Effect of Bio-Mos® and outdoor access housing on pig growth, feed efficiency, health, behavior and carcass ultrasound traits

THESIS

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Abstract

The increase of niche marketing opportunities and also of antibiotic regulation dictates the need for alternatives to antibiotic growth promoters for use in grower/finisher pigs. This project consisted of experiments regarding both live animal growth and efficiency measures, as well as evaluations of pig health, and finally analysis of fecal populations for differences in antibiotic resistance genes. We utilized a high health swine herd and evaluated the effect of Bio-Mos® at 0.2%, 0.1% and 0.05% inclusion rates for 3 feeding phases, respectively, and outdoor access housing when compared with tetracycline and control diets, and conventional indoor housing on pig growth, feed efficiency, hematocrit, lesions, carcass ultrasounds and observed activities over 2 farrowing groups. Outdoor access housing (OUT) increased ADG 0.04 kg/d (P < 0.0005), ADFI 0.1 kg/d (P = 0.01) and decreased G:F by 0.01 kg gain/kg feed (P = 0.05) and days to 113.6 kg by 4 days (P < 0.0005) when compared to indoor housing (IN). Bio-Mos® (BM) and Control (C) diets increased ADG 0.02 kg/d (P < 0.05) and decreased days to 113.6 kg by 3 days (P < 0.05) when compared to Antibiotic (AB) diets. There were no treatment effects on carcass ultrasounds. Outdoor housing increased hematocrit by 1 (P < 0.05) consistently over the trial while diet had no effect on hematocrit. With respect to increasing demand for antibiotic-free pork, the dietary treatments compared in the present study give perspective on the future promise of Bio-Mos® inclusion as an antibiotic replacement in systems with high herd health.
To my wife. Amanda.

Your love, support and patience have carried me through this endeavor.

Thank you.
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Chapter 1: Introduction

BACKGROUND

In a rapidly changing global pork market, there is rising consumer interest in alternative production methods, in both domestic and export markets (Gentry & McGlone, 2003; Honeyman et al., 2006; Lammers, Stender & Honeyman, 2007). These alternative methods include free-range, outdoor access and pasture housing systems, as well as antimicrobial-free, pasture, natural and certified organic management. A goal of the present research study was to add scientific knowledge of key animal measures of growth, efficiency, and welfare as they relate to the production of pigs under near-organic or antibiotic-free production standards and to identify areas within organic production which might be altered or improved for greater growth rate and efficiency when compared with current organic production standards. An objective of the present study was to evaluate the influence of antibiotic free and an organic-alternative feed additive on production efficiency and cost, animal well-being and food safety when compared with the feeding of a common, sub-therapeutic antimicrobial in grower-finisher pigs. A second objective was to evaluate the influence of dietary treatments in conventional, indoor confinement housing when compared with contemporary pigs housed in facilities with outdoor access. Alternatives to dietary antimicrobial use and the influence of housing system are controversial topics that are debated as to the economic value and viability of
organic production, the environmental and animal welfare impacts of organic production, and the most efficient way to produce pork organically or antibiotic-free if the market or a future governmental intervention might mandate such a production system.

Changes in Historical Pork Production

Authors and researchers agree on one fact—the number of pig farms in the U.S. has been in decline and the pig inventory within existing farms and annual production have been on the rise since the mid-1900s. Cromwell and Hays (1999) reported the number of hog farms has declined from 645,000 in 1969 to under 200,000 in 1999. United States pork production has changed most dramatically since the early 1990’s. The United States Department of Agriculture (USDA) Economic Research Service states that between 1992 and 2004 alone, the number of pig farms decreased by 70 percent, from 240,000 to less than 70,000 while the pig inventory held steady (Key & McBride, 2007). Pork production has transitioned from mostly small-scale production systems into large-scale production which has more specialized buildings or sites for one or two aspects of pork production such as farrowing and weaning, or growing and finishing (Key & McBride, 2007). In 2006, 29% of farms were wean to finish, 32% were purchasing replacement gilts, 35% were growing their own grain and 94% were feeding pigs indoors (Lawrence & Grimes, 2007). Average farm size has increased in terms of total animal units per farm as production has become more focused on efficiency and reduced unit cost of production (Key & McBride, 2007). The number of large and very large farm operations (50,000+ hogs marketed annually and 500,000+ hogs marketed annually) has tripled since 1994 (Lawrence & Grimes, 2007). This trend has resulted in a decreased
number of total farms, but has increased the total number of pigs grown and harvested annually in the United States. Pressures for increased environmental control and regulation, improved animal care, and the decreased relative cost of food in the U.S. have been driving factors behind these changes (Key & McBride, 2007). Larger producers are also more likely to use marketing contracts (Lawrence & Grimes, 2007), which create a more predictable market value and assures market access. Pig operations are also more likely compartmentalized for gestation and farrowing, with separate nursery and finishing in order to better utilize space, employee training and resources (Key & McBride, 2007). The use of artificial insemination has increased among farms of all sizes (Lawrence & Grimes, 2007), improving genetic selection opportunity for breeders and the average number litters born per sow per year (Key & McBride, 2007). In the 2006 study, disease and health management, compliance with environmental regulations, and operation productivity were the top concerns among U.S. hog producers (Lawrence & Grimes, 2007).

Globally, the U.S. ranks 3rd in pork production and is also 3rd in domestic pork consumption (USDA-ERS, 2009) (Figure 1). U.S. production in 2012 is forecasted to be similar at 10.5 million tons, 20% of China’s total and 50% of the European Union’s projected totals (USDA-FAS, 2012; USDA-FAS, 2011; USDA-FAS, 2010). Pork ranks as the 3rd most consumed meat product behind beef and chicken in the U. S. (USDA-ERS, 2009). In 2010, the U.S. pig inventory was 64.3 million pigs annually, with 115 million harvested (USDA-NASS, 2011). Globally, the U.S. exports rank 1st with 2.1
million tons of pork forecasted for 2012 (USDA-FAS, 2012). Japan, Mexico and Canada are the U.S.’s largest importers (USDA-ERS, 2009).

Domestically, the leading states for pig inventory are Iowa (19.3 million), North Carolina (10.1 million) and Minnesota (7.7 million) (USDA-NASS, 2008a) (USDA-ERS, 2009), and this is influenced heavily by the close proximity of cost effective, available feedstuffs and ready access to facilities for harvesting and processing pigs and pork products.

**Recent Consumer-Driven Market Changes**

Urbanization has gradually moved consumers of agricultural products further away from a knowledge and experience perspective as well as geographically from the sources of food production and placed farming practices out of their minds. However, improved transportation infrastructure has allowed timely delivery and decreased relative transportation costs per unit, and, coupled with improved food processing and storage options, has enabled consumers to express purchasing power preference for food items. Many niche markets have developed that are oriented towards capitalizing on targeted segments of consumers who have a desire for perceived healthful food; one of these markets being organic products and organic pork production in particular.

Health and healthy eating is a critical component of consumer food choices. Consumers have demonstrated increased concern over origin of food and methods involved in its production (Scholderer et al., 2004), including the use of feed grade antibiotics. Fears that the use of antibiotics in food animal production may be leading to an increased prevalence of antibiotic resistant pathogens have not been scientifically
confirmed, but the theoretical possibility of antibiotic usage in animal production leading to drug resistant pathogens infecting humans might have been influential in antibiotic bans, most notably in Denmark (Casewell et al., 2003). Although the advantages in growth performance from feed-grade antibiotic use are well documented (Carlson & Fangman, 2000; McEwan & Fedork-Cray, 2002; Casewell et al., 2003; Zimmerman, 1986), there is growing opposition to their use in animal feed within the U.S. Consumers are beginning to show increased preference for niche production methods (Gentry & McGlone, 2003; Honeyman et al., 2006; Lammers, Stender & Honeyman, 2007) that reflect either their health preferences or moral viewpoints, such as antibiotic-free, hormone-free, free-range, humanely-raised, and organic production methods. The need for standardization of terminology led the USDA to publish and regulate guidelines for some more prevalent alternative production methods to protect consumers from false product claims. Antibiotic-free production is now labeled with a “no antibiotics added” label (USDA-FSIS, 2011). Hormone-based growth and efficiency promoting agents are not legal in U.S. pork production; therefore, there is no label for hormone-free (USDA-FSIS, 2011). Free-range is defined as being given access to the outdoors (USDA-FSIS, 2011). Natural meat is simply defined as containing no artificial ingredients and being minimally processed (USDA-FSIS, 2011), thus including nearly all products in a retail meat case and there is no “natural” label for animal production. Currently, humanely-raised labeling is conducted by privately certified organizations which have taken on the role of auditing farms and selling their seal of approval (USDA-FSIS, 2011). Finally, organic production methods are well defined, including rules that animals cannot be fed
antibiotics, similar to antibiotic-free systems, but including further regulations as well.
The USDA has regulated the organic certification process since 1990 (Mikel, 1998).

**Historical Organic Farming**

Organic farming is not new but rather precludes the rise of industrialized agriculture. Writers, as early as 50 A.D., have supported sustainable agriculture with methods that are closely and historically tied to modern organic production (Gold & Gates, 2008). Sir Albert Howard is considered to be the founder of the organic “movement” in the mid-1900s, publishing his opinions on recycling waste in balance with production outcomes (Heckman, 2005). The organic point of view was also closely tied with the environmental movements of the 1960s and 1970s as concerned citizens tried to influence farmers to naturally control and improve their production environments (Gold & Gates, 2008) without the use of synthetic chemicals. Organic regulations in Europe stemmed from third-party certification audits, eventually becoming the first legal definitions of organic farming. The organic farming regulation would undergo many additions and revisions prior to incorporation into the regulatory body of the European Union (EEC, 1991). Jerome Rodale brought the modern organic ideals into the U.S. (Heckman, 2005) and the organic movement gained momentum in the U.S. marked by the publication of *Report and Recommendations on Organic Farming* in 1980 by the USDA (Heckman, 2005) and by the passage of the 1990 Organic Foods Production Act (Mikel, 1998). Proponents of organic production cite the healthfulness of organic foods and a preference for a return to traditional livestock raising methods, in hope of bettering
the welfare of the animals raised through animal housing requirements such as outdoor access and reduced intensity of production.

Since 1990, U.S. organic farming in general has grown in importance as a niche market; tripling growth estimates for the past decade (Mikel, 1998) and recently reporting a $24 billion market (OTA, 2010). However, organic pork production is a small fraction of U.S. production, currently representing a mere 0.01% of total U.S. pork (OTA, 2010; USDA-NASS, 2008a; USDA-NASS, 2008b). Iowa leads the U.S. in organic-production pig inventory (3,413 pigs in 2008), while Wisconsin leads the U.S. in total number of organic pig farms (32 farms in 2008) (OTA, 2010; USDA-NASS, 2008b). National organic pig inventory estimates included 8,940 pigs on 258 farms (OTA, 2010; USDA-NASS, 2008b).

Survey data characterizing organic farmers is sparse, with the most recent national survey completed by Walz in 2004. Walz (2004) reported 94% of organic farmers work in a family-based operation. Seventy-five percent of farmers used word-of-mouth for marketing and only 48% used a Certified Organic label (Walz, 2004). Market expansion was reported in 44% of survey respondents (Walz, 2004). One-fifth of organic farmers raise livestock, selling 32% of this livestock in a value-added market; and 47% sell livestock products more than 500 miles away from the origin of production (Walz, 2004). A common challenge contributing to the distance between origin and markets is the scarcity and location of organically certified harvest facilities. In 2012, Ohio reported only one organically certified harvest facility was in operation. Finally, according to
survey data, approximately 50% of organic pork production farms were derived from a modified conventional facility (Walz, 2004).

**USDA Certified Organic Pork**

Current legislation regulating organic pork production and pork products is limited in scope, as it is still a relatively new facet in U.S. pork production. As organic pork production numbers grow, amendments to existing regulations may be necessary. The USDA considers organic pork production to be one aspect of a broader category, sustainable agriculture, which was included in the 1990 Farm Bill, the same year as the implementation of the Organic Foods Production Act (1990) which officially established the national organic program in the U.S. (USDA, 1990).

**Differences Between Organic and Conventional Pork Production**

Organic and conventional pig production methods generally differ in terms of housing, diet and health protocols. Organically raised pigs must be provided with a greater minimum indoor space allocation when compared with conventionally grown pigs and must be provided with outdoor access (available at the discretion of the farmer based on his/her perception of the adequacy of weather conditions). In the U.S., the recent minimum recommended space for finisher pigs raised in facilities with indoor-outdoor access, at or near a standard 110 to 115 kg market weight is 0.6 m\(^2\) inside (NSOB, 2011), slightly less than National Pork Board recommendations at 0.75 m\(^2\) for conventionally housed pigs (NPB, 2003), but also includes 0.3 m\(^2\) outside (NOSB, 2011), ultimately totaling 0.9 m\(^2\) per pig.
Feedstuffs cannot be from genetically modified organisms (GMOs), byproducts from animal origin, or byproducts of grain processing, and must be derived from sources meeting organic certification standards (Mikel, 1998; U.S. Govt., 2011b), which limits feedstuff availability and increases the cost of these feedstuffs dramatically. Additions of synthetic amino acids to diets are not allowed, leading to challenges for balancing amino acid levels to meet the pigs’ requirements. The use of atypical feedstuffs is common in an attempt to balance or meet minimal amino acid requirements, further contributing to the cost of feeding organic pigs. Feed additives and supplements are disallowed above that which is required for adequate nutrition (Mikel, 1998; U.S. Govt., 2011b) but this is vague and not clearly defined for implementation.

In organic animal production systems antibiotics are disallowed, as are the use of synthetic pesticides (Mikel, 1998; U.S. Govt., 2011b). Vaccinations are permitted in organic pork production systems if preventative for diseases known to affect pigs in a given region, and owners are obligated to appropriately treat pigs with a health condition (Mikel, 1998). However, any pig treated with antibiotics or synthetic medications prohibits their sale under the organic label (Mikel, 1998; U.S. Govt., 2011b). Further, sows are required to be raised using organic care and feeding from the last trimester of gestation in order for their offspring to be considered eligible for organic labeling (Mikel, 1998; U.S. Govt., 2011b). Shelter must be provided to animals, as well as outdoor access and exposure to sunlight (Mikel, 1998; U.S. Govt., 2011b). Operations are certified over a multi-year application process and after completing certification and meeting the
requirements of pending unscheduled recheck visits, may use the organic label (Mikel, 1998; U.S. Govt., 2011b).

