the response to ractopamine in finishing pigs.

Materials and Methods

General

This experimental protocol was approved by the Kansas State University Institutional Animal Care and Use Committee.

Diets were mixed in a 1,360-kg-capacity horizontal ribbon mixer (DS30, Davis and Sons Manufacturing Company, Bonner Springs, KS) at the Kansas State University Animal Science Feed Mill. Batch size was 907 kg and batches were mixed separately. Mix times were the amount of time the mixer was turned on before opening the discharge gate. The mixer discharge time is approximately 60 to 100 s. After mix times were completed, the feed was discharged via a 2.5 m-long screw conveyor, dropped into a bucket elevator, elevated 29.5 m, and dropped 11 m into a bin. The feed then was carried 11 m horizontally via a round-bottom conveyor, and dropped 13 m into a surge bin to be bagged. Each bag of feed was labeled and a sample was collected from every 4th bag (a total of 10) as the feed was added to individual feeders.

Pigs and feeders were weighed at d 0 and the final day of the growth assay to allow calculation of ADG, ADFI, and G:F. The pigs were tattooed and shipped to a commercial abattoir (Farmland Foods, Inc., Crete, NE) for collection of carcass data that included hot carcass weight (HCW) and fat thickness and loin depth at the 10th rib (SFK Technology A/S model S 82; Herlev, Denmark). Dressing percentage was calculated with HCW as a percentage of preshipping live weights. Fat free lean index was calculated using the equation suggested by the National Pork Producers Council (NPPC, 2001) and carcass lean percentage was calculated with fat free lean index as a percentage of HCW.

Experiment 1

Two hundred finishing pigs (TR4 x PIC 1050; initial BW of 90 kg) were used in a 33-day growth assay to determine the effects of mix time of diets with ractopamine on growth performance. The pigs were weighed, blocked by BW, and allotted to pens based on sex and ancestry. Pigs then were assigned to pens with concrete slatted flooring that were 2.44 m × 1.53 m. Each pen had a nipple waterer and single-hole self-feeder allowing ad libitum consumption of feed and water. There were a total of 40 pens, with 5 pigs per pen 8 pens per treatment.

All diets (Table 3.1) were formulated to 16% CP, 1.01% total Lys, 0.65% Ca, 0.56% total P, and to meet or exceed all other nutrient requirements suggested by the National Research Council (NRC, 1988) for 80 to 120 kg pigs. To prepare the diets, the major ingredients (corn and soybean meal) were augured into the stopped mixer, the micro ingredients (monocalcium phosphate, limestone, synthetic amino acids, salt, vitamins, and minerals) were added, and the complete diet was mixed for 360 s.

The control diet was ~~a~~ corn-soybean meal-based and mixed for 360 seconds. Other treatments were the control diet mixed for 360s, 10 mg/kg of ractopamine (Elanco Animal Health, Greenfield, IN) and 0.5% chromic oxide added, and the diet mixed for an additional 0, 30, 120, and 360 seconds. Chromium concentrations were determined using the procedures of Williams et al. (1962) and a Perkin-Elmer 3110 atomic absorption spectrophotometer. A CV was calculated by expressing the standard deviation for Cr concentration ~~s~~ in the 10 samples as a percentage of the grand mean.

All data were analyzed as a randomized complete block design using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Pen was the experimental unit with the shape of the response to increasing mix time characterized using polynomial regression for unequally spaced treatments. Hot carcass weight was used as a covariate for analyses of carcass data.

Experiment 2

One hundred and sixty finishing pigs (TR4 × PIC 1050; initial BW of 93 kg) were used in a 27-day growth assay. The pigs were weighed and allotted to pens based on weight, sex, and ancestry. Pigs then were assigned to pens with concrete slatted flooring that were 1.22 m × 1.53 m. Each pen had a nipple waterer and single-hole self-feeder allowing ad libitum consumption of feed and water. There were a total of 80 pens, with 2 pigs per pen 16 pens per treatment.

All diets (Table 1.1) were formulated to 16% CP, 1.01% total Lys, 0.65% Ca, 0.56% total P, and to meet or exceed all other nutrient requirements suggested by the National Research Council (NRC, 1988) for 80 to 120 kg pigs. To prepare the diets, the major ingredients (corn and soybean meal) were augured into the stopped mixer, the micro ingredients (monocalcium phosphate, limestone, synthetic amino acids, salt, vitamins, and minerals) were added, and the complete diet was mixed for 360 s.

The control diet was a corn-soybean meal-based and mixed for 360 seconds. Other treatments were the same formulation as the control with 10 mg/kg of ractopamine. These diets were mixed for 0, 30, 120, and 360 seconds. In contrast with Exp. 1, mix uniformity was determined using Quantab Cl titrators (low range 0.005 to 0.1% as NaCl; Environmental Test Systems) to measure the concentration of salt.

All data were analyzed as a completely randomized design using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Pen was the experimental unit and initial BW used as a covariate with the shape of the response to increasing mix time characterized using polynomial regression for unequally spaced treatments. Hot carcass weight was used as a covariate for analyses of carcass data.

Results and Discussion

Experiment 1

Pigs fed diets with ractopamine HCl had greater ($P < 0.01$) ADG and G:F and a decreased ($P < 0.002$) ADFI compared to pigs fed the control diet (Table 3.2). Crome et al. (1996) observed similar results with an improvement in ADG and G:F and a decrease in ADFI when pigs were fed diets with ractopamine from 85 to 125 kg BW and Armstrong et al. (2004) reported an improvement in G:F when feeding diets with 10 mg/kg ractopamine for 34 days.

There was an improvement ($P < 0.05$) in HCW and dressing percentage when pigs were fed diets with ractopamine compared to those fed the control diet. These results are in agreement with those of Armstrong et al. (2004), Carr et al.(2005a), Crome et al. (1996), and Stites et al. (1991) who also reported improvements in HCW and dressing percentage in pigs fed diets with 10 mg/kg ractopamine. In addition to the improvements in HCW and dressing percentage for the pigs in our experiment, pigs fed diets with ractopamine had decreased ($P < 0.005$) backfat thickness compared to those fed the control diet. These results are in agreement with the reports of Carr et al. (2005b) and Marchant-Forde et al. (2003) but in contrast with a large number of publications (Armstrong et al., 2004; Brumm et al. 2004; Carr et al., 2005a; Crome et al., 1996; See et al., 2005) suggesting no differences in fat thickness when ractopamine was fed to finishing pigs. Finally, loin depth ($P < 0.003$) and percentage fat free lean ($P < 0.002$) were greater for pigs fed diets with ractopamine and these results are in agreement with those of Brumm et al. (2004) who also observed greater loin depth and percentage lean when ractopamine was added to the diet.

As additional mix time was increased from 0 to 360 s, CVs for Cr decreased from 67 to 12% (Table 3.2). The majority of this improvement in uniformity occurred during the first 30 s of mixing, with CVs dropping from 67 to 37, and an additional 360 seconds of mix time needed to decrease the CV further to 12%.

As for the effect of these changes in CV on animal performance, increasing mix time of diets after addition of ractopamine had no affect ($P > 0.15$) on ADG, ADFI, and G:F. Traylor et al. (1994) reported no differences in growth performance of finishing pigs fed diets when mix time was increased from 0 minutes(CV for salt at 54) to 4 minutes (CV for salt at 9.6%).

Furthermore, increasing mix time from 0 to 360 s yielded no differences ($P < 0.15$) in HCW or loin depth. There was a quadratic response ($P < 0.03$) for backfat thickness and a tendency ($P < 0.08$) for this same quadratic response in dressing percentage and percentage carcass lean, but these effects did not indicate a positive effect of increased mix time.

Experiment 2

As in Exp. 1, pigs fed diets with ractopamine had greater ($P < 0.001$) ADG and G:F (Table 3.3), which is in agreement with the work of Armstrong et al. (2004) and Marchant-Forde et al. (2003) who fed 10 mg/kg of ractopamine. Also, as in Exp 1, pigs fed diets with ractopamine had greater ($P < 0.05$) HCW, dressing percentage, loin depth and percentage fat free lean. These results are in agreement with those of Crome et al. (1996), Armstrong et al. (2004), Carr et al. (2005), Carr et al. (2009), and Kutzler et al. (2010) who also have shown positive effects on carcass merit with feeding of ractopamine. In contrast to Exp 1, backfat was not decreased among pigs fed ractopamine vs the control ($P < 0.07$). However, the 7% numerical advantage in backfat for pigs fed ractopamine does support the generally positive effects of ractopamine on growth performance and carcass merit in our experiments. Thus, in both of our experiments, ractopamine was indeed having the expected effects on growth performance and carcass merit leaving only the question of whether these response would be affected by increasing mix times for the diets.

Resulting CVs for salt (Table 3.3) were decreased from 51 to 12 as mix time was increased from 0 to 360 s. The lowest CV for a diet with ractopamine was 12% with 360s of mixing which compares favorably with the CV for the control (without ractopamine) also mixed for 360s. As in Exp. 1, the majority of improvement in diet uniformity was achieved with the first 30 s of mixing with CVs dropping from 51 to 19, and an additional 330 seconds of mix time needed to decrease the CV further to 12%. Traylor et al. (1994) reported similar results with CVs for salt decreasing from 54 to 15% for the first 30 s of mixing, and an additional 210 s of mixing was required to further decrease the CV to 10%. Increasing mix time of diets with ractopamine from 0 to 360 s had no affect ($P > 0.15$) on ADG and ADFI. However there was a trend for an improvement (quadratic, $P > 0.11$) in G:F, with a 5% increase in G:F as mix time was increased from 0 to 120 s (CV from 51 to 13%). Similarly, Traylor et al. (1994) reported no improvements in growth performance with a decrease in diet CV. However, the authors observed a 5% numerical increase in G:F as mix time was increased from 0 to 30 s (CVs from 54 and 15%).

There were no differences (*P* > 0.10) in carcass characteristics when mixed time was increased from 0 to 360 s. In contrast to the current experiment, Traylor et al. (1994) reported an improvement in backfat thickness as salt CV was decreased from 54 to 15%.

