EFFECT OF DISTILLERS DRIED GRAINS WITH SOLUBLES AND A FEED ADDITIVE CONTAINING ESSENTIAL OILS ON PERFORMANCE OF WEAN-TO-FINISH PIGS

By

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Abstract: Two studies were conducted to evaluate the effect of distillers dried grains with solubles (DDGS) and a feed additive containing essential oils on growth performance of wean-to-finish and nursery pigs. Feed disappearance and BW were recorded to calculate ADG, ADFI, and G:F ratio. One study was performed to test the effect of high levels of DDGS and high levels of DDGS plus essential oils on wean-to-finish pigs growth performance. High DDGS levels significantly decrease G:F ratio when compared to control overall. Pigs fed high DDGS + essential oils had a tendency to improve BW at d 42 of the study and G:F from d 0-42 compared to control. The same group of pigs fed high DDGS + essential oils had a significant improvement in overall G:F compared to those fed high DDGS. Upon completion of the study carcass data was collected from the pigs utilized in the study. There were no differences observed among dietary treatments live weight, HCW, percent yield and BF. However, there was a tendency for LD and percent lean to decrease in pigs fed high DDGS dietary treatment compared to those fed control. Additionally, pigs fed high DDGS + essential oils compared to pigs fed high DDGS tended to increase LD. Another study was conducted to evaluate the effect of essential oils on nursery pigs growth performance. There was no effect on nursery pigs growth performance from d 0-41. Similarly, no effect on growth performance was observed from d 14-41 when essential oils were added to nursery pigs diets in this study. In summary, high DDGS alone in wean-to-finish diets significantly decreased G:F, while there was tendency to decrease both LD and percent lean compared to control. The addition of essential oils to high DDGS containing diets significantly improved G:F and tended to improve loin depth in wean-to-finish pigs compared to high DDGS. High DDGS + essential oils tended to improve d 42 average weight and d 0-42 G:F vs control. However, in the study conducted looking at the effect of essential oils in standard nursery diets, no effects were observed.

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CHAPTER I

REVIEW OF LITERATURE

Introduction

Pork is one of the most widely consumed animal proteins in the world, simply due to the fact that it is relatively quick to produce while being a safe wholesome protein sources that is affordable. There is no question that changes in management practices, genetic advancements, and housing strategies have made pork a reliable source of protein for the world, but swine nutrition still plays a large part in keeping pork a safe affordable protein source. Swine nutrition plays a large role in pork production due to the cost of feed ingredients, availability, and dietary allowance of ingredients.

Feed alone accounts for 2/3 of the total cost associated with pork production (Lammers et al., 2008). Due to cost of feed being a large portion of the total cost associated in producing pork, producers and nutritionist are always trying to find new ingredients or strategies to incorporate into production. While utilizing new ingredients and strategies to reduce cost, growth performance, carcass traits and overall health are factors that must be accounted for in order to reduce cost. One ingredient that is used by nutritionist in swine diets is distillers dried grains with solubles (DDGS). In 2007, President George W. Bush announced the need for alternative fuel sources to alleviate foreign gas importance; this resulted in the use of corn for producing ethanol (Zangaro, 2018). The result of producing ethanol from corn grain is a coproduct known as DDGS. The production of ethanol using corn grain occurs when the starch in corn is fermented into ethanol and carbon dioxide, leaving behind DDGS that have concentrated amounts of other nutrients. Distillers dried grains with solubles when compared to yellow dent corn, has higher content of amino acids, and phosphorus (NRC, 2012). Amino acids and phosphorus are some of more expensive nutrients in swine diet cost. Distillers dried grains with solubles may have a higher amino acid levels than that of corn, but the drying process of DDGS production can result in a Maillard reaction leading to a reduced availability of amino acids, especially lysine. With the potential for reduced amino acid availability in DDGS it is also known to be higher in fiber, fiber is poorly digested by pigs which can reduce nutrient utilization by reducing nutrient digestibility (Stein and Shurson, 2009). Producers and nutritionist utilize DDGS in swine diets because they still have nutritional value as a feed ingredient. Additionally, DDGS have economical value due to the ability to replace corn in swine diets. Economic Research Service of the United States Department of Agriculture (USDA-ERS) estimated that 75 percent of DDGS produced are fed to livestock in the U.S., with 5 percent being utilized in swine diets (USDA-ERS, 2007). Studies have found that 0.45 kg of DDGS are estimated to replace 0.39 kg of corn in swine diets based on a dry matter bases (Shurson et al., 2003; Vander Pol et al., 2006; Bista et al., 2008). Bista et al. (2008) reported that a grower diet containing no DDGS cost $0.18 per kg, with the cost of the same grower diet formulated with DDGS to cost $0.15 per kg. This report shows the potential economic value of including DDGS in place of corn, but only when it is beneficial to do so in order to reduce cost.