**Antibiotic Legislation**

With the increased identification of genes inferring antibiotic resistance and the increased prevalence of drug resistant pathogens in human medicine, there has been pressure to regulate the use of antibiotics in the conventional livestock production sector. In the U.S., this pressure has been mainly been driven via consumer priorities for antibiotic-free products, including organic meat, and large purchasers such as McDonald’s requiring reduced antibiotic usage by their suppliers and removal of feed-grade antibiotics in livestock which are also approved for human medicine (McDonald’s Corporation, 2010). There is recent legislative movement toward placing additional restrictions on antibiotic use in food animal production within the U.S. including the introduction of HR965, “The Preservation of Antibiotics for Medical Treatment Act”, reintroduced in March, 2011 (U.S. Govt., 2011a). The proposed bill would focus on removing antibiotics from farm use which also qualify for use in human medicine. United States Food and Drug Administration (FDA) research and review of literature over the past few decades did not find significant supportive evidence that antibiotic usage in animal production was contributing to the antibiotic-resistant bacteria concerns encountered in hospitals (FDA, 2011). The FDA position on the issue is a non-binding recommendation to reduce antibiotic usage in both animal and human medicine (FDA, 2012). Discussion of removal of antibiotics from food animal production in the U.S.
continues to receive staunch disapproval, most recently from the American Veterinary Medical Association (Carlson, 2011).

Denmark banned the use of sub-therapeutic antibiotic inclusion in pig diets in 1999 (Massow & Ebner, 2010). The Danish ban slightly reduced antibiotic resistance among monitored bacteria on farms (Cervantes, 2005). The EU banned the first antibiotic in 1997, subsequently banning additional antibiotics and culminating in a full ban on sub-therapeutic antibiotic usage in food animal production in 2006 (Cervantes, 2005). South Korea announced a ban on the use of antibiotics in animal feed beginning in July of 2011, a movement that may have a larger impact on U.S. exports.

Research indicates that antibiotic use contributes to antibiotic resistance (Gellin et al., 1989; Thakur & Gebreyes, 2005; Gebreyes, Thakur & Morrow, 2006; Akwar et al., 2008; Varga et al., 2009). However, Denmark did not experience a significant decline in antibiotic resistance at the human level from removal of antibiotics in animal feed (Casewell et al., 2003; Cervantes, 2005). In Denmark, total antibiotic use declined from over 200 tons (1994) to 128 tons (2008) whereas, the amount used for therapeutic treatment increased by 40% after the ban took effect (Massow & Ebner, 2010). Further, the antibiotic resistance observed in Danish hospitals after the ban was not different from before the ban in 1994 to after the ban in 2008, indicating that there are more factors involved in the resistance issue than solely the use of sub-therapeutic antibiotics in animal feed (Massow & Ebner, 2010).

Also important is the potential increase in total pathogenic bacteria present among animals and meat products after a ban or removal is in place. Antibiotic-free systems
have been shown to have an increased presence of pathogenic bacteria when compared with antibiotic-using systems (Thakur & Gebreyes, 2005; Gebreyes, Thakur & Morrow, 2006; Gebreyes et al., 2008) although this is not always true (Rollo et al., 2010; Tadesse et al., 2011). This increase in bacteria poses a food safety risk to human health (Cervantes, 2005). Hayes and Jensen (2003) also argued that the removal of antibiotics from the finisher stage of Danish pork production, which occurred in the initial years of the ban, had little economic impact or pig disease impact, but the subsequent ban of antibiotics at the weaning stage of production in the year 2000 increased piglet morbidity and mortality (Hayes & Jensen, 2003).

**Increased Cost of Production for Organic Pork**

It is generally accepted that organic pork has a higher cost of production. Increased space requirements and additional management considerations for rearing pigs with outdoor access will increase the construction cost of facilities and labor. In addition, the cost of feed inputs is greater and value of carcasses reduced in organic production as confirmed by Sundrum et al. (2000) who reported a carcass value reduction of 6.7% and overall profit reduction of 30.7% when comparing organic feeding with conventional feeding. These findings illustrate the subsequent need for a higher value market for organic pork in order to justify adaption to this system.
ORGANIC FEED

Cost Comparison of Organic and Conventional Feed Ingredients

A central stipulation for pigs to qualify for organic certification is the use of organic feed ingredients. Organic grain production in the U.S. represents only 0.4% of total harvested acreage (Gianessi & Rinkus, 2010; USDA-NASS, 2008b) and thus is logically more expensive with a limited supply available. Contributing to the increased cost of certified organic feedstuffs are the prohibition of genetically modified varieties, pesticides, and fertilizers that increase the probability of increased yields in conventional crop production. Organic feedstuffs are commercially available from growers nationwide, including all major cereal grains, beans and peas; however, unfavorable distribution logistics for inclusion in animal diets can reduce local availability or increase costs when transportation costs are accounted for in diet costs.

End of year cost reports for organic grains reported by the USDA in 2011 indicate organic grains were much higher in cost per unit than conventional grains. Nationally, organic corn was priced at $11.31 per bushel and organic soybeans at $20.12 per bushel (USDA-MNS, 2011) (Figure 2). July of 2012 price reports show that organic corn was priced at up to $11.50 per bushel and soybeans up to $27.00 per bushel (Rodale Institute, 2012). These prices stand in stark contrast to the values of similar conventional feedstuffs in the market end of year report (USDA-MNS, 2011). Conventional corn was priced at $6.60 per bushel and soybeans at $11.94 per bushel (USDA-MNS, 2011). In July, 2012, corn was reported as $7.61 per bushel and soybeans as $16.07 per bushel (USDA-MSN, 2012). With organic corn being nearly $4.00 more per bushel and organic soybeans being
approximately $11.00 more per bushel, the direct impact of feeding organic feedstuffs on the cost of pork production is clear (Figure 2). The increased cost of producing organic feedstuffs can be associated with decreased yields due to a reduced ability to control pests and weeds, and the inability to utilize modern hybrids and fertilizer programs. With global grain usage negating increased yields, the price differential between organic and conventional feedstuffs costs are not expected to ease in the near future.

Another consideration in the cost scheme for organic production is the restrictions on the use of synthetic amino acids and animal-based feedstuffs in feed for organically feed animals. Diet costs are thus increased when protein and energy balance can only be achieved using grown feedstuffs. An additional challenge using crude protein instead of synthetic amino acids is a greater loss of nitrogen in the feces which can contribute to negative environmental implications.

**Increased Labor and Time for Organic Crops**

One contributor to the increase of cost for organic crops is time. A leader in organic systems research in the mid-1900s, Howard argued that a true comparison of crops would take 10 years, including 5 years to switch systems, and should take into account the ecology of the soil, not just yields (Heckman, 2005). Pimentel et al. (2005) performed a 22-year analysis on harvest data from Rodale Institute’s Farming Systems Trial, which compared three methods of cropping: conventional, animal manure based organic, and legume-based organic. They reported that the first five years of conversion to organic resulted in decreased corn yields among organic systems (4222 and 4743 kg/ha) when compared with conventional corn yields (5903 kg/ha) (Pimentel et al.,
To balance soil nutrients, organic corn was then grown less often than conventional corn, resulting in decreased grain yields in the long term (Pimental et al., 2005. They also reported a 35% increase in labor hours in organic systems, although the time requirement was more evenly spread throughout the year (Pimental et al., 2005). Energy inputs for corn production were significantly decreased for animal manure organic (28%) and legume-based organic corn production (32%) when compared with conventional corn production (Pimental et al., 2005). There were no significant differences in energy inputs for soybean production (Pimental et al., 2005).

**Organic Crop Yields**

Reports generally agree that organic crop yields are significantly reduced when compared with conventional treatments. In research trials for corn, reductions were from 5% to 28% (Clark et al., 1999; USDA-NASS, 2008b), in soybeans reductions were 34% (USDA-NASS, 2008b), in oats yields were reduced 14% to 29% (Entz et al., 2003; USDA-NASS, 2008b), in barley from 25% (Entz et al., 2003), and in wheat reductions were from 10% to 50% (Mäder et al., 2002; Entz et al., 2003; Mazzoncini et al., 2007; USDA-NASS, 2008b). Some projects have reported equivalent yields in specific years, but also an overall loss of yields over time due to increased crop rotation and the fallow years when growing corn (Poudel et al., 2002; Pimental et al., 2005) or wheat (Clark et al., 1999; Poudel et al., 2002). However, the amount of difference between treatments tends to be variable and related to specific climate and year, and could be related to soil types, although these were not reported. A survey of EU organic production reported that
organic yields were reduced by an average of 60% to 70% when compared to conventional yields (Offermann & Nieberg, 2000).

Clark and colleagues cited weed control as a major problem in their organic corn plots (Clark et al., 1999). As reported previously, organic grain yields on the Rodale Institute’s Farming Systems Trial were significantly reduced over time due to the increased need for crop rotation and recuperation of the soil (Pimental et al., 2005). However, organic corn far out-produced conventional corn during a five-year period of drought, yielding 28% greater for animal manure organic and 34% greater for legume-based organic (Pimental et al., 2005). Organic soybean yields were also significantly greater than conventional yields during the drought period of five years, 100% greater for animal manure organic and 56% greater for legume-based organic (Pimental et al., 2005). This might possibly be due to better water availability and decreased soil compaction in the organic plots; water percolation was reported at 20% and 15% greater in the animal manure organic and legume-based organic treatments, respectively, when compared with the conventional treatments (Pimental et al., 2005).

**Organic Grain Quality**

Although yield is a limiting factor of organic grain production, grain nutrient composition is not frequently reported to be different. Organic grain has been shown to be more highly variable in nutrients (Jacob, 2009) but not statistically different from conventional grain for protein (Jacob, 2009), amino acids (Mäder et al., 2007; Jacob, 2009), or fatty acids (Jacob, 2009). Mäder et al. (2007) did report increased total protein content in organic wheat while Mazzoncini et al. (2007) reported decreased protein
content and 0.5% decreased nitrogen. Kokornaczyk et al. (2008) reported a 42% decreased protein content in organic wheat (P<0.05).

Mycotoxins are also a grain quality consideration, and no significant differences have been reported in two studies that measured trichothecenes deoxynivalenol and nivalenol in wheat (Mäder et al., 2007) or fusarium, trichothecenes and zearalenone in wheat (Edwards, 2009). While there was a significant difference in the presence of some toxins based on location and year (Edwards, 2009), this is to be expected due to variable weather conditions in a wet, temperate climate.

**ORGANIC PORK QUALITY**

Many research papers have evaluated the impact of organic production systems on pork quality or have separated the effects into housing or diet. Because quality is influenced by many other aspects of production such as length of feeding, breed, genetics and sex, it is difficult to attribute characteristics as stemming from organic production. However, it can generally be said that while composition does not change dramatically, feeding in pasture settings or with forage can change the fatty acid composition balance. Carcass composition, in terms of lean and fat content, has been shown to be more a function of days on feed, genetics and adequacy of diets used rather than production system.

*Organic Systems*

In a survey of Swedish organic pigs, they were found to be fatter than conventional counterparts (Hannson et al., 2000). Further research showed that there
were no significant differences in hot carcass weight (Kelly et al., 2007), hot carcass yield (Kelly et al., 2007), backfat thickness (Hansen et al., 2006; Kelly et al., 2007), carcass lean percentages (Hansen et al., 2006; Kelly et al., 2007), percent IMF (Hansen et al., 2006), pH (Hansen et al., 2006), drip loss (Hansen et al., 2006), CIE L,a, and b (Hansen et al., 2006) or fatty acid profile (Hansen et al., 2006). Organically reared pigs did produce carcasses with 50% less vitamin A (P<0.01) (Hansen et al., 2006) although the importance of this measurement is questionable.

**Organic Housing Standards**

Housing meeting organic standards has been reported to have variable effects on carcass composition and pork quality, largely because of the variability in conditions including pasture environments, housing densities, and housing designs. Housing meeting organic certification standards has been shown to increase lean by 0.5% to 0.1% (Sather et al., 1997) but in other studies had no effect (Hoffman et al., 2003) or resulted in a 2% decrease in lean percentage. Some studies indicate no effect on dressing percentage (Hamilton et al., 2001; Guy et al., 2002; Hoffman et al., 2003; Lebret et al., 2006). Housing under organic standards had no effect on backfat (Sather et al., 1997; Hoffman et al., 2003; Gentry et al., 2004) or loin eye area (Hamilton et al., 2001; Gentry et al., 2002; Gentry et al., 2004). In contrast, carcasses of pigs housed under organic housing standards have been reported to have increased backfat (0.8 cm, P=0.04) thickness (Gentry et al., 2002).

Rearing pigs in housing meeting organic standards resulted in no significant differences for pH (Hamilton et al., 2001; Gentry et al., 2002; Gentry et al., 2004; Lebret
et al., 2006), drip loss (Hamilton et al., 2001; Hoffman et al., 2003) cooking loss (Hamilton et al., 2001; Hoffman et al., 2003) or shear force (Hamilton et al., 2001; Hoffman et al., 2003). Lebret et al. (2006) reported a 1% (P<0.01) greater drip loss in pigs reared in housing meeting organic standard. In another study shear force was increased 0.2 kg (P=0.04) (Gentry et al., 2002).

Housing meeting organic standards has been reported to have no influence on subjective loin color score (Hamilton et al., 2001; Gentry et al., 2004). However, loins from pigs reared in housing meeting organic standards exhibited a 2.4 to 2.5 unit greater (paler) objective L* value (P < 0.05) (Hamilton et al., 2001; Gentry et al., 2002) with no effect on a* and b* values (Hamilton et al., 2001; Gentry et al., 2002). In other cases, L* and b* values were not changed when pigs were housed to meet organic standards (Hoffman et al., 2003; Gentry et al., 2004) but a* value was reported as 0.65 units greater (P<0.01, Hoffman et al., 2003) and 1.6 units less (P<0.05, Gentry et al., 2004). Lebret et al. (2006) reported that meat from pigs reared to meet organic housing standards was not different for L* and a* but increased b* by 0.7 units (P<0.01). Housing meeting organic standards had no effect on saturated (SFAs) or monounsaturated fatty acid (MUFAs) content of meat but increased polyunsaturated fatty acids (PUFAs) by 6.2% (P=0.0001) (Hoffman et al., 2003).