In conclusion, addition of 10 mg/kg ractopamine HCl to diets for finishing pigs resulted in improved ADG, G:F, HCW, dressing percentage, loin depth, and percentage fat free lean in both of our experiments. Increasing the mix times from 0 to 360 s reduced CV for Cr (Exp. 1) from 67 to 12% and CV for salt (Exp.2) from 51 to 12%. These decreases in CV had no effect on growth performance or carcass measurements. However, in Exp. 2 a mix time of 120 s for the complete diet and ractopamine (CV of 15) resulted in the highest numerical G:F.

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Table 3.1 Composition of diets, Exp. 1 and 2 (as-fed basis)[1,2]

Ingredient, %	
Corn	76.50
Soybean meal (47.5%)	20.4
L-Lysine HCl	0.25
DL-Methionine	0.03
L-Threonine	0.09
L-Tryptophan	0.01
Monocalcium Phosphate	0.96
Limestone	1.11
Salt[3]	0.35
Vitamin premix[4]	0.15
Mineral premix[5]	0.15
Calculated Analysis, %	
Total Lysine	1.01
Total Methionine	0.3
Ca	0.65
Available P	0.27

[1]Experimental treatments contained 10 mg/kg of ractopamine HCl (Elanco Animal Health, Greenfield, IN.

[2] In Exp. 1, 4.5 kg/ton of chromic oxide was added as a marker for determination of mix uniformity.

[3]In Exp. 2 salt was used as a marker for determination of mix uniformity.

[4]Provided (per kilogram of diet) 6,600 IU of vitamin A, 990 IU of vitamin D, 26.4 IU of vitamin E, 2.64 mg of vitamin K (as menadione dimethyprimidinol bisulfite), 29.7 mg of niacin, 16.5 mg of pantothenic acid (as d-calcium pantothenate), 4.95 mg of riboflavin, 23.1 μg of vitamin B_{12}.

[5]Provided (per kilogram of diet) 16.5 mg of copper, 0.3 mg of iodine, 165.3 mg of iron, 39.6 mg of manganese, 0.3 mg of selenium, 165.3 mg of zinc.

Table 3.2 Effects of a thoroughly mixed diet with a potentially non-uniform distribution of ractopamine on finishing pig performance (Exp. 1)[1]

		Mixing time, s					*P*-value		
Item	Control	0	30	120	360	SE	Control vs others	Linear	Quadratic
CV for chromium, %[2]	15	67	37	24	12	3	0.43	0.001	0.001
ADG, g	1,151	1,205	1,238	1,223	1,242	27	0.02	0.49	0.91
ADFI, kg	3.88	3.43	3.49	3.54	3.54	0.10	0.001	0.37	0.40
G:F, g/kg	298	352	356	346	352	7	0.001	0.83	0.45
HCW, kg	94.8	97.4	99.4	97.1	98.6	2.6	0.001	0.66	0.31
Dressing percent[3]	73.4	74.8	74.5	74.1	74.8	0.4	0.05	0.74	0.08
Backfat thickness, mm[3]	25.4	21.9	23.4	24.1	22.5	0.9	0.005	0.88	0.03
Loin depth, mm[3]	59.1	63.7	63.9	66.3	65.8	1.5	0.003	0.17	0.18
FFLI, % [3,4]	47.7	50.0	49.3	49.0	49.8	0.5	0.002	0.69	0.08

[1]A total of 200 finishing pigs (average initial BW of 90 kg, 5 pigs/pen and 8 pens/treatment) were used in a 33-d growth assay.

[2]Coefficient of variation for chromium concentration was determined from ten samples, taken from every 4th bag, for each batch of feed.

[3]HCW used as a covariate.

[4]Fat-free lean index (NPPC, 2001).

Table 3.3 Effects of potentially non-uniform distribution of both nutrients and ractopamine on finishing pig performance (Exp. 2)[1]

Item	Control	Mixing times, s 0	30	120	360	SE	*P*-value Control vs others	Linear	Quadratic
CV for salt, %[2]	11	51	19	15	12	7	0.90	0.04	0.05
ADG, g[3]	1,077	1,246	1,234	1,284	1,253	23	0.001	0.69	0.20
ADFI, kg[3]	3.56	3.54	3.46	3.47	3.41	0.06	0.18	0.22	0.77
G:F, g/kg[3]	303	354	359	372	371	7	0.001	0.07	0.11
HCW, kg	88.8	93.5	93.8	95.0	94.6	0.7	0.001	0.30	0.19
Dressing percentage, %[4]	72.8	73.8	74.3	74.1	74.4	0.4	0.003	0.36	0.81
Backfat thickness, mm[4]	21.5	19.4	20.3	19.2	20.0	0.8	0.07	0.83	0.64
Loin depth, mm[4]	61.7	69.8	67.1	67.1	70.9	1.4	0.001	0.18	0.10
FFLI, %[4,5]	50.4	52.0	51.2	51.9	51.7	0.5	0.05	0.92	0.87

[1]A total of 160 finishing pigs (average initial BW of 93 kg, 2 pig/pen and 16 pens/treatment) were used in a 27-d growth assay.

[2]Average coefficient of variation for salt concentration was determined from 2 batches/treatment, ten samples/batch, and samples taken from every 4th bag.

[3] Initial BW used as a covariate.

[4] HCW used as a covariate.

[5]Fat-free lean index (NPPC, 2001).

Chapter 4 - Effects of feeding cracked corn to nursery and finishing pigs

Abstract

Four experiments were conducted to determine the effects of supplementing cracked corn into diets of nursery and finishing pigs. In the first experiment, 144 pigs were used in a 28-d experiment to determine the effects of adding a pelleted protein supplement to processed corn in diets for nursery pigs. The pigs (average initial BW of 7.5 kg) were weaned and allotted by sex, weight, and ancestry to 24 pens. There were 6 pigs/pen (3 barrows and 3 gilts) and 6 pens/treatment. All pigs were fed a common diet for 7 d post weaning and the experimental treatments for the next 28 d. Treatments were corn-soybean meal-based in the form of mash, pellets, and pellets with 100% of the corn either ground (618 μm) or cracked (3,444 μm) and blended into the diet after the rest of the formulation (the supplement) had been pelleted. Overall (d 0 to 28), ADG and G:F were greater for pigs fed the mash control compared to the pelleted treatments ($P < 0.001$). However, this response was caused by the poor performance of pigs fed the supplement treatments with the pigs fed the complete pellets having greater ($P < 0.02$) ADG and G:F than pigs fed the pelleted supplement blended with ground and cracked corn. Finally, pigs fed the supplement blended with cracked corn had a numerically lower ($P < 0.11$) ADG and decreased ($P < 0.005$) G:F compared to those fed the supplement blended with ground corn. For Exp. 2, 224 nursery pigs (average initial BW of 7.4 kg) were used with 7 barrows or 7 gilts/pen and 8 pens/treatment. Treatments were corn-soybean meal-based and fed as mash, pellets, and pellets with 50% of the corn either ground (445 μm) or cracked (2,142 μm) and blended into the diet after the rest of the diet had been pelleted. For the 28-d experiment, pigs fed mash had greater ($P < 0.03$) ADG and G:F compared to pigs fed the other treatments. However, this resulted from adding ground or cracked corn outside the pellets (complete pellets vs pelleted supplement with ground and cracked corn, $P < 0.001$). For Exp. 3, 208 pigs (average initial BW 62.6 kg) were used in a 63-d experiment to determine the effects of adding cracked corn to diets for finishing pigs. The pigs were sorted by ancestry and blocked by weight with either 13 barrows/pen or 13 gilts/pen and 4 pens/treatment. Treatments were corn-soybean meal-based with none, 10, 20, and 40% cracked corn (3,549 µm). Overall (d 0 to 63), increasing cracked corn from none to 40% had no effect ($P > 0.41$) on ADG and ADFI. There was a numerical decrease of 3% for G:F as cracked corn in the diet was increased from none to 40%, but the means were not statistically different ($P > 0.10$). Adding cracked corn to diets had no effect ($P > 0.17$) on hot carcass weight (HCW) or backfat thickness but dressing percentage was decreased (linear effect, $P < 0.05$). Finally, scores for keratinization and ulcers in the stomach decreased (linear, $P < 0.009$) as the percentage of cracked corn in diets was increased. However even the worst treatment had an average lesion score of less than mild. For Exp. 4, 252 finishing pigs (average BW of 40 kg) were used with 4 barrows and 3 gilts/pen and 9 pens/treatment. The treatments were corn-soybean meal-based and fed as mash, pellets, and pellets with 50% of the corn (ground or cracked) blended into the diet after the rest of the formulation (the supplement) had been pelleted. For the 80-d experiment, pigs fed mash had lower ($P < 0.004$) ADG compared to pigs fed diets with pellets. Pigs fed complete pellets had greater ($P < 0.03$) ADG and G:F compared to pigs fed corn and the pelleted supplement and pigs fed the supplement blended with cracked corn had greater ($P< 0.02$) ADG than pigs fed the supplement blended with ground corn. With hot carcass weight used as a covariate, dressing percentage of pigs fed mash was greater than for pigs fed the other treatments with no differences for fat thickness or percentage fat free lean index among pigs (FFLI) fed the various treatments ($P > 0.13$). However, pigs fed the complete pellet had lower ($P < 0.03$) loin depth than those fed corn and the pelleted supplement. In conclusion, adding ground or cracked corn to a pelleted supplement had negative effects on ADG and G:F for nursery pigs. Scores for stomach lesions were lowest for pigs fed diets containing cracked corn. However, pigs fed pellets had the greatest efficiency of gain with average scores for keratinization and ulcers being only 0.5 units greater than the mash control.

Introduction

For 2008 to present, historically high grain prices have pressured swine producers to strive for maximizing efficiency of gain by pigs as never before. An effective means to battle high feed costs is by improving nutrient utilization through feed processing. Research has demonstrated that grinding grains leads to improvements in nutrient digestibility and efficiency of gain in pigs (Healy et al., 1994). Pelleting has been shown to improve nutrient digestibility and efficiency of gain even beyond that of simple grinding (Wondra et al. 1995). However, there are negative aspects to these feed manufacturing practices. Fine grinding of cereals will decrease bulk density, production rate, and flowability of feed while increasing dustiness and the amount of energy required for processing. Pelleting can be used to reduce or eliminate bridging and dustiness and restore bulk density but it adds to the energy costs for feed processing and most often becomes the limiting factor in feedmill throughput (Skoch et al. 1983). Additionally, fine grinding and pelleting have been shown to increase the incidence and severity of ulceration of the pars esophagea region of the pigs stomach (Mahan et al., 1966; Maxwell et al., 1967; Nuwer et al., 1967; Riker et al., 1967; Reimann et al., 1968; Wondra et al., 1994; Wondra et al., 1995; Eisemann at al., 1999). Although, the effects stomach ulcers can have on growth performance is unclear, once severe enough they can result in death (Hedde et al., 1985; Backstrom et al., 1988; Wondra et al., 1995; Ayles et al., 1996).

