EFFECTS OF MIX UNIFORMITY IN DIETS WITH HIGH INCLUSION OF ALTERNATIVE INGREDIENTS ON GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS IN SWINE AND POULTRY

by

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Abstract

Three finishing pig and one broiler chick experiment were completed to determine the effect of diet formulation, mix time, and diet form on growth performance and carcass measurements. In Exp. 1, finishing pigs fed corn-soy diets had greater ADG, HCW, DP, and BF ($P < 0.05$) compared to pigs fed diets with 30% DDGS and 10% wheat middlings. However, increasing mix time from 60 to 420 s did not affect growth performance or carcass measurements ($P > 0.38$). In Exp. 2, pigs were fed diets with 32% DDGS and 32% wheat middlings and were mix for 0, 15, 30, 60, or 420 s. There were no differences in growth performance or carcass measurements as mix time was increased from 0 to 420 s ($P > 0.06$). In Exp. 3, pigs were fed 32% DDGS and 32% wheat middlings in meal and pelleted diets that were mixed for 0 or 180 s. Pelleting diets increased ADG and improved G/F ($P > 0.01$). Increasing mix time had no effect on ADG or G/F ($P > 0.16$) as mix time was increased from 0 to 180 s. There were no differences in carcass measurements because of diet form or mix time. In the final experiment (Exp. 4), broiler chicks were fed a corn-soy diet or a diet with 20% DDGS and 20% wheat middlings and mixed for 0, 15, 30, 60, and 300 s. Broiler chicks fed the corn-soy diet had greater G/F ($P < 0.01$) but increasing mix time from 0 to 300 s did not affect growth performance or carcass characteristics ($P > 0.13$). Increased mix time in diets with high levels of alternative ingredients does not affect growth performance or carcass measurements when fed to finishing pigs or broiler chicks.

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Dedication

This is dedicated to my parents, Scott and Kim Morts. Without their love and support for all these years I would not be where I am today. You two mean the world to me. I love you!

Chapter 1 - Literature Review

Introduction

Because feed costs represent 70% of the cost for production (Feedstuffs Reference Issue, 2000), pig and chicken producers are continually seeking ways to reduce its impact. However, reducing feed costs, if not managed properly, can negatively affect feed intake, growth performance, and carcass value and lower producer profit. There are ways to reduce the cost of feed without negatively impacting animal performance and profitability. Such strategies include use of cheaper ingredients and optimized feed manufacturing technologies (e.g., pelleting). There may even be ways to improve production and reduce cost with a slightly more expensive diet if performance of the animal is improved. Pelleting may be an option to help improve animal performance and profitability that carries a slight increase in diet cost. It is important for a producer to understand how each option can be implemented and managed to lower costs without having a negative impact on animal performance.

Use of Alternative Ingredients

One strategy used to help reduce the overall diet cost is to include lower priced ingredients that replace traditional ingredients such as corn and soybean meal. This cost management strategy has become more popular as alternative ingredients have become more readily available. A cost dilution strategy may also be effective. While adding a less expensive ingredient to replace a portion, rather than all of a more expensive ingredient may not reduce the cost of 1 ton of feed by as many dollars, when multiplied over a large number of tons the reduction in cost will save money over an extended period of time. As stated in a review by Woyengo et al. (2014), commonly used alternative ingredients include other cereal grains (triticale and sorghum), oilseeds, oilseed coproducts, and pulses (field pea, lentil, and faba bean). Two of the more common alternative ingredients in the United States are dried distillers grains with solubles and wheat middlings. The goal is to include alternative ingredients in animal feeds without negatively affecting growth performance, carcass value, animal health, and reproductive performance in hope of increased profitability.

Dried Distillers Grains with Solubles

Dried distillers grain with solubles (DDGS) have become available in greater volume as the ethanol industry has dramatically increased production. These DDGS result when ethyl alcohol or "ethanol" is fermented from grain and then distilled (AAFCO, 2015). A variety of different grains can be used for production of ethanol, but corn-based DDGS are most frequently available for use in animal feeds. The DDGS generally replace corn, so it is important to know how the nutritional values of both compare to each another. Gross energy (GE) and digestible energy (DE) are both higher in DDGS than in corn (4,710 vs 3,933 kcal/kg and 3,582 vs 3,451 kcal/kg; NRC, 2012). Metabolizable energy (ME) in corn and DDGS are equal (3,396 and 3,395 kcal/kg) but corn has higher net energy (NE) compared to DDGS (2,672 vs 2,343 kcal/kg). Crude protein (CP) and crude fiber (CF) are both approximately three times greater in DDGS vs corn.

There are performance concerns when feeding diets with elevated levels of DDGS. Even though DDGS are a good source of protein, the ingredient itself may not be as digestible as corn. Also the nutritional value of DDGS can vary depending on the source. Cromwell et al. (1993) reported that darker colored sources of DDGS were of lower nutritional value because of overheating during drying. Traditionally, DDGS contain 8% to 10% crude fat and can lead to increased unsaturated fatty acid content in pig meat. Increase in unsaturated fatty acids leads to soft carcass fat, which causes handling problems during processing and later during retail. These problems include difficult fabrication and slicing of bellies for bacon, oily appearance in the retail package, reduced shelf life, and increased chance for oxidative damage (Wood and Enser, 1997; National Pork Producers Council, 2000).

The effects of DDGS inclusion in diets fed to nursery pigs has been studied extensively. In 3 experiments, Senne (1997) examined the effects of DDGS in nursery pig diets. In Exp. 1, pigs were fed diets with either 0, 10, or 20% DDGS. There were no differences in ADG, ADFI, or G/F with 20% DDGS inclusion ($P > 0.05$). For Exp. 2 and 3, DDGS were included at 0, 15, 30, 45, or 60%. In Exp. 2, ADG was maximized at 15% before decreasing at 30% ($P < 0.01$). Average daily feed intake decreased linearly as inclusion increased from 0 to 60% ($P < 0.01$). Gain/feed increased as DDGS inclusion was increased from 0 to 45% before decreasing at 60% ($P < 0.03$). Similar to Exp. 2, pigs in Exp. 3 showed maximum gain at 15% DDGS inclusion ($P < 0.01$). Average daily feed intake increased until inclusion reached 45% ($P < 0.01$). Increasing inclusion from 0 to 60% reduced G/F linearly ($P < 0.01$). Whitney and Shurson (2004) conducted two experiments that had 0, 5, 10, 15, 20, or 25% DDGS included in the diets. These pigs were fed a common diet for 4 d post-weaning followed by Phase 2 (10 d) and Phase 3 (21 d). The authors found no differences in pig performance during the experimental period. The inclusion of 10% (Lineen et al., 2006) or 22.5% to 30% (Gains et al., 2006; Spencer et al., 2007; Barbosa et al., 2008) DDGS had no effect on ADG. However, ADFI was reduced in the Gains et al. (2006) and Barbosa et al. (2008) studies while G/F was improved. To evaluate the introduction of DDGS in nursery diets at different phases Spencer et al. (2007) conducted a study where DDGS were included in the diets at 7.5% for Phase 1, 15% for Phase 2, and 15% for Phase 3. A control diet, without DDGS, was also fed during all three phases. At the conclusion of the study there were no differences in pig performance and it was suggested that DDGS can be included in the diet as soon as the pigs are weaned. However, Burkey et al. (2008) found that nursery pig performance was negatively affected if DDGS were fed before day 21 of the nursery phase.

Cromwell et al. (1993) conducted an experiment to evaluate the effects of DDGS on growth performance in growing-finishing pigs. There were six dietary treatments. The first three were corn-corn starch-dextrose-based with soybean meal was added to replace portions of the cornstarch and dextrose. In these diets, the amount of soybean meal was increased to achieve crude protein (CP) levels of 8.6, 11.3, and 14 %. The remaining three treatments had 20% DDGS and were formulated to 14% CP. The DDGS treatments represented a “best source”, “average source”, and “poor source”. Increasing the amount of soybean meal improved ADG and G/F (linear effect, $P < 0.01$). There were no differences among pigs fed the best and average DDGS with those fed the poor source of DDGS having reduced ADG and increased G/F. Comparing the best DDGS source with the corn soybean meal diet with 14% CP, ADG was reduced from 599 g to 390 g and G/F was reduced from 0.38 to 0.28 when 20% DDGS were included in the diet.

Senne (1997) conducted two finishing experiments with varying inclusion levels of DDGS. In Exp.1, DDGS were included at 10, 20, or 30%, with no effect on ADG, ADFI, or G/F ($P > 0.13$). For Exp. 2, DDGS were included at 20, 40, or 60% and ADG was unaffected by increased inclusion level ($P > 0.11$). However, ADFI decreased linearly as DDGS was increased from 0 to 60% ($P < 0.01$). The reduction in ADFI resulted in a linear improvement in G/F as DDGS inclusion level was increased ($P < 0.01$). In a different experiment, conducted by Whitney et al. (2006), diets with DDGS inclusions of 0, 10, 20, or 30% were fed to growing/finishing pigs. ADG was reduced from 862 g to 808 g ($P < 0.05$) when DDGS were included at 20% and 30%. Final body weight, hot carcass weight, and dressing percentage were also reduced ($P < 0.05$) with inclusion of 20% and 30% DDGS. Gain to feed was negatively affected when DDGS were included at 30% and pigs had lower scores for belly firmness ($P < 0.05$), indicating that the belly was softer compared to those fed a diet with no DDGS.

Three experiments were conducted in a commercial setting to determine the effects of increased amounts of DDGS in the diet when fed to finishing pigs (Linneen et al., 2008). In the first experiment diets with no DDGS or 15% DDGS with 0, 3, or 6% added fat resulted in no differences in ADG, ADFI, or G/F ($P > 0.59$) when DDGS were included in the diet at 15%. There were also no DDGS by fat interactions ($P > 0.13$) in the experiment. For the second experiment diets had 0, 10, 20, or 30% DDGS with 6% added fat in each diet, wherein ADG tended ($P = 0.09$) to decrease as DDGS were included in the diet at 20 and 30%. Average daily feed intake ($P < 0.05$) was decreased from 1,946 g/d to 1,900 g/d when DDGS were included in the diet at 20 and 30%. The final experimental diets had 0, 5, 10, 15, or 20% DDGS with 6% added fat in each diet. Average daily gain and ADFI decreased linearly ($P < 0.05$) as the inclusions of DDGS were increased in the diet. There were also linear decreases in hot carcass weight and dressing percent (P < 0.05). Backfat thickness tended to decrease as inclusion rate was increased (P = 0.07). Feoli (2008) fed finishing pigs diets with either 0 or 40% DDGS and examined the effects of DDGS on growth performance, carcass measurements, and nutrient digestibility. Average daily gain decreased when DDGS were included in the diet at 40% (P < 0.01). However, there were no differences in ADFI or G/F (P > 0.12). As for carcass measurements, HCW, dressing percent, and loin depth were all lower with the inclusion of 40% DDGS (P < 0.06) with no differences (P > 0.15) for FFLI and BF among pigs fed the dietary treatments. Digestibility of DM, N, and GE were all lower for pigs fed DDGS containing diets (P < 0.03).

In a study reported by Xu et al. (2010), pigs were fed 0, 10, 20, or 30% DDGS and growth performance, carcass composition, and pork fat quality were measured. There were no differences in final body weight or ADG (P > 0.65) as inclusion was increased to 30%. There was a reduction in ADFI (P < 0.01) and G/F improved as DDGS were included in the diet at 20% (P < 0.01). Slaughter weight, hot carcass weight, last rib backfat depth, and fat-free lean index were not affected by inclusion of DDGS (P > 0.10). However, dressing percentage decreased as inclusion was increased (P < 0.001). Pork quality characteristics were also measured in this experiment and marbling and firmness decreased when DDGS were included at 20 and 30% (P < 0.04). Drip loss was not affected by inclusion of DDGS. In 2012, Sayler et al. determined the effects on growth performance, carcass characteristics, and fat quality in finishing pigs fed diets with no DDGS or wheat middlings, diets with 30% DDGS, and diets with either 10 or 20% wheat middlings. In this study, ADG, ADFI, and G/F were not affected as DDGS were included in the diet at 30% (P > 0.10). Carcass yield decreased slightly from 74.2% to 73.4% and BF was reduced from 24.8 mm to 22.9 mm when DDGS were included at 30% (P < 0.04). However, FFLI and jowl iodine value were increased with the inclusion of DDGS (P < 0.03).