Organic Diet

Organic diet generally has no effect on pork quality, except in cases where unique feedstuffs or pasture were used to provide supplemental protein for a balanced amino acid composition of the diet. Organic diet had no effect on dressing percentage.
(Sundrum et al., 2000), percent lean (Sundrum et al., 2000) or lean-to-fat ratio (Sundrum et al., 2000). Further, organic diet did not affect backfat thickness (Sundrum et al., 2000) or loin muscle area (Sundrum et al., 2000). Organic diet did not affect CIE L, a, or b color criteria (Hansen et al., 2006).

**Consumer Preference**

Most published organic pork consumer taste preference tests have been conducted in Europe over the past decade. It would be desirable to include U.S.-based consumer preference testing in this literature review but this is limited in availability. More tests on consumer preference for labels and comparing this label preference when compared with actual eating preference are needed.

Consumers, when provided labels and label claims, expect a better product when it is labeled as organic, free-range or similar (Scholderer et al., 2004) and they report improved eating experiences for taste, tenderness, juiciness and overall acceptability (Scholderer et al., 2004) when compared with pork from conventionally reared pigs. However, when consumers are subjected to a blinded test design with no labels or label claims, they do not distinguish the difference as clearly (Jonsäll et al., 2002), even preferring conventional pork for taste and choosing the opposite of what they preferred when a label was present. Conventional pork scored greater than organic pork for taste, juiciness, and overall acceptability (Scholderer et al., 2004) when origin was not shown. It is important to realize that while these results are significantly different, they represent minuscule and biologically insignificant decimal differences on a scale of 1-7. The
largest change was willingness to pay for organic label being 0.35 greater than conventionally labeled pork.

Within trained sensory panels, pork from pigs meeting organic standards scored lower for juiciness (Jonsäll et al., 2002; Lebret et al., 2006) when compared with conventional samples and also scored greater for crumbliness when compared with conventional samples (Jonsäll et al., 2002). Hansen et al (2006) concluded that the conventional, concentrate-fed pork possessed a less acidic odor than the organic concentrate-fed pork. Outdoor housing resulted in poorer color scores over the period of 4 days ranging from 0.3 to 0.6 on a 6 point scale (P<0.05) (Gentry et al., 2002). Lebret et al. (2006) reported no significant differences between housing treatments regarding sensory analysis of normal and abnormal fat odor, normal and abnormal lean odor, tenderness and flavor.

GROWTH AND EFFICIENCY MEASURES

Growth and efficiency measures are a combination of traits that include average daily gain, average daily feed intake and feed conversion efficiency. A summary of the literature indicates, in general, that pigs fed under organic standards do not exhibit the consistency of growth or efficiency when compared with pigs reared in conventional settings, with large inter-trial variation reported.

Organic Systems Analyses

In a whole system setting, organic production was not found to have an effect on average daily gain (ADG) (Millet et al., 2004; Millet et al., 2005), average daily feed
intake (ADFI) (Millet et al., 2004) or feed efficiency (FE) (Millet et al., 2004; Millet et al., 2005). However, Millet et al. (2005) did report increased ADFI (200 g/day; P < 0.005) in the second feeding phase of a three-phase finishing system. Hansen et al. (2006) reported that pigs fed under organic standards had increased ADG by 64 g/day (P < 0.05) for the entire finishing phase when compared with commercial standards.

**Organic Housing Analyses**

Feed intake (ADFI) is generally a driver of both ADG and FE outputs. Studies evaluating the impact of organic housing conditions on ADFI have reported an increased ADFI ranging from 0.23 to 0.29 kg/day (Gentry et al., 2004; Millet et al., 2004; Millet et al., 2005; Lebret et al., 2006) while one study (Gentry et al., 2002) noted no change in ADFI (Gentry et al., 2002).

Organic housing studies have reported variable influences on pig production parameters. Sather et al. (1997) reported that organically housed pigs required an additional 16 days to reach market weight, while additional studies have reported a 7.2 to 8.4 kg heavier pig at the same age on trial (Gentry et al., 2004; Lebret et al., 2006). Hoffman et al. (2003) reported a 7 kg (P < 0.05) reduction in final weight for organically housed pigs, supported by work from others reporting a decreased ADG of 0.09 to 0.15 kg/day (Sather et al., 1997; Hoffman et al., 2003) or no change in ADG (Gentry et al., 2002). In contrast, reports of increased ADG, ranging from 0.09 to 0.11 kg/day (Millet et al., 2004; Millet et al., 2005; Lebret et al., 2006), when pigs were housed under organic standards in the finishing stage of production have been shown.
Organic housing was reported to have no impact on FE (Sather et al., 1997; Millet et al., 2004; Millet et al., 2005), but elsewhere has been reported to result in a decreased FE ranging from 0.02 to 0.4 kg gain/kg feed (Gentry et al., 2002; Gentry et al., 2004).

**Organic Diet Influences**

Millet et al. (2004) reported that feeding diets that meet organic standards had no effect on ADG, ADFI or FE. They confirmed this finding in a subsequent study (Millet et al., 2005).

**BEHAVIORAL AND HEALTH ASPECTS OF OUTDOOR HOUSING**

In a study evaluating pig behavior when comparing outdoor and indoor housing conditions, researchers reported that pigs reared in outdoor housing had a 10-fold increase (P = 0.05) in the time pigs spent standing when compared with contemporaries housed in indoor housing (Rudine et al., 2007). There were no significant differences for walking, sitting, lying, eating, drinking, rooting, oral activity or total activity measured (Rudine et al., 2007). Housing treatment increased lying and drinking activities in indoor system by time interactions (P < 0.05) (Rudine et al., 2007). In a second study, outdoor housed pigs were more likely to walk and root, as determined by count data, when compared to indoor housed pigs (P < 0.05) (Presto et al., 2008). This indicates increasing exploratory and activity overall by outdoor pigs but this has no direct effect on pig health.

Kleinbeck and McGlone (1999) recorded greater concentrations of blood hemoglobin present in piglets born and raised outdoors for 28 days (P < 0.05). This was consistent for three treatment levels of hemoglobin injections at 0 mg, 100 mg and 400
mg of iron dextran. Lymphocyte percentage was also lower for these piglets when reared in outdoor housing and when compared with those in indoor housing (P < 0.01) (Kleinbeck & McGlone, 1999).

In a survey of slaughter pigs, there were significant differences in lesion type and the number of lesions when comparing conventionally- and organically- raised pigs whereby organically-raised pigs had a decreased occurrence of abscesses (0.9%) tail biting (0.9%), pleuritis (5.6%), and liver ascariasis (1.5%) (Hansson et al., 2000). Conventionally-raised pigs yielded carcasses with a decreased incidence of tumours (0.1%), arthritis (0.8%), and arthrosis (0.9%) (Hansson et al., 2000).

Cagienard et al. (2005) identified recumbence, dog sitting and unthrifty appearance to be more likely present in pigs among traditional farms than “animal friendly” farms (P < 0.05). Sunburn was a characteristic only observed, and thus significantly increased, in pigs provided outdoor access (P < 0.05) (Cagienard et al., 2005). Injuries identified during animal examinations were increased foe pigs reared in traditional housing as were tail bites, but pigs inside also were cleaner as defined by less dirt on the body (P < 0.05) (Cagienard et al., 2005). This study did not identify any parasite or pathogenic health differences between housing types, possibly due to what they described as a high health status of all farms visited (Cagienard et al., 2005).

Rudine et al. (2007) reported that pigs reared outdoors pigs had hemoglobin levels 1 g/dL greater when compared with pigs reared in the indoor housing treatment (P<0.005). Hematocrit was also increased by 3% (P < 0.005) in the outdoor housing treatment (Rudine et al., 2007). Pigs were tested for antibody response to sheep red blood
cells and there were no significant differences in immune response observed (Rudine et al., 2007).

**ALTERNATIVES TO ANTIBIOTICS**

*Antibiotic Inclusion in Pig Diets*

In the U.S. pork industry today, it is common to include sub therapeutic concentrations of antibiotics as a form of growth promotion. There is little argument to the fact that antibiotic inclusion in the diet results in improved pig growth performance. Moore et al. (1946) are credited with first discovering that antibiotics can help increase growth rate in young animals (Gordon & Taylor, 1954). Stokstad et al. (1949) found that fermented Vitamin B₁₂ contained an antibiotic (Mathew et al., 2007), and then aureomycin was shown to improve growth rate in the chick (Stokstad & Jukes, 1950) and the pig (Jukes et al., 1950; Gordon & Taylor, 1954). Subsequent experimental findings indicated that aureomycin, streptomycin and penicillin, when added to swine diets, improved pig growth rate by 0.1 to 0.33 lb/day (P<0.05) (Luecke et al., 1951; Hanson et al., 1955).

Today, it is accepted that the addition of antibiotics to pig diets can function in three ways to improve growth rate of the pig. First, the antibiotics promote a bacterial balance that improves digestion and production of absorbable nutrients (Carlson & Fangman, 2000). Second, the antibiotics inhibit populations of bacteria that compete for the available nutrients needed by the pig, especially glucose and amino acids (Carlson & Fangman, 2000; Dibner & Richards, 2005). Lastly, antibiotics restrict intestinal cell wall
growth and reduce the thickness of the intestinal wall, increasing nutrient absorption (Carlson & Fangman, 2000; Dibner & Richards, 2005). Antibiotics fed sub-therapeutically also have the potential to inhibit population growth of pathogenic bacteria, preventing enteric disease, thus, improving growth performance (Carlson & Fangman, 2000; Dibner & Richards, 2005). Because rearing environment and pig or herd health status can have large effects on gut microbial populations, antibiotic-based growth promotion agents can also have different degrees of efficacy when used to improve pig growth and efficiency traits (Dibner & Richards, 2005; Barton, 2000).

In modern pig genetic types and commercial production environments, the inclusion of an antibiotic in pig diets have been reported to improve average daily gain in pigs between 9 and 30% (P < 0.05) (Barton, 2000; Rozeboom et al., 2005), and increased ADFI by 0.04 kg/day (P < 0.05) (Rozeboom et al., 2005). Results were reported to be dependent on the age of the pig, the quality of rearing environment and the quality of care given to the animal.

Antibiotic use in feed has been reported to affect enzyme activity in the digestive system of the young pig, specifically increasing sucrase and lactase activity at 17 days of age, but activity levels returned to normal by day 42 (Collington et al., 1990). In Salmonella challenge trials, feeding antibiotics increased ADFI by 0.04 kg/day, improved growth rate by up to 37%, and improved FE (Burkey et al., 2004; Gebru et al., 2010), when compared with a non-antibiotic control. In contrast, others reported no differences in production parameters (Estienne, Hartsock & Harper, 2005). Chlorate, carbadox and chlortetracycline were reported to decrease pathogen shedding after Salmonella challenge
(Burkey et al., 2004; Gebru et al., 2010). After challenge, carbadox-fed pigs returned to normal rectal temperature sooner (Burkey et al., 2004; Gebru et al., 2010) when compared to pigs not receiving an antibiotic in the feed. Thus, the studies indicate that antibiotics are a valuable resource for farmers as they strive to improve pig health and growth rate, ultimately improving their farm productivity. Increased productivity may lead to increased farm profitability. Removal of feed-grade antibiotics in an organic setting or in conventional production setting in response to consumer demands would represent a significant challenge to maintain optimal pig health and swine enterprise profitability through a reduction in key economic efficiency parameters.

Data released in 2005 by the National Animal Health Monitoring System stated that the primary cause for antibiotic usage in swine production is respiratory disease; 75% of swine farmers in the United States used antibiotics for respiratory disease (USDA-NAHMS, 2006). Further, 43% of farmers used antibiotics to treat entire rooms during cases of pigs sick with respiratory disease (USDA-NAHMS, 2006). Fifty-one percent of farms used a feed additive for growth promotion (USDA-NAHMS, 2006). Of this 51%, 28% used ractopamine, sometimes in addition to antibiotics (USDA-NAHMS, 2006). The 3 primary antibiotics identified as being used for growth promotion in 2005 were bacitracin (25%), tylosin (13%) and chlortetracycline (12%) (USDA-NAHMS, 2006). Overall, 53% of farms used chlortetracycline, 44% used tylosin and 29% used bacitracin either for growth promotion, respiratory disease treatment or disease prevention (USDA-NAHMS, 2006).

**Antibiotic Resistance**

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As early as the implementation of penicillin in human medicine in the 1940s, there were reports of antibiotic resistance (Barton, 2000), especially resistance to food-borne pathogens such as *E. coli* and *Salmonella* (Barton, 2000). Some bacteria are naturally resistant to some antibiotic classes due to natural resistance that has developed through evolution and survival of those bacteria that blocked entry of antibiotics to the cell. Bacterial resistance to antibiotics is typically acquired as a function of 4 methods: inactivation of the antibiotic drug, alteration of the attachment site so that drug cannot bind, a changed metabolic pathway that inhibits the incorporation of the drug, or an increasing efflux of antibiotic. Mutation and survival of mutated resistance genes in bacteria would allow successful colonies to spread resistance genes (Mathew et al., 2007). Bacteria share their genes with other species through conjugation of plasmids or transduction of DNA fragments (Mathew et al., 2007). Transposons also would allow removal of gene fragments and insertions of resistance gene fragments from nearby or host DNA (Mathew et al., 2007).

It is thought that continued exposure to antibiotics through sub-therapeutic usage in animal feed (Starr & Reynolds, 1951; Dibner & Richards, 2005) and in human medicine (Barton, 2000) is a leading cause of antibiotic resistant bacteria today, with the Denmark ban on antibiotic use considered a leading example of the lack of change in the occurrence of bacterial resistance after an antibiotic ban (Casewell et al., 2003; Cervantes, 2005). Total therapeutic drug use in Denmark has risen from 1996 to 2002 by 4,400 kg (5%) (Dibner & Richards, 2005). In the U.S., resistance to antibiotics has been shown to be 313 to 635% greater on farms using antibiotics when compared with farms
that were antibiotic-free (Gellin et al., 1989; Thakur & Gebreyes, 2005; Gebreyes, Thakur & Morrow, 2006; Akwar et al., 2008), although the use of antibiotics has been reported to decrease the total presence of pathogens by 64% (P<0.05) in nursery systems (Thakur & Gebreyes, 2005).