Dozier et al. (2006) suggested that negative effects of fine grinding and pelleting in poultry can be reduced by adding 35% rolled corn to a pelleted protein supplement without negative effects on broiler performance. Thus, we designed 4 experiments to determine the effects of adding cracked corn to diets on growth performance and milling efficiency while preparing diets for nursery and finishing pigs.

Materials and Methods

All animal use in these experiments was approved by the Kansas State University Animal Car and Use Committee.

Experiment 1

A total of 144 pigs (PIC line TR4 × 1050) were weaned at 21 days of age, sorted by sex and ancestry, blocked by weight, and assigned to pens. There were 3 barrows and 3 gilts/pen and 6 pens/treatment. The pigs were housed in an environmentally-controlled nursery with pens (1.22-m x 1.52-m) having woven wire flooring. Animal level temperature was initially 32°C and was decreased by 1.5°C each week. Each pen had a self-feeder and nipple water to allow ad libitum consumption of feed and water. Pigs were fed a common pelleted diet (Rapid Start N/T; Suther Feeds Inc., Frankfort, KS) for the first 7 d post-weaning and then used in a 28-d growth assay (average initial body weight of 7.5 kg). Treatments were corn-soybean meal-based and fed in the form of mash, pellets, and pellets with 100% of the corn (ground or cracked) blended into the diet after the rest of the formulation (the supplement) had been pelleted. The experimental diets (Table 4.1) were fed in 2 phases, with phase 1 being fed from day 0 to 14 of the experiment and phase 2 from day 14 to 28 of the experiment. All diets were formulated to meet or exceed the nutrient concentrations suggested by the National Research Council (NRC, 1998). Pigs and feeders were weighed on d 0, 14, and 28 of the experiment to allow calculation of ADG, ADFI, and G:F.

All feed processing was completed at the Kansas State University Grain Science Pilot Feed Mill. The corn was milled using a three-high roller mill (1:1, 1.5:1, 1.5:1 differential drives; 3.2, 4.7, and 6.3 corrugations per centimeter; and 0, 8.3, and 8.3 cm of spiral/meter of roller, Model K, Roskamp Manufacturing, Cedar Falls, IA). The ASAE (1983) standard method was used to determine particle size of the ground and cracked corn with Tyler sieves (numbers 6, 8, 10, 14, 20, 28, 35, 48, 65, 100, 150, 200, 270, and a pan), and Ro-Tap® shaker (W. S. Tyler, Mentor, Ohio). One hundred gram samples were sifted for 10 minutes and the weight of the residue on each screen used to calculate geometric mean particle size (d_{gw}) and the log normal standard deviation (s_{gw}).

For the complete pellets and the pelleted supplement, a 30 horsepower pellet mill (30 HD Master Model®, California Pellet Mill, San Francisco) equipped with a 32 mm-thick (hole diameters of 4 mm) was used. Feed was steam conditioned to approximately 71 and 82°C prior to pelleting for phase 1 and 2, respectively. In order to preserve pellet quality, fat exceeding 2% was added postpellet. Pellet durability index (PDI) was determined using the procedure recommended by the American Society of Agricultural and Biological Engineers (ASAE, 1987). Finally, an amp-volt meter (Model DM-II, Amprobe Instrument, Lynbrook, NY) was used to calculate energy used during the grinding and pelleting processes.

All data were analyzed as a randomized complete block design using the MIXED procedure of SAS (v9.2; SAS Inst. Inc., Cary, NC) with BW at d 7 (the initiation of the growth assay) used as a covariate. Orthogonal contrasts were used to separate treatment means with comparisons of: 1) mash vs treatments with pellets; 2) complete pellets vs pelleted supplement with ground and cracked corn; and 3) pelleted supplement with ground vs cracked corn.

Experiment 2

A total of 224 pigs (PIC line TR4 × 1050) were weaned at 21 days of age, sorted by sex and ancestry, blocked by weight, and assigned to pens. There were 7 barrows/pen and 7 gilts/pen and 8 pens/treatment. Pigs were housed in an environmentally-controlled nursery with the pens (1.22-m × 1.52-m) having woven wire flooring. Animal level temperature was initially 32°C and was decreased by 1.5°C each week. Each pen had a self-feeder and nipple water to allow ad libitum consumption of feed and water. Pigs were fed a common pelleted diet (Rapid Start N/T; Suther Feeds Inc., Frankfort, KS) for the first 7 d post weaning and then used in a 28-d~~ay~~ growth assay (average initial BW of 7.5 kg). Treatments were corn-soybean meal-based and fed as mash, pellets, and pellets with 50% of the corn (ground or cracked) blended into the diet after the rest of the formulation (the supplement) had been pelleted. The experimental treatments (Table 4.2) were fed in 2 phases, with Phase 1 being 0 to 13 and Phase 2 being d 13 to 28 of the experiment. All diets were formulated to meet or exceed the nutrient concentrations suggested by the National Research Council (NRC, 1998).

Pigs and feeders were weighed on d 0, 13, and 28 of the experiment to allow calculation of ADG, ADFI, and G:F. All feed processing was completed at the Kansas State University Grain Science Pilot Feed Mill. All diets were processed as in Exp. 1. However, for Exp. 2 fat exceeding 5% was added postpellet. Grain particle size, PDI, modified PDI, and energy consumption were also determined as described for Exp. 1.

All data were analyzed as a randomized complete block design using the MIXED procedure of SAS (v9.2; SAS Inst. Inc., Cary, NC). Orthogonal contrasts were used to separate treatment means with comparisons of: 1) mash vs treatments with pellets; 2) complete pellets vs pelleted supplement with ground and cracked corn; and 3) pelleted supplement with ground vs cracked corn.

Experiment 3

Two hundred and eight finishing pigs (PIC line TR4 × 1050) were used in the 63 day experiment. The pigs were sorted by sex and ancestry and blocked by weight with 13 barrows or 13 gilts/pen and 4 pens/treatment. Pens were 1.8-m × 4.9-m with half solid and half slatted concrete flooring. Each pen had a self-feeder and nipple waterer to allow ad libitum consumption of feed and water. Pigs (average initial BW of 62.6 kg) were fed experimental treatments for 63 d in 2 phases. Treatments diets were corn-soybean meal-based (Table 4.2) with 0, 10, 20, or 40% cracked corn (mean particle size of 3,549 µm). Pigs and feeders were weighed on day 0 and 63 to determine ADG, ADFI, and G:F. On d 63 of the experiment pigs were tattooed and shipped to a commercial abattoir (Farmland Foods, Inc. Crete, NE) to allow collection hot carcass weight (HCW), loin depth and 10^{th} rib fat thickness (SFK Technology A/S model S 82; Herlev, Denmark), and stomachs. The esophageal region of the stomachs was removed and scored for ulcers and keranitization by a trained veterinary pathologist. For keratinization, the non-glandular mucosa of the esophageal region that was not ulcerated was scored on the scale of 1 = none (normal or no keratinization), 2 = mild (keratin covering < 25% of the non-glandular mucosa), 3 = moderate (keratin covering 25 to 75% of the non-glandular mucosa), and 4 = severe (keratin covering > 75% of the non-glandular mucosa). Because keratinization is a precursor to ulceration, stomachs that were fully ulcerated and, thus, had no remaining squamous epithelium, were assumed to have been fully keratinized prior to ulcer development and given a score of 4 for keratinization. For ulceration, the esophageal region was scored as 1 = none, 2 = mild (ulceration present but affecting < 25% of the non-glandular mucosa), 3 = moderate (ulceration of 25-75% of the non-glandular mucosa), and 4 = severe (ulceration of > 75% of non-glandular mucosa). Dressing percentage was calculated with HCW as a percentage of preshipping live weight ~~s~~. Fat free lean index was calculated using the equation suggested by the National Pork Producers Council (NPPC, 2001) and this allowed calculation of as a percentage of HCW.

All data were analyzed as a randomized complete block design using the MIXED procedure of SAS (v9.2; SAS Inst. Inc., Cary, NC). Polynomial regression was used to define the shape of the response to increasing concentration of cracked corn in the diets. HCW was used as a covariate for analyses of carcass characteristics.

Experiment 4

Two hundred and fifty two finishing pigs (PIC line TR4 × 1050; average initial BW of 40.3 kg) were sorted by weight, sex, and ancestry and assigned to pens and treatments were randomly assigned. Pigs were housed in an environmentally controlled finishing facility having a complete slatted concrete floor with adjustable gates to allow for 0.93 m^2/pig. Each pen contained a self-feeder and cup waterer to allow ad libitum consumption of feed and water. An automated feeding system (FeedPro; Feedlogic Corp., Willmar, MN) was used to feed individual pens and record feed weights for each pen. There were 7 pigs/pen (4 barrows and 3 gilts) and 9 pens/treatment for the 80-d experiment. Treatments were the same as described in Exp. 2. The automated feeding system was used to blend ground or cracked corn with the pelleted supplement. Diets were fed in 3 phases (Table 4.3) from approximately 40 to 69 kg, 69 to 98 kg, and 98 to 127 kg. Diets were formulated to meet or exceed all nutrient requirements recommended by the National Research Council (NRC, 1998).