Another tool that has been previously used by nutritionist is antibiotic growth promoters in feed, but with the Veterinary Feed Directive (VFD) being enacted in the United States the use of antibiotic growth promoters has been banned. The VFD was a result of actions taken by the European Union (EU) in regard to trade along with consumer concern about a safe, antibiotic free protein source. The result of these changes has led to nutritionist looking for alternatives like essential oils to replace the antibiotic growth promoters previously used. An essential oil is a concentrated hydrophobic liquid containing volatile aromatic compounds (Brenes and Roura, 2010). Essential oils are extracted from plants and used in the feed industry for their antimicrobial property as a potential replacement for antibiotics to improve growth performance and the health of the animals (Pettigrew, 2006; Stein and Kil, 2006).The use of essential oils in swine diets is becoming popular as they show positive results in relation to growth performance and health of pig during different stages of production. However, the potential benefits of essential oils are difficult to understand due to the large variation in the composition of essential oils.

Overall, the cost of producing pork is greatly influenced by feed cost. Producers and nutritionist face limitations when it comes to nutritional value, ingredients and laws that limit or prohibit the use of feed ingredients that influences their feeding strategies along with diet formulation. Nutritionist and producers have used many strategies that incorporate DDGS or essential oils to improve growth performance, health, and carcass traits in commercial swine production.

Nursery Phase

The nursery phase of pork production utilizes a facility designed specifically to house newly-weaned pigs until they reach the grow-finish stage of production. This stage of production is very critical for pig performance and health status. The transition between being weaned from the sow and housed in nursery facilities is one of the most stressful single events in commercial swine production (Campbell et al., 2013). Weaning can occur as early as 14 days after birth and with some weaning at 28 days after birth. The common weaning age for most commercial pork operations is 21 to 26 days post farrowing. Weaning age varies depending on the farm's standard operating procedure (SOPs) and goals set regarding the yearly sow productivity numbers. Upon weaning pigs are placed on a truck and transported to a nursery facility, where they can be exposed to several stressors that impact growth performance and health. As a result, there is a period known as post-weaning lag that occurs. Ravindran and Kornegay (1993) defined post-weaning lag as the period manifested by slow growth, and scouring, as a result of pigs exposed to nutritional, environmental, and social stressors. Similar report by Pluske et al. (1997) stated changes in diet, new pen mates, and a new environment are all contributors to the stressors newly-weaned pigs face. Upon weaning pigs are abruptly transitioned from a highly digestible liquid diet to a solid diet that is more complex (Lalles et al., 2007). The stressors that newly weaned pigs face includes social stress from mixing of pigs and interaction of new pen mates, establishing hierarchy, new environment, transportation, change in physiology of the small intestine, and dietary changes from a liquid to a solid diet are all related to post-weaning lag that result in morbidity, mortality, severe diarrhea, and post-weaning depression. However, one of the most noted results of post-weaning lag is the reduced overall growth performance of weaned pigs.

Reduced growth performance is a result of both psychological stress that occurs at weaning and both voluntary and involuntary food deprivation that contribute to changes in intestinal physiology (Goldstein et al., 1985). Boudry et al. (2004) stated that the acute and long-lasting effects on the intestine that are induced by weaning could be reduced with increasing voluntary feed intake of weaned pigs. There is an interest to achieve this increased feed intake without the addition of antibiotics or more expensive feed ingredients, but research is still needed to determine the best alternatives. Reduced growth performance is also the result of having low feed intake for the first several days post-weaning and low levels of metabolizable energy (ME) intake. It was reported that pre-weaning ME intake levels are not achieved until the end of the second week post-weaning (Le Dividich and Herpen, 1994). This means pigs are energy deficient in the time following weaning. The reduced energy intake accompanied with the other stressors result in effects on the gastrointestinal system and ultimately result in reduced growth performance during this phase of production.