Dried distillers grains with solubles are also fed in poultry diets. Waldroup et al. (1981) conducted two experiments to examine the potential to use high levels of DDGS in broiler diets. In the first experiment, energy level was held constant as DDGS were included in the diet and in the second experiment energy was allowed to fluctuate with DDGS inclusion. When energy was held constant there were no differences in final body weight or feed efficiency. But when energy was allowed to change, final BW and feed efficiency were negatively affected at 15% inlclusion of DDGS. Parsons et al. (1983) conducted a study to evaluate DDGS as a protein source in broiler chicks. They concluded that in a standard corn-soybean meal diet up to 20% of the soybean meal could be replaced by DDGS. But, if lysine is supplemented in the diet, the replacement of soybean meal could be doubled to 40%. Cromwell et al. (1993) conducted two broiler chick experiments to determine the effects of DDGS source and inclusion rate on growth performance. In Exp. 1, there were 12 dietary treatments, three of which were corn-soybean meal diets with varying levels of soybean meal. These diets had CP levels of 13.6, 16.5, and 19%. The remaining nine diets had 20% DDGS of different sources and were formulated to approximately 19% CP. The DDGS sources were classified as normal, smoky, slightly burnt, and burnt. Weight gain and F/G both improved when soybean meal was increased in the diet ($P < 0.01$), to 19% CP. Of the DDGS cources, the normal DDGS source ($P < 0.01$) supported the highest weight gain and G/F. In Exp. 2, four experimental diets had increasing amounts of soybean meal (CP levels of 12, 14.7, 17.4, and 20% and six diets had 10, 20, and 30% DDGS. The DDGS were blended from three sources to have superior and inferior nutritional value. Chicks had increased ADG and G/F with increasing levels of soybean meal and DDGS ($P < 0.01$). However, the improvements were more substantial for the soybean meal diet. Growth performance for chicks fed the inferior DDGS source improved with increased levels of DDGS, but to a lesser degree than those fed the superior DDGS source.

Lumpkins et al. (2004) fed broilers diets with 0 or 15% DDGS and found no differences in weight gain or G/F with 15% DDGS ($P > 0.30$). In a second experiment, DDGS were included at 0, 6, 12, and 18% of the diet and found that weight gain was lower ($P < 0.05$) at 18% DDGS. There were no differences in G/F, carcass weight, breast weight, or wing weight. The authors suggested a limit of 6% DDGS for a starter diet and 12 to 15% in the grower/finisher diets without adverse effects. Wang et al. (2007) performed a similar study with inclusion of 0, 5, 10, 15, 20, and 25% DDGS and found no differences in final BW, G/F, or ADFI ($P < 0.05$) at 20%. Gain to feed decreased from 0.56 to 0.54 as DDGS increased in the diet to 25% ($P < 0.05$), but ADFI, dressing percentage, breast weight, and wing weight decreased ($P < 0.05$). The heaviest wing weights were recorded with 15% inclusion of DDGS. Because of this, it was suggested by the authors that inclusion of DDGS be limited to 15 to 20% to avoid adverse effects on broiler performance. Shim et al. (2011) reported no differences in body weight gain, feed consumed, or feed conversion during a 42-d experiment in which diets had 0, 8, 16, and 24% DDGS. In the starter phase of their experiment in which DDGS were included, body weight gain improved from 688 g to 723 g. The chicks had the most body weight gain when the diet had 16% DDGS. Carcass measurements did not differ for weights, fat pad, breast meat, legs, or wings ($P > 0.23$). In Exp. 2, body weight gain was improved when DDGS were included in the diet at 8% or more ($P < 0.05$). Feed consumption was not affected during the experiment. Based on the data from both experiments, DDGS could be included in the diet at 24% without negative effects on performance.

From the literature it appears that DDGS can be included in grower-finisher diets up to 20% without showing negative effects on growth performance or carcass characteristics. However, the literature is less clear as to maximum levels nursery pigs. Burkey et al. (2008) stated that there were negative effects anytime DDGS were included in the diet before d 21. Whitney and Shurson (2004) found that adding DDGS at 25% did not negatively affect nursery pig performnace. Several experiments for broiler chicks suggest there is no consensus as to what inclusion rate of DDGS will affect broiler performance. Some experiments suggest improved performance when DDGS were added to the diet while others showed negative effects. Similar to pigs, there are different inclusion levels that are suggested to be effective in poultry throughout the literature. For starter diets the range from 6% to 24% often is suggested with a broader range for grow/finish: the low being 12% and the high being 24%.

Wheat Co-Products

Wheat is commonly used in Canada more than in the United States (Swine Nutrition, 2000). Wheat has slightly lower gross energy (GE), metabolizable energy (ME), digestible energy (DE), and net energy (NE) than corn, but the CP and crude fiber content are almost double that of corn (NRC, 2012). In a study conducted by Lennon et al. (1972), 36 pigs were fed corn, barley, wheat, and corn-wheat diets. When the wheat-based diet was fed there were no differences in ADG or ADFI, but G/F was less ($P < 0.05$) compared to other treatments. To determine the effect of feeding wheat or corn to young pigs, Rodriguez and Young (1981) conducted a study with weanling pigs fed whey-, wheat-, or corn-based diet in a two phase program. In phase 1, the pigs fed corn and wheat had greater ADG than those fed the diet with whey. However, those fed the corn diet had the greatest ADG. In phase 2, the pigs fed diets with whey had greater ADG than those fed the corn and wheat diets.

Not only can growth performance be affected in pigs fed wheat, but digestibility of wheat based diets can also be changed. The changes in digestibility could cause differences in growth performance. Lin et al. (1987) reported that the apparent total tract digestibilities of amino acids, gross energy, and starch varied by grain sources; wherein dry matter and GE digestibilites were reduced by 3% when pigs were fed diets with wheat compared to corn. Likewise ME decreased from 3.83 kcal/g to 3.65 kcal/g when pigs were fed wheat and total tract digestibility most amino acids also was reduced.

Wheat bran is the coarse outer covering of the wheat kernel that is separated from cleaned and scoured wheat during the commercial milling process (AAFCO, 2015). Based on the 2012 NRC wheat bran is much lower in ME, DE, and NE than wheat. However, the GE in wheat bran is higher than that of wheat and the CP content is 0.5% units higher. The crude fiber content of wheat bran is 7.8% while in wheat it is 2.6%. The lower energy content and the increased amount of fiber can have a negative effect on performance when fed to animals. Therefore animals may need to consume more feed to meet their energy needs when fed bran containing diets compared to a wheat or corn-based diet. To illustrate, Matte et al. (1994) used 99 gilts to determine the effect of diet bulkiness on reproductive performance. In this trial, the gilts were fed diets of corn and soybean meal, wheat bran and corn cobs, or oat hulls and oats. During the first parity sows fed the wheat bran diet had similar BW compared to those fed the corn-soybean meal diet. But, by the second parity sows fed the wheat bran diet were heavier than sows fed the corn-soybean meal-based diet ($P < 0.05$). Sows fed the corn-soybean meal diet and wheat bran-corn cob diet had greater backfat than sows fed the diet with oat hulls ($P < 0.05$). There was no difference in feed intake during lactation for sows fed the diet with wheat bran and cobbs compared to corn and soybean meal. In parity 2, mean birth weight was higher when fed the wheat bran and corn cob diet. Piglets from the wheat bran fed sows also were approximately 20% heavier at weaning than piglets from the other two treatments.

Wheat shorts consist of fine particles of wheat bran, wheat germ, wheat flour, and offal from the "tail end of the mill" and are obtained through the commercial flour-milling process (AAFCO, 2015). The GE value for wheat shorts is much higher than that of wheat (4,505 vs 4,010 kcal/kg). Wheat shorts are also higher in ME, DE, and NE compared to wheat bran but still lower than the values for wheat (NRC, 2012). Wheat shorts have slightly more CP compared to wheat and wheat bran. Young and King (1981) reported a range of 12.8 to 14.9% for fiber content in wheat shorts. Patience et al. (1977a) conducted an experiment to determine the effects of increasing levels of wheat shorts in a corn-soy diet for growing and finishing pigs. As wheat shorts in the diet increased from 0 to 96.6% of the diet, ADG was not affected. However, the author reported significant differences for G/F and dressing percentage ($P < 0.05$) wherein G/F decreased from 0.30 to 0.25 and dressing percentage decreased form 80% to 75%. A separate study was completed to determine the limiting amino acids in wheat shorts and the authors found that when either lysine or threonine was added to the diet there were no differences in ADG or G/F. But, when both were added to the diet simultaneously there was an improvement in ADG and G/F ($P < 0.05$).

Although wheat bran and wheat shorts can be used in livestock diets the most commonly used by-product from commercial wheat milling is wheat middlings (midds). These are fine particles of wheat bran, wheat shorts, wheat germ, wheat flour, and some of the offal from the “tail end of the mill” (AAFCO, 2015). They are obtained when the grain is placed in roller mills to remove the bran and grind the endosperm. The end product is wheat flour with wheat bran, wheat shorts, and wheat middlings as co-products. The Association of American Feed Control Officials state that crude fiber content of wheat middlings must be 9.5% or less. Like any alternative ingredient, there are pros and cons to feeding these products. The gross energy and CP in wheat middlings is higher than that of wheat (5.2% vs 2.6% respectively; NRC 2012). Wheat middlings have lower DE, ME, and NE than wheat. Since wheat middlings are commonly used to replace corn, it is important to compare the nutritional values of the two. According to the 2012 NRC, wheat middlings provide less DE, ME, and NE than corn. Because of the lower energy content there is potential for animals to consume more feed to meet their energy requirements at the same production level. As for the comparison in protein content, wheat middlings contain 15.8% while corn only contains 8.2%. The crude fiber content in corn is much less than what is provided by wheat middlings (2.0% vs 5.2%). The increased fiber in the diet may also reduce overall nutrient digestibility.

Pals and Ewan (1978) fed 28-d old pigs to determine the energy value of wheat middlings. Pigs were fed diets with 0, 1, or 2% wheat middlings based on body weight. Average daily gain increased from 126 g to 238 g as wheat middlings were included in the diet at 2% of BW ($P < 0.01$). Feed efficiency was not affected, but digestibility of DM decreased form 86% to 75% and N digestibility decreased from 90% to 82% ($P < 0.01$). Digestible energy, ME, and NE all decreased when wheat middlings were added to the diet (P < 0.05). Shaw et al. (2002) found that adding 15% wheat middlings into nursery diets led to no differences in ADG, ADFI, or G/F (P > 0.15). De Jong et al. (2012a) fed nursery pigs diets with 0, 5, 10, 15, or 20% wheat middlings over a 35-d period and reported that as inclusion rate increased in the diet to 20%, ADG and ADFI were not affected (P > 0.10) but G/F decreased (P < 0.01). In a second experiment (De Jong et al., 2012b), fed nursery pigs similar diets and as wheat middlings were increased in the diet from 0 to 20%, ADG was decreased from 576 g to 549 g, average daily feed intake decreased from 943 g to 894 g and G/F was not affected.

The performance depression with high levels of wheat midds in nursery diets may carry into growing and finishing pigs.. Erikson et al. (1985) performed two studies to evaluate the effects of inclusion rates of wheat middlings in growing and finishing pigs. In the first study, pigs were fed diets with 0, 10, 20, or 30% wheat middlings. In both the grower and the finisher phases ADG was not affected but ADFI increased (P < 0.01). Gain to feed was not affected during the growing phase, but during the finishing phase G/F suffered as it decreased from 338 to 292 g/kg (P < 0.01). In a second study, wheat middling inclusion rates were doubled to 0, 20, 40, and 60%. Unlike the first study, there were no differences in ADFI. However, in both the growing and finishing phases ADG and G/F were reduced (P < 0.01) as inclusion rate of wheat middlings was increased. Carcass yield was increased in the second experiment from 73% to 74% as wheat middlings were increased in the diet from 0 to 60% (P < 0.01). These results differ from data reported by Shaw et al. (2002) in which ADG was only impacted during the grower phase and ADFI and G/F were not affected in either phase as wheat middlings were added at 30% of the diet. Once the finishing pigs were harvested no differences were reported for back fat or loin eye area. There was a trend for a decreased dressing percentage (P = 0.10). In 2012, Sayler et al. conducted an experiment to determine the effects of adding wheat middlings and DDGS to finishing pig diets on growth performace, carcass characteristics, and fat quality. The dietary treatments were a control diet, a diet with 30% DDGS and diets with either 10 or 20% wheat middlings. Rate of gain was reduced as wheat middlings were added to the diet (P < 0.02). Gain to feed was also reduced as wheat middlings were included in the diet as were carcass yield, HCW, and loin depth were reduced with wheat middling inclusion (P < 0.06).