Feed processing was completed at a commercial feedmill (Key Feeds, Clay Center, KS). For the complete mash, complete pellet, and pelleted supplement with ground corn treatments, corn was milled through a hammermill (Jacobson P24209 series 2) equipped with a full circle screen having 3.18 mm diameter openings. For the cracked corn treatment, the corn was processed using a 40 horsepower two-high roller mill (1.5:1, 1.5:1 differential drives; 1.55, and 1.55 corrugations per centimeter; and 6, and 16 cm of spiral/meter of roller, Ferrell Ross 10 × 36, Hereford, TX). The geometric mean particle size, log normal standard deviation, PDI, modified PDI, and energy consumption were determined as described in Exp. 1. The complete pellet and the pelleted supplement were pelleted in a 125 horsepower pellet mill (Century, California Pellet Mill, San Francisco) equipped with a die having die holes with a diameter of 4.8 mm. All supplemental fat was added in the mixer before conditioning with steam at 75°C before pelleting. Pellets were analyzed for pellet durability index (PDI; ASAE, 1987) and modified PDI (procedure modified by adding five 13-mm hexagonal nuts prior to tumbling). An amp-volt meter (Model DM-II, Amprobe Instrument, Lynbrook, NY) was used to calculate energy used during grinding and pelleting.

Pigs and feeders were weighed on day 0, 26, 54, and 80 to allow calculation of ADG, ADFI, and G:F. On d 80, the pigs were tattooed and shipped to a commercial abattoir (Farmland Foods, Inc.; Crete, NE) for collection of carcass data and stomachs as described for Exp. 3.

All data were analyzed as a randomized complete block design using the MIXED procedure of SAS (v9.2; SAS Inst. Inc., Cary, NC). Orthogonal contrasts were used to separate treatment means with comparisons of: 1) mash vs treatments with pellets; 2) complete pellets vs pelleted supplement with ground and cracked corn; and 3) pelleted supplement with ground vs cracked corn. HCW was used as a covariate for analyses of carcass characteristics.

Results and Discussion

Experiment 1

The particle sizes of the ground and cracked corn were 618 and 3,444 μm, respectively. The difference in milling procedure resulted in 7.6 times more energy (7.5 vs 1.0 kWh/t) being required to fine grind corn in the hammermill vs cracking corn in the roller mill. Fine grinding corn in the hammermill also reduced throughput from 3.90 to 1.00 t/h compared to cracking corn in the roller mill.

Energy required to pellet the supplement was similar, 0.8 kWh/t less, to that required to pellet the complete diet (Table 4.4). The supplement and complete diet for Phase 1 had similar pellet durabilities (PDI), but for phase 2 the PDI for the supplement was 7% points greater than the PDI for the complete diet.

Grinding and pelleting the complete diet required 5 times more energy (19.1 vs 3.9 kWh/t) than simply grinding the mash (Table 4.5). However, total energy required to produce the pelleted supplement with ground or cracked corn was reduced by 8.2 and 11.02 kWh/t respectively, when compared to pelleting the entire diet

For d 0 to 14 and 14 to 28, pigs fed the mash diet had greater ($P < 0.05$) ADG than pigs fed the pelleted diets, resulting in pigs fed the mash diet having a greater ($P < 0.001$) final BW (Table 4.5). Also, for d 14 to 28 pigs fed the mash diet had greater ($P < 0.001$) G:F than those fed the pelleted treatments. However, these negative effects resulted primarily when feeding the pelleted supplement with decreased ($P < 0.003$) ADG and G:F during d 14-28 when the corn (ground and cracked) was blended into the diet outside the pelleting process, and a majority of this negative effect on G:F resulted from cracking the corn that was added to the supplement (P < 0.01; ground corn plus the supplement vs cracked corn plus the supplement). Traylor et al. (1996) demonstrated no difference in ADG and improved G:F when nursery pigs (d 0 to 29 after weaning) were fed a pelleted diet. Johnston et al., (1999) reported a 5% increase in rate of gain when standard conditioned diets were pelleted, but a 3% reduction in ADG when long term conditioned diets were pelleted. Although, condition retention time was not measured, this demonstrates that feed not properly processed can eliminate expected benefits or even cause negative effects.

Experiment 2

The particle sizes of the ground and cracked corn were 445 and 2,412 μm, respectively. Grinding the corn using the hammer mill required 8.3 times the amount of energy (7.4 vs 0.9 kWh/t) as the roller mill used to crack corn (Table 4.6).

The average energy required to pellet the complete diet (8.97 kWh/t) and the supplement (8.68 kWh/t) were similar (Table 4.6). The PDI (96.6% and 96.7%) and modified PDI (95.8% and 95.8%) were almost identical for both the complete and supplement pellets for phase 1, respectively. For phase 2 diets, The PDI and modified PDI for the supplement were 1.6 and 3.5% points higher than the PDI and modified PDI for the complete pellets, respectively.

The total energy required to grind and pellet the complete diet required 3 times more energy (13.6 vs 4.6 kWh/t) than simply grinding the mash (Table 4.7). However, total energy required to produce the pelleted supplement with ground or cracked corn was reduced by 2.6 and 4.6 kWh/t, respectively, compared to pelleting the entire diet.

For d 13 to 28 pigs fed the mash diet had greater ($P < 0.02$) ADG and G:F than pigs fed the pelleted diets (Table 4.7). However, this response was caused by the poor performance of pigs fed the supplement treatments with the pigs fed the complete pellets having greater ($P < 0.005$) ADG and G:F than pigs fed the pelleted supplement blended with ground and cracked corn. Moreover, pigs fed the complete pellet had similar ADG and 6% greater G:F than those fed the mash. This is in agreement with Johnston et al. (1999) who reported no difference in ADG and a 6% improvement in G:F when phase 3 nursery pigs were fed a standard conditioned pellet compared to mash. In addition, pigs fed the supplement plus 50% of the corn outside of the pellet had increased ($P < 0.001$) ADFI and decreased (0.005) G:F for d 0 to 13 and d 13 to 28 compared to those fed the complete pellet. This can partly be explained by the increase of fines in the diet, due to the percentage of corn being removed from the diet. Stark et al (1993) demonstrated a decrease in efficiency of gain when nursery pigs were fed a pelleted diet that contained up to 25% fines. However, the authors reported that pellets with 25% fines still led to an improvement in nursery pig performance compared to diets fed in the meal form. In contrast, for d 0 to 28, pigs fed the pelleted treatments had decreased ($P < 0.01$) G:F compared to those fed the mash. This negative effect resulted primarily when feeding the pelleted supplement with decreased ($P < 0.001$) G:F when the corn was added postpellet. The G:F of pigs fed the pelleted supplement with ground or cracked corn was reduced by 8 and 11%, respectively, compared to the mash and 13 and 15%, respectively, compared to the complete pellet.

Experiment 3

Increasing the percentage of cracked corn in the diet from 0 to 40% resulted in an increase in diet particle size from 684 to 1,187 μm and an increase in s_{gw} from 2.22 to 2.68 μm (Table 4.8). As cracked corn was added to the diet of finishing pigs, there was no difference ($P > 0.15$) in ADG or ADFI (Table 4.8). However, there was a numerical decrease (linear, $P < 0.09$) in G:F of pigs as cracked corn was increased from 0 to 40%. Therefore, It was determined that when replacing 10, 20, and 40% of ground corn with cracked corn, G:F is improved by 0.8% for every 100 μm reduction in mean particle size. Wondra et al. (1995) demonstrated a 1.3% improvement in G:F for every 100 μm reduction in particle size. It is hypothesized that a smaller reduction in G:F is observed, because a proportion of the grain in the cracked corn diets is still under 600 μm. Therefore, the distribution of particle size may have an effect on G:F. Patience et al. (2011) tested the effects of feeding ground corn with an average mean particle size of 561 μm, and s_{gw} of 1.9, 2.1, 2.3, 2.5, or 2.7. The authors reported a quadratic response to particle size variation, with DM and GE digestibility decreasing from s_{gw} of 1.9 to 2.3, and increasing back to the level similar to that of 1.9 as s_{gw} was increased from 2.3 to 2.7, respectively. This suggests that increasing the amount of larger particles while decreasing the particle size of smaller particles in the diet may affect the GIT in a way that has positive effects on igestion. However, since a portion of the grains has a lower surface area to volume ration, the G:F is still reduced due to larger particle size, but the decrease is less dramatic.

Increasing cracked corn had no effect ($P > 0.15$) on HCW, backfat thickness, or fat fre lean percentage (FFL), but dressing percentage was decreased (linear; $P < 0.05$). This reduction in dressing percentage could be caused by increased gut fill. Supporting this, Maxwell et al. (1967) reported an increase in weight of stomach contents for pigs fed coarsely-ground oat hulls compared to those fed finely-ground oat hulls. Lawrence et al. (1998) also observed increases in gut fill when pigs were fed coarse diets.

Intensive management strategies of pigs have led to more common occurrences of ulceration of the pars esophagea region of the stomach. After collecting surveys from abattoirs, scientists have indicated that approximately 20% of pigs have extensive lesions and 60% have pre-ulcerative parakeratosis lesions (Driesen et al., 1987; Elbers et al., 1995; O'Sullivan et al., 1996). Stomach keratinization is described as irritation of the pars esophagea that occurs before erosion (Jubb et al., 1985). It is important to understand what factors influence gut morphology and how to maximize efficiency without inducing ulceration. Common feed manufacturing practices, such as fine grinding has been shown to increase the incidences of ulceration of the pars esophageal region of the stomach (Mahan et al., 1966, Maxwell et al., 1970, Wondra et al., 1995, and Ayles et al., 1996). It has been hypothesized that this is because of increased fluidity which results in more mixing of stomach contents. Mixing of the fluid stomach content allows for continuous exposure of the unprotected mucosa of the esophageal region to pepsin and digestive acids (Reimann et al., 1968; Maxwell et al., 1970; Maxwell et al., 1972). Dirkzwager et al. (1998) reported a lower proportion of pig stomachs having severe esophageal lesions when fed either coarsely ground diets or finely ground diets plus 5% whole sunflower hulls compared to those fed finely ground diets. Furthermore, Ayles et al. (1996) demonstrated that feeding a coarser diet for a 3-wk period could decrease the severity of stomach ulcers. Similar effects were demonstrated in the current experiment. Adding up to 40% of cracked corn to a mash diet reduced scores for keratinization (quadratic, $P < 0.05$) and ulcers (linear, $P < 0.01$; Table 4.9). However, even though pigs fed diets with 40% cracked corn had the lowest numerical score (i.e., the least lesion development), their scores still would be considered less than mild.