Weaning weight, feed intake, diet type, and the environment that the pigs are housed should all be taken into consideration when diagnosing the cause of post-weaning lag (Dreau and Lalles, 1999). Research is still being conducted to determine alternatives that could potentially mitigate the effects of post-weaning lag in order to obtain greater growth performance and health status of nursery pigs.

Wean-to-Finish Production

Pork production practices are an individual producers' preference, but producers still look for ways to improve their operations. With labor forces, consumer awareness, and disease pressures changing so does management and production systems. As a result, producers incorporated a system into swine production adapted from the poultry industry known as wean-to-finish production. The concept utilizes one facility to house pigs from weaning until slaughter. The idea behind this production practice is to reduce the stress associated with moving pigs from a nursery site to a finishing site. Brumm (1999) reported that even if pen integrity is maintained, each move through production costs a day of growth. Moving pigs from nursery to finisher sites costs $1/pig or more, with the elimination of moving pigs results in less trucking, labor, and cleaning cost (Brumm, 1999).

Other benefits for reducing cost and stress of pigs with the utilization of wean-to-finish production practices is the potential benefit of improved growth performance. Brumm et al. (2002) found that pigs housed in wean-to-finish production system tended to weigh more due to higher ADG, and ADFI at the end of the nursery phase compared to a traditional nursery production setting. Knauer and Hostetler (2013) analyzed the US swine industry productivity from 2005 to 2010 looking at that the exit day and weight of pigs from wean-to-finish and finishing barns. They found that wean-to-finish pig exit age and weight were 183 days and 118.8 kg respectively, while pigs from finishing barns exit days and weight were 186 days and 119.7 kg respectively. The findings support that extra days of growth are needed when pigs are relocated from a nursery to a finisher site. The reduced cost and labor associated with wean-to-finish production coupled with reduced pig stress and improved performance has led to producers utilizing wean-to-finish production systems. Wean-to-finish production also allows health status to be maintained among the group. The limited movement allows for all-in, all-out practices to be used to reduce risk of disease transfer and increased biosecurity.

Even though research and statistics support the use of wean-to-finish facilities, there are downfalls to this production practice. Wean-to-finish facilities incur increased cost during the early nursery stage as the barn is designed for finishing pigs, the environment must be adjusted to meet the needs for newly weaned pigs. This requires environmental management to be perfected by increasing heating and reduced ventilation to maintain an appropriate environment. Wean-to-finish facilities are also less efficient in square footage utilization (Firkins, 1998), as the pens are stocked to meet finishing pig requirements and not nursey pig stocking rates.

Wean-to-finish facilities may incur increased facility costs during the nursery stage and be less efficient in square footage utilization. However, this can be offset by the reduced transportation cost, lower labor cost, along with increased facility flexibility, and utilization days due to less down time between groups. There is also the potential for improved feed conversion and average daily gain due to less stress on pigs from moving and resocialization.

Distillers Dried Grains with Solubles

In the United States, ethanol production produces approximately 38 million metric tons of DDGS (Olson and Capehart, 2019). Distillers dried grains with solubles are the major co-product of cereal grain utilized in the dry milling process of ethanol production, but a small portion of DDGS are produced from the ethanol beverage industry. The DDGS from ethanol beverage production is often characterized as having a darker color and having more variability in nutrient composition than the "new generation" DDGS that are primarily used in the livestock industry.