Like DDGS it appears there is no clear affect with use of wheat middlings in diets fed to young, growing, and finishing pigs. Results range from improvement in performance when wheat middlings are added to lowered ADG and G/F.

Mixing

There are several steps in the production of animal feed. Ingredient procurement, particle size reduction, weighing, and packaging are just a few of the important steps throughout the production process. A critical step is the mixing of ingredients to obtain a uniform diet and ensure that animals can meet their daily nutrient requirements through the feed they consume. To achieve this goal it's important to understand what may impact mixing and methods that can be used to evaluate whether the mixer is functioning properly and if these affect animal performance.

There are different factors that contribute to how well ingredients blend inside a mixer. Particle shape, size, and density are factors that contribute to mixing of ingredients (Axe, 1995). Particles that are similar in size are less likely to segregate as feed is moved throughout a feed mill. Different densities among ingredients lead to segregation as denser particles settle when feed is moved. Static charge, hygroscopicity, and adhesiveness may also affect mix uniformity (Axe, 1995). Some particles adhere to equipment which causes them to separate from the other ingredients. Some ingredients, such as vitamin premixes, may absorb water (hygroscopicity), while ingredients like fat and molasses stick to equipment. When there is build-up of material to the mixer it may not mix ingredients as well as it would if the equipment was clean.

Cereal grains and other coarse ingredients that are in pellet form are often ground to a specific particle size via a hammer mill or roller mill before being put into the mixer. Reducing particle size helps keep ingredients from segregating as they are mixed and moved throughout the mill. Ingredients are then weighed and added to the mixer. Ingredients with the highest inclusion level are added to the mixer first while low inclusion ingredients are added at the end. This ensures that minor ingredients have a better chance of getting thoroughly mixed with the bulk ingredients during the mixing process (Fairfield et al., 2005). Mixing times depend on the type of mixer that is being used and whether it is a dry or a wet mixture. The primary mixer types that are commonly used are paddle mixers and ribbon mixers. A paddle mixer takes approximately 3 minutes to mix a diet. If it is a twin-shaft paddle mixer the time is reduced to 1 minute or less. A ribbon mixer takes 1 to 2 minutes for a dry mixture and 2 to 3 minutes for a wet mixture. If the mixer is a twin shaft ribbon mixer it takes 45 s 1 minute for a dry mix and 2 minutes for a wet mix. Drum mixers takes much longer to mix a diet and are not used commonly in the commercial feed industry. There are mixers, such as the "Forberg", than can mix a diet within 15 to 30 seconds and achieve a mix that is uniform.

It is a strongly held belief that a diet must be uniformly mixed to maximize animal performance (Benke,1996). It has long been assumed that a diet is uniformly mixed when the CV (coefficient of variation) for distribution of a key nutrient or marker is less than 10% (Beumer, 1991; Lindley, 1991; Wicker and Poole, 1991). There are several assays, such as the distribution of salt, chromic oxide, and dyed iron particles, used to determine how efficiently a mixer is operating. It is important to choose the right indicator and/or marker when conducting a mixer uniformity tests. Criteria to keep in mind are: 1) the marker should be specific to one ingredient; 2) the assay should be accurate and precise regarding the markers inclusion level; and 3) the assay should not be cost prohibitive (Feed Manufactruing Technology V, 2005). It is also important that the marker comes from only one ingredient within the diet. If the marker is found in two or more ingredients, the assay will be confounded and will not determine the actual uniformity of a batch of feed. Keep in mind that marker assays provide different CVs with samples from the same batch of feed. This was apparent in the study by McCoy et al. (1994) where four markers were used to determine mix uniformity within the same batch of feed. In their experiment, the mixer was allowed to turn for 20, 40, or 80 revolutions. At 20 revolutions the CVs varied from 43% with salt to 50% with red iron particles and at 80 revolutions, the range was 13.1% with salt to as high as 17.1% with the red iron particles.

A commonly used, quick, and cost effective mixer assay is the Quantab assay. This assay measures Cl- from salt. It is typical to use 10 samples from a single batch of feed to determine the diet CV. This assay requires Quantab indicator strips, boiling or hot water, filter paper, and glass beakers. To complete this assay, 10 g of sample and 90 mL of boiling distilled water are mixed for 30 s, allowed to sit for 1 minute, and then mixed again for 30 s. The filter paper is folded into a closed funnel and placed in the container to keep the Quantab strip from clogging. Once the water has reached the top of the strip, the indicator will turn black indicating the assay is complete. The number on the strip corresponds with percentage NaC. Each container is specific for the strips that are inside, which means it is important not to use other container readings. Once the readings are obtained the standard deviation and mean are calculated. Using the standard deviation and mean the CV for the batch of feed can be determined.

In addition to Quantab for salt analysis, atomic absorption can be used to determine distribution of chromic oxide in a mixed diet. Approximately 1 g of samples is weighed into a crucible then put in an oven for 24 hours at 100°C. Samples are placed in a desiccator to cool for 1 hour before being weight to calculate DM content. After DM determination, the sample is placed into an ash oven for 6 hours at 600°C, cooled, and weighed. Two solutions (phosphoric acid-manganese sulfate and potassium bromate) are added to the sample and placed on a hot plate to digest. Once the sample has cooled CaCl is added to the mixture. The sample is diluted with distilled water and Cr concentration is determined with an atomic absorption spectrophotometer.

Dyed iron particles can be used to determine mix uniformity. To complete this assay samples are weighed and poured onto a spinning magnetic disk that is covered in filter paper. The filter paper, once it is removed from the magnet, is wetted with 70% ethanol and allowed to dry on a hot plate. As it dries, red or blue dye will dissolve and form dots on the filter paper. These dots are counted and used to determine particle counts within the sample and calculate CV. Assays for drugs, vitamins, crystalline amino acids, and other minerals are sometimes used, however, these assays may be cost prohibitive (Hancock and Behnke, 2001).

The effects of variation in mix uniformity on animal performance were evaluated in nursery and finishing pigs by Traylor et al. (1994). Mix times for the nursery and finishing trials were 0, 0.5, 2, and 4 minutes. In the nursery trial, the CV for Cr was reduced from 106.5% at 0 minutes to 12.3% at 4 minutes mix time. Growth performance improved as mix time was increased from 0 to 4 minutes ($P < 0.05$). Gain to feed increased from 446 g to 552 g as diet CV was decreased ($P < 0.05$). In the finishing trial, CV for salt was reduced from 53.8% to 9.6% as mix time was increased from 0 to 4 minutes. Results were different from the nursery trial with ADG, ADFI, G/F, last rib fat thickness, and bone breaking strength unaffected as mix time increased from 0 to 4 minutes ($P > 0.15$). In a nursery pig study, Groesbeck et al. (2007) reported similar results to Traylor et al. (1994) wherein mix times of 0, 30, 60, 120, and 330 s led to reduced CV (10% for salt) and this corresponded to increased ADG and ADFI ($P < 0.01$). The G/F improved at 60 s (salt CV of 28%) and leveled off thereafter ($P < 0.01$). Authors speculated that nursery pigs were more likely to be affected by poorly mixed diets because they consume less feed each day. Both also suggested that specialty ingredients that are commonly added to nursery diets could have performance limiting effects in poorly mixed diets.

Two recent finishing pigs studies were completed to determine the effect of mix time when ractopamine was added into diets (Paulk et al., 2015). In the first experiment, diets were mixed throroughly for 360 s before Cr and ractopamine were added to the mixer. The diets were then mixed for an additional 0, 30, 120, and 360 sec. The CV for Cr was reduced from 67% at 0 s mix time to 12% at 360 s. There were no differences in ADG, ADFI, G/F, HCW, DP, BF, loin depth, and FFLI (fat free lean index) when mix time was increased from 0 to 360 s ($P > 0.16$). In a following experiment, diets were not previously mixed before ractopamine was added. This was done to determine how mix time affects the finishing pigs when ractopamine and nutrients are not evenly dispersed. Diets were mixed for 0, 30, 120, and 360 s. The CV for salt was reduced from 51% to 12% as mix time increased from 0 to 360 s. Like the first experiment, growth performance and carcass characteristics were not affected by increasing mix time of the diets ($P > 0.07$).

There have also been mix uniformity experiments done to evaluate the effect in broiler chicks. Like nursery pigs, broiler chicks do not consume large quantities of feed on a daily basis. Ensminger et al. (1990) stated that since only small amounts of feed are consumed daily by broiler chicks it is important to have all nutrients evenly distributed in the feed they consume. However, there was no data substantiating an effect on growth performance when a diet was not adequately mixed. McCoy et al. (1994) conducted two experiments to evaluate the effects of mix times on broiler chick performance. In the first experiment, broiler chicks were fed diets that met nutrient levels recommended in the 1984 NRC for poultry. Salt, red iron particles, blue iron particles, and Cr were all used as markers to test mix uniformity. The CVs for all markers were reduced as mixer revolutions were increased from 20 to 80 but there were no differences in ADG, ADFI, G/F, bone breaking strength, bone ash, carcass CP, carcass fat, or carcass ash ($P > 0.08$) due to increased mix uniformity. In the second experiment, diets were mixed for 5, 20, or 80 revolutions and the diets were formulated to only 80% of the requirements for key nutrients as suggested in the 1984 NRC. Average daily gain improved from 24 g to 30 g, and G/F was improved from 0.548 to 0.575 as mixer revolutions were increased to 80 ($P < 0.05$). Johnston and Southern (2000) studied the effects of mix time (simulated) of phytase on growth performance, mineral retention, and bone mineralization in broiler chicks. The only differences among the CV of 0 and CV of 103 diets were bone breaking strength and bone ash ($P < 0.05$). No differences in growth performance or percentage of minerals excreted or retained were observed. This confounds conventional wisdom.

The literature is clear that growing/finishing pigs and broiler chicks are not sensitive to diets that are not mixed well. However, performance of nursery pigs does suffer if diets are not uniformly mixed. Literature has also shown that when a diet is marginal in nutrient concentrations, growth performance and carcass characteristics are more likely to be negatively affected. There is little, if any, research for diets with liquids additions and how mix time can affect an animal when those types of diets are fed. None the less, if performance of animals is not affected there is no need to mix diets longer than needed. Not only will reduced mix time improve feed mill throughput, but it will also reduce cost of production.

Pelleting

Once a diet has been mixed the process can stop and the feed can be offered to the pig or chick in a meal form. However, there is an option to agglomerate the mix into a pellet. There are two primary reasons that one would choose to pellet livestock diets. The first reason is to improve feed efficiency. Pelleting diets allows heat to gelatinize starch which may improve diet digestibility. Improved feed handling is the second primary reason to pellet animal feed. Pelleted feed has greater bulk density allowing more product to be stored within a bin and it improves flowability of the diet. To achieve these improvements there are several steps and pieces of equipment that are required. The first step in the process is to move the mash feed into a supply bin that is directly above the pellet mill. The bin must be large enough to provide a continuous flow of material to the pelleting press (Fairfield et al., 2005). The feed is then conditioned with steam, dropped into the pelleting chamber, and pushed through the pellet die. The newly formed pellets are fed into a cooler before being bagged or delivered in bulk.

The major components of a pellet mill are the die, conditioner, and roll. The die is the main piece of equipment in the pellet-forming process. Dies have several features to consider that include total thickness, effective thickness, and inlets. Total thickness determines strength of the die itself and dies with smaller diameters require less total thickness than dies with larger diameters (Fairfield et al., 2005). The effective thickness is the “working area” of the die as determined by length of the hole where the pellets are formed. The inlets are where the mash is fed into the holes of the die so that pellets can be formed. The rolls are inside the die chamber and push the mash feed into the inlets. Corrugated rolls are the most popular design and have good traction with the surface of the die while rolls made of tungsten and have a surface similar to that of sand paper and are harder than corrugated or dimpled rolls (Fairfield et al., 2005).