Experiment 4

To pellet the supplement it required 9% less energy (kWh/t) but had a production rate 1% less than the complete diet (Table 4.10). This does not account for treatment differences due to removing 50% of the corn and adding it postpellet. PDIs and modified PDIs were similar between the complete pellet and the pelleted supplement. Milling of the corn using a rollermill and hammermill (3.18 mm screen) achieved corn particle sizes of 2,841 μm and 493 μm, respectively. Grinding the corn using the hammermill required 9 times the energy (kWh/t) and reduced the production rate by 102%, compared to the rollermill.

It is important to also take into consideration the cost effects pelleting can have on a feed mill. To grind and pellet the complete diet, an additional 16.9 kWh/t of energy was required compared to simply grinding the mash (Table 4.11). However, removing 50% of the corn from the pellet and either grinding or cracking it reduced total energy consumed, by grinding and pelleting, by 36 % and 48%, respectively. Energy was based on $0.07/kWh when calculating energy cost. Pelleting the complete diet increased the electrical cost alone from $0.42 to $1.61 when compared to simply grinding the mash. However, removing 50% of the corn from the pellet and cracking it can reduce diet cost by $0.70/t compared to the pelleted complete diet.

However, adding 50% of the corn postpellet can reduce cost from $1.61/ton (complete pellet) to $1.03/t (pelleted supplement with ground corn) or it can further be reduced to $0.84/t (pellet supplement with cracked corn). A feed mill with the capability of producing 6 tons of pellets per hour and running 50 hours a week could produce 300 t/wk. Pelleting the complete diet would increase electrical cost from $126 to $483 per week, costing them an extra $357/wk for electrical cost alone. If 50% of the corn is removed from the pellet and cracked it could reduce electrical cost from $483 (complete pellet) to $309 (pelleted supplement with ground corn) or $252 (pelleted supplement with cracked corn) per week, saving the feed mill $174 or $231/wk, respectively. Applying this scenario to an integrated feed mill, producing 10,000 t/wk, would reduce the electrical cost per week from $16,100 (complete pellet) to $10,300 (pellet supplement with ground corn) or $8,400 (pellet supplement with cracked corn, saving the feedmill $5,800 or $7,700/wk, respectively. However, energy is not the only factor that effects cost in the feed mill.

Throughput is another key factor that affects milling cost. Pelleting is the limiting factor in feed mill production rates; therefore, it will be the only thing considered when calculating the treatment effects on production rates. Key Feeds was able to pellet 5.5 t/h. If a feed mill producing 6 t/h needed to produce 300 t/wk, they would be required to run the pellet mill for 50 h/wk. Pulling 50% of the corn from the finishing pig diet resulted in an average of 60% of the diet as the pelleted supplement and 40% of the diet as corn outside of the pellet. Removing 50% of the corn would reduce the amount of pellets required from 300 t/wk to 180 t/wk. This would require the feed mill to only run 30 h/wk, instead of 50 h/wk. Assuming it would cost a feed mill of this size $175/h to run, reducing the operating time by 20 h would save the feed mill approximately $3,500/wk. When removing 18% of diet as corn from the pellet, Clark and Behnke (2004) demonstrated a 16 hour reduction in time required to meet production targets, with pellet mills producing 45.8 t/h. It cost a feed mill of this size approximately $300/h to operate (Agri. Stats, 2004). Therefore, reducing the running time of the mill by 16 h/wk will save the feed mill approximately $4,800/wk. Applying the 40% removal of the complete pellet as corn, to the scenario presented by Clark and Behnke (2004) would reduce the targeted pellet production of 4,400 t/wk to 2,640 t/wk. For a feed mill producing 45.8 t/h, this would reduce the required operating time from 96 h/wk to 58 h/wk. Reducing the operating time by 38 h will save the feed mill $11,400/wk.

For the overall experiment (d 0 to 80), pigs fed the diets with pellets had increased ($P <$ 0.02) ADG and ADFI, with no difference ($P > 0.72$) in G:F compared to those fed the mash (Table 4.12). However, pigs fed the pelleted supplement with ground or cracked corn had decreased ($P < 0.03$) ADG and G:F and a trend for increased ADFI ($P < 0.08$) compared to those fed the complete pellet, with the pelleted supplement and ground corn being the reason for the decrease (P < 0.02; the supplement plus ground corn vs the supplement plus cracked corn) in ADG. After review of the literature, Hancock and Behnke (2001) reported a 6 and 6 to 7% improvement in ADG and G:F, respectively, when growing-finishing pigs were fed pelleted diets. Although the contrast statements did not directly compare the complete pellet to the mash, we observed a 6 and 4% increase in ADG and G:F, respectively, when pigs were fed the complete pellets. There were no differences ($P > 0.64$) in G:F when feeding the pelleted supplement and either ground or cracked corn. This does not agree with previous research which demonstrates that coarser particle size grains decrease nutrient availability and efficiency of gain in pigs (Hedde et al., 1985; Giesemann et al., 1990; and Wondra et al., 1995; Mahan et al., 1996). However, due to particle size of the cracked corn, it blended better with the supplement than did the ground corn. It also provided for easier feeder management and less sorting of feed than the ground corn treatment. Therefore, any loss in digestibility with the cracked grain may be masked by differences in feeding behavior (as in greater sorting and wastage for the gorund grain vs the cracked grain). However, it is important to note that this was based on observation alone, and feed wastage was not measured. Schell and van Heugten (1998) demonstrated decreases in G:F as pelleting fines increased in diets for growing pigs.

There were no differences ($P > 0.15$) in HCW, backfat thickness, or percentage FFLI % between treatments (Table 4.12). Pigs fed the pelleted treatments had reduced ($P < 0.02$) dressing percentages compared to those fed the mash. This resulted from pigs fed the complete pellet and the pelleted supplement and cracked corn treatment with no difference ($P > 0.78$) in the complete pellet and pellet supplement plus corn and decreased ($P < 0.002$) dressing percentage when pigs were fed the pelleted supplement plus cracked corn compared to those fed the pelleted supplement with ground corn. The reduced dressing percentage resulting from feeding cracked corn could result in increased gut fill. Maxwell et al. (1967) reported an increase in weight of stomach contents for pigs fed coarsely-ground oat hulls compared to those fed finely-ground oat hulls. Lawrence et al. (1998) also observed increases in gut fill when pigs were fed coarse diets. Pigs fed the complete diet had decreased ($P < 0.03$) loin depth compared to those fed the pellet supplement and corn either ground or cracked. This reduced loin depth resulting from feeding the complete pellet is not easily explained. However, Potter et al. (2010) also reported a trend for a 2% decrease in loin depth when pigs were fed pelleted diets.

As previously described, stomach ulcers have a large influence on mortality rate of finishing pigs. It is important to realize that common feed manufacturing practices, such as pelleting (Chamberlain et al., 1967; Flatlandsmo and Slagsvold, 1971), have been shown to increase the incidences of ulceration of the pars esophageal region of the stomach. Pigs fed the pelleted diets had similar keratinization scores as those fed the mash diet (Table 4.13). However, pigs fed the pelleted supplement plus corn had reduced ($P < 0.02$) stomach keratinization scores, with a majority of this reduction caused by adding cracked corn postpellet ($P < 0.004$; pellet supplement plus ground corn vs pellet supplement plus cracked corn). Pelleting the diet led to an increase ($P < 0.05$) ulceration scores. However, these negative effects on ulcer scores were reduced ($P < 0.001$) by adding cracking 50% of the corn and adding it postpellet, which resulted in the lowest stomach scores. In agreement, Dirkzwager et al. (1998) reported a lower proportion of pig stomachs having severe esophageal lesions when fed either coarsely ground diets or finely ground diets plus 5% whole sunflower hulls compared to those fed finely ground diets. Furthermore, Ayles et al. (1996) demonstrated that feeding a coarser diet for a 3-w period could decrease the severity of stomach ulcers.

In conclusion, pelleting the complete diet for nursery pigs improved efficiency of gain in 1 of the 2 experiments. However, adding a percentage of the corn postpellet is not a viable option for nursery pigs. In finishing pigs, pelleting the complete diet led to improvements in performance. However, pelleting the diet increased feedmill energy consumption and it increased the incidence of pars esophageal lesions in the stomach. The negative effects of pelleting on stomach morphology and feedmill cost were alleviated by removing a 50% of the corn from the diet. Although, pigs still achieved maximum rates of gain, feed efficiency was reduced by 6% compared to pigs fed the complete pellet. It was also demonstrated that adding up to 40% cracked corn to a mash diet reduced stomach ulcers with no significant effects on rate of gain and a trend for reduction of efficiency of gain.

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Table 4.1 Composition of experimental diets (Exp. 1[1] and 2[2]; as-fed basis)

Ingredient, %	Phase 1	Phase 2
Corn	44.50	57.82
Soybean meal (46.5% CP)	29.00	33.10
Spray dried whey	15.00	—
Spray dried plasma	2.50	—
Menhaden fishmeal	3.00	—
Soybean oil	3.00	5.00
Monocalcium phosphate	0.63	1.31
Limestone	0.86	1.11
Salt	0.30	0.37
L-Lys·HCl	0.21	0.32
DL-Met	0.13	0.13
L-Thr	0.03	0.10
Viamin premix[2]	0.25	0.25
Mineral premix[3]	0.15	0.15
Zinc oxide[4]	0.19	—
Copper sulfate[5]	—	0.09
Antibiotic[6]	0.25	0.25

[1]Experimental treatments were fed as mash, pellets, and pellets with 100% of the corn (ground or cracked) blended into the diet after the rest of the formulation (the supplement) had been pelleted.

[2]Experimental treatments were fed as mash, pellets, and pellets with 50% of the corn (ground or cracked) blended into with the pelleted supplement.

[3]Provided (per kilogram of diet) 11,000 IU of vitamin A, 1,375 IU of vitamin D, 44 IU of vitamin E, 4.4 mg of vitamin K (as menadione dimethyprimidinol bisulfite), 49.5 mg of niacin, 27.5 mg of pantothenic acid (as d-calcium pantothenate), 8.25 mg of riboflavin, 38.5 μg of vitamin B_{12}.

[4]Provided (per kilogram of diet) 16.5 mg of copper, 0.3 mg of iodine, 165.3 mg of iron, 39.6 mg of manganese, 0.3 mg of selenium, 165.3 mg of zinc.