In finisher pigs, antibiotic usage increased antibiotic resistance for some drugs (Gebreyes, Thakur & Morrow, 2006; Akwar et al., 2008) and when testing other drugs had no effect on the population of finisher pigs (Thakur & Gebreyes, 2005; Gebreyes, Thakur & Morrow, 2006). Other research has indicated that the use of antibiotics has resulted in an increased prevalence of Salmonella (up to 362%) when compared with what has been observed on antibiotic-free farms (Gebreyes, Thakur & Morrow, 2006). However, in one study cephalothin resistance was greatest (P < 0.05) on the antibiotic-free farm (Gellin et al., 1989) and a pentaresistance pattern (ampicillin, chloramphenical, streptomycin, sulfamethoxazole and tetracycline) was greater in antibiotic-free systems (P = 0.01) (Gebreyes, Thakur & Morrow, 2006); therefore, resistance is not always directly related to antibiotic use. However, carcasses from antimicrobial-free systems also yielded increased prevalence of Salmonella (+ 221%) when compared to conventional systems (Gebreyes, Thakur & Morrow, 2006).

Further, the removal of antibiotics doesn’t guarantee a reduction in bacterial resistance. Langlois et al. (1983) reported that removal of all antibiotics significantly reduced tetracycline resistance on their research farm from 82% to 42% over a 10.5 year period, with similar results 6 years later (Gellin et al., 1989). Economically, the removal of antibiotics from pork production represents a loss of growth benefits and or health
benefits associated with sub-therapeutic and therapeutic antibiotic use. The reported impact in one field study has been reported to be an average loss of $4.40 per cwt (Main et al., 2010) stemming from a combined negative effect on average daily gain (0.05 lb/d), increased feed to gain ratio (0.19 kg/kg), and an associated increased mortality rate (4.7%). The lost value ($4.40/cwt) signifies a large financial gap if a move is made toward the US being antibiotic-free country.

**ORGANIC ALTERNATIVES TO ANTIBIOTICS IN PIG FEED**

Raising pigs to meet organic production standards will likely require the use of an alternative(s) to antibiotics to improve pig growth and efficiency and ultimately maintain farm productivity. There is an extensive list of alternatives to antibiotics that have been studied, and the list provided below represents a sampling of the alternatives available to producers wishing to rear pigs under organic standards. Phytogenic feed additives, those derived from plant materials, represent a class of compounds gaining substantial interest as alternatives to antibiotics due to claims of antimicrobial activity, improved gut health, improvement of animal feed efficiency and improved growth performance (Windisch et al., 2008; Jacela et al., 2010a). Options include seed cakes, essential oils, herbs and spices (Windisch et al., 2008). The use of probiotic treatment, with live beneficial bacteria, are another viable option for organic producers to increase growth performance (Vondruskova et al., 2010). Lastly, prebiotic treatments focus on nutrition of beneficial bacteria within the gut, and thus control of negative factors associated with gut health, are
an option to be considered for growth performance improvement (Vondruskova et al., 2010).

**Cannabis Sativa**

The use of *Cannabis sativa* for its health benefits in livestock animals has been reported and there is some evidence of limited success. With the advent of legalized medical marijuana production in the United States, this alternative medicine approach offers access to a potential by-product feed ingredient that may meet natural and organic production standards and improve pig health and growth. Hempseed as a protein supplement fed to finisher pigs decreased total tract dry matter digestibility by 4% when compared with rapeseed, linseed and faba bean as protein supplements (P<0.001) (Presto et al., 2011).

**Ginger**

Ginger represents an opportunity for improved pig health through antioxidant properties (Windisch et al., 2008); however, Zhang et al. (2009) found no significant differences in ADFI, ADG, or FE from ginger when fed to growing poultry (Zhang et al., 2009).

**Garlic**

Cullen et al. (2005) found garlic reduced ADFI in pigs by 0.12 kg/day and 0.16 kg/day (P<0.05) when included in the diet at 0.1% and 1% levels, respectively, but improved feed efficiency FE by 0.14 and 0.16 kg feed/kg gain (P<0.05) for the 0.1% and 1% diets, respectively, when compared with the control (Cullen et al., 2005). Feeding
supplemental garlic did not influence ADG; however, feeding a 1% garlic diet altered meat sensory perception by panelists significantly (Cullen et al., 2005).

**Rosemary**

Disk diffusion testing indicated antimicrobial activity of rosemary when tested against *Escherichia coli*, *Salmonella indiana* and *Listeria innocua* (Mathlouthi et al., 2012), but Cullen et al. (2005) found rosemary to be ineffective for altering growth rate, feed efficiency or feed intake in the experiment with grower/finisher pigs. In addition, rosemary addition to feed had no effect on pork sensory characteristics or carcass yield components (Cullen et al., 2005).

**Oregano**

Disk diffusion testing indicated antimicrobial activity of oregano and double the antimicrobial activity when compared with rosemary when tested against *Escherichia coli*, *Salmonella indiana*, *Listeria innocua*, *Staphylococcus aureus* and *Bacillus subtilis* (Mathlouthi et al., 2012). Ragland, Stevenson and Hill (2008) reported that flavomycin-fed pigs grew at 35 g/d (P < 0.05) and the control-fed pigs grew 19 g/d faster (P<0.05) than the pigs provided 1.5% oregano treatment. Reduced growth rates were generally considered to be the result of decreased ADFI (36 g/day (P<0.05)) when comparing the 1.5% oregano to the control and decreased ADFI (68 g/d (P<0.05)) when comparing oregano to flavomycin (Ragland, Stevenson & Hill, 2008). Feed efficiency was not changed by adding oregano in substitution for a control or flavomycin addition (Ragland, Stevenson & Hill, 2008).

**Organic Acids**
Organic acids still lack research justification as a growth promotion alternative to antibiotics (Jacela et al., 2009a), but there is evidence that they might modify pH in the gut (Jacela et al., 2009a) or inhibit bacterial replication (Vondruskove et al., 2010). In some research, improved efficiency and growth performance in young pigs (Jacela et al., 2009a) has been noted. Because the organic acids are typically added directly to the feed before feeding, they can also function to improve feed stability in storage (Vondruskova et al., 2010).

**Copper**

Copper has been shown to improve growth performance when fed at 100 to 250 ppm, more than 20 times normal supplementation, typically provided as copper sulfate (Jacela et al., 2010b). Inclusion of copper at 175 ppm in grower/finisher pigs increased average daily gain in pigs by 0.1 kg/d (P<0.05), and had no effect on ADFI or FE (Davis et al., 2002). Concerns that bacterial co-selection for resistance to both antibiotics and metal should also be considered when using this as an alternative (Baker-Austin et al., 2006).

**Zinc**

Zinc functions to improve immune system response to pathogens and reduces growth of some pathogens (Vondruskova et al., 2010) with possible antimicrobial action in the pig’s gut (Jacela et al., 2010b) (Vondruskova et al., 2010). When fed at levels far in excess of requirements (2000 to 3000 ppm) zinc has been shown to help limit nursery pig diarrhea and thus improve growth rate in young pigs. Recommendations are supplement Zn for only the first 3 weeks after weaning (Jacela et al., 2010b).
Among weaning pigs, zinc chelate, fed at 80 mg/kg, did not result in significant differences in ADG, ADFI or related to changes on gut morphology, but did improve gain to feed ratio by 0.02 kg gain/kg feed (P<0.05) (Castillo et al., 2008). Again, there are further concerns that usage of zinc can lead to co-selection of zinc resistance and antibiotic resistance (Baker-Austin et al., 2006), thereby increasing antibiotic resistance while using an antibiotic alternative.

**Probiotics**

Probiotics consist of live bacterial populations thought to out-compete pathogenic bacteria and improve pig growth performance and health (Vondruskova et al., 2010) (Jacela et al., 2010a). The balance of bacteria offered in the probiotic product can impact the results from the animals in question, as can the age of the animal (Vondruskova et al., 2010). Some of this research is presented below, although research in this field has not yielded clear, concise or consistent results (Jacela et al., 2010a).

Genus *Bacillus* are more focused on out-competing less desirable bacteria for nutrients and supporting the natural bacteria within the gut (Vondruskova et al., 2010). *Bacillus* treatments were found to have no effect on average daily gain (Morrison & Kritas, 2003; Wang et al., 2009), average daily feed intake (Morrison & Kritas, 2003; Alexopoulos et al., 2004; Wang et al., 2009), feed efficiency (Morrison & Kritas, 2003; Wang et al., 2009) or mortality (Morrison and Kritas, 2003; Alexopoulos et al., 2004) when compared to antibiotic-fed pigs or a negative control. In another study, feeding *Bacillus* increased average daily gain by 0.008 to 0.024 kg/day and improved feed efficiency by 0.08 and 0.15 kg feed/kg gain (Alexopoulos et al., 2004). *Bacillus* increased
average daily gain by 0.07 kg/day in nursery pigs (P=0.05) (Estienne, Hartsock & Harper, 2005). When challenged with *Salmonella, Bacillus* treatment increased average daily feed intake 0.231 kg/day (P<0.05), average daily gain 0.128 kg/day (P<0.05), and improved gain to feed ratio 0.44 kg gain/kg feed (P<0.05) when compared to control, but was less than chlortetracycline (Gebru et al., 2010).

**Prebiotics**

Prebiotics consist of short-chain oligosaccharides which are indigestible to the animal but provide nutrition to beneficial bacteria in the intestine (Jacela et al., 2010a) (Vondruskova et al., 2010). By selectively feeding these bacteria, gut health is maintained through advantages over undesirable bacteria and pig growth performance is improved (Vondruskova et al., 2010). It is also thought that they bind to enterocytes and prevent colonization by pathogenic bacteria (Vondruskova et al., 2010). Test results indicated that 64% of *E. coli*, 67% of *Salmonella* spp., 86% of *S. enteritidis*, 70% of *S. typhimurium*, 80% of *Clostridium* spp. and 14% of *Campylobacter* spp. samples agglutinated to Bio-Mos®, a commercially available yeast product, (Kogan & Kocher, 2007) which corroborated previous tests (Spring et al., 2000; Pirvulescu et al., 2000). Although many yeast extract products and mannan oligosaccharide products exist commercially, they are very similar in design and suggested inclusion rates in feed. Data from leading research on the efficacy of prebiotics for antibiotic replacement and as a standalone feed additive will be included in the following section.

In field reports, Bio-Mos® has been shown to have no effect on average daily gain or feed efficiency when compared with sub therapeutic feeding of antibiotics (King,
In contrast, Kavanagh (1999) reported that Bio-Mos® treatment improved average daily gain by 3.5% (P < 0.05) (Dvorak, 1996). Pirvulescu et al. (2000) found Bio-Mos® to have no significant effect on immunoglobulin response to infection, but lymphocyties and inflammatory cytokines were increased by Bio-Mos® diet in response to infection. There is some indication that prebiotics can be successfully combined with acid or probiotics to improve gain and reduce pathogenic populations in the small intestine (White et al., 2002).

Bio-Mos® in nursery pig diets increased average daily gain by 4% to 23% (P < 0.05) (Miguel et al., 2003; Rozeboom et al., 2005; Zhao, Jung & Kim, 2012), increased average daily feed intake by 2% to 15% (P < 0.05) (Miguel et al., 2003; Zhao, Jung & Kim, 2012) and decreased feed to gain ratio of 2% to 8% (P < 0.05) (Miguel et al., 2003; Castillo et al., 2008) when compared to control, and improved average daily gain 0.32 kg/day (P < 0.05) when compared to a commercial probiotic (Keegan et al., 2003a). In 17 comparisons utilizing low growth rate pigs, the effect of feeding Bio-Mos® on average daily gain was greater by 2.8% (P < 0.05) when compared with control-fed pigs. The study further determined that inclusion rates between 0.5% and 0.1% of diet did not have significant impact on the efficacy of Bio-Mos® in feed, while 0.2% and 0.1% of dietary inclusion was most common due to cost efficacy and would represent largest return on investment (Miguel et al., 2003). In other studies, Bio-Mos® has also been shown to have no effect on average daily gain (Davis et al., 2002; Keegan et al., 2003b; Castillo et al., 2008), average daily feed intake (Davis et al., 2002; Keegan et al., 2003b; Castillo et al., 2008), or gain to feed ratio (Davis et al., 2002; Rozeboom et al., 2005).
SUMMARY

We have looked at the pressures on current pork markets, the increased cost of organic production and the alternatives to antibiotics in current literature. It can be concluded that organic feeding presents a more expensive dietary cost but if cost of production is balanced by increased sale price, organic production is economically feasible. Organic grain quality and organic muscle product quality are not scientifically shown to be different in any objective or unbiased measures from consumers or researchers. However, surveyed consumers have indicated preference for presumed quality that they associate with organic products and have indicated some willingness to pay additionally for this improved perceived quality.

With increased domestic demand for restricted use of antibiotics in swine feed and increased market demand for organic production, this represents a valuable niche market for small business livestock agriculture. Many challenges face producers using an organic system, specifically maintaining healthy pigs, achieving commercially comparable growth, and harboring pathogens and possibly antibiotic resistance within the gut microflora.

While many antibiotic alternatives are in circulation, both commercial and homeopathic, this project specifically focused on one alternative which has a strong market presence and limited research in grower/finisher pigs – *Saccharomyces cerevisiae*. With organic approval and indication that of its effectiveness in controlling dynamic microbial population changes in young pigs, Bio-Mos® and its substitutes represent a potential growth promotant and bacterial population control feed additive. More research
into this product and its efficacy in grower/finisher pigs in commercial-type housing systems will indicate more tangible data about its relevance in the future of organic pork production, as well as potential ability within antibiotic-free systems.