Before reaching the die chamber, the diet goes through the conditioner where steam is used to alter physical properties of the mash. Other liquids such as water, molasses, or pellet binders also can be added at the conditioner. Conditioning of mash is done to improve pellet quality and mill throughput. By definition, to condition a diet is to achieve a predetermined moisture level and/or temperature before processing the material further (Feed Mfg Technology, Appendix A). Conditioning is achieved by adding heat and steam to the material. The time that mash spends in the conditioner is important for both throughput and quality of pellets. Retention time is controlled by the pick angle and shaft speed in the conditioner. When steam is added to the conditioner the pressure needs to be held constant and the condensate should be removed to prevent additional moisture within the conditioner (Fairfield et al., 2005).

After leaving the pellet mill, pellets are cooled and moved to a storage bin. There are three types of coolers used depending on the amount of space a manufacturer has available. If there is a limited amount of floor space a vertical or counterflow cooler will be more appropriate. The most appropriate cooler for a facility with limited height would be a horizontal cooler. But, regardless of orientation important things to keep in mind with coolers are bed depth and retention time. Excessive bed depth or short retention time can result in pellets not cooling properly and retaining moisture and a gentle conveyance system is needed in order to keep pellets from breaking apart and producing excess fines (Fairfield et al., 2005). Using a belt or drag conveyor should produce less damage than a screw type conveying system.

Pellet quality is determined by a pellet durability test. To measure durability 500 g of sieved sample is tumbled in a box for 10 minutes. After 10 minutes, the sample is sieved again, the weight of remaining pellets is recorded, and pellet durability it calculated as:

$$\text{Pellet durability} = (\text{weight after}/\text{weight before})\times 100$$

There are several factors that impact pellet durability. Such factors include anything from ingredient characteristics to settings on equipment. Particle size of ingredients in a diet can impact quality of pelleted diets. If particle size is too large, there can be fracture points in pellets and increased amount of fines. Wondra et al. (1995) showed that as particle size was reduced from 1,000 to 400 microns, pellet durability increased from 79 to 86%. Depending on type of diet, there are differences in the amount of steam that needs to be added to the conditioner. Complete feeds which tend to be high in grain need 17 to 18% added moisture at a temperature (82°C) for good pellet quality (Fairfield et al., 2005). Skoch et al. (1983a) confirmed this with results from a study pelleting a corn-soy diet with and without steam conditioning. When the diet was not conditioned, pellet durability was 80% but when the diet was conditioned with steam at 80°C pellet durability was 96%. In other types of feed there may be little to no added steam (urea feeds) and feeds where temperature is more important than moisture (high natural-protein feeds, such as supplements and concentrates). Equipment can impact pellet durability via roll gap, die speed, die thickness, die retention time, feed distribution within the die, and corrosion within the die.

As previously stated the primary reason to pellet swine and poultry feeds is to improve feed efficiency. In 1960, Larsen and Oldfield conducted a study to determine the effects of pelleting and supplementation with barely malt in weanling pigs. Diets consisted of a corn-based basal ration, a barley-based basal ration, and a barley + malt ration. Treatments were set up as a 3 × 3 factorial arrangement with diets fed as meal, pellets, or reground pellets. Pigs fed the corn diet had lower ADG and G/F fed pellets ($P < 0.05$). However, when barely was the main grain source both ADG and G/F were improved when the diets were pelleted ($P < 0.05$). Jensen and Becker (1965) also conducted experiments to examine the effects of pelleting diets for young pigs. In the first experiment, pigs were fed a corn-casein or a corn-soy diet in pellet or meal form. For both diets, ADG increased while ADFI decreased when diets were fed in pelleted form. This led to improved feed efficiency for pigs fed both diet formulations ($P < 0.05$). In a second experiment, when a corn-casein diet was fed pelleting resulted in lower ADG ($P < 0.01$) but G/F was improved. In a third experiment, corn was replaced with wheat as the main grain source. Average daily gain was not affected by diet form but ADFI decreased from 310 to 250 g/d and G/F was improved with pelleting. In their final experiment, diets contained 50% corn and 25% dried skim milk and like the 2nd experiment, ADG and ADFI were reduced for pigs fed the pelleted diet but feed efficiency was improved. Studies conducted by Chamberlain et al. (1967) and Flatlandsmo and Slagsvold (1971) showed improvements in ADG, reductions in ADFI, and improved G/F when diets were pelleted. Skoch et al. (1983a) did not find significant differences in a first study. But in a second effort (Skoch et al., 1983b) diets with 15% wheat middlings supported greater ADG and the G/F ($p < 0.05$) when pelleted.

Nursery pig diets can include a large variety of specialty ingredients to help improve performance. For example, Steidinger et al. (2000) added 5% spray dried animal plasma to diets that were fed in meal and pellet form. The authors reported that ADG increased by 10% and G/F improved by 14% with pelleting. The effect of adding fat to diets that are pelleted was examined by Xing et al. (2004) and they found no differences for ADG or ADFI, but G/F improved when diets were pelleted ($P < 0.01$). This study also examined digestibility of DM, organic matter, and crude fat and significant differences were attributed to higher DM and crude fat digestibility when diets were pelleted ($P < 0.01$).

Pelleting diets also can affect performance of growing/finishing pigs. For example, Hanke et al. (1972) determined that pelleting a soy protein source improved ADG ($P < 0.01$) and G/F ($P < 0.05$). Skoch et al. (1983a) found that when finishing pigs were fed pelleted diets there were improvements in ADG and G/F. In an experiment conducted by Baird (1973) there were improvements in both ADG ($P < 0.05$) and G/F ($P < 0.01$) with pelleting, but meal diets had greater DE and ME compared to the pelleted form. Wondra et al. (1995) determined the effects mash and pelleted diets on growth performance and nutrient digestibility when fed to finishing pigs. The diets fed were corn-soy with varying particle sizes. When comparing the mash vs pelleted diets, ADG was higher in pigs fed pelleted diets ($P < 0.05$). The pigs fed pelleted diets also had significantly higher G/F ($P < 0.01$). As for effects on nutrient digestibility, DM and N digestibilites were higher for the pelleted diets ($P < 0.04$; $P < 0.01$). In turn, with digestibility increased for both DM and N with pelleting, there was less excretion for both nutrients as pollutants.

Finishing pig diets also commonly contain alternative ingredients because of their increasing availability. Young et al. (1980) examined the effects of pelleting on finishing pigs fed diets with increasing amounts of wheat shorts. Corn was replaced with wheat shorts at 0, 32.2, 64.4, and 96.6 of the diet. Averaging across all treatments, ADG was increased from 0.61 to 0.64 kg ($P < 0.05$) while G/F improved from 0.32 to 0.34 ($P < 0.05$) with pelleting. Skoch et al. (1983b) conducted a second study in finishing pigs in which diets had 15% wheat middlings and were fed as mash or pellets. With no steam conditioning prior to pelleting, G/F improved compared to mash ($P < 0.05$). When the pellets were conditioned prior to pelleting, there were no differences for ADG or G/F compared to mash.

There also have been several studies examining the effects of pelleting on growth performance and carcass characteristics in broiler chicks. Zang et al. (2009) conducted a study feeding broiler chicks a corn-soy diet with different particle sizes and different feed form. The particle sizes were 953 µm and 597 µm and the diets were fed in a meal or pelleted form. Over the 42-d growth assay, ADG, ADFI, and G/F improved with pelleting ($P < 0.001$). Selle et al. (2012) completed a similar study using three different sorghums fed as mash, pellets, and re-ground pellets. Birds fed pellet diets gained 1,448 g vs 1,208 g when fed the mash form. Feed intake increased from 2,135 to 2,412 g and G/F increased from 565 to 599 g for birds fed pellets. Ghobadi and Karimi (2012) determined the effect of feed form on broilers fed a wheat-based diet. From d 0 to 36 chicks fed pelleted diets consumed more feed (94.7 g vs 85.8 g) and G/F was improved from 1.77 to 1.83.

Research has demonstrated that pelleting diets, especially those with alternative ingredients, can improve growth performance of pigs and poultry. Although there have been mixed results in nursery pigs, there are consistent improvements when growing/finishing pigs are fed pelleted diets. Like finishing pigs, when diets are pelleted for broiler chicks there is an overall improvement on performance, especially with diets containing alternative ingredients.

Conclusion

Several authors have reported DDGS can be included in finishing pig diets at 30% without impacting growth performance (Lineen et al., 2008; Xu et al., 2010; Sayler et al., 2012). Distillers dried grains with solubles have been reported to have no adverse effects on growth performance when included in broiler diets at 25% (Wang et al., 2007; Shim et al., 2011). Wheat middlings can be added to finishing pig diets at 20% without impacting feed efficiency (Erikson et al., 1985; Sayler et al., 2012). Pelleting in general has been reported to improve growth performance of pigs and broilers. But, how do alternative ingredients, like DDGS and wheat middlings, effect mix uniformity? How does mix uniformity impact pelleting diet with high levels of alternative ingredients? The objective of ours current research is to determine how mix uniformity impacts finishing pigs and broiler chicks performance when fed high levels of alternative ingredients in meal or pelleted form.

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Figures and Tables

Table 1.1 Summary of research pertaining to the effects of DDGS on growth performance in nursery pigs

		Inclusion , %								
Reference	Item	0	5	10	15	20	25	30	45	60
Senne (1997)	ADG, g	463	–	479	–	459	–	–	–	–
Exp. 1	ADFI, g	745	–	776	–	797	–	–	–	–
	G/F	0.62	–	0.62	–	0.58	–	–	–	–
Senne (1997)	ADG, g	486	–	–	499	–	–	766	398	324
Exp. 2	ADFI, g	784	–	–	728	–	–	633	640	566
	G/F	0.62	–	–	0.69	–	–	0.74	0.62	0.57
Senne (1997)	ADG, g	535	–	–	548	–	–	505	446	356
Exp. 3	ADFI, g	835	–	–	868	–	–	853	818	652
	G/F	0.64	–	–	0.63	–	–	0.59	0.55	0.55
Whitney &	ADG, g	480	463	470	442	489	466	–	–	–
Shurson	ADFI, g	756	748	761	737	789	774	–	–	–
(2004) Exp. 1	G/F	0.65	0.62	0.65	0.59	0.62	0.62	–	–	–
Whitney &	ADG, g	431	433	427	400	425	398	–	–	–
Shurson	ADFI, g	637	652	659	579	644	591	–	–	–
(2004) Exp. 2	G/F	0.70	0.67	0.68	0.71	0.66	0.66	–	–	–
Lineen et al.	ADG, g	431	–	399	–	–	–	–	–	–
(2006)	ADFI, g	649	–	621	–	–	–	–	–	–
	G/F	0.67	–	0.65	–	–	–	–	–	–

Table 1.2 Summary of research pertaining to the effects of DDGS on growth performance in gorw-finish pigs

		Inclusion %							
Reference	Item	0	5	10	15	20	25	30	40
Cromwell et al. (1993)	ADG, g	599	–	–	–	390	–	–	–
	ADFI, g	1,562	–	–	–	1,416	–	–	–
	G/F	0.38	–	–	–	0.28	–	–	–
Senne (1997)	ADG, g	893	–	898	–	878	–	878	–
	ADFI, g	2,360	–	2,350	–	2,260	–	2,300	–
	G/F	.38	–	.38	–	.39	–	.38	–
Whitney et al. (2006)	ADG, g	862	–	859	–	827	–	808	–
	ADFI, g	2,379	–	2,371	–	2,309	–	2,354	–
	G/F	0.36	–	0.36	–	0.36	–	0.34	–
Feoli (2008)	ADG, g	944	–	–	–	–	–	–	931
	ADFI, g	2,880	–	–	–	–	–	–	2,830
	G/F	0.33	–	–	–	–	–	–	0.33
Lineen et al. (2008)	ADG, g	849	–	858	–	834	–	835	–
Exp. 2	ADFI, g	1,946	–	1,975	–	1,913	–	1,900	–
	G/F	0.44	–	0.44	–	0.44	–	0.44	–
Lineen et al. (2008)	ADG, g	921	915	915	896	883	–	–	–
Exp. 3	ADFI, g	2,392	2,317	2,368	2,310	2,288	–	–	–
	G/F	0.39	0.40	0.39	0.39	0.39	–	–	–
Xu et al. (2010)	ADG, g	920	–	920	–	920	–	910	–
	ADFI, g	2,570	–	2,550	–	2,490	–	2,460	–
	G/F	0.36	–	0.36	–	0.37	–	0.37	–
Sayler et al. (2012)	ADG, g	1,050	–	–	–	–	–	1,040	–
	ADFI, g	3,220	–	–	–	–	–	3,110	–
	G/F	0.33	–	–	–	–	–	0.33	–