[5]To provide 1,368 mg/kg zinc.

[6]To provide 226.8 mg/kg copper.

[7]To provide 154 g/ton oxytetracycline and 154 g/ton neomycin.

Table 4.2 Composition of experimental diets (Exp. 3; as-fed basis)

	d 0 to 31				d 31 to 63			
		Cracked Corn, %				Cracked Corn, %		
Ingredient, %	Control	10	20	40	Control	10	20	40
Corn[1]	73.88	63.88	53.88	33.88	80.46	70.46	60.46	40.46
Cracked corn[2]	—	10.00	20.00	40.00	—	10.00	20.00	40.00
Soybean meal (46.5% CP)	21.28	21.28	21.28	21.28	14.96	14.96	14.96	14.96
Soy oil	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
L-Lysine HCl	0.15	0.15	0.15	0.15	0.18	0.18	0.18	0.18
L-Threonine	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04
Monocalcium Phosphate	0.94	0.94	0.94	0.94	0.58	0.58	0.58	0.58
Limestone	0.97	0.97	0.97	0.97	1.05	1.05	1.05	1.05
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Viamin premix[3]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Mineral premix[4]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Antibiotic[5]	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Calculated analysis, %								
SID lysine[6]	0.85	0.85	0.85	0.85	0.71	0.71	0.71	0.71
Ca	0.60	0.60	0.60	0.60	0.55	0.55	0.55	0.55
Total P	0.55	0.55	0.55	0.55	0.45	0.45	0.45	0.45

[1]Ground in a hammer mill to 600 μm.

[2]Cracked in a roller mill to 3,549 μm.

[3]Provided (per kilogram of diet) 6,608 IU of vitamin A, 826 IU of vitamin D, 26.4 IU of vitamin E, 2.64 mg of vitamin K (as menadione dimethyprimidinol bisulfite), 29.7 mg of niacin, 16.5 mg of pantothenic acid (as d-calcium pantothenate), 4.95 mg of riboflavin, 23.1 μg of vitamin B_{12}.

[4]Provided (per kilogram of diet) 11 mg of copper, 0.2 mg of iodine, 110 mg of iron, 26.4 mg of manganese, 0.2 mg of selenium, and 110 mg of zinc.

[5]To provide 40 g/ton of tylosin.

[6]Standardized ileal digestible lysine.

Table 4.3 Composition of experimental diets (Exp. 4; as-fed basis)[1]

Ingredient, %	Phase 1	Phase 2	Phase 3
Corn	74.04	79.25	84.70
Soybean meal (46.5% CP)	22.00	17.15	11.90
Choice White Grease	1.00	1.00	1.00
L-Lysine HCl	0.35	0.34	0.35
DL-Methionine	0.074	0.070	0.048
L-Threonine	0.110	0.117	0.110
L-Tryptophan	0.019	0.023	0.037
Monocalcium phosphate	0.91	0.720	0.540
Limestone	1.08	0.91	0.89
Salt	0.25	0.25	0.25
Viamin premix[2]	0.08	0.08	0.08
Mineral premix[3]	0.04	0.04	0.04
Folic acid[4]	0.001	0.001	0.001
Antibiotic[5]	0.05	0.050	0.05
Calculated analysis, %			
SID lysine[6]	1.00	0.88	0.76
Ca	0.70	0.55	0.50
Available P	0.30	0.21	0.17

[1]Experimental treatments were fed as mash, pellets, and pellets with 50% of the corn (ground or cracked) blended into the diet after the rest of the formulation (the supplement) had been pelleted.

[2]Provided (per kilogram of diet) 3,524 IU of vitamin A, 441 IU of vitamin D, 14.1 IU of vitamin E, 1.4 mg of vitamin K (as menadione dimethyprimidinol bisulfite), 15.9 mg of niacin, 8.8 mg of pantothenic acid (as d-calcium pantothenate), 2.6 mg of riboflavin, 12.3 μg of vitamin B_{12}.

[3]Provided (per kilogram of diet) 4.4 mg of copper, 0.1 mg of iodine, 44 mg of iron, 10.6 mg of manganese, 0.1 mg of selenium, 44 mg of zinc.

[4] Provided (per kilogram of diet) 1 mg of folacin

[5] Provided (per kilogram of diet) 9.1 mg/kg of tylosin

Table 4.4 Processing characteristics (Exp. 1)

Item	Complete pellet	Supplement pellet	Ground corn[1]	Cracked corn[1]
Grinding				
Energy, kWh/t	N/A[2]	N/A	7.50	0.99
Production rate, t/h	N/A	N/A	1.00	3.90
Particle Size				
dgw, µm[3]	N/A	N/A	618	3,444
sgw, µm[4]	N/A	N/A	2.16	1.4
Pelleting				
Phase 2				
Energy, kWh/t	15.76	14.33	N/A	N/A
Production rate, t/h	0.68	0.77	N/A	N/A
PDI, %[5]	97	98	N/A	N/A
Phase 3				
Energy, kWh/t	14.66	14.32	N/A	N/A
Production rate, t/h	0.75	0.77	N/A	N/A
PDI,%[5]	87	94	N/A	N/A

[1] Corn was milled using a three-high roller mill (Model K, Roskamp Manufacturing, Cedar Falls, IA).

[2]Not applicable.

[3]Geometric mean particle size (ASAE, 1983).

[4]Log normal standard deviation (ASAE, 1983).

[5]Pellet durability index determined using the ASAE (1987) method.

Table 4.5 Effects of replacing 100% of ground corn in pellets with cracked corn in nursery pig diets (Exp. 1)[1]

Item	Complete mash	Complete pellet	Ground corn + supplement	Cracked corn + supplement	SE	Contrasts[2] 1	2	3
Energy kWh/ton[3]	3.86	19.07	10.91	8.05				
d 0 to 14								
ADG, g	350	330	325	307	11	0.05	0.55	0.35
ADFI, kg	0.46	0.44	0.46	0.45	0.15	0.65	0.28	0.82
G:F, g/kg	753	753	706	680	23	0.15	0.06	0.56
d 14 to 28								
ADG, g	655	629	575	544	19	0.001	0.003	0.15
ADFI, kg	0.87	0.83	0.85	0.86	0.31	0.36	0.28	0.81
G:F, g/kg	752	761	677	632	8	0.001	0.001	0.01
d 0 to 28								
ADG, g	497	472	445	420	11	0.001	0.02	0.11
ADFI, kg	0.66	0.62	0.65	0.65	0.14	0.28	0.10	0.96
G:F, g/kg	753	758	687	647	9	0.001	0.001	0.005
Final BW, kg	20.9	20.2	19.5	18.8	0.3	0.001	0.012	0.11

[1]A total 144 pigs (average initial BW of 7.5 kg) were used in the 28-d growth assay with 6 pigs/pen and 6 pens/treatment.

[2]Contrast were: 1) mash vs treatments with pellets, 2) complete pellets vs pellet supplement with ground or cracked corn, and 3) ground corn plus pellet supplement vs cracked corn + pellet supplement.

[3]Energy (kWh/ton) = (corn % * grinding energy (kWh/ton)) + (supplement % * pelleting energy (kWh/ton)).

Table 4.6 Processing characteristics (Exp. 2)

Item	Complete pellet	Supplement pellet	Ground corn[1]	Cracked corn[2]
Grinding				
Energy, kWh/t	N/A[3]	N/A	7.44	0.90
Production rate, t/h	N/A	N/A	2.09	4.55
Particle Size				
dgw, µm[4]	N/A	N/A	445	2,412
sgw, µm[5]	N/A	N/A	2.63	2.14
Pelleting				
Phase 2				
Energy, kWh/t	6.83	6.07	N/A	N/A
Production rate, t/h	1.41	1.32	N/A	N/A
PDI, %[6]	96.6	96.7	N/A	N/A
Modified PDI, %[7]	95.8	95.8	N/A	N/A
Phase 3				
Energy, kWh/t	11.11	11.29	N/A	N/A
Production rate, t/h	0.91	0.91	N/A	N/A
PDI, %[6]	88.9	90.5	N/A	N/A
Modified PDI, %[7]	82.6	86.1	N/A	N/A

[1]Corn was milled using a hammer mill (Jacobseen P240D) with a screen size of 3.18 mm (“tear-drop” full circle screen).

[2]Corn was milled using a three-high roller mill (Model K, Roskamp Manufacturing, Cedar Falls, IA).

[3]Not applicable.

[4]Geometric mean particle size (ASAE, 1983).

[5]Log normal standard deviation (ASAE, 1983).

[6]Pellet durability index determined using the ASAE (1987) method.

[7]Modified the ASAE (1987) by adding 5 13-mm hexagonal nuts prior to tumbling.

Table 4.7 Effects of replacing 50% of ground corn in pellets with cracked corn in nursery pig diets (Exp. 2)

Item	Complete mash	Complete pellet	Ground corn + pelleted supplement	Cracked corn + pelleted supplement	SE	Contrasts[2] 1	2	3
Energy kWh/ton[3]	4.63	13.56	11.00	8.93				
d 0 to 13								
ADG, g	396	372	397	382	14	0.30	0.16	0.29
ADFI, kg	0.54	0.48	0.55	0.56	0.02	0.63	0.001	0.62
G:F, g/kg	735	770	727	683	19	0.67	0.005	0.08
d 13 to 28								
ADG, g	610	607	566	551	14	0.02	0.005	0.41
ADFI, kg	0.86	0.81	0.91	0.89	0.02	0.12	0.001	0.54
G:F, g/kg	710	753	626	622	12	0.001	0.001	0.76
d 0 to 28								
ADG, g	510	498	487	473	12	0.03	0.12	0.26
ADFI, kg	0.71	0.66	0.74	0.74	0.02	0.96	0.001	0.78
G:F, g/kg	719	759	660	643	12	0.01	0.001	0.25
Final BW, kg	21.8	21.4	21.0	20.7	0.59	0.03	0.14	0.53

[1]A total 224 pigs (average initial BW of 7.5 kg) were used in the 28-d growth assay with 7 pigs/pen and 8 pens/treatment.