There is additionally the challenge of outdoor housing. While some aspects of pig health improve with outdoor housing and increased space allotments, some also decline. Thus, it is necessary to evaluate the trade-offs and consider the whole health and efficiency of the pigs housed in different systems. More importantly, type of outdoor housing can influence the response seen in pigs and controlled experiments which evaluate types of housing in adequate number of experimental units per treatment are needed to fully appreciate the diversity of this response.

The purpose of this project is to determine if Bio-Mos® is a suitable growth promotant available for antibiotic-free systems as well as organic systems in replacement of feed-grade antibiotics. We further hoped to discover if Bio-Mos® could reduce presence of antibiotic resistance genes in populations. Finally, the researchers hoped to discover if Bio-Mos® is effective in promoting good health for grower finisher pigs, and if it had any negative effect on observed activities.
LITERATURE CITED


CHAPTER 2: Effect of mannan oligosaccharide (Bio-Mos®) and housing on pig growth, feed efficiency, carcass composition, health and observed activities

ABSTRACT

The increase of niche marketing opportunities (Lammers, Stender & Honeyman, 2007) and also of antibiotic regulation dictates the need for alternatives to sub-therapeutic antibiotics for use in grower/finisher pigs. The current research evaluated the effects of feeding Bio-Mos® (BM; at 0.2%, 0.1% and 0.05% inclusion rates for phase 1, 2, and 3 diets, respectively), a sub-therapeutic antibiotic (AB; tetracycline) and standard, no additive control (C) diets when fed to pigs housed in both a conventional, indoor (IN) and an indoor with outdoor access (OUT) housing system. Measures of pig growth, feed intake, feed efficiency, blood hematocrit, skin lesion scores, carcass composition, and observed pig activities were measured in two distinct farrowing groups and totaling seven replications. Of note, there were no significant dietary × housing treatment interactions observed in the study. Outdoor access housing increased pig average daily gain (ADG) by 0.04 kg/d (P < 0.0005), average daily feed intake (ADFI) by 0.1 kg/d (P = 0.01), decreased gain per unit of feed (G:F) by 0.01 kg gain/kg feed (P = 0.05), and reduced days to a standard 113.6 kg endpoint (DAYS) by 4.0 days (P < 0.0005) when compared
to pigs reared inside. Feeding the BM and C dietary treatments resulted in increased ADG (0.02 kg/d, P < 0.05) and required 3 fewer days to reach market weight (P < 0.05) when compared with pigs fed the AB diet. Neither dietary nor housing treatment influenced carcass composition. Pigs reared with outdoor access had a 1.0 unit increase in hematocrit level (P < 0.05) across the entire trial (farrowing group 1 measured only), and there were no differences in hematocrit levels observed across dietary treatments. Findings indicate that feeding Bio-Mos® improved ADG and subsequently reduced days to market weight when compared with pigs fed the AB diet across both housing systems assessed, suggesting that Bio-Mos® was an acceptable alternative to feeding a sub-therapeutic level of tetracycline as a means to improve production efficiency in the observed swine population.

**INTRODUCTION**

In a rapidly changing global pork market, there is rising interest in alternative production and marketing methods (Gentry & McGlone, 2003; Honeyman et al., 2006; Lammers, Stender & Honeyman, 2007). Many niche markets have developed that are oriented towards capitalizing on the consumers’ desire for perceived healthful food; one of these markets being organic production. Fears that the use of antibiotics in food animal production may be leading to an increased prevalence of antibiotic resistant pathogens (Casewell et al., 2003) may lead to increased desire for organic pork which is antibiotic-free by definition (Mikel, 1998). However, antibiotics continue to be used sub-therapeutically in animal feed in the U.S. to improve growth and pig health by 37% of
pork farmers (USDA-NAHMS, 2006) because the advantages in growth and efficiency from incorporating feed-grade antibiotic in the diet are well documented (Zimmerman, 1986; Carlson & Fangman, 2000; McEwan & Fedork-Cray, 2002; Casewell et al., 2003). The theoretical possibility of antibiotic usage leading to drug resistant pathogens infecting humans might have been influential in the ban of sub-therapeutic antibiotic use, most notably in Denmark (Casewell et al., 2003), with more recent bans in the EU and South Korea. The loss in growth performance associated with the removal of antibiotics from organic systems has resulted in niche producers searching for alternative feed additives to enhance health, growth and efficiency of grower/finisher pigs.

Phytoprogenic, organic acids and elemental alternatives to antibiotics for growth promotion and health management in organic pork production have had limited efficacy (Cullen et al., 2005; Ragland, Stevenson & Hill, 2008; Jacela et al., 2009a; Jacela et al., 2010a; Jacela et al., 2010b). Probiotic treatments have had variable effects with limited consistency (Jacela et al., 2010a), with no effect on average daily gain (Morrison & Kritas, 2003; Wang et al., 2009), average daily feed intake (Morrison & Kritas, 2003; Alexopoulos et al., 2004; Wang et al., 2009), feed efficiency (Morrison & Kritas, 2003; Wang et al., 2009) or mortality (Morrison and Kritas, 2003; Alexopoulos et al., 2004) when compared to pigs receiving control diets or diets supplemented with antibiotics.

Prebiotic products provide an alternative approach to improve growth and efficiency. Thought to help control bacterial populations through adherence (Jacela et al., 2010a; Vondruskova et al. 2010), yeast products have been shown to agglutinate pathogenic bacteria (Spring et al., 2000; Pirvulescu et al., 2000; Kogan & Kocher, 2007).
Feeding prebiotic, yeast products has been reported to improve production and health in nursery pigs (Miguel et al., 2003; Keegan et al., 2003a; Rozeboom et al., 2005; Castillo et al., 2008; Zhao, Jung & Kim, 2012) although some studies have shown no effect of yeast products (Davis et al., 2002; Keegan et al., 2003b; Rozeboom et al., 2005; Castillo et al., 2008).

Organic pork also appeals to consumers who have expressed a desire to consume pork from pigs that have been provided access to the outdoors (Mikel, 1998) during finishing and who have associated access to outdoors as a component of animal well-being. Reports indicate that outdoor housing resulted in decreased the number of recorded injuries and biting (Hansson et al., 2000; Cagienard et al., 2005), which could be a function of decreased stocking density (Deen, 2005). However, provision of outdoor housing raises concern in relation to an increased occurrence of sunburn (Cagienard et al., 2005). Reports indicate increased rooting when pig are exposed to dirt when provided outdoor access (Presto et al., 2008), but in other reports, results show a minimal effect on other pig activities (Rudine et al., 2007).

As the removal of antibiotics represents a potential increase in production costs, which can only be offset by an increased price for carcasses and resulting retail pork products, there is a need to scientifically evaluate alternatives to feeding sub-therapeutic antibiotics that will enhance pig growth and efficiency. The present study investigated the effects of a yeast product (Bio-Mos®) on growth and efficiency, animal health, and animal activities in both an indoor and an outdoor access housing system. Our working hypotheses were: 1) housing pigs with outdoor access would improve pig gain; 2)
housing pigs with outdoor access housing would have negative effects on pig health when compared contemporaries housed indoors; 3) dietary supplementation with BioMos® would improve growth rate and production efficiency and animal health when compared to a control diet, but not to the same level that would be observed by including a sub-therapeutic antibiotic in the diet; 4) behavioral observations of pig activities would not differ across either dietary or housing treatment. Therefore, an objective of the present study was to assess the impact of dietary inclusion of Bio-Mos® and tetracycline, at label recommend levels and when compared with a no additive control diet, on pig growth, feed efficiency, carcass composition, and pig health. The second objective of the study was to evaluate the influence of dietary treatments in pigs reared in indoor and indoor with outdoor access housing systems and to assess the potential for interactions between dietary treatments and housing systems.

MATERIALS AND METHODS

Experimental Design and Animals

The experiment was approved by The Ohio State University IACUC; protocols #2011A00000061 and #2011A00000061-AM1. Research was conducted at Ohio Agricultural Research and Development Center’s Western Agricultural Research Station. Standard operating procedures (SOP) on the farm, supplemented with information in The Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010), were outlined for pig health and care. Treatments were in a three
by two factorial arrangement in a replicated, randomized complete block design consisting of three dietary treatments and two housing treatments.

The research was replicated across two farrowing groups, separated by approximately six months. Crossbred Duroc × Landrace (Farrowing Group 1) and proportionally allocated Duroc × Landrace and purebred Landrace (Farrowing Group 2) pigs. Pigs were farrowed within a two-week interval within each farrowing group evaluated. The herd was free of clinical signs of PRRS and blood-tested free of PRRS during the trial. Pigs were weaned between 21 and 24 days of age, housed in an environmentally controlled nursery for approximately six weeks, and fed herd-standard, three-phase nursery diets with diets one and two fed using a feed budget. Existing herd health protocols included vaccinations for *erysipelas, mycoplasma pneumonia*, swine influenza and porcine circovirus (PCV). Pigs were de-wormed (injectable Dectomax®) prior to movement to the finisher test facilities. Pigs were weighed, tagged and sorted into weight blocks (replicates) balanced equally for sex with littermates, where possible, assigned to each diet × housing treatment combination. In farrowing group 1, four indoor and three outdoor access replications were evaluated. In farrowing group 2, three indoor and three outdoor access replications were evaluated.

**Experimental Treatments**

Dietary treatments were a corn- and soy-based commercial control diet (C), the control diet supplemented with Biomos® (Alltech®, Nicholasville, KY), an organically certified supplement, at 0.2%, 0.1% and 0.05% inclusion rates for phases 1, 2 and 3, respectively, (BM), and the control diet with supplemented tetracycline at 0.006%
inclusion rate (AB). Pigs were provided *ad libitum* access to treatment diets (Table 9) (Tokach, 2011) in three-phases (phase 1: start to 63.5 kg; phase 2: 63.5 to 90.5 kg; phase 3: 90.5 to end of test). Phase changes were made for the entire replicate when the average weight of any pen of pigs within the replicate reached or exceeded the target weight. Corn and soybean meal were derived from conventional, non-organic production methods due to high cost; therefore, the findings of the present study represent an evaluation of available animal health feed additives for antibiotic-free (C or BM) or conventional (AB) production methodologies and are not a direct comparison of certified organic standards with conventional, non-organic feeding methods.

Housing treatments compared conventional, indoor confinement (IN) with a non-confinement, indoor with outdoor access facility (OUT). The IN facility was a naturally ventilated, gable-roofed, curtain-sided facility with 2/3 solid concrete and 1/3 slotted floors in each pen. The OUT treatment facility was naturally ventilated with a hover positioned 1.2 m above the sleeping area. Pigs in the OUT facility were provided bedding material in the sleeping area. All treatments provided 1.1 m²/pig of covered, indoor sleeping space with 12 and 6 pigs per pen for IN and OUT treatments, respectively. Pigs were provided 9.4 cm/pig linear feeder space and were provided *ad libitum* access to feed and water.

Ill pigs on C and AB treatments were treated immediately following identification. Pigs failing to recover within two days, or gaining less than 0.5 kg/day over a two week weighing interval were removed from the trial. Within the BM treatment, to meet organic production standards, any ill pigs were allowed two days after
illness identification to recover prior to the administration of any therapeutic or antibiotic treatment, with any pig requiring therapeutic antibiotic or analgesic treatment removed from the BM treatment group per recognition of organic marketing system requirements (Mikel, 1998; NOSB, 2011; USG, 2011). Individual pig health and treatment records were maintained for all animals used in study.

**Animal Measurement**

Pigs were individually weighed every two weeks following allocation and weekly if weight projections indicated a dietary phase switch or slaughter was necessary. Pigs on all treatments within a replication were weighed off test when the largest pen within replication was above 113.6 kg average weight. Tenth rib backfat thickness (BF) and loin muscle area (LMA) were measured (ALOKA 500V, Aloka Corporation, Japan) when pigs were weighed off test. Individual average daily gain (ADG) and pen-based pig average daily feed intake (ADFI) and feed conversion ratio (G:F) were calculated for each dietary phase and in total for each pen of pigs. Pigs removed for poor health, poor growth, or mortality, were weighed and their removal date and weight included in pen growth and feed measurements. The three heaviest OUT and six heaviest IN pigs for each dietary treatment within a replicate were commingled during the 3 hour transit to the commercial packing plant. Days to 113.6 kg was calculated using the following equation:

$$\text{Adjusted days} = \text{actual age} + \left(\frac{\text{desired wt.} - \text{actual wt.}}{\text{actual wt.}}\right) \times \frac{\text{actual age} - a}{\text{actual wt.}}$$

where $$a = 50$$ for barrows and 40 for gilts (NSIF, 2012).
Lesion scoring

When pigs were handled for weighing, each pig was assessed for skin lesions and scored using a 9 unit, 1 to 5 point (0.5 unit increment) scale (Table 7).

Hematocrit

In the Farrowing Group 1, blood was drawn every 4 weeks from the vena cava on snared pigs using an 18-gauge, 3.8-cm transfer needle into 10-mL vacutainers (Fisher Scientific, Pittsburgh, PA) coated with heparin. Blood was transported to The Ohio State University’s Department of Animal Sciences Swine Nutrition Lab on ice and subsequently blood was siphoned into microcapillary tubes (Fisher Scientific, Pittsburgh, PA) and centrifuged for a packed cell volume score (hematocrit) to assess general pig blood health.

Pig Illness and Treatment

Pig treatment records were kept throughout the experiment for pigs lame, sick, treated, died, removed and euthanized. These were utilized to determine morbidity and mortality differences between treatments.

Behavioral Assessment Procedures

Video footage was collected, stored on DVR, and evaluated by a single researcher to observe pig activity for each treatment combination. Thirty-minute sampling periods were chosen to evaluate pigs during times when activity level, diversity in activity, and overall quantity of activity was greatest (Croney, personal communication). Using continuous, 24-hour video information collected in week 1 of farrowing group 1 of the trial, and assessed on 1 pen from each treatment combination, optimal sampling periods
were 1 hour after sunrise, 13:30 to 14:00 EST, and 3 hours prior to sunset during which the greatest quantity and diversity of actions occurred. These times were used throughout the trial in both seasons. One camera was permanently positioned on a focal pen of each diet × housing combination of treatments, and 1 camera was rotated weekly between the remaining pens within a diet × housing combination to ensure random observation of all pens during the experiment (Croney, personal communication). Video data were analyzed from footage collected on Sunday and Wednesday, providing a total of 12 video segments analyzed weekly within each diet × housing treatment combination. Health observations included coughing, isolation, huddling, poor ambulation, and arching of backs (Croney, personal communication; Johnson, 2002). Additionally, aggression activities were monitored: riding, fighting, ear biting and tail biting (Croney, personal communication). Pig activities are defined in table 8. Video footage was viewed and activities tallied as count data. To combine a measurement for length of action as well as number of total occurrences, actions were measured at start for duration of 5 seconds. If the action continued for longer than 5 seconds, it would receive an additional count value for each 5 second segment during which it continued. Final counts served to provide comparative data for evaluating differences for an activity between treatments.