Table 1.3 Summary of research pertaining to the effects of DDGS on growth performance in broiler chicks

		Inclusion %						
Reference	Item	0	5	10	15	20	25	30
Waldroup et al.	BW, g[1]	1,288	1,237	1,237	1,220	1,246	1,247	−
(1981)	G/F[1]	0.51	0.52	0.51	0.51	0.50	0.50	−
	BW, g[2]	1,206	1,227	1,203	1,165	1,164	1,096	−
	G/F[2]	0.49	0.51	0.49	0.44	0.47	0.45	−
Cromwell et al.	ADG, g	309	−	200	−	213	−	244
(1993)	G/F	0.75	−	0.60	−	0.62	−	0.64
Lumpkins et al.	BW gain, g	540	−	−	536	−	−	−
(2004) Exp. 1	G/F	0.75	−	−	0.74	−	−	−
Lumpkins et al.	BW gain, g	2,314	2,289	2,291	−	2,243	−	−
(2004) Exp.2[3]	G/F	0.57	0.55	0.57	−	0.55	−	−
Wang et al.	BW, kg	3.73	3.80	3.79	3.71	3.72	3.76	−
(2007)	G/F	0.56	0.56	0.55	0.56	0.56	0.55	−
Shim et al. (2011)	BW gain, kg	2.50	−	2.49	2.47	−	2.49	−
Exp.1[4]	G/F	0.59	−	0.58	0.58	−	0.58	−
Shim et al. (2011)	BW gain, kg	1.84	−	1.97	1.93	−	1.94	−
Exp. 2[4]	G/F	0.62	−	0.64	0.63	−	0.62	−

[1]Diets formulated to constant energy levels.
[2]Diets formulated with varying energy levels.
[3]DDGS inclusion rates of 0, 6, 12, and 18%.
[4]DDGS inclusion rates of 0, 8, 16, and 24%.

Table 1.4 Summary of research pertaining to the effects of wheat middlings on growth performance in nursery pigs

		Inclusion %						
Reference	Item	0	5	10	15	20	25	30
Shaw et al. (2002)	ADG, kg	0.55	−	−	0.53	−	−	−
	ADFI, kg	1.06	−	−	1.02	−	−	−
	G/F	0.52	−	−	0.52	−	−	−
De Jong et al. (2012a)	ADG, kg	0.43	0.44	0.43	0.42	0.41	−	−
	ADFI, kg	0.66	0.64	0.65	0.64	0.65	−	−
	G/F	0.66	0.68	0.66	0.65	0.63	−	−
DeJong et al. (2012b)	ADG, kg	0.58	0.57	0.57	0.57	0.55	−	−
	ADFI, kg	0.94	0.94	0.90	0.92	0.89	−	−
	G/F	0.61	0.60	0.63	0.62	0.61	−	−

Table 1.5 Summary of research pertaining to the effects of wheat middlings on growth performance in grow-finish pigs

		Inclusion %								
Reference	Item	0	5	10	15	20	25	30	40	60
Erikson et al. (1985)	ADG, kg	0.81	–	–	–	0.77	–	–	0.75	0.75
	ADFI, kg	2.25	–	–	–	2.14	–	–	2.18	2.17
	G/F,	0.36	–	–	–	0.36	–	–	0.35	0.46
Shaw et al. (2002)	ADG, kg	1.01	–	–	–	–	–	1.05	–	–
	ADFI, kg	3.52	–	–	–	–	–	3.53	–	–
	G/F	0.29	–	–	–	–	–	0.30	–	–
Sayler et al. (2012)	ADG, kg	1.04	–	1.01	–	0.99	–	–	–	–
	ADFI, kg	3.11	–	3.10	–	3.09	–	–	–	–
	G/F	0.33	–	0.32	–	0.32	–	–	–	–

Table 1.6 Summary of research pertaining to the effects of pelleting on growth performance in pigs and poultry

			Meal			Pellet		
Ref.	Stage	Grain Source	ADG, g	ADFI, g	G/F	ADG, g	ADFI, g	G/F
Jensen & Becker (1965)	1	Corn	180	370	0.49	200	320	0.63
	1	Corn	320	480	0.67	260	280	0.68
	1	Wheat	180	310	0.58	180	250	0.72
	1	Corn/SBM	320	520	0.62	280	490	0.57
Chamberlain et al. (1967)	1	Corn/SBM	680	2,180	0.31	770	2,210	0.34
Skoch et al. (1983a)	2	Corn/SBM	370	730	0.51	340	680	0.50
Skoch et al. (1983b)	2	Wheat midds	610	1,350	0.45	670	1,360	0.49
Steidinger et al. (2000)	2	Corn/SBM	418	577	0.72	433	595	0.73
Xing et al. (2004)	2	Corn/SBM	455	596	0.77	468	569	0.83
Hanke et al. (1972)	3	Corn/SBM	781	−	0.30	835	−	0.32
Young et al. (1980)	3, 4	Corn/Wheat shorts	610	−	0.32	610	−	0.34
	4	Corn/SBM	770	2,390	0.32	840	2,460	0.34
	4	Wheats midds	750	2,790	0.27	790	2,890	0.27
Baird (1973)	4	Corn/SBM	690	2,520	0.27	720	2,430	0.29
Wondra et al. (1995)	4	Corn	950	3,260	0.29	1,020	3,200	0.32
Zang et al. (2009)	5	Corn/SBM	50.5	93.9	0.53	58.7	105.5	0.56
Ghobadi & Karimi (2012)	5	Wheat	74.4	137.8	0.54	82.0	153.8	0.53

[1]Stage:1 = nursery; 2 = weanling; 3 = grower; 4 = finishing; 5 = broiler

Chapter 2 - Effects of mix uniformity in diets with high inclusion of alternative ingredients on growth performance and carcass characteristics when fed to finishing pigs

Abstract

Three experiments were completed to determine the effects of mix uniformity on diets with high inclusion of alternative ingredients (DDGS and wheat middlings) on growth performance and carcass characteristics when fed to finishing pigs. In Exp. 1, a total of 200 pigs (average BW of 76 kg) were used in a 54-d growth assay. Pigs were sorted by gender and ancestry and assigned to pens with 5 pigs/pen and 10 pens/treatment. Treatments were arranged as a 2 × 2 factorial with main effects of mix time (60 and 420 s) and inclusion of cereal grain co-products (without and with 30% DDGS and 10% wheat middlings). There were no interactions among mix time and inclusion of cereal grain co-products ($P > 0.07$) for growth performance or carcass characteristics. Increasing mix time from 60 to 420 s decrease CVs for salt from 13.8 to 11.7 and CVs for Cr from 23.2 to 16.2 when DDGS were included. However, increasing mix time did not affect measurements for growth performance or carcass value ($P > 0.43$). Pigs fed diets with DDGS and wheat middlings had reduced ($P < 0.05$) ADG, HCW, DP, and BF compared to pigs fed the corn-soy diet. In Exp. 2, 200 pigs (average BW of 68 kg) were used in a 62-d growth assay. Pigs were sorted by gender and ancestry and assigned to pens with 5 pigs/pen and 8 pens/treatment. Diets had 32% DDGS and 32% wheat middlings and were mixed for 0, 15, 30, 60, and 420 s. Increasing mix time from 0 to 420 s reduced CVs for salt from 32.9 to 14.0 and CVs for Cr from 81.3 to 1.4 ($P < 0.01$). There was a trend for ADG to decrease from 0 to 30 sec and increase from 30 to 420 sec ($P < 0.07$). Increasing mix time also resulted in a trend for G/F to increase as mix time increased ($P < 0.06$). Mix time did not affect ADFI, HCW, DP, or BF ($P > 0.10$). In Exp. 3, 200 pigs (average BW of 72 kg) were used in a 51-d growth assay to determine the effects of mix time and diet form in diets with 32% DDGS and 32% wheat middlings. Once again, pigs were sorted by gender and ancestry and were assigned to pens with 5 pigs/pen and 10 pens/treatment. Treatments were arranged as a 2 × 2 factorial with main

effects of mix time (0 vs 180 s) and diet form (meal vs pellets). There were no interactions for diet form and mix time ($P > 0.31$). Pelleting improved ($P < 0.01$) ADG and G/F, but did not affect HCW, BF, or DP ($P > 0.48$). Mix time did not have an impact growth performance or carcass measurements ($P > 0.16$). In conclusion, increasing mix time of diets did not affect growth performance or carcass characteristics in finishing pigs fed diets with high inclusion of cereal grain co-products.

Introduction

To ensure that an animal receives its intended daily intake of nutrients, diets are mixed thoroughly. Many have suggested that a CV of 10% or less is an adequately mixed diet (Beumer, 1991; Lindley, 1991; Wicker and Poole, 1991). Traylor et al. (1994) and Groesbeck et al. (2007) reported negative effects when mixing was reduced in nursery pigs. However, research has shown that there is no significant benefit to mixing diets for long periods of time when fed to finishing pigs. Traylor et al. (1994) reported no effects on ADG, ADFI, G/F, backfat thickness, or bone breaking strength when CV for salt was reduced from 53.8% to 9.6%. Paulk et al. (2015) also reported no significant effects on growth performance or carcass characteristics when mix time was increased from 0 to 360 sec. However, most research in the area of mixing is with diets that do not contain significant levels of cereal grain co-products. Therefore our objective was to determine the effects of mix uniformity in diets with high inclusion of DDGS and wheat middlings on growth performance and carcass characteristics in finishing pigs.

Materials and Methods

Experiment 1

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

For Exp. 1, a 1,360 kg capacity Davis and Sons horizontal ribbon mixer was used to mix separate 907 kg batches. All ingredients were added to a stopped mixer before mix times were applied. Batches were then discharged via a 2.5 m-long screw conveyor, dropped into a bucket elevator, elevated 29.5 m, and then dropped 11 m into a bin. Batches were then carried 11 m, horizontally, and dropped 13 m into a surge bin in order to be sacked into 22.6 kg bags for delivery to the swine farm.

Two hundred finishing pigs (average initial BW of 76 kg) were used in a 54-d growth assay to determine the effect of mix time in diets without and with inclusion of cereal grain co-products (DDGS and wheat middlings). The pigs were sorted by gender and ancestry in a completely randomized design. Pigs were assigned to pens (2.44 m × 1.53 m) with 5 pigs/pen and 10 pens/treatment. Each pen had two nipple waterers and a single-hole self-feeder to allow ad libitum access to feed and water. Feed was weighed (by bag) before it was added to each feeder. On the final day of the growth assay, the remaining feed was weighed and subtracted from the total feed consumed by the pen. Pigs were weighed at d 0 and on the final day of the growth assay to allow for calculation of ADG, ADFI, and G/F. The pigs were tattooed and shipped to a commercial abattoir (Farmland Foods, Inc., Crete, NE) for the collection of hot carcass weight and last rib backfat thickness.

All diets (Table 2.1) were formulated to be at least 120, 120, and 110% of requirements for essential amino acids, vitamins, and minerals, respectively, as suggested in the 2012 National Research Council guidelines for feeding swine. To prepare diets, the major ingreadients (corn, soybean meal, DDGS, and wheat middlings) were added to a stopped mixer, the micro ingredients (limestone, salt, vitamin pre-mix, mineral pre-mix, crystalline amino acids, and tylosin) were added, and then mixed for either 60 or 420 s.

Salt concentrations were determined using the Quantab assay. Chromium concentrations were determined using the procedure from Williams et al. (1962) and a Perkin-Elmer atomic absorption spectrophotometer. Each assay was done on 10 samples from each batch of feed. All data were analyzed using the PROC MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) with pen as the experimental unit. Hot carcass weight was used as a covariate for analysis of carcass characteristics.