Yellow dent corn is the most commonly used cereal grain for dry mill ethanol plants due to it being an excellent source of readily fermentable fiber. Corn contains about 62% starch, 3.8% oil, 8.0% protein, 11.2% fiber and 15% moisture (Shurson, 2002). During the fermentation and distillation processes used in dry mill ethanol plants, most of the starch is converted into ethanol and carbon dioxide. This leaves a by-product that has a low concentration of starch and a high concentration of non-starch components such as fiber, amino acids, fat, and phosphorus. Traditionally the use of DDGS were used to formulate diets for ruminates due to the high fiber content and variable nutrient composition (Singh et al., 2005). However, production of DDGS from new generation plants has become popular to use in formulating non-ruminant diets because of its significantly higher levels of digestible and metabolizable energy, digestible amino acids, and available phosphorus (Shurson 2002; Singh et al., 2005; Belyea et al., 2010). Distillers dried grains with solubles produced in the upper Midwest new generation ethanol plants have higher digestible energy and nutrient content (Whitney and Shurson, 2004). New generation ethanol plants use enzymes and yeast to increase starch conversion to ethanol, and also use low temperature drying techniques that improve the nutritional value of DDGS making it suitable for swine (Whitney and Shurson, 2004). These factors make DDGS an economical option for the use in all stages of swine production.

Economic Impact as Livestock Feed

Historically, the majority of DDGS used in livestock feeding were fed to ruminates, due to the variability in quality, and nutrient content among sources (Singh et al., 2005). The main reasons for limited uses in swine diets was poor amino acid digestibility due to overheating during drying and high fiber content (Shurson, 2002). Pigs cannot efficiently digest fiber because they lack the enzymes needed to digest dietary fiber (Agyekum and Nyachoti, 2017).Along with the inability to digest the high fiber of DDGS produced by ethanol plants, the overheating of the DDGS during the drying process leads to damaged and/or indigestible amino acids for the pig (Shurson, 2002). This was the reason why historically the majority of DDGS from ethanol plants were fed to cattle.

With the implication of the Energy Policy Act of 2005, and the Energy Independence and Security Act of 2007, it stimulated the ethanol production in the United States. This increased the amount of “new generation” ethanol plants in the United States in order to meet the demands for ethanol production. It is reported that there are approximately 211 ethanol plants in the United States (Renewable Fuels Association, 2020). As a result, the use of “new generation” DDGS in the United States swine industry feeding programs have increased from about 30,000 tons in 2000 to more than 80,000 tons in 2002 (Shurson, 2003). The trend has remained as the utilization of DDGS in swine diets is an economical option for reducing feed cost.

With the high prices of conventional feedstuff like corn, soybean meal, and di-calcium phosphorous, the abundance of DDGS has made it an economical option. Distillers dried grains with soulbles can be used as an alternative or partial replacement for corn, soybean meal, and di-calcium phosphors in swine diets (Shurson and Noll, 2005; Belyea et al., 2010). The use of DDGS in swine diets not only can have an economic incentive by saving producers money it can also have a positive environmental impact due to reduced phosphorus excretion (Shurson, 2011). These benefits have made DDGS a popular economical cost saving ingredient for the use in swine diets.

Physical Characteristics and Nutrient Composition

The physical characteristics and nutrient composition of DDGS tend to vary among sources. Physical appearance, chemical composition, and nutrient digestibility are the most commonly affected components of DDGS due to the processing method, and/or drying procedures. The color of DDGS is an important indicator of quality and nutrient digestibility. "Golden colored" DDGS generally indicates higher amino acid digestibility compared to darker colored DDGS (Shurson, 2002). Color is known to be moderately to highly correlated with many physical properties, such as moister content, water activity, and bulk density (Rosentrater and Muthukumarappan, 2006). Color is an indicator of many properties of DDGS and closely associated with color is smell. Cromwell et al. (1993) reported smell and color of DDGS correlate with the nutritional value for non-ruminates. The "new generation" golden colored DDGS are recognized for a sweet, fermented smell that tend to be of higher quality while lower quality DDGS are darker colored and often has a burned or smoky smell. Lighter golden brown DDGS, which are ideal for feed usage, have greater digestible amino acid content than DDGS with darker color (Belyea et al., 2010). The darker colored DDGS is an indication of heat damage that negatively affects amino acids (Shurson and Noll, 2005; Stein, 2007). Color and smell differences are mainly due to the types of dryers and drying temperatures used in the ethanol plants but can also be influenced by the liquid solubles added to distiller's grains to produce DDGS (Shurson, 2002).