Statistical Analysis

Measurements were collected between August 2011 and June 2012. Data were analyzed with SAS® version 9.2 (SAS Institute, Inc., Cary, NC) using PROC MIXED procedures. Pig average daily gain was analyzed within each phase and overall with model fixed effects included diet (D), housing (H), and the diet x housing interaction
(D×H). Starting weight on trial was included as a linear covariate to standardize pig growth rate measures across replications. Replication (Rep) within farrowing group (FG) was modeled as a random effect. Model statement was $Y_{ijklm} = \mu + H_i + D_j + (H\times D)_{ij} + (\text{Rep} \times \text{FG})_k + b_{\text{swt}} + \varepsilon_{ijkl}$.

Where: $Y$ = observed trait, ADG, ADFI or G:F

Given: $\mu$ = population estimate for observed trait

$H$ = fixed effect of housing either IN or OUT, $i = 2$

$D$ = fixed effect of diet, AB, BM or C, $j = 3$

$H\times D$ = interaction of housing and diet, $ij = 6$

$\text{Rep}\times\text{FG}$ = random effect of replication (1-4) within farrowing group (1-2), $k = 8$

$b_{\text{swt}}$ = covariate for starting body weight on trial

$\varepsilon$ = individual error term, $l$ = remaining degrees of freedom

Average daily feed intake (ADFI) and gain to feed efficiency ratio (G:F) were assessed on a pen basis and were assessed in each dietary phase and overall with model fixed effects that included diet (D), housing (H), and the diet $\times$ housing interaction (D×H). Replication (Rep) within farrowing group (FG) was modeled as a random effect. The model statement was $Y_{ijkl} = \mu + H_i + D_j + (H\times D)_{ij} + (\text{Rep} \times \text{FG})_k + b_{\text{swt}} + \varepsilon_{ijkl}$.

Where: $Y$ = observed trait ADFI or G:F

Given: $\mu$ = population estimate for observed trait

$H$ = fixed effect of housing either IN or OUT, $i = 2$

$D$ = fixed effect of diet, AB, BM or C, $j = 3$
H×D = interaction of housing and diet, ij = 6

Rep×FG = random effect of replication (1-4) within farrowing group (1-2), k = 8

ε = individual error term, l = remaining degrees of freedom

Ultrasonic estimates of backfat (BF) and loin muscle area (LMA) were analyzed using PROC MIXED. Model effects included diet, housing, sex and diet × housing with random effect of replication (Rep) within farrowing group (FG). Off-test weight was included as a linear covariate to standardize backfat and loin muscle area to a weight constant basis. The model statement was: 

\[ Y_{ijklmn} = \mu + H_i + D_j + S_k + (H\times D)_{ij} + (Rep\times FG)_l + b_{offwt} + \epsilon_{ijklm} \]

Where: Y = observed trait, ADG, ADFI or G:F

Given: \( \mu = \) population estimate for observed trait

H = fixed effect of housing either IN or OUT, i = 2

D = fixed effect of diet, AB, BM or C, j = 3

S = fixed effect of sex, gilt (G) or castrated male (X), k = 2

H × D = interaction of housing and diet, ij = 6

Rep × FG = random effect of replication (1-4) within farrowing group (1-2), l = 8

\( b_{offwt} = \) covariate for ending body weight pre-transport on trial

ε = individual error term, m = remaining degrees of freedom

Pig activity traits were analyzed using PROC GLIMMIX. Activity data from Farrowing Group I included only measurements obtained within IN housing due to a
computer crash that resulted in elimination of data from OUT housing. Video data from Farrowing Group 2 was complete. Therefore, dietary effects on pig activities were analyzed across Farrowing Groups 1 and 2 using data only compiled for IN housing. Comparisons across housing type, dietary treatment and their interaction effects were tested only on data collected only in Farrowing Group 2. The model statement dietary treatment effects within IN housing was $Y_{ijkl} = \mu + D_i + Day_j + \epsilon_{ijk}$

Where: $Y = $ observed activity

Given: $\mu = $ population estimate for observed trait

$D = $ fixed effect of diet, AB, BM or C, $i = 3$

$Day = $ random effect of day, $j = 24$ observation periods

$\epsilon = $ individual error term, $l = $ remaining degrees of freedom

Model statement for farrowing group 2 activities was $y_{ijklmn} = \mu + H_i + D_j + (H\times D)_{ij} + Day_k + \epsilon_{ijkl}$

Where: $Y = $ observed activity

Given: $\mu = $ population estimate for observed trait

$H = $ fixed effect of housing, IN or OUT, $i = 2$

$D = $ fixed effect of diet, AB, BM or C, $j = 3$

$H\times D = $ interaction of housing and diet, $ij = 6$

$Day = $ random effect of day, $k = 24$ observation periods

$\epsilon = $ individual error term, $m = $ remaining degrees of freedom
RESULTS

Growth and Efficiency

Overall, pigs reared in the OUT system had improved ADG (0.04 kg/day; P < 0.001) and ADFI (0.12 kg/day; P < 0.05) but decreased G:F (0.01 kg gain/kg feed; P = 0.05) when compared with pigs reared in IND system (Table 10). Pigs fed the BM and C treatments had increased ADG (0.02 kg/day; P < 0.05) when compared with pigs fed the AB treatment. Additionally, in phase 1, OUT increased ADFI (0.09 kg/day; P = 0.01), and BM increased ADG (0.03 kg/day; P < 0.05) when compared with pigs fed the AB treatment. There were no significant differences in phase 2; however, during phase 3 pigs reared in the OUT system had increased ADG (0.09 kg/day; P = 0.0001) and ADFI (0.22 kg/day; P < 0.005) but had reduced G:F (0.024 kg gain/kg feed; P < 0.05) when compared with IN. During phase 3, both BM and C treatments increased ADG by 0.07 kg/day (P = 0.001) when compared with AB.

Ultrasound Estimates of Carcass Composition

Housing and diet treatments had no effect (P > 0.05) on loin muscle area (LMA) or 10th rib backfat (BF) measurements (Table 11). As expected, based on known sex effects that influence carcass composition, gilts had greater LMA (1.5 cm²; P = 0.001) and less BF (0.41 cm; P = 0.0001) when compared with contemporary barrows measured at a standard end weight.

Hematocrit

Diet treatments had no effect (P > 0.05) on hematocrit scores across housing systems evaluated (Table 12). Hematocrit scores were 1.0, 1.5 and 2.0 units greater for
pigs reared in the OUT system when compared to IN for measurements taken on days 28, 56 and 84 of the test, respectively.

**Pig Illness and Treatment**

There were no differences in the number of pigs that were reported lame, dead, removed, or euthanized across both dietary and housing treatments (Table 13). The number of pigs identified as sick (P < 0.0001) and requiring medical treatment (P < 0.001) increased statistically for pigs reared in the indoor housing system. Although statistically significant, the percentage of pigs with a reported sickness was less than 2.5% of the population within the IN treatment and less than 1% required treatment following subsequent observation. There is no practical difference between indoor and outdoor housing in the number of pigs reported as sick or requiring medication.

**Lesion Scores**

Lesion scores were not different (P > 0.05) for the first 42 days of the trial (Table 14). However, at day 56, pigs reared in the OUT housing system had every small, albeit statistically reduced lesion score (0.04 units on a 5 point scale; P = 0.005) when compared with IN. At day 70, lesion scores for OUT pigs decreased by 0.06 units (P < 0.001) and at day 84 lesion scores for OUT decreased by 0.07 units (P < 0.0005) when compared with IN. Dietary treatment had no influence on lesion score.

**Aggressive Activity**

When comparing dietary treatments within IN housing, the number of pigs observed to be riding was greater (P < 0.05) for the C dietary treatment when compared with AB, while the number of pigs showing riding behavior in the BM treatment was
intermediate and not different from either C or AB (Table 15). When assessing the influence of housing on aggression activity frequency, there were no differences (P > 0.05) observed (Table 16).

**Illness Activity**

Overall, there were very few observations of illness behavior assessing dietary (Table 17) and housing (Table 18) treatment effects, a finding consistent with the summary of health issues reported across the study (Table 13). Statistically, the number of pen pig count adjusted coughing observed was different to a very small degree across dietary treatments, whereby pigs in AB treatment coughed more often (P < 0.05) than pigs on BM and C diets. When comparing housing influences, pigs in the OUT system exhibited a slightly greater frequency of isolation (P < 0.0001) incidences, which is likely attributable to opportunity given the additional space available in OUT housing systems.

**DISCUSSION**

Although previous research has shown little effect of organic production methods on pig growth and efficiency (Millet et al., 2004; Millet et al., 2005), there has been some indication that meeting organic housing standards alone can improve growth and efficiency (Millet et al., 2004; Millet et al., 2005). However, housing pigs under organic housing standards has been previously shown to affect pig growth in larger pen groups (Gentry et al., 2002) and has resulted in decreased feed efficiency (Gentry et al., 2002; Gentry et al., 2004). Many studies have shown that, in trials meeting organic housing standards, pig had increased ADFI (Gentry et al., 2004; Millet et al., 2004; Millet et al.,
Lebret et al., 2006), a finding similar to the results of the present study. Results of the present study indicate that housing pigs in facilities that provide outdoor access on concrete, in accordance with described organic standards (NSOB, 2011), can improve pig growth and efficiency in the grower/finisher production phase when compared with pigs housed indoors with similar space allocation in the sleeping area. In the present study, the decreased rate of pig growth may be related to the decreased overall stocking density within the indoor housing treatment when compared to the pigs provided outdoor access pens (Gonyou, 2005) or may be related to an increase in exercise opportunity for pigs housed in the outdoor access treatment. Air quality may also be a cause of improved growth rate in the outdoor access treatment, as dust concentrations in indoor facilities can be increased when compared with outdoor pens; albeit pig coughing and illness frequencies were very low in each housing treatment.

The pigs in this experiment grew very well. There are conflicting reports on impact of Bio-Mos® treatment compared with antibiotic or control treatments, but Miguel et al. (2003) reported an increased effect when used in poor growth herds. In the present study, perhaps the relative lack of health issues among the pig population allowed for very good growth among all treatments and reduced the growth rate differences observed when compared with expectations. Regardless, in the present study, feeding Bio-Mos® improved performance consistently relative to the AB diet and suggests that Bio-Mos® has the potential to replace sub-therapeutic antibiotics in grower finisher pig diets. In a situation where health challenges are prevalent in a herd, additional research may need to be completed to test the efficacy of Bio-Mos®.
Of note, feeding the control diet, resulted in pig performance (growth rate and days to market) that exceeded pigs fed a sub-therapeutic level of antibiotic. Thus, in the present study, economic and pig health considerations regarding the necessity of feeding sub-therapeutic antibiotics must be assessed. A viable option for the herd used in the present study may be to consider an antibiotic-free production option. Further, the authors are not certain why feeding a sub-therapeutic level of tetracycline resulted in reduced growth rate and poorer feed conversion efficiency. Perhaps feeding a sub-therapeutic level of tetracycline may have caused bacterial population fluctuation in otherwise healthy pigs or the pig population may have had a population of Tetracycline-resistant pathogens in their system which in turn thrived in the presence a sub-therapeutic inclusion environment.

Ultrasound data from this project confirms previously reported sex differences for LMA and BF (Martin et al., 1972; Wiseman et al., 2007) while housing treatment and dietary treatment had no effects on the carcass composition. The lack of dietary and housing treatment differences provide supportive evidence for antibiotic-free production and the housing of pigs on concrete with outdoor access that meet organic production standards, will likely result in carcasses with similar carcass merit value when compared with carcasses of conventionally housed pigs.

Rudine et al. (2007) previously reported that housing pigs to meet organic standards resulted in increased pig hematocrit score by 3%, a finding similar to the results for the present study. This is greater than the difference in one blood unit between treatments, but none of the treatments were reported deficient for hematocrit. Thus, while
it is not understood what increases the pig hematocrit when pigs were provided outdoor access, it is important to note that all treatments fell within the normal range of healthy pigs. Even though this is a numerical improvement, it has no tangible biological impact in our system analysis.

Although there were significant differences in lesion scores observed in the pigs on this trial, these changes in lesion score never totaled more than 0.1 on a 9 unit (5 point scale) scale, therefore having no biological significance. While both Hansson (2000) and Cagienard et al. (2005) indicated greater injury in indoor housing, there were no differences observed between housing or diet treatments in the present study.

When the cost of diets is taken into account (Table 9), there is concern that the increased per kilo cost of BM treatment does not improve gain enough to justify the expense. However, in the present study, improved average daily gain observed for pigs fed the BM diet when compared to feed a sub-therapeutic antibiotic level, resulted in a $1.23 reduction in cost per pig. In a time-based production system, pigs fed the BM diet required approximately 3 fewer days to reach market, a result that reduces labor and management cost as well. Following a similar logic, in the present study, feeding the control diet also represented a similar cost reduction when compared with feeding a sub-therapeutic antibiotic. Findings imply that, in high health herds, the use of sub-therapeutic antibiotics are likely not necessary.
SUMMARY

In summary, results for the present study suggest that, under the conditions monitored, providing outdoor access resulted in improved growth rate with a slight reduction in feed conversion efficiency that may be due to slightly greater maintenance needs. Additional housing research must address confounding of space with housing system and will benefit if facilities allow research to evaluate smaller space allocation parameters. Additional research is needed to define and evaluate animal behavior, especially as it pertains to activity and exercise. Providing pigs with outdoor access did not negatively influence pig health. Adding Bio-Mos® improved pig growth and efficiency across housing systems evaluated, with similar performance results to feeding a control diet, while feeding sub-therapeutic tetracycline resulted in an unexplained reduction in growth rate. With respect to increasing demand for antibiotic-free pork, the dietary treatments compared in the present study give perspective on the future promise of BM inclusion as an antibiotic replacement in systems with high herd health.
LITERATURE CITED


Bacteria in the Ceca of *Salmonella*-Challenged Broiler Chicks. Poultry Science 79:205-211.