Experiment 2

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

As in Exp. 1, a 1,360 kg capacity Davis and Sons horizontal ribbon mixer was utilized to mix separate 907 kg batches. Ingredients were added to a stopped mixer before being mixed for a specified amount of time. Batches were discharged via a 2.5 m-long screw conveyor, dropped into a bucket elevator, elevated 29.5 m, and then dropped 11 m into a bin. Batches were then carried 11 m, horizontally, and dropped 13 m into a surge bin in order to be sacked into 22.6 kg bags for delivery to the swine farm.

Two hundred finishing pigs (average initial BW of 68 kg) were used in a 62-d growth assay to determine the effects of mix time in diets with high inclusion of DDGS (32%) and wheat middlings (32%). Pigs were sorted by gender and ancestry in a completely randomized design. Pigs were assigned to pens (2.44 m × 1.53 m) with 5 pigs/pen and 10 pens/treatment. Each pen had two nipple waterers and a single-hole self-feeder to allow for ad libitum access of feed and water. Feed was weighed (by bag) before being added to each feeder. On the final day of the growth assay, the remaining feed was weighed and subtracted from the total feed consumed for the pen. Pigs were weighed at d 0 and on 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 HCW and last rib backfat thickness.

All diets (Table 2.2) were formulated to be at least 120, 120, and 110% of requirements for essential amino acids, vitamins, and minerals, as suggested by the NRC (2012) guidelines for feeding swine. To prepare the diets, major ingredients (corn, soybean meal, DDGS, and wheat middlings) were added to a stopped mixer, followed by the addition of micro ingredients (limestone, salt, vitamin mix, mineral mix, crystalline amino acids, and tylosin). Once all ingredients were added to the stopped mixer, mix times of 0, 15, 30, 60, and 420 s were applied.

Salt concentrations were determined with the Quantab assay. Chromium concentrations were determined using a Perkin-Elmer atomic absorption spectrophotometer and the procedure of Williams et al. (1962). Each assay was completed on ten samples from each batch of feed. All data were analyzed using the PROC MIXED procedure of SAS (SAS Inst. Inc., Cary, NC.) with polynomial regression for unequally spaced treatments. Pen was the experimental unit. Hot carcass weight was used as a covariate for analysis of carcass characteristics.

Experiment 3

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

In Exp. 3, diets were mixed in a 1-ton Hayes & Stolz twin-shaft ribbon mixer. The 907 kg batches were mixed separately with all ingredients were added to a stopped mixer before mix times were applied. Mash diets were then discharged via 3 drag conveyors, each 15 ft. long, and sacked into 22.6 kg bags for delivery to the swine farm. Pelleted diets were discharged from the mixer to the pellet mill via 2 15 ft. drag conveyors and one 10 ft. screw conveyor. Once in pelleted form the diet was transferred to sack-off via one 25 ft. and one 20 ft. drag conveyor. These diets were then delivered to the swine farm.

Two hundred finishing pigs (average initial BW of 72 kg) were used in the 51-d growth assay. The pigs were sorted by gender and ancestry in a completely randomized design. Pigs were assigned to pens (2.44 m × 1.53 m) with 5 pigs/pen and 10 pens/treatment. Each pen had a single-hole self-feeder and two nipple waterers to allow ad libitum access to feed and water. Feed was weighed (by bag) then added to each feeder. On the last day of the growth assay, the remaining feed was weighed and subtracted from the total feed consumed for the pen. Pigs were weighed at d 0 and on 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 HCW and last rib backfat thickness.

All diets (Table 2.2) were formulated to be at least 120, 120, and 110% of requirements for essential amino acids, vitamins, and minerals as suggested in the NRC (2012) guidelines for feeding swine. To prepare diets, all ingredients (corn, soybean meal, DDGS, wheat middlings, limestone, salt, vitamin mix, mineral mix, crystalline amino acids, and tylosin) were added to a stopped mixer. Mix times of 0 or 180 seconds were then applied. Diets were pelleted and sacked or sacked as meal form.

Salt concentrations were completed using the Quantab assay with 10 samples from each batch of feed. Chromium analysis was completed using procedure of Williams et al. (1962) and a Perkin-Elmer atomic absorption spectrophotometer. All data were analyzed using the PROC MIXED procedure of SAS (SAS Inst. Inc., Cary, NC.) with pen being the experimental unit. Hot carcass weight was used as a covariate for analysis of carcass measurements.

Results and Discussion

Experiment 1

When mix time was increased from 60 to 420 s (Table 2.3), CVs for salt decreased ($P < 0.05$) from 18.2 to 14.1 in the corn-soy diet and from 13.8 to 11.7 in the DDGS-wheat midds diet. But there were no consistent effects on CVs for chromium as mix time was increased. As for effects because of the change in CVs, there were no differences in growth performance or carcass measurements (P > 0.38) as mix time increased from 60 to 420 s. Traylor et al. (1994) reported similar results. (Paulk et al. 2015) also reported no improvements on carcass measurements or growth performance because of increased mix time.

Pigs fed diets with 30% DDGS and 10% wheat middlings had reduced (P < 0.01) ADG compared to those fed the corn-soy diet (Table 2.3). Whitney et al. (2006) and Cromwell et al. (1993) also reported that increased DDGS inclusion decreased ADG. Other authors, however, reported no changes in ADG as DDGS were added to the diet (Xu et al., 2010). Sayler et al. (2012) also fed a diet with 30% DDGS and 10% wheat middlings and reported a decreased ADG when the diet was fed to finishing pigs. There were no differences in ADFI or G/F when comparing the two diets (P > 0.11). Lineen et al. (2008) also reported results in which ADFI and G/F were not affected as DDGS were added into the diet. Feoli (2008) added 40% DDGS into finishing pig diets and reported no differences for ADFI or G/F. However, Senne (1997) reported that ADFI was reduced and G/F was improved when DDGS were added to diets up to 60%. Like Senne, Xu et al. (2010) had reduced ADFI and improved G/F with 20% DDGS.

Pigs fed the corn-soy diet had approximately 3 kg greater HCW (P < 0.05) compared to pigs fed the diet with DDGS and wheat middlings. Several authors have reported that as DDGS and/or wheat middlings increase in the diet HCW decreases (Whitney et al., 2006; Linneen et al., 2008; and Sayler et al., 2012). Dressing percentage also decreased (P < 0.03) in pigs fed the diet formulated with DDGS and wheat middlings. Backfat thickness was 3 to 4 mm greater for pigs fed the corn-soy diet (P < 0.001).

Experiment 2

As mix time was increased from 0 to 420 s (Table 2.4), CVs for salt decreased from 32.9 to 14.0% while CVs for chromium decreased from 81.3 to 1.4%. Results for ADG showed a quadratic trend for ADG to decrease (P = 0.061) between 0 and 30 s and increase from 30 to 420 s of mix time. There were no differences in ADFI (P > 0.3) as mix time was increased from 0 to 420 seconds. There was a linear trend (P = 0.06) for G/F to decrease with 0 to 60 s and increase with 60 to 420 s of mix time. Similar to experiment 1, there were no differences in HCW, dressing percentage, back fat thickness, or FFLI (P > 0.11).

Paulk et al. (2015) reported similar results when mix times were increased from 0 to 360 s. They found that when pigs were fed thoroughly mixed diets with ractopamine there were no differences in growth performance or carcass measurements (P > 0.16). In a second experiment, when both ractopamine and nutrients were not mixed thoroughly, there was no response in growth performance or carcass measurements as mixed time was increased. Traylor et al. (1994) also reported that there were no adverse effects in finishing pigs for growth and carcass measurements in diets that had high CVs for salt.

Nursery pigs may be more sensitive when fed diets that are not mixed thoroughly. For example Traylor et al. (1994) and Groesbeck et al. (2007) both reported improved ADG, ADFI, and G/F when diets were mixed for 4 to 5 minutes. The authors suggested that because nursery pig diets are high in speacialty ingredients, such as animal plasma, they require more mixing in order to prevent adverse effects.

Experiment 3

As mix time was increased from 0 to 180 s (Table 2.5), CV for salt decreased from 22.5 to 13.0% in meal diets and from 9.8 to 7.9% in pelleted diets (P < 0.01). There were no consistent effects on CV for Cr as mix time was increased (P >0.90).

There were no interactions between mix time and diet form on growth performance or carcass characteristics (P > 0.27). Pigs fed diets in pellet form had increased ADG (P < 0.01), no differences in ADFI, and greater G/F (P < 0.01) compared to pigs fed the diets in meal form. Results for carcass characteristics showed no differences because of diet form (P > 0.48). Several authors reported improvements in ADG and G/F when pigs were fed pelleted diets instead of mash diets (Hanke et al., 1972; Baird, 1973; Skoch et al., 1983; Wondra et al., 1995). There is also evidence that pelleting diets with alternative ingredients will improve feed efficiency. For instance, Young et al. (1980) replaced corn with increasing levels of wheat shorts and fed the diets in pelleted form which resulted in greater ADG and G/F (P < 0.05). Diets with 15% wheat middlings also supported improved G/F when diets were pelleted (P < 0.05).

There was no difference (P > 0.16) in ADG or G/F as mix time was increased from 0 to 180 s. Carcass measurements were not affected by mix time or diet from (P > 0.12).

Conclusion

Many opportunities still exist in the topic area of mix uniformity in diets. Diets in the above experiments were all adequately formulated. There may have been different response had the diets been formulated below recommendations. Nursery pigs have shown to be more sensitive to unmixed diets compared to finishing pigs. Many suggest that this is because of the ingredients in these diets and low consumption of feed. There is no research examining how stomach morphology of these young pigs may be impacting their responses to unmixed diets. Also, once the batch of feed leaves the mixer additional mixing does take place. There is additional mixing in all the conveyance systems, during the pelleting processing, and during sack-off. Research to determine how much mixing takes place outside the mixer itself would be very beneficial. Nonetheless, for the experiments reported herein, increasing mix time in diets with high inclusion of alternative ingredients (DDGS and wheat middlings) did not affect growth performance or carcass measurements in finishing pigs.

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Tables

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

	Corn/Soy		DDGS/Wheat Midds	
Ingredient, %	Phase 1	Phase 2	Phase 1	Phase 2
Corn	79.86	79.85	53.31	53.43
Soybean meal	17.00	17.00	3.50	3.40
Dried distillers grain w/ solubles	–	–	30.00	30.00
Wheat middlings	–	–	10.00	10.00
L-Lysine HCl	0.36	0.36	0.60	0.60
DL-Methionine	0.07	0.07	0.02	0.02
L-Threonine	0.12	0.12	0.14	0.14
L-Tryptophan	0.02	0.02	0.06	0.05
Monocalcium phosphate	1.00	1.00	0.50	0.48
Limestone	0.90	0.90	1.20	1.20
Vitamin Premix[3]	0.10	0.10	0.10	0.10
Mineral Premix[4]	0.08	0.08	0.08	0.08
Antibiotic	0.13	0.13	0.13	0.13
Salt[2]	0.25	0.25	0.25	0.25
Cr_2O_3[2]	0.25	0.25	0.25	0.25
Calculated Composition				
ME, kcal/kg	3,295	3,295	3,276	3,277
CP, %	15.17	15.17	16.57	16.53
SID Lysine, %	0.84	.84	0.84	0.84
Ca	0.57	0.57	0.57	0.57
Total P	0.52	0.52	0.52	0.52

[1]Formulated to 120, 120, 110% of requirements for essential amino acids, vitamins, and minerals as suggest by the 2012 NRC.
[2] Salt and Cr_2O_3 used as a marker for determination of mix uniformity.
[3]Provided (per kilogram of diet) 4409 IU of vitamin A, 551 IU vitamin D, 18 IU vitamin E, 1.76 mg vitamin K, 18.84 mg Niacin, 11.02 mg pantothenate, 3.31 mg riboflavin, and 15.43 µg B_{12}.
[4]Provided (per kilogram of diet) 8.8 mg Cu, 0.16 mg I, 58.4 mg Fe, 17.6 mg Mn, 0.16 mg Se, and 58.40 mg Zn.
[5]Tylosin 40 provided 100 mg of tylosin per kg of complete diet. For control of porcine proliferative enteropathies (ileitis).