The nutrient composition of DDGS has been studied extensively for many years. In North America, most ethanol is produced from corn, with some plants using sorghum, wheat, or a blend of cereal grains. The DDGS produced by these ethanol plants are characterized by the nutrient composition of the grain used to produce the ethanol, but even when the same grain is used, variability in chemical composition has been observed among ethanol plants (Spiehs et al., 2002). The dry matter content of DDGS is around 89%, whereas the crude protein, and crude fat contents in DDGS are approximately 27% and 8.9% respectively (NRC, 2012). The average phosphorus content in DDGS is around 0.6% and apparent total tract digestibility (ATTD) of phosphorus is around 60% (NRC, 2012). The phosphorus values of DDGS is much greater than in corn, which only has an average 0.26% phosphorus content and ATTD of phosphorus average at 26% (Pendersen et al., 2007; NRC, 2012). The benefits of having higher availability of phosphors in DDGS fed to swine is the utilization of organic phosphorus will increase and the need for supplementation of inorganic phosphorus will be reduced. This can result in a reduction in the amount of expensive inorganic phosphorus fed. An additional benefit of high availability of phosphorus in DDGS is a reduction in phosphorus that is excreted in the manure. In addition to the higher total and available phosphorus, DDGS have a higher total amino acid content then corn. DDGS contain on average 27% crude protein, but because the majority of protein originates from corn, it is low in lysine (0.5% - 1.0%) and tryptophan (0.1% - 0.34%) (Spiehs et al., 2002; Stein and Shurson, 2009; Liu, 2011; NRC, 2012). The concentration of lysine is more variable than the concentration of most other amino acids in DDGS (Shurson and Alghamdi, 2008), this is due to overheating which destroys lysine or converts it into other compounds that cannot be used for protein synthesis (Fastinger and Mahan, 2006; Pahm et al., 2008; Stein and Shurson, 2009; NRC, 2012). Maillard reactions increases in DDGS thereby reducing the ATTD and standardized ileal digestible (SID) of lysine making it more variable in digestibility than other amino acids in DDGS (Pahm et al., 2008; Fastinger and Mahan, 2006; Stein and Shurson, 2009). Amino acids are required for swine diet formulation making it important to know the amino acid composition of DDGS. This has resulted in extensive research to obtain the amino acid composition of DDGS. Total lysine, methionine, threonine, and tryptophan content of golden-colored non-damaged DDGS are 0.9%, 0.57%, 0.99%, and 0.2% respectively (NRC, 2012). It is recommended before utilizing DDGS in swine diets to have a chemical composition analysis performed to ensure the nutritional values before using.

Most of the starch in corn is converted to ethanol during fermentation, and only a small part is not converted to ethanol, as a result DDGS contain higher fiber than most other cereal grain co-products. High fiber concentration reduces digestion in swine, which results in reduction of digestibility of dry matter and is the reason digestible energy in DDGS is reduced compared to other feed ingredients (Stein and Shurson, 2009; Jaworski et al., 2015).The concentration of neutral detergent fiber (NDF) is between 30 and 35% in DDGS, but because of the high concentration of fat and protein the digestible and metabolizable energy in DDGS is similar to corn (Spiehs et al., 2002; Pederson et al., 2007; Stein et al., 2009; Urriola et al., 2010; NRC, 2012).

The concertation of energy and nutrients in DDGS have been studied to determine values and as a result it can be compared to its original grain values. Research has found that digestibility and metabolizable energy values of corn and DDGS are similar. The gross energy (GE), digestible energy (DE), metabolizable energy (ME), and net energy (NE) values of corn are 3,933, 3,451, 3,395, and 2,672 kcal/kg, respectively (NRC, 2012). Distillers dried grains with solubles have slightly higher GE value (4,710 kcal/kg) than that of corn, yet similar DE value (3,582 kcal/kg) and ME value (3,396 kcal/kg), however the NE value (2,343 kcal/kg) is lower than that of corn (NRC, 2012). Distillers dried grains with solubles are still used as an energy source in swine diets because of its ability to replace corn and reduce the cost of the diet.

With a co-product that has such a big impact on the feed industry as a component of many diets, no industry quality standards exist for DDGS at this time. Quality can be effected due to the processing technologies used in the plant such as, type of yeast used for fermenting, fermentation and distillation time, the amount of solubles added to the distillers' grains, even the drying process and/or temperature all can effect or alter the nutritional composition of DDGS (Kerr and Shurson, 2013). Other factors such as the variability in the composition of corn used, the variation of handling, and storage of DDGS at production plants make it hard to incorporate industry quality standards.