Appendix A:

Figures and Tables
Figure 1. Global pork production, million tons. Source: USDA-FAS, 2012.

<table>
<thead>
<tr>
<th>Country</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>51.0</td>
<td>49.5</td>
<td>51.6</td>
</tr>
<tr>
<td>EU</td>
<td>22.6</td>
<td>22.8</td>
<td>22.6</td>
</tr>
<tr>
<td>US</td>
<td>10.2</td>
<td>10.3</td>
<td>10.6</td>
</tr>
<tr>
<td>Brazil</td>
<td>3.2</td>
<td>3.2</td>
<td>3.3</td>
</tr>
<tr>
<td>Russia</td>
<td>1.9</td>
<td>2.0</td>
<td>2.1</td>
</tr>
<tr>
<td>Vietnam</td>
<td>1.9</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Canada</td>
<td>1.7</td>
<td>1.7</td>
<td>1.8</td>
</tr>
<tr>
<td>Japan</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Phillipines</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Mexico</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>S. Korea</td>
<td>1.1</td>
<td>0.8</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Figure 2. Cost comparison of grain prices. Sources: USDA-MNS (2011 & 2012), Rodale Institute (2011 & 2012)
Table 1. Summary of organic grain quality and yield studies.

<table>
<thead>
<tr>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic grains tested for protein, amino acids, fatty acids. No differences found when compared to conventional but great variation in organic grain</td>
<td>Jacob, 2009</td>
</tr>
<tr>
<td>Organic wheat increased in total protein but no significant amino acid differences, no differences in mycotoxin content</td>
<td>Mäder et al., 2007</td>
</tr>
<tr>
<td>Organic wheat decreased total protein and 0.5% less nitrogen</td>
<td>Mazzoncini et al., 2007</td>
</tr>
<tr>
<td>Organic wheat decreased total protein by 42%</td>
<td>Kokornaczyk et al., 2008</td>
</tr>
<tr>
<td>Organic barley showed no differences in mycotoxins</td>
<td>Edwards, 2009</td>
</tr>
</tbody>
</table>
Table 2. Summary of research on impact of organic systems on pork quality.

<table>
<thead>
<tr>
<th>Study</th>
<th>Findings</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey of 3483 organic pigs, organic pigs 0.6% less lean</td>
<td>Hansson et al., 2000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No carcass differences in organic pigs</td>
<td>Kelly et al., 2007</td>
</tr>
<tr>
<td></td>
<td>No effect of organic diet on percent lean, percent IMF, backfat, pH,</td>
<td>Hansen et al., 2006</td>
</tr>
<tr>
<td></td>
<td>drip loss, CIELab or fatty acid profile. Organic diet 50% less vitamin A (P&lt;0.01)</td>
<td></td>
</tr>
</tbody>
</table>
Table 3. Summary of research on impact of organic housing on pork quality

<table>
<thead>
<tr>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free-range pigs increased lean by 0.5% in winter and 1% in summer, no changes in backfat</td>
<td>Sather et al., 1997</td>
</tr>
<tr>
<td>No effect of housing on dressing percentage, LEA, pH, drip loss, cooking loss, shear force, subjective color, a* or b*. Increased L* 2.5 (P&lt;0.05)</td>
<td>Hamilton et al., 2001</td>
</tr>
<tr>
<td>Outdoor housing increased backfat by 0.8 cm (P=0.04), no change in LEA, pH, a*, b*. Shear force increased 0.2 kg (P=0.04), L* 2.4 (P=0.01)</td>
<td>Gentry et al., 2002</td>
</tr>
<tr>
<td>Outdoor housed on alfalfa, no difference for backfat, LEA, pH, subjective color, L*, b* but decreased a* 1.6 (P&lt;0.05)</td>
<td>Gentry et al., 2004</td>
</tr>
<tr>
<td>Indoor, indoor with straw and outdoor had no effect on carcass yield. Strawpenned pigs 1.6 mm (P&lt;0.05) fatter</td>
<td>Guy et al., 2002</td>
</tr>
<tr>
<td>Free-range pigs no effect on dressing percentage, fat or percent lean, pH, drip loss, cooking loss, shear force, L*, b*, SFAs, MUFAs. Organic housing increased a* by 0.65 (P&lt;0.01) and increased PUFAs by 6.2%</td>
<td>Hoffman et al., 2003</td>
</tr>
<tr>
<td>Organic housed pigs not different for dressing percentage, but decreased percent lean 2% (&lt;0.001), no effect on pH, L* or a*. Increased b* by 0.7 (P&lt;0.01) and increased drip loss 1% (P&lt;0.01)</td>
<td>Lebret et al., 2006</td>
</tr>
</tbody>
</table>
Table 4. Summary of research on the impact of organic system on pig growth and efficiency.

<table>
<thead>
<tr>
<th>Research Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>No significant difference for organic vs. conventional growth</td>
<td>Millet et al., 2004</td>
</tr>
<tr>
<td>No significant differences reported except phase 2 feeding, organic increased ADFI 200g/day (P&lt;0.005)</td>
<td>Millet et al., 2005</td>
</tr>
<tr>
<td>Organic increased ADG 64 g/day (P&lt;0.05)</td>
<td>Hansen et al., 2006</td>
</tr>
</tbody>
</table>
Table 5. Summary of research on impact of organic housing on pig growth and efficiency.

| Study                           | Results                                                                       |
|---------------------------------|                                                                           |
| Sather et al., 1997             | Increased finishing period by 16 days, decreased ADG by 148 g/day (P<0.05), no impact on FE |
| Lebret et al., 2006             | Increased fixed endpoint weight by 8.4 kg (P<0.05), increased ADG by 85 g/day (P<0.01), increased ADFI by 0.23 kg/day (P<0.01, no effect FE) |
| Gentry et al., 2002             | No effect on growth performance except FE decreased by 0.02 kg gain/kg feed (P=0.02) |
| Hoffman et al., 2003            | Decreased fixed endpoint weight by 7 kg (P<0.05), decreased ADG 0.09 kg/day (P<0.05) |
| Gentry et al., 2004             | No differences for stage weights or ADG, but final weight increased by 7.2 kg (P=0.02) for outdoor housing. ADFI increased outdoors by 0.29 kg/day (P=0.01), FE decreased by 0.4 kg gain/kg feed (P=0.01) |
| Millet et al., 2004             | Increased ADG 60 g/day, 113 g/day, 132 g/day, 113 g/day for phases 1, 2, 3 & total, respectively (P<0.05). Also increased ADFI 147 g/day, 130 g/day, 363 g/day, 284 g/day for phases 1, 2, 3 & total, respectively (P<0.05). Improved FE by 0.28 kg feed/kg gain in phase 2 |
| Millet et al., 2005             | Increased ADG 49 g/day, 116 g/day, 119 g/day, 100 g/day for phases 1, 2, 3 & total, respectively (P<0.05). Also increased ADFI 130 g/day, 326 g/day, 305 g/day, 253 g/day for phases 1, 2, 3 & total (P<0.05). No effect on FE. |
Table 6. Summary of research on impact of organic diet on pig growth and efficiency.

| Decreased ADG 51 g/day in phase 1, increased ADG 38 g/day, 24 g/day for phase 2 & 3, respectively, no effect overall. Increase ADFI in phase 2 by 45 g/day. Improve FE 0.26 & 0.11 kg feed/kg gain for phase 1 & 3, respectively. No effect overall. | Millet et al., 2004 |
| Decrease ADG 108 g/day in phase 1. No other effect for ADG, ADFI, FE | Millet et al., 2005 |
Table 7. Descriptors of lesion scoring system on 9 unit scale.

<table>
<thead>
<tr>
<th>Lesion Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>No lesions</td>
</tr>
<tr>
<td>1.5</td>
<td>Minimal surface scratches, light sunburn</td>
</tr>
<tr>
<td>2.0</td>
<td>Minor abrasions, rashes, moderate sunburn, raw tail bites</td>
</tr>
<tr>
<td>2.5</td>
<td>Moderate abrasions, cuts below surface of skin, infective lesions</td>
</tr>
<tr>
<td>3.0</td>
<td>Severe abrasion, cuts below surface of skin, large lesions</td>
</tr>
<tr>
<td>3.5</td>
<td>Severe cuts, infected tissue, ears, neck and/or tail</td>
</tr>
<tr>
<td>4.0</td>
<td>Severe cuts, infected tissue, ears, neck, tail, limbs and/or elsewhere</td>
</tr>
<tr>
<td>4.5</td>
<td>Severe lesions and infections requiring immediate removal</td>
</tr>
<tr>
<td>5.0</td>
<td>Severe lesions resulting in death</td>
</tr>
</tbody>
</table>
Table 8. Descriptors of pig activities recorded by DVR and observed as count data.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isolation</td>
<td>Pig intentionally separates itself from group and lays down after fighting or coughing</td>
</tr>
<tr>
<td>Coughing</td>
<td>Observed on video with sharp motion of lungs, repeatedly, involved change of recumbent position if laying to discern from panting in sleep</td>
</tr>
<tr>
<td>Itching</td>
<td>Scratching against objects or with feet</td>
</tr>
<tr>
<td>Huddling</td>
<td>Pig hunched over and compact, in recumbent position</td>
</tr>
<tr>
<td>Fighting</td>
<td>Two or more pigs engaged in biting and with erratic motion, not similar to ear or tail biting, or playful behavior</td>
</tr>
<tr>
<td>Ear Biting</td>
<td>Chewing or biting at ear, each count is no greater than 5 seconds in duration</td>
</tr>
<tr>
<td>Tail Biting</td>
<td>Chewing or biting at tail, each count is no greater than 5 seconds in duration</td>
</tr>
<tr>
<td>Riding</td>
<td>Mounting of another standing or moving pig and maintaining this position, being moved by the pig while only on 2 feet</td>
</tr>
</tbody>
</table>
Table 9. Diets provided ad libitum for 3 feeding phases (as-fed basis) (Tokach, 2011).

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn, %</td>
<td>57.6</td>
<td>63.0</td>
<td>68.0</td>
<td>57.4</td>
<td>62.9</td>
<td>67.9</td>
<td>57.6</td>
<td>63.0</td>
<td>68.0</td>
</tr>
<tr>
<td>SBM, %</td>
<td>27.3</td>
<td>22.1</td>
<td>17.3</td>
<td>27.3</td>
<td>22.1</td>
<td>17.3</td>
<td>27.3</td>
<td>22.1</td>
<td>17.3</td>
</tr>
<tr>
<td>Wheat midds, %</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Dicalcium P, %</td>
<td>1.20</td>
<td>0.90</td>
<td>0.75</td>
<td>1.20</td>
<td>0.90</td>
<td>0.75</td>
<td>1.20</td>
<td>0.90</td>
<td>0.75</td>
</tr>
<tr>
<td>Limestone, %</td>
<td>0.83</td>
<td>0.88</td>
<td>0.88</td>
<td>0.83</td>
<td>0.88</td>
<td>0.88</td>
<td>0.83</td>
<td>0.88</td>
<td>0.88</td>
</tr>
<tr>
<td>Salt, %</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>Vit. Premix, %</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Trace Min., %</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Tetracycline, %</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Bio-Mos®, %</td>
<td>0.20</td>
<td>0.10</td>
<td>0.05</td>
<td>0.20</td>
<td>0.10</td>
<td>0.05</td>
<td>0.20</td>
<td>0.10</td>
<td>0.05</td>
</tr>
<tr>
<td>Pellet binder, %</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Se, %</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Total lysine, %</td>
<td>1.03</td>
<td>0.89</td>
<td>0.76</td>
<td>1.03</td>
<td>0.89</td>
<td>0.76</td>
<td>1.03</td>
<td>0.89</td>
<td>0.76</td>
</tr>
<tr>
<td>ME, kcal/lb</td>
<td>1450</td>
<td>1455</td>
<td>1458</td>
<td>1447</td>
<td>1453</td>
<td>1457</td>
<td>1450</td>
<td>1454</td>
<td>1458</td>
</tr>
<tr>
<td>SID Lysine:ME, g/Mcal</td>
<td>2.85</td>
<td>2.43</td>
<td>2.05</td>
<td>2.85</td>
<td>2.44</td>
<td>2.05</td>
<td>2.85</td>
<td>2.43</td>
<td>2.05</td>
</tr>
<tr>
<td>CP, %</td>
<td>19.2</td>
<td>17.2</td>
<td>15.4</td>
<td>19.2</td>
<td>17.2</td>
<td>15.4</td>
<td>19.2</td>
<td>17.2</td>
<td>15.4</td>
</tr>
<tr>
<td>Cost/kg, $</td>
<td>0.334</td>
<td>0.325</td>
<td>0.320</td>
<td>0.344</td>
<td>0.331</td>
<td>0.323</td>
<td>0.334</td>
<td>0.325</td>
<td>0.320</td>
</tr>
</tbody>
</table>
Table 10. The influence of housing type and dietary treatment on pig growth and efficiency.