[2]Contrast were: 1) mash vs treatments with pellets, 2) complete pellets vs pellet supplement with ground or cracked corn, and 3) ground corn plus pellet supplement vs cracked corn + pellet supplement.

[3]Energy (kWh/ton) = (corn % * grinding energy (kWh/ton)) + (supplement % * pelleting energy (kWh/ton)).

Table 4.8 Effects of replacing ground corn with 10, 20, and 40% cracked corn in finishing pig diets (Exp. 3)[1]

		Cracked corn, %				P value	
Item	Control	10	20	40	SE	Linear	Quadratic
Particle Size							
dgw, µm[2]	684	926	979	1,187			
sgw, µm[3]	2.22	2.53	2.68	2.68			
d 0 to 63							
ADG, g	918	952	935	928	23	0.98	0.43
ADFI, kg	2.6	2.7	2.7	2.7	0.1	0.41	0.46
G:F, g/kg	358	352	350	344	10	0.09	0.83
Carcass characteristics							
HCW, kg	89.2	90.6	89.9	88.0	2.5	0.23	0.17
Dress, %	74.0	73.7	73.7	72.7	0.1	0.05	0.66
Backfat thickness, mm	26.7	26.7	26.9	26.7	1.1	0.93	0.69
FFL,%[4]	50.9	50.9	50.8	50.9	0.1	0.93	0.72

[1]A total of 208 pigs (initial BW of 62.6 kg) were used in a 63-d growth assay.
[2]Geometric mean particle size (ASAE,1983).
[3]Log normal standard deviation (ASAE, 1983).
[4]Fat-free lean as a percentage of HCW calculated using NPPC (2001) equation.

Table 4.9 Effects of replacing ground corn with 10, 20, and 40% cracked corn on stomach morphology in finishing pig (Exp. 3)[1]

		Cracked corn, %				*P* Value	
Item	Control	10	20	40	SE	Linear	Quadratic
Stomach keratinization[2]							
No. observations	47	47	49	50			
Normal	33	35	44	47			
Mild	13	11	4	3			
Moderate	1	1	1	0			
Severe	0	0	0	0			
Mean	1.21	1.18	1.08	1.05	0.04	0.01	0.48
Stomach ulceration[3]							
No. observations	47	47	49	50			
Normal	44	46	48	50			
Erosions	1	0	1	0			
Ulcers	1	1	0	0			
Severe ulcers	3	0	0	0			
Mean	1.22	1.04	1.02	1.00	0.04	0.01	0.05

[1]A total of 208 pigs (initial BW of 62.6 kg) were used in a 63-d growth assay and an average final BW of 121.5kg.

[2]Scoring system was: 1 = normal; 2 = mild; 3 = moderate; 4 = severe.

[3]Scoring system was: 1 = normal; 2 = mild; 3 = moderate; 4 = severe.

Table 4.10 Processing characteristics of grinding or cracking corn and pelleting the complete diet or supplement (Exp. 4)

Item	Complete pellet	Supplement pellet	Ground corn[1]	Cracked corn[2]
Grinding				
Energy, kWh/t	N/A[3]	N/A	7.66	0.83
Production rate, t/h	N/A	N/A	5.44	11.97
dgw, µm[4]	N/A	N/A	493	2,841
sgw, µm[5]	N/A	N/A	2.64	1.97
Pelleting				
Energy, kWh/t	16.84	15.33	N/A	N/A
Production rate, t/h	5.49	5.43	N/A	N/A
PDI, %[6]	89.3	90.4	N/A	N/A
Modified PDI,%[7]	84.9	85.5	N/A	N/A

[1]Corn was milled using a hammer mill (JacobseenP24209 Series 2) with a screen size of 3.18 mm (full circle screen).

[2]Corn was milled using a two-high roller mill (Ferrell Ross 10 × 30, Hereford, TX)

[3]Not applicable.

[4]Geometric mean particle size (ASAE, 1983).

[5] Log normal standard deviation (ASAE, 1983).

[6]Pellet durability index determined using the ASAE (1987) method.

[7]Modified the ASAE (1987) by adding 5 13-mm hexagonal nuts prior to tumbling.

Table 4.11 Electrical consumption and cost for experimental treatments (Exp. 4)

Item	Complete mash	Complete pellet	Ground corn + pelleted supplement	Cracked corn + pelleted supplement
Energy, kWh/t[1]	6.06	22.93	14.66	12.02
Electrical cost, $/ton[2]	0.42	1.61	1.03	0.84
Hammer mill	0.42	0.42	0.42	0.21
Roller mill	0.00	0.00	0.00	0.02
Pellet mill	0.00	1.19	0.61	0.61

[1]Energy (kWh/ton) = (corn % * grinding energy (kWh/ton)) + (supplement % * pelleting energy (kWh/ton)).

[2]Energy cost was based on $0.07/kWh

Table 4.12 Effects of replacing 50% of ground corn in pellets with cracked corn in finishing pig diets (Exp. 4)[1]

Item	Complete mash	Complete pellet	Ground corn + pelleted supplement	Cracked corn + pelleted supplement	SE	Contrast[2] 1	Contrast[2] 2	Contrast[2] 3
d 0 to 80								
ADG, g	1,045	1,107	1,055	1,093	11	0.004	0.03	0.02
ADFI, kg	2.66	2.72	2.76	2.88	0.05	0.02	0.08	0.06
G:F, g/kg	393	408	384	380	6	0.72	0.001	0.64
HCW, kg	92.6	95.6	93.2	94.5	1.1	0.17	0.19	0.41
Dressing, %[3]	74.4	74.0	74.4	73.7	0.1	0.02	0.78	0.001
Backfat thickness, mm[3]	18.65	19.98	19.81	18.87	0.53	0.15	0.33	0.22
Loin depth, mm[3]	68.25	65.93	68.52	67.57	0.73	0.29	0.03	0.36
FFLI, %[3,4]	52.39	51.51	51.64	52.12	0.32	0.10	0.37	0.29

[1]A total 252 pigs (average initial BW of 40.3 kg) were used in the 80-d growth assay.

[2] Contrasts are: 1) mash vs treatments with pellets; 2) complete pellets vs pelleted supplement with ground and cracked corn; and 3) pelleted supplement with ground vs cracked corn.

[3]HCW used as a covariate.

[4]Fat-free lean index, calculated using NPPC (2001) equation, as a percentage of HCW.

Table 4.13 Effects of cracked corn on stomach morphology in finishing pigs (Exp. 4) [1]

Item	Complete mash	Complete pellet	Ground corn + pellet supplement	Cracked corn + pellet supplement	SE	Contrast[2] 1	Contrast[2] 2	Contrast[2] 3
Stomach keratinization[3]								
No. observations	44	41	45	46				
Normal	8	3	3	16				
Mild	11	13	12	14				
Moderate	12	2	10	4				
Severe	13	23	20	12				
Mean	2.67	3.22	3.08	2.25	0.26	0.43	0.02	0.004
Stomach ulceration[4]								
No. observations	44	41	45	46				
Normal	29	16	19	36				
Erosions	8	15	12	6				
Ulcers	6	5	12	2				
Severe ulcers	1	5	2	2				
Mean	1.53	2.05	2.02	1.36	0.12	0.05	0.02	0.001

[1]A total 252 pigs were used in the 80-d growth assay with an average initial BW of 40.3 kg and an average final BW of 126.7 kg.

[2] Contrasts are: 1) mash vs treatments with pellets; 2) complete pellets vs pelleted supplement with ground and cracked corn; and 3) pelleted supplement with ground vs cracked corn.

[3]Scoring system was: 1 = normal; 2 = keratin covering < 25% of the nonglandular mucosa; 3 = keratin covering 25 to 75% of the nonglandular mucosa; 4 = keratin covering > 75% of the nonglandular mucosa.

[4]Scoring system was: 1 = no ulcer; 2 = ulceration present, but affecting < 25% of nonglandular mucosa; 3 = ulceration of 25-75% of the nonglandular mucosa; 4 = ulceration of > 75% of nonglandular mucosa

Chapter 5 - Effects of abrupt changes between mash and pellet diets on growth performance in finishing pigs

Abstract

A total of 200 finishing pigs (average initial BW of 60 kg) were used in a 58-d growth assay to determine the effects of an abrupt change from mash to pellets and pellets to mash on growth performance and carcass measurements. The experiment was designed as a randomized complete block with 5 pigs/pen and 10 pens/treatment. Treatments were mash to mash, mash to pellets, pellets to mash, and pellets to pellets for Phases 1 and 2 of the experiment. For Phase 1 (d 0 to 36), pigs fed the pelleted diet had 4% greater ADG and 8% greater G:F ($P < 0.02$) compared to pigs fed mash. For Phase 2 (d 36 to 58) and overall (d 0 to 58), pigs fed the mash diet had worse ($P < 0.02$) G:F than pigs fed the pelleted treatments. Indeed, pigs fed pellets the entire experiment had ADG and G:F that were 5 and 8% better, respectively, than pigs fed mash the entire experiment. Pigs fed mash during Phase 1 then pellets during Phase 2 had an greater ($P < 0.01$) ADG and G:F for Phase 2 compared to pigs fed pellets then mash. However, the overall effect was for pigs fed pellets for either Phase 1 or 2, but not both, tended to have growth performance intermediate to those fed mash and pellets for the entire experiment. With hot carcass weight used as a covariate, no differences ($P > 0.15$) were observed in dressing percentage, fat thickness, loin depth, or percentage fat free lean index (FFLI). In conclusion, pigs fed pellets tended to have the greatest growth performance, pigs fed mash the worst, and pigs fed pellets for only part of the grow-finish phase fell in between.

Introduction

Corn is a major cereal grain fed to swine in the U.S. The recent price of corn has reached record highs and has pushed swine producers to try and maximize efficiency of gain. Moreover, producers are turning to feed processing technologies to maximize feed utilization. Pelleting swine diets has been shown to improve efficiency of gain by 7 % (Wondra et al., 1995). Adding the necessary infrastructure to allow for pelleting consist of a high initial cost, along with decreasing production rates, and increasing energy usage, which leads to higher feed cost for the producer. However, this extra cost for pelleting pays off more with increasing grain prices.