Table 2.2 Composition of experimental diets, Exp. 2 and Exp. 3 (as-fed basis) [1]

Ingredient, %	Phase 1	Phase 2
Corn	32.00	32.16
Soybean meal	1.04	1.00
Dried distillers grains w/ solubles	32.00	32.00
Wheat middlings	32.00	32.00
L-Lysine HCl	0.58	0.53
L-Threonine	0.12	0.10
L-Tryptophan	0.05	0.04
Limestone	1.55	1.50
Vitamin premix[3]	0.04	0.05
Mineral premix[4]	0.08	0.08
Antibiotic[5]	0.05	0.05
Salt[2]	0.25	0.25
Cr_2O_3[2]	0.25	0.25
Calculated Composition		
ME, kcal/kg	3,189	3,190
CP, %	17.59	17.52
SID Lysine, %	0.88	0.84
Ca	0.57	0.57
Total P	0.52	0.52

[1]Formulated to be at least 120, 120, and 110% of essential aminoacids, vitamins, and minerals as suggested by the 2012 NRC.
[2] Salt and Cr_2O_3 used as a marker for determination of mix uniformity.
[3]Provided (per kilogram of diet) 2205 IU vitamin A, 276 IU vitamin D, 9 IU vitamin E, 0.88 mg vitamin K, 9.92 mg Niacin, 5.51 mg pantothenate, 1.65 mg riboflavin, and 7.72 µg B_{12}.
[4]Provided (per kilogram of diet) 8.8 mg Cu, 0.16 mg I, 58.4 mg Fe, 17.6 mg Mn, 0.16 mg Se, and 58.4 mg Zn.
[5]Tylosin 100 provided 100 mg of tylosin per kg of complete diet. For control of porcine proliferative enteropathies (ileitis).

Table 2.3 Effects of mix uniforminty in diets with high inclusion of alternative ingredients on growth performance and carcass measurements in finishing pigs (Exp. 1)[1]

	Corn/Soy		DDGS/Midds			P-value		
Item	60	420	60	420	SE	Diet	Mix	Diet×Mix
CV for salt, %[2]	18.2	14.1	13.8	11.7	1.3	0.014	0.024	0.444
CV for chromium, %[2]	18.6	22.7	23.2	16.2	4.0	0.764	0.654	0.102
ADG, g[3]	1,011	1,014	966	954	17	0.002	0.759	0.631
ADFI, kg[3]	3.41	3.49	3.52	3.33	0.14	0.751	0.435	0.079
G/F, g/kg[3]	298	292	278	288	13	0.113	0.811	0.267
HCW, kg	100.4	100.8	97.6	97.7	3.8	0.043	0.848	0.942
Dressing percentage, %[4]	74.2	74.2	73.8	73.8	0.7	0.024	0.979	0.938
Backfat thickness, mm[4]	26.3	26.9	23.6	22.7	1.4	<0.001	0.847	0.338
FFLI, %[5]	51.0	50.8	52.2	52.5	0.7	<0.001	0.776	0.465
CV for BW variation	3.7	4.5	4.1	4.1	0.6	0.983	0.390	0.390

[1]A total of 200 finishing pigs (average initial BW of 76 kg, 5 pigs/pen and 10 pens/treatment) were used in a 54-d growth assay.
[2]Coefficient of variation for salt and chromium concentration was determined from 10 samples (taken from every 4th bag) for every batch of feed.
[3]Initial BW used as a covariate.
[4]HCW used as a covariate.
[5]Fat-free lean index (NPPC, 2001).

Table 2.4 Effects of mix uniformity in diets with high inclusion of alternative ingredients on growth performance and carcass measurments in finishing pigs (Exp. 2)[1]

	Mix Time, s						P-value			
Item	0	15	30	60	420	SE	Linear	Quad	Cubic	Quartic
CV for salt, %[2]	32.9	26.2	24.8	15.8	14.0	2.4	<0.001	<0.001	0.982	0.363
CV for chromium, %[2]	81.3	40.7	33.5	21.9	1.4	14.3	<0.003	<0.006	0.141	0.464
ADG, g[3]	932	934	882	903	936	31	0.260	0.061	0.246	0.080
ADFI, kg[3]	3.03	3.18	3.00	3.08	2.99	0.13	0.309	0.911	0.887	0.068
G/F, g/kg[3]	309	295	296	294	315	6.9	0.060	0.109	0.303	0.505
HCW, kg	90.2	91.5	88.1	89.2	90.6	1.1	0.523	0.117	0.643	0.026
Dressing percentage, %[4]	72.2	72.2	72.5	71.9	72.1	0.6	0.641	0.593	0.258	0.368
Backfat thickness, mm[4]	20.9	20.8	20.6	20.4	20.1	1.2	0.295	0.678	0.987	0.993
FFLI, %[5]	53.4	53.5	53.5	53.6	53.8	0.5	0.299	0.586	0.948	0.999
CV for BW variation	4.2	4.3	4.5	3.9	4.2	0.6	0.978	0.733	0.624	0.840

[1]A total of 200 finishing pigs (average initial BW of 68 kg, 5 pigs/pen and 8 pens/treatment) were used in a 54-d growth assay.
[2]Coefficient of variation for salt and chromium concentration was determined from 10 samples (taken from every 4th bag) for every batch of feed.
[3]Initial BW used as a covariate.
[4]HCW used as a covariate.
[5]Fat-free lean index (NPPC, 2001).

Table 2.5 Effect of mix uniformity in diets with high inclusion of alternative ingredients fed in meal or pelleted form on growth performance and carcass characterisitcs in finishing pigs (Exp. 3)[1]

	Meal		Pellets			P-value		
Item	0	180	0	180	SE	Form	Mix	Form×Mix
CV for salt, %[2]	22.5	13.0	9.8	7.9	2.2	<0.001	<0.005	0.052
CV for chromium, %[2]	18.3	14.6	7.9	11.1	3.1	0.036	0.943	0.282
ADG, g[3]	909	893	969	944	28	< 0.001	0.169	0.762
ADFI, kg[3]	3.10	3.00	3.11	2.97	0.09	0.753	0.018	0.617
G/F, g/kg[3]	294	298	312	319	05	0.001	0.306	0.780
HCW, kg	87.4	86.9	88.2	88.1	3.2	0.487	0.839	0.903
Dressing percentage, %[4]	73.3	73.1	72.6	73.0	0.7	0.511	0.921	0.610
Backfat thickness, mm[4]	23.3	22.5	22.5	22.4	1.1	0.571	0.545	0.672
FFLI, %[5]	52.4	52.8	52.8	52.9	0.5	0.522	0.540	0.748
CV for BW variation	4.2	4.5	3.9	5.4	0.7	0.623	0.133	0.312

[1]A total of 200 finishing pigs (average initial BW of 72 kg, 5 pigs/pen and 10 pens/treatment) were used in a 54-d growth assay.

[2]Coefficient of variation for salt and chromium concentration was determined from 10 samples (taken from every 4th bag)
for every batch of feed.

[3]Initial BW used as a covariate.

[4]HCW used as a covariate.

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

Chapter 3 - Effects of mix uniformity on diets with high inclusion of alternative ingredients on growth performance and carcass characteristics when fed to broiler chicks

Abstract

A total of 1,610 male broiler chicks (initial age of 14-d) were used in a 32-d growth assay to determine the effects of mix uniformity in diets with high inclusion of alternative ingredients (20% DDGS and 20% wheat middlings) on growth performance and carcass characteristics. There were 23 birds/pen and 7 pens/treatment in a completely randomized design. The diets were blended in a Scott twin-shaft, double-ribbon, mixer in 454 kg batches. All ingredients (corn, soybean meal, DDGS, wheat middlings, vitamins, minerals, and amino acids) were added to a stopped mixer before mix times of 0, 15, 30, 60, and 300 s were applied. Treatments were arranged as a 2 × 5 factorial with main effects of diet formulation (corn/soy vs DDGS/wheat middlings) and mix time (0, 15, 30, 60, and 300 s). Diets were formulated to be at least 120, 120, and 110% of requirements for essential amino acids, vitamins, and minerals as suggested in Nutrient Requirements of Poultry (NRC, 1994). Feed and water were consumed on an ad libitum basis until birds were harvested for collection of carcass data. There were no interactions among diet formulation and mix time ($P > 0.14$) for carcass measurements or growth performance. Diet formulation did not affect ADG ($P > 0.19$), but birds fed the corn/soy diets had greater G/F ($P < 0.001$) compared to those fed the DDGS/wheat middlings diet. Mix time did not affect growth performance or carcass characteristics ($P > 0.22$). In conclusion, corn/soy diets supported greater efficiency of growth than diets that had 20% DDGS and 20% wheat middlings, but increasing mix time from 0 to 300 s did not improve growth performance or carcass measurements regardless of diet formulation.

Introduction

The goal of a livestock producer is to feed animals nutritionally adequate diets to achieve the greatest growth performance and carcass value. It has been stated many times through the years that in order to achieve this goal a diet needs to be thoroughly mixed and have a CV of 10% or less (Beumer, 1991; Lindley, 1991; Wicker and Poole, 1991). Ensminger (1990) suggested that because of the low amount of feed consumed by chicks, it is critical to have all essential nutrients in required amounts in each meal. However, research suggests that a CV of 10% or less may not be required to optimize growth performance in broiler chicks. McCoy et al. (1994) conducted experiments in which diets met the NRC (1984) requirement or were formulated to 80% of the NRC requirements for those same nutrients. Results showed no performance improvement as mix time was increased from 20 to 80 revolutions. The results suggested that a CV between 15 to 40% would support growth performance without negative effects. However, when the diet was formulated to 80% of NRC requirements, a CV of 12% to 23% or less was needed to supported maximum growth. In both experiments, the CV's that supported maximum growth both exceeded the industry standard of 10%. Johnston and Southern (2000) conducted an experiment that simulated unmixed diets to determine the effects on broiler chicks. In their experiment, no differences in growth performance were noted, but there were differences in calcium and phosphorus retention and excretion. The authors stated that a CV of 34 to 69% would be adequate to optimize growth performance in broiler chicks. Both of these studies examined the effects in corn/soy diets but less is known about how diets based on cereal grain co-products might impact performance. Thus, the objective of the experiment reported herein was to determine the effects of mix uniformity in diets with high inclusion of alternative ingredients (DDGS and wheat middlings) on growth performance and carcass characteristics when fed to broiler chicks.

Materials and Methods

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

A total of 1,610 male broiler chicks (Cobb, initial age of 14-d) were used in a 32-d growth assay to determine the effects of mix uniformity on growth performance and carcass measurements. There were 23 birds/pen and 7 pens/treatment with a total of 70 pens. Birds were randomly sorted into pens and used in a completely randomized design. Each pen had a single self-feeder and nipple waterers to allow for ad libitum access to feed and water.

Diets were made in a Scott twin-shaft, double-ribbon, mixer in 454 kg batches. Main effects for the experiment were diet formulation and mix time. Diets fed were either a simple corn/soy diet or a diet with 20% DDGS and 20% wheat middlings. Treatment diets were formulated to a minimum of 120%, 120%, and 110% for essential amino acids, vitamins, and minerals, as suggested in the 1994 NRC for poultry. All ingredients were added to the stopped mixer before mix times of 0, 15, 30, 60, and 300 s were applied. The diets were then emptied directly from the mixer into two small bins then added directly to the hopper above the pelleting press to avoid additional mixing. Diets were then sacked into 22.6 kg bags for delivery to the poultry unit.

Salt concentrations in feed samples were determined with the Quantab assay using 10 samples from each batch of feed. Samples were collected from every other bag, starting on bag 2. Pellet durability index was calculated at three separate collection times throughout each batch of feed. Samples were collected at ¼, ½, and ¾ completionof the pelleting run for each batch of feed. Along with PDI, mash temperature (°C), hot pellet temperature (°C), and throughput readings were also collected for analysis.

Pens were weighed at the beginning and end of the experiment for calculation of ADG, ADFI, and G/F. In order to collect carcass data, 4 birds from each pen were weighed prior to and after slaughter to obtain a HCW and to calculate dressing percentage. All data were analyzed using the PROC MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) with pen as the experimental unit. Polynomial regression was used for unequally spaced treatments. Live weight was used as a covariate for analysis of carcass measurements.