<table>
<thead>
<tr>
<th>Dietary Phase</th>
<th>Trait(^3)</th>
<th>Housing(^1)</th>
<th>Diet(^2)</th>
<th>P Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IN</td>
<td>OUT</td>
<td>Pooled SEM</td>
<td>AB</td>
</tr>
<tr>
<td>1</td>
<td>ADG, kg/d</td>
<td>0.930</td>
<td>0.948</td>
<td>0.025</td>
</tr>
<tr>
<td></td>
<td>ADFI, kg/d</td>
<td>1.98(^b)</td>
<td>2.07(^a)</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>G:F, kg/kg</td>
<td>0.468</td>
<td>0.456</td>
<td>0.010</td>
</tr>
<tr>
<td>2</td>
<td>ADG, kg/d</td>
<td>1.048</td>
<td>1.081</td>
<td>0.018</td>
</tr>
<tr>
<td></td>
<td>ADFI, kg/d</td>
<td>2.91</td>
<td>3.03</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>G:F, kg/kg</td>
<td>0.358</td>
<td>0.352</td>
<td>0.006</td>
</tr>
<tr>
<td>3</td>
<td>ADG, kg/d</td>
<td>1.083(^c)</td>
<td>1.167(^d)</td>
<td>0.014</td>
</tr>
<tr>
<td></td>
<td>ADFI, kg/d</td>
<td>3.36(^c)</td>
<td>3.58(^d)</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>G:F, kg/kg</td>
<td>0.333(^a)</td>
<td>0.309(^b)</td>
<td>0.009</td>
</tr>
<tr>
<td>Total</td>
<td>ADG, kg/d</td>
<td>1.004(^c)</td>
<td>1.042(^d)</td>
<td>0.015</td>
</tr>
<tr>
<td></td>
<td>ADFI, kg/d</td>
<td>2.59(^b)</td>
<td>2.71(^a)</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>G:F, kg/kg</td>
<td>0.385(^a)</td>
<td>0.375(^b)</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td>DAYS</td>
<td>148.6(^d)</td>
<td>144.5(^e)</td>
<td>1.8</td>
</tr>
</tbody>
</table>

\(^1\) Housing - Indoor (IN) or Outdoor Access (OUT)  
\(^2\) Diet - Tetracycline (AB), Bio-Mos® (BM) or Control (C)  
\(^3\) Traits: ADG, individual pig average daily gain, ADFI, pen average daily feed intake, G:F, pen gain to feed ratio, DAYS = Adjusted days to 113.6 kg (NSIF adjustments, 2012)  
\(^a, b\) Least squares means within dietary phase and treatment (housing and diet) without a common superscript differ (P < 0.05)  
\(^d, e\) Least squares means within dietary phase and treatment (housing and diet) without a common superscript differ (P < 0.001)
Table 11. Least squares means for ultrasonic estimates of carcass composition for housing, dietary, and sex effects.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Housing Pooled</th>
<th>Diet Pooled</th>
<th>Sex Pooled</th>
<th>P Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IN</td>
<td>OUT</td>
<td>SEM</td>
<td>AB</td>
</tr>
<tr>
<td>LMA, cm²</td>
<td>42.0</td>
<td>42.4</td>
<td>0.9</td>
<td>42.5</td>
</tr>
<tr>
<td>BF, cm</td>
<td>1.90</td>
<td>1.89</td>
<td>0.07</td>
<td>1.88</td>
</tr>
</tbody>
</table>

<sup>1</sup> Housing - Indoor (IN) or Outdoor Access (OUT)
<sup>2</sup> Diet - Tetracycline (AB), Bio-Mos® (BM) or Control (C)
<sup>3</sup> Sex - gilt (G) or castrated male (X)
<sup>4</sup> LMA = ultrasonic loin muscle area, cm², BF = ultrasonic 10<sup>th</sup> rib backfat thickness, cm

<sup>a, b</sup> Within a row and main effect, least squares means without a common superscript differ (P < 0.001).
<sup>c, d</sup> Within a row and main effect, least squares means without a common superscript differ (P < 0.0001).
Table 12. Least squares means for blood hematocrit score at the start and at 28 day intervals within housing and dietary treatments.

<table>
<thead>
<tr>
<th>Day</th>
<th>Housing</th>
<th>Pooled</th>
<th>Diet</th>
<th>Pooled</th>
<th>P Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IN</td>
<td>OUT</td>
<td>AB</td>
<td>BM</td>
<td>C</td>
</tr>
<tr>
<td>0</td>
<td>34.6</td>
<td>35.2</td>
<td>0.6</td>
<td>34.7</td>
<td>34.7</td>
</tr>
<tr>
<td>28</td>
<td>35.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>36.4&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.5</td>
<td>35.8</td>
<td>35.9</td>
</tr>
<tr>
<td>56</td>
<td>36.1&lt;sup&gt;d&lt;/sup&gt;</td>
<td>37.6&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0.5</td>
<td>37.0</td>
<td>37.1</td>
</tr>
<tr>
<td>84</td>
<td>36.9&lt;sup&gt;d&lt;/sup&gt;</td>
<td>38.9&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0.6</td>
<td>38.1</td>
<td>38.3</td>
</tr>
</tbody>
</table>

<sup>1</sup> Housing - Indoor (IN) or Outdoor Access (OUT)
<sup>2</sup> Diet - Tetracycline (AB), Bio-Mos® (BM) or Control (C)
<sup>a,b</sup> Within a row and main effect, least squares means without a common superscript differ (P < 0.05).
<sup>d,e</sup> Within a row and main effect, least squares means without a common superscript differ (P < 0.0005).
Table 13. Least squares means for the number (count) of pigs for health characteristics reported within housing and dietary treatments.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Housing</th>
<th>Pooled</th>
<th>Diet</th>
<th>Pooled</th>
<th>P Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IN</td>
<td>OUT</td>
<td>SEM</td>
<td>AB</td>
<td>BM</td>
</tr>
<tr>
<td>Lame</td>
<td>0.48</td>
<td>0.60</td>
<td>0.22</td>
<td>0.15</td>
<td>0.57</td>
</tr>
<tr>
<td>Sick</td>
<td>10.6d</td>
<td>0.9e</td>
<td>1.1</td>
<td>5.05</td>
<td>5.85</td>
</tr>
<tr>
<td>Treated</td>
<td>1.02a</td>
<td>0.28b</td>
<td>0.15</td>
<td>0.88a</td>
<td>0.24b</td>
</tr>
<tr>
<td>Dead</td>
<td>0.024</td>
<td>0.000</td>
<td>0.019</td>
<td>0.00</td>
<td>0.04</td>
</tr>
<tr>
<td>Removed</td>
<td>0.10</td>
<td>0.06</td>
<td>0.05</td>
<td>0.07</td>
<td>0.15</td>
</tr>
<tr>
<td>Euthanize</td>
<td>0.02</td>
<td>0.06</td>
<td>0.04</td>
<td>0.04</td>
<td>0.08</td>
</tr>
</tbody>
</table>

1 Housing - Indoor (IN, n = 252) or Outdoor Access (OUT = 108)
2 Diet - Tetracycline (AB, n = 120), Bio-Mos® (BM, n = 120) or Control (C, n = 120)
3 Traits – Lame – count of pigs treated for mobility, Sick – count of pigs observed for conditions other than lameness, Treated – count of pigs medicated for observed conditions, Dead – count of pigs that died, Removed – count of pigs removed due to lameness, treatment or euthanasia, Euthanize – count of pigs removed and euthanized as prescribed by IACUC protocols.

a, b Within a row and main effect, least squares means without a common superscript differ (P < 0.01).
d, e Within a row and main effect, least squares means without a common superscript differ (P < 0.0001).
<table>
<thead>
<tr>
<th>Day</th>
<th>Housing1</th>
<th>Pooled SEM</th>
<th>Diet2</th>
<th>Pooled SEM</th>
<th>P Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IN</td>
<td>OUT</td>
<td>AB</td>
<td>BM</td>
<td>C</td>
</tr>
<tr>
<td>0</td>
<td>1.34</td>
<td>1.37</td>
<td>0.07</td>
<td>1.34</td>
<td>1.34</td>
</tr>
<tr>
<td>14</td>
<td>1.30</td>
<td>1.32</td>
<td>0.07</td>
<td>1.29</td>
<td>1.30</td>
</tr>
<tr>
<td>28</td>
<td>1.26</td>
<td>1.26</td>
<td>0.07</td>
<td>1.25</td>
<td>1.26</td>
</tr>
<tr>
<td>42</td>
<td>1.22</td>
<td>1.20</td>
<td>0.07</td>
<td>1.21</td>
<td>1.22</td>
</tr>
<tr>
<td>56</td>
<td>1.19\textsuperscript{a} 1.15\textsuperscript{b}</td>
<td>0.07</td>
<td>1.17</td>
<td>1.18</td>
<td>1.16</td>
</tr>
<tr>
<td>70</td>
<td>1.15\textsuperscript{d} 1.09\textsuperscript{e}</td>
<td>0.07</td>
<td>1.13</td>
<td>1.13</td>
<td>1.10</td>
</tr>
<tr>
<td>84</td>
<td>1.11\textsuperscript{d} 1.04\textsuperscript{e}</td>
<td>0.07</td>
<td>1.09</td>
<td>1.09</td>
<td>1.04</td>
</tr>
</tbody>
</table>

1 Housing - Indoor (IN) or Outdoor Access (OUT)
2 Diet - Tetracycline (AB), Bio-Mos® (BM) or Control (C)
\textsuperscript{a, b} Within a row and main effect, least squares means without a common superscript differ (P < 0.01)
\textsuperscript{d, e} Within a row and main effect, least squares means without a common superscript differ (P < 0.001)
Table 15. Least squares means for aggression activities within dietary treatments for pigs housed indoors; number of occurrences adjusted for number of pigs per pen within 30 minute focal sampling periods.

<table>
<thead>
<tr>
<th>Activity</th>
<th>AB</th>
<th>BM</th>
<th>C</th>
<th>Pooled SEM</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fight</td>
<td>0.28</td>
<td>0.24</td>
<td>0.33</td>
<td>0.05</td>
<td>0.06</td>
</tr>
<tr>
<td>Ear Bite</td>
<td>0.124</td>
<td>0.131</td>
<td>0.081</td>
<td>0.024</td>
<td>0.17</td>
</tr>
<tr>
<td>Tail Bite</td>
<td>0.022</td>
<td>0.020</td>
<td>0.042</td>
<td>0.013</td>
<td>0.42</td>
</tr>
<tr>
<td>Ride</td>
<td>0.035\textsuperscript{b}</td>
<td>0.066\textsuperscript{ab}</td>
<td>0.079\textsuperscript{a}</td>
<td>0.017</td>
<td>0.04</td>
</tr>
</tbody>
</table>

\textsuperscript{1} Diet - Tetracycline (AB), Bio-Mos® (BM) or Control (C)
\textsuperscript{2} Activity - Tail Bite – 0 to 5 seconds of tail biting by 1 pig, Ear Bite – 0 to 5 seconds of ear biting by 1 pig, Ride – 0 to 5 seconds of riding by 1 pig, Fight – 0 to 5 seconds of fighting between 2 specific pigs.
\textsuperscript{a,b} Within a row and main effect, least squares means without a common superscript differ (P < 0.005).
Table 16. Least squares means for aggression activities across housing type treatments; number of occurrences adjusted for number of pigs per pen within 30 minute focal sampling periods.

<table>
<thead>
<tr>
<th>Activity</th>
<th>IN</th>
<th>OUT</th>
<th>Pooled SEM</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fight</td>
<td>0.31</td>
<td>0.18</td>
<td>0.05</td>
<td>0.004</td>
</tr>
<tr>
<td>Ear Bite</td>
<td>0.131</td>
<td>0.034</td>
<td>0.025</td>
<td>0.002</td>
</tr>
<tr>
<td>Tail Bite</td>
<td>0.033</td>
<td>0.006</td>
<td>0.012</td>
<td>0.14</td>
</tr>
<tr>
<td>Ride</td>
<td>0.063</td>
<td>0.045</td>
<td>0.018</td>
<td>0.42</td>
</tr>
</tbody>
</table>

1 Housing - Indoor (IN) or Outdoor Access (OUT)
2 Activity - Tail Bite – 0 to 5 seconds of tail biting by 1 pig, Ear Bite – 0 to 5 seconds of ear biting by 1 pig, Ride – 0 to 5 seconds of riding by 1 pig, Fight – 0 to 5 seconds of fighting between 2 specific pigs.
Table 17. Least squares means for illness activities within dietary treatments for pigs housed indoors; number of occurrences adjusted for number of pigs per pen within 30 minute focal sampling periods.

<table>
<thead>
<tr>
<th>Activity</th>
<th>AB</th>
<th>BM</th>
<th>C</th>
<th>Pooled SEM</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isolate</td>
<td>0.100</td>
<td>0.094</td>
<td>0.090</td>
<td>0.010</td>
<td>0.55</td>
</tr>
<tr>
<td>Itching</td>
<td>0.124</td>
<td>0.107</td>
<td>0.120</td>
<td>0.018</td>
<td>0.53</td>
</tr>
<tr>
<td>Coughing</td>
<td>0.152&lt;sup&gt;a&lt;/sup&gt; 0.102&lt;sup&gt;b&lt;/sup&gt; 0.116&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.016</td>
<td>0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Huddling</td>
<td>0.014</td>
<td>0.010</td>
<td>0.017</td>
<td>0.003</td>
<td>0.10</td>
</tr>
</tbody>
</table>

<sup>1</sup> Diet - Tetracycline (AB), Bio-Mos® (BM) or Control (C)

<sup>2</sup> Activity - Isolate – migration of 1 pig away from group, Cough – 0 to 5 seconds of coughing by 1 pig, Itch – 0 to 5 seconds of itching by 1 pig, Huddle – pig hunched over in recumbent position.

<sup>a, b</sup> Within a row and main effect, least squares means without a common superscript differ (P < 0.05).
Table 18. Least squares means for aggression activities within housing treatments; number of occurrences adjusted for number of pigs per pen within 30 minute focal sampling periods.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Housing</th>
<th>IN</th>
<th>OUT</th>
<th>Pooled SEM</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isolate</td>
<td></td>
<td>0.077&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.164&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.011</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Itching</td>
<td></td>
<td>0.112</td>
<td>0.138</td>
<td>0.018</td>
<td>0.17</td>
</tr>
<tr>
<td>Coughing</td>
<td></td>
<td>0.121</td>
<td>0.137</td>
<td>0.017</td>
<td>0.46</td>
</tr>
<tr>
<td>Huddling</td>
<td></td>
<td>0.016&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.004&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.004</td>
<td>0.002</td>
</tr>
</tbody>
</table>

<sup>1</sup> Housing - Indoor (IN) or Outdoor Access (OUT)

<sup>2</sup> Activity - Isolate – migration of 1 pig away from group, Cough – 0 to 5 seconds of coughing by 1 pig, Itch – 0 to 5 seconds of itching by 1 pig, Huddle – pig hunched over in recumbent position.

<sup>a, b</sup> Within a row and main effect, least squares means without a common superscript differ (P < 0.05)