Feeding pelleted diets has become a common practice in poultry production and is increasing in swine. With this increase in use of pelleted feeds, some feed manufacturing facilities may not be able to meet pelleted feed demands. This could be potential problem with an increase in pork and chicken demands.

Not being able to achieve adequate production rates could be a problem for some feed manufactures and swine producers are looking for ways to cut cost while still achieving optimum efficiencies of gain. Although pelleting may have some concerns, it is a promising route for improving production. However, little data has been produced on the effects of switching from mash to pelleted diets and vice versa and if feeding pellets throughout the entire grower and finisher stage is necessary to achieve benefits from pelleting. Therefore, our objective was to determine the effects of abrupt changes between mash and pellet diets on growth performance in finishing pigs.

Materials and Methods

Kansas State University Institutional Animal Care and Use Committee approved of this experimental protocol.

All feed processing was completed at Key Feeds (Clay Center, Ks). For the mash diets, corn was milled through a hammer mill (Jacobseen P24209 Series 2) with a screen size of 3.18 mm (full circle screen). The ASAE (1983) standard method was used to determine the particle size of ground corn. Tyler sieves, with numbers 6, 8, 10, 14, 20, 28, 35, 48, 65, 100, 150, 200, 270, and a pan, were used for particle size determination. A Ro-Tap® shaker (W. S. Tyler, Mentor, Ohio) was used to sift the 100 g samples for ten minutes. A geometric mean particle size (d_{gw}) and the log normal standard deviation (s_{gw}) were calculated by measuring the amount of ground grain remaining on each screen. The complete pellet and the pelleted supplement were pelleted in a 125 horsepower pellet mill (Century, California Pellet Mill, San Francisco) and the die had 4.8 mm openings. Pellets were analyzed for pellet durability index (PDI; ASAE, 1987) and modified PDI by altering the procedure by adding 5 13-mm hexagonal nuts prior to tumbling.

A total of 200 finishing pigs (TR4 × PIC 1050) with an average initial BW of 60 kg were used in a 58-d growth assay. The pigs were weighed prior to the experiment, blocked by BW, and allotted by sex and ancestry. Pigs were then assigned to pens with concrete slatted flooring that were 2.44 m × 1.53 m. Each pen consisted of a nipple waterer and single-hole self-feeder allowing ad libitum consumption of feed and water. There were a total of 40 pens, with 5 pigs per pen 10 pens per treatment. All diets (Table 5.1) were the same formulation fed in either mash or pellet form. Diets were fed in 2 phases and formulated to 0.88% SID Lys, 0.55% Ca, and 0.21% available P for d 0 to 36, and 0.76% SID Lys, 0.50% Ca and 0.17% available P for d 36 to 58. All other nutrients met or exceeded NRC recommendations (NRC, 1998). Treatments were mash to mash, mash to pellets, pellets to mash, and pellets to pellets for phases 1 and 2 of the experiment. Pigs and feeders were weighed on day 0, 36, and 58 to determine ADG, ADFI, and G:F. On d 58 of the experiment, pigs (average BW of 128 kg) were tattooed and shipped to a commercial abattoir (Farmland Foods, Inc.; Crete, NE) for slaughter the following morning. Measurements were acquired immediately after slaughter for hot carcass weight (HCW), loin depth, and 10^{th} rib fat thickness (SFK Technology A/S model S 82; Herlev, Denmark). Dressing percentage was calculated with HCW as a percentage of preshipping live weights. Carcass fat free lean percentage (FFLI) was calculated with fat free lean index as a percentage of HCW. Fat free lean index was calculated using the equation suggested by the National Pork Producers Council (NPPC, 2001)

Data was analyzed as a randomized complete block design using the MIXED procedure of SAS (v9.1; SAS Inst. Inc., Cary, NC) with initial weight and location as the blocking criterion and pen as the experimental unit. Initial BW was used as a covariate for analyses of growth performance. Orthogonal contrasts were used to separate treatment means with comparisons of: 1) control vs pelleted treatments; 2) treatments pelleted for the entire experiment vs treatments pelleted for either phase 1 or 2 but not both; 3) treatments fed in pelleted form for phase 1 and mash form for phase 2 vs treatments fed in mash form for phase 1 and pelleted form for phase 2. For analyses of carcass measurements, HCW was used as a covariate.

Results and Discussion

For phase 1 and phase 2 the pelleted diets resulted in PDI's of 86 and 87% and modified PDI's of 80 and 77%, respectively. The average mean particle size for corn was 433 μm.

For Phase 1 (d 0 to 36), pigs fed the pelleted diet had 4% greater ADG and 8% greater G:F ($P < 0.02$) compared to pigs fed mash (table 5.2). For Phase 2 (d 36 to 58) and overall (d 0 to 58), pigs fed the mash diet had worse ($P < 0.02$) G:F than pigs fed the pelleted treatments. Pigs fed mash during Phase 1 then pellets during Phase 2 had an greater ($P < 0.01$) ADG and G:F for Phase 2 compared to pigs fed pellets then mash. Previous research has reported that pelleting swine diets has improved ADG and G:F (Baird, 1973; Chamberlain el al., 1967; Hank et al., 1972; Wondra et al., 1995). However, there has been research that did not demonstrate a significant improvement in rate of gain when pelleting swine diets, but these results did show an improvement in efficiency of gain (Jensen and Becker, 1965; NCR-42 Committee on Swine Nutrition, 1969; Skoch et al., 1983). The overall effect for pigs fed pellets for either Phase 1 or 2, but not both, tended to have growth performance intermediate ($P < 0.09$) to those fed mash and pellets for the entire experiment. Indeed, pigs fed pellets the entire experiment had ADG and G:F that were 5 and 8% better, respectively, than pigs fed mash the entire experiment.

There was a tendency for pigs fed the mash diet for the entire experiment to have a decreased ($P < 0.15$) final BW and HCW compared to those fed treatments that were pelleted for the entire experiment and for either phase 1 or 2 but not both. Pigs fed the diets pelleted for the entire experiment resulted in a numerically heavier ($P < 0.07$) final BW compared to those fed pelleted diets for either phase 1 or phase 2, but not both. With hot carcass weight used as a covariate, no differences ($P > 0.15$) were observed in dressing percentage, fat thickness, loin depth or percentage fat free lean index (FFLI). This is in agreement with previous research, which reported no significant differences in carcass characteristics due to diet form (Baird, 1973; Meade et al., 1966; Wondra et al., 1995).

In conclusion, pigs fed pellets tended to have the greatest growth performance, pigs fed mash the worst, and pigs fed pellets for only part of the grow-finish phase fell in between.

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Table 5.1 Composition of diets fed to finishing pigs (as-fed basis)

Item,%	Phase 1[1]	Phase 2[2]
Corn	79.25	84.70
Soybean meal (47.5% CP)	17.15	11.90
Choice white grease	1.00	1.00
L-Lysine HCl	0.34	0.35
DL-Methionine	0.070	0.048
L-Threonine	0.117	0.110
L-Tryptophan	0.023	0.037
Monocalcium Phosphate	0.72	0.54
Limestone	0.91	0.89
Salt	0.25	0.25
Vitamin premix[3]	0.08	0.08
Mineral premix[4]	0.04	0.04
Folic acid[5]	0.001	0.001
Antibiotic[6]	0.05	0.05
Calculated Analysis,%		
SID lysine	0.88	0.76
Ca	0.55	0.50
P	0.49	0.43
Available P	0.21	0.17

[1]Diets fed in meal or pelleted form from d 0 to 36.

[2]Diets fed in meal or pelleted form from d 36 to 58.

[3]Supplied (per kilogram of complete diet) 1,764 IU vitamin A, 265 IU vitamin D_3, 7.05 IU vitamin E, 0.71 mg vitamin K (as menadione nicotinamide bisulfite), 6.2 µg vitamin B_{12}, 7.9 mg niacin, 4.4 mg pantothenic acid (as calcium pantothenate), and 1.32 mg riboflavin.

[4]Provided (per kg of complete diet) 39.7 mg Mn from manganese oxide, 165 mg Fe from iron sulfate, 165 mg Zn from zinc oxide, 16.5 mg Cu from copper sulfate, 0.298 mg I from calcium iodate, and 0.298 mg Se from sodium selenite.

[5]Provided 1 mg/kg of complete feed.

[6]Provided 44g/ton tylosin.

Table 5.2 Effects of abrupt change between mash and pellet diets on growth performance in finishing pigs

Item	Mash to mash	Mash to pellet	Pellet to mash	Pellet to pellets	SE	Probability, *P* <		
						1	2	3
d 0 to 36								
ADG, g	1,124	N/A	N/A	1,167	23			
ADFI, kg	2.87	N/A	N/A	2.76	0.07			
G:F, g/kg	393	N/A	N/A	423	4			
d 36 to 58								
ADG, g	1,163	1,230	1,117	1,240	25	0.21	0.02	0.002
ADFI, kg	3.54	3.45	3.41	3.51	0.08	0.29	0.30	0.66
G:F, g/kg	330	358	327	354	6	0.01	0.11	0.001
d 0 to 58								
ADG, g	1,134	1,168	1,148	1,195	22	0.06	0.08	0.39
ADFI, kg	3.13	3.09	3.00	3.05	0.07	0.16	0.91	0.25
G:F, g/kg	363	381	382	392	5	0.001	0.08	0.84
Final BW, kg	126.4	127.9	126.8	129.5	1.2	0.12	0.07	0.38
HCW, kg	94.1	95.3	95.0	95.9	1.7	0.15	0.41	0.78
Dressing, %[3]	74.6	74.3	74.3	74.4	0.3	0.43	0.61	0.97
Backfat thickness, mm[3]	19.0	19.7	19.6	19.6	0.9	0.34	0.91	0.90
Loin depth, mm[3]	66.7	67.3	68.2	67.4	0.8	0.34	0.74	0.42
FFLI, %[3,4]	52.0	51.7	51.7	51.7	0.5	0.47	0.93	0.93

[1]A total of 200 pigs (average initial BW of 60 kg) were used in 58 d growth assay

[2]Contrast statements: 1) mash vs others, 2) Pellets for entire experiment vs pellets fed for only part of experiment, 3) Mash to pellet vs pellet to mash

[3]HCW used as a covariate.

[4]Fat-free lean index, calculated using NPPC (2001) equation, as a percentage of HCW.