Results and Discussion

There were no differences in mash temperature or hot pellet temperature among diet formulations ($P > 0.21$). Pellet durability was greater when diets were formulated with 20% DDGS and 20% wheat middlings ($P < 0.01$). Differences among the diet formulations for pellet durability was greater when pellet durability was determined using the modified procedure ($P < 0.01$). Coefficient of variation was also determined for pellet durability to determine if there were differences because of diet formulation. The diet formulated using DDGS and wheat middlings had lower CVs for pellet durability compared to the corn-soy diet (P > 0.03). These pellet durability results differ from those of Behnke (2007), Srinivasan et al. (2009), and Loar et al. (2010), who all reported decreased pellet durability when DDGS were included in the diet. These diets contained varying levels of DDGS and fat. DDGS are a co-product of the ethanol industry, and lack the starch found in corn. During the pelleting process, the starch in corn is gelatinized and upon cooling form new bonds that increase its binding capacity (Maier et al., 1999). Loar et al. (2010) suggest that lack of starch found in diets with DDGS could explain why pellet durability was decreased in their study. Their diets also had added fat which could have a lubricating effect at the die, reducing its pressure. Catala-Gregori et al. (2009) reported that diets with little added fat had greater pellet durability than diets with increased levels of added fat.

As for mix time effects on processing characteristics, there were no differences in mash temperature of hot pellet temperature as mix time increase to 300 s (P > 0.21). There were no differences in pellet durability (P > 0.12) or CVs for pellet durability or modified pellet durability as mix time was increased to 300 s (P > 0.19).

As for animal performance, there were no interactions among diet formulation and mix time (P > 0.12). Broilers fed the diet with DDGS-midds had higher ADFI and reduced G/F compared to birds fed corn-soy (P < 0.01). However, ADG and final BW were not affected by diet formulation (P > 0.19). Cromwell et al. (1993) reported that weight gain was reduced from 577 to 434 g while F/G increased from 1.49 to 1.64 when DDGS were included in the diet at 20%. In their experiment, corn levels were held constant and CP was 19%. In a second experiment, CP levels were allowed to increase as DDGS were increased in the diet. When comparing DDGS to a similar CP content soybean meal diet, there were reductions in weight gain and G/F. Metabolizable energy was decreased as DDGS inclusion rate increased. Lumpkins et al. (2004) found that when birds were fed 18% DDGS, they had reduced ADG with no effect on G/F. In this experiment, DDGS replaced a greater proportion of soybean meal than corn, reducing the protein content of the diets. The authors speculated that there was a reduction in ADG because of an overestimation of lysine content in the diets and a less favorable amino acid profile. Shim et al. (2011) conducted two studies and found that birds fed 25% DDGS had no differences in G/F compared to birds fed diets without DDGS. The only body weight gain difference were in the starter phase. Previously, Cromwell et al. (1993) determined that there are differences in DDGS quality and composition depending on how it is processed. Shim et al. (2011) suspect that during their starter phase, diets contained a high quality DDGS source which led to the improvement in weight gain.

There were no differences in HCW, dressing percentage, or breast weight ($P > 0.11$). However, leg weight was greater in birds fed the corn-soy diet ($P < 0.01$). Wang et al. (2007) found that dressing percent was reduced when DDGS were included in the diet at 25%. This could be attributed to increase gut weight in the birds fed the DDGS diet. As a percentage of live weight, breast weight was decreased with 25% inclusion. However, as a percentage of carcass weight, there were no significant differences in breast weight. This could be attributed to increased gut weight in birds fed DDGS diets.

As mix time was increased from 0 to 300 s, CVs for salt decreased from 25.6 to 8.3 in the corn-soy diet and from 11.2 to 6.0 in the DDGS-midds diet. These changes in diet CV did not affect in final BW, ADG, ADFI, G/F, or survivability ($P > 0.13$). Hot carcass weight, dressing pertenct breast weight, and leg weight also were not affects as mix time was increased ($P > 0.22$). McCoy et al. (1994) found no differences in ADG, ADFI, or G/F when CV for salt was reduced from 43% to 13% when NRC requirements were met ($P > 0.08$). However, when diets were formulated to 80% of requirements ADG and G/F were improved as CV for salt decreased from 41% to 10%. Johnston and Southern (2000) also found no differences in ADG, ADFI, or G/F as phytase CV was reduced from 103 to 0.

In conclusion, birds fed the corn-soy diet had improved growth performance. Increasing mix time from 0 to 300 seconds did not result in large differences in CVs for salt and there were no differences in growth performance as mix time was increased to 300 s. This could be attributed to the fact that diets were mixed after they left the mixer. Extra mixing occurs in augers, hopers, in the conditioner, in the cooler, during sack-off, and during delivery to the feeders. Because there is a substantial amount of mixing that occurs after the feed leave the mixer, there is an opportunity for further research in this area to determine how much mixing occurs. Finally, this experiment was completed with diets that were highly adequate for nutrients. More research can also be done in this area to determine if a CV of 10% or less is need in diets that are formulated to the recommendations or diets that are formulated below recommendations.

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Figures and Tables

Table 3.1 Composition of experimental diets (as-fed basis) [1]

Ingredient, %	Corn/SBM	DDGS/Wheat Midds
Corn	62.15	34.46
Soybean meal	34.00	21.80
Dried distiller's grains w/ solubles	–	20.00
Wheat middlings	–	20.00
L-Lysine HCl	0.06	0.21
DL-Methionine	0.18	0.12
L-Threonine	0.09	0.09
Monocalcium phosphate	1.05	0.70
Limestone	1.80	2.10
Poultry vitamin/mineral premix[3,4]	0.42	0.27
Salt[2]	0.25	0.25
Calculated composition		
ME, kcal/kg	2,919	2,596
CP, %	21.55	22.19
Total Lysine, %	1.20	1.20
Ca	0.99	0.99
P	0.39	0.39

[1]Formulated to 120, 120, and 110% of requirements for essential amino acids, vitamins, and minerals as suggested by the 1994 NRC.
[2]Salt used for determination of mix uniformity.
[3]Provided (per kilogram in corn/soybean diet) 5880 IU vitamin A, 2100 ICU vitamin D, 13 IU vitamin E, 1.39 mg vitamin K, 0.06 mg biotin, 0.65 g choline, 1.16 mg folacin, 48.85 mg niacin, 11.11 mg pantothenate, 11.11 mg riboflavin, 1.85 mg thiamin, 2.31 mg B_6, and 18.52 µg B_{12}.
[4]Provided (per kilogram DDGS/wheat midds diet) 3850 IU vitamin A, 1375 ICU vitamin D, 8 IU vitamin E, 0.91 mg vitamin K, 0041 mg biotin, 0.42 mg choline, 0.76 mg folacin,31.98 mg niacin, 7.28 mg pantothenate, 7.28 mg riboflavin, 1.21 mg thiamin, 1.52 mg B_6, and 12.13 µg B_{12}.

Table 3.2 Effect of mix uniformity on processing characteristics in diets for broiler chicks

	Mixing Time, s										
	Corn/Soy					DDGS/Wheat Midds					
Item	0	15	30	60	300	0	15	30	60	300	SE
Mash Temp	77	77	78	75	77	77	77	78	77	77	2
Hot Pellet Temp	87	87	88	86	86	87	88	87	89	88	3
PDI	95.4	95.2	95.4	95.2	95.4	97.3	96.8	96.7	96.7	96.9	0.2
Mod PDI	94.7	94.6	94.4	93.9	94.4	96.9	96.5	96.2	96.3	96.4	0.3
PDI CV	0.87	0.63	0.40	0.63	1.0	0.40	0.67	0.53	0.63	0.40	0.16
Mod PDI CV	0.80	1.0	0.50	1.1	1.1	0.43	0.30	0.60	0.63	0.40	0.22

Table 3.3 Effect of mix uniformity on processing characteristics in diets for broiler chicks, P-values

Item	*Diet*	*Lin*	*Quad*	*Cubic*	*Quartic*	*Diet × Lin*	*Diet × Quad*	*Diet × Cubic*	*Diet × Quartic*
Mash Temp	0.691	0.901	0.633	0.217	0.478	0.969	0.553	0.569	0.959
HPT	0.273	0.641	0.727	0.626	0.918	0.305	0.326	0.432	0.493
PDI	< 0.001	0.991	0.125	0.604	0.410	0.667	0.341	0.342	0.851
Mod PDI	< 0.001	0.702	0.013	0.671	0.929	0.899	0.684	0.261	0.988
PDI CV	0.023	0.217	0.886	0.196	0.993	0.122	0.062	0.322	0.498
Mod PDI CV	0.007	0.490	0.419	0.439	0.528	0.338	0.635	0.582	0.097

Table 3.4 Effects of mix uniformity in diets without or with high inclusion of alternative ingredients on growth performance and carcass measurement in broiler chicks [1]

	Mixing Time, s										
	Corn/Soy					DDGS/Wheat Midds					
Item	0	15	30	60	300	0	15	30	60	300	SE
CV for salt, %[2]	25.6	14.2	9.4	10.3	8.3	11.2	12.8	7.6	8.0	6.0	1.7
Final BW, g	3,116	3,264	3,182	3,257	3,177	3,207	3,129	3,137	3,209	3,127	45
ADG, g[3]	88	92	90	91	90	91	88	88	91	88	1.3
ADFI, g[3]	142	144	144	143	144	162	159	161	162	154	3.4
G/F, g/kg[3]	621	647	624	639	625	559	552	549	560	571	14
Survival, %[3]	98	97	98	96	98	97	96	97	97	97	1
HCW, g	2,485	2,521	2,496	2,506	2,498	2,488	2,494	2,478	2,472	2,479	18
Dressing %[4]	75.3	76.4	75.7	76.0	75.7	75.4	75.6	75.1	74.9	75.1	0.5
Breast wt. g[4]	780	780	773	785	779	796	777	784	779	804	11
Leg wt., g[4]	735	737	740	740	727	710	712	733	720	719	8.7

[1]A total of 1,610 male broiler chicks (initial age of 14-d, 23 bird/pen and 7 pens/treatment) were used in a 32-d growth assay.
[2]Salt concentration determined using 10 samples from each batch of feed, starting with the 2nd bag and every other one thereafter.
[3]Initial body weight used as a covariate.
[4]Live weight used as a covariate.

Table 3.5 Effects of mix uniformity in diets without or with high inclusion of alternative ingredients on growth performance and carcass measurements in broiler chicks, P-values [1]

Item	*Diet*	*Lin*	*Quad*	*Cubic*	*Quartic*	*Diet × Lin*	*Diet × Quad*	*Diet × Cubic*	*Diet × Quartic*
CV for salt, %[2]	<0.001	<0.001	<0.001	<0.001	0.929	0.032	<0.001	<0.001	0.046
Final BW, g	0.203	0.473	0.136	0.509	0.274	0.692	0.323	0.109	0.121
ADG, g[3]	0.191	0.605	0.173	0.472	0.511	0.576	0.610	0.064	0.143
ADFI, g[3]	< 0.001	0.265	0.578	0.953	0.706	0.180	0.725	0.477	0.663
G/F, g/kg[3]	< 0.001	0.635	0.717	0.805	0.298	0.316	0.589	0.528	0.359
Survival, %[3]	0.379	0.741	0.755	0.824	0.391	0.995	0.569	0.783	0.526
HCW, g	0.134	0.757	0.856	0.604	0.231	0.870	0.381	0.772	0.593
Dressing %[4]	0.120	0.735	0.890	0.644	0.233	0.871	0.366	0.740	0.607
Breast wt., g[4]	0.221	0.291	0.506	0.404	0.785	0.302	0.305	0.977	0.332
Leg wt., g[4]	0.005	0.543	0.221	0.321	0.349	0.379	0.746	0.457	0.392

[1]A total of 1,610 male broiler chicks (initial age of 14-d, 23 bird/pen and 7 pens/treatment) were used in a 32-d growth assay.
[2]Salt concentration determined using 10 samples from each batch of feed, starting with the 2nd bag and every other one thereafter.
[3]Initial body weight used as a covariate.
[4]Live weight used as a covariate.