Overall, the high energy, moderate protein content, along with relatively high concentration of phosphorus and digestibility are the key nutritional components that make DDGS an attractive alternative feed ingredient. However, DDGS have some limitations that must be managed in order to achieve the greatest economic and performance benefits that DDGS can have when added to swine diets.

Effect of DDGS on Nursery Pig Performance

The use of DDGS in swine diets can be incorporated as early as the weaning stage. The inclusion rates for nursery diets varies but has been reported at rates up to 30% without negative effect on performance (Whitney and Shruson, 2004; Almeida and Stein, 2010; Jones et al., 2010). Senne et al. (1996) observed that the performance of pigs fed diets containing 30% DDGS was similar to the performance of pigs fed control diets, whereas inclusion of 45 or 60% DDGS reduced ADG and G:F. Tran et al. (2011) reported that DDGS can be included in nursery diets at 15% for the entire period, and or 30% inclusion during the late nursery stage without compromising growth and performance. A study conducted looking at the effect of pelleting diets for nursery pigs containing 30% DDGS found no effect on ADG, ADFI, or G:F(Zhu et al., 2010). However, reports of reduced growth performance have been reported at 20% inclusion rates in diets fed to weanling pigs (Kim et al., 2012). While conflicting results do not support an optimum inclusion rate of DDGS in nursery diets, the commercial standard is no more than 25% for nursery pigs with the body weight up to 7 kg (Whitney and Shurson, 2004; Shurson and Noll, 2005). Inclusion of DDGS in nursery diets can be beneficial from a cost reduction practice, but it has limitation that must be accounted for when being used in nursery diets. The use of DDGS in nursery diets to reduce corn and soybean meal require the supplementation of synthetic amino acids to ensure the dietary supply of amino acids are sufficient for the pig (Zangaro, 2018). Along with DDGS having the lower amino acids compared to the corn and soybean meal combination, DDGS also has a lower density than corn or soybean meal. The lower density of DDGS compared to corn or soybean meal limits the inclusion rate of DDGS in nursery diets that are nutrient dense.

Overall, the inclusion of DDGS in early nursery diets is not largely utilized, however when included in later nursery phase diets it can reduce cost without a negative impact on performance. The biggest reason for DDGS not being used commonly in early nursery diets is the higher fiber content, lower palatability, and the need for the addition of synthetic amino acids (Zangaro, 2018). Synthetic amino acids increase the cost of nursery diet that includes expensive products like whey, lactose, blood cell, animal plasma, and fish meal. Research has shown benefits to including DDGS during the later stage of the nursery phase.

Effect of DDGS on Grow-Finish Pig Performance

The effect of feeding DDGS in diets for grow-finish pigs has been studied for over decades. The early research showed that the inclusion of 20% DDGS in diets fed to growing and finishing pigs could maintain growth performance whereas performance would be reduced when 40% inclusion was used (Cromwell et al., 1983). Majority of studies performed report no difference between pigs fed diets containing DDGS compared to corn-soybean meal diets in regard to growth performance. Within the last decade more studies have been performed to look at the inclusion rates of DDGS in grow-finish diets to find an optimum level. Numerous experiments have been performed looking at the inclusion rate of 30% of DDGS in grow-finish diets without reducing growth performance (Widayrante and Zijlstra 2007; Widmer et al., 2008; Xu et al., 2010a; Yoon et al., 2010; McDonnell et al., 2011), but several observed reduced growth performance in grow-finish pigs (Whitney et al., 2006b; Linneen et al., 2008; Leick et al., 2010; Hoffman and Baker, 2011; Kim et al., 2012). Hastad et al. (2005) observed that preference of DDGS by grow-finish pigs decreased linearly as the inclusion rate increased from 0 to 30% in the diets. However, Xu et al. (2007a) found ADG was not affected, but ADFI was reduced while G:F was linearly improved in pigs fed diets containing 0,10,20,or 30% DDGS.

The effect on growth performance in grow-finish pigs in relation to the inclusion rate in diets has proven to be inconsistent. The reason behind the inconsistency can only be speculated, but it is possible where performance is reduced it could be related to the quality of the DDGS, or excess nitrogen from the crude protein at high inclusion rates. The use of low quality DDGS and the use of DDGS that have a low lysine level when added to a diet can be hypothesized as a reason for reduced growth performance due to low digestibility. Pig performance would be expected to decline since lysine is known to be the first limiting amino acid in many swine diets. The ability to know if negative performance in grow-finish pigs is related to the DDGS or increase in crude protein can be determined by the inclusion of crystalline lysine or tryptophan in diets (Stein, 2007). High fiber content of DDGS may also have an effect on reduced growth performance due to reduced nutrient digestibility (Whitney and Shurson, 2004).

In general, DDGS can be used in grow-finish diets at inclusion rates up to 30% without a negative impact on growth performance (Stein and Shurson, 2009). However, when using DDGS at levels that exceed 30% reduction in growth performance can be noted in grow-finish pigs. This may be related to the higher fiber content accompanied with variation in nutritional composition, and low lysine content in DDGS. The inclusion rate of DDGS in grow-finish diets depends a lot on the nutritional value and quality of the DDGS being included.

Effect of DDGS on Carcass Composition

The inclusion of DDGS has been reported to have varying effects on carcass traits of pigs. In the Stein and Shurson (2009) summary, 18 experiments measuring carcass dressing percentage was looked at that compared pigs fed DDGS with pigs fed corn-soybean meal diets containing no DDGS and found no difference in the majority of the studies (Fu et al., 2004; McEwen, 2006, 2008; Xu et al., 2007b; Augspurger et al., 2008; Drescher et al., 2008, Duttlinger et al., 2008; Hill et al., 2008a; Stender and Honeyman, 2008; Widmer et al., 2008). Yet, the findings of 8 experiments showed feeding diets containing DDGS had reduced carcass dressing percentage (Cook et al., 2005; Whitney et al., 2006a; Gaines et al., 2007a and b; Hinson et al., 2007; Xu et al., 2010a; Linneen et al., 2008; Weimer et al., 2008). The reason for the different findings among the studies is not fully understood, but previous studies may suggest an answer. Kass et al. (2008) reported that adding ingredients with high fiber content to growing-finishing pig diets may reduce dressing percentage because of increased gut fill and increased intestinal mass. Although this finding may explain why some studies find a decrease in dressing percentage of pigs fed DDGS, it doesn't explain why the finding is not observed in all experiments.

Generally, grow-finish pigs fed 30% DDGS dietary inclusion show no effect on backfat thickness, loin depth, and lean percentage. Stein and Shurson (2009), concluded that growth performance is not affected when DDGS are included at 30%, but carcass characteristics are negatively affected when DDGS are included at dietary levels greater than 30%. Bergstrom et al, (2014) reported that the inclusion of DDGS from 20 to 60% decreased final body weight, hot carcass weight, and backfat while also increasing iodine values. The negative effect of high DDGS levels is believed to be due to the high fiber and unsaturated fatty acid content in DDGS. The increase of unsaturated fatty acids results in pigs having softer bellies, which might reduce bacon slicing quality (Whitney et al., 2006a; Leick et al., 2010; Cromwell et al., 2011). Elevated unsaturated fatty acid levels are known to increase carcass fat iodine levels, an important measures of carcass quality. A study found iodine values were linearly increased with an increase in DDGS dietary levels, suggesting a linear increase in unsaturated fatty acids (Xu et al., 2008; Cromwell et al., 2011). Removal of DDGS from diets 3 to 4 weeks prior to slaughter has shown that belly firmness can be partially restored (Xu et al., 2010b).

Overall, the inclusion of high dietary levels of DDGS has shown to negatively affect carcass characteristics. The iodine levels are greatly impacted by high DDGS levels due to the presence of unsaturated fatty acids (Madsen et al., 1992). Other impacts of high DDGS dietary inclusion is decreased carcass yield due to the high fiber associated with DDGS (Stein and Shurson, 2009). The inclusion of DDGS in finisher diets may be limited during the last few weeks prior to slaughter in order to optimize the value of the carcass (Xu et al., 2008).

Feed Additives

The increased awareness of potential negative effects of including antibiotic growth promoters in diets fed to pigs along with the current laws in place has increased the use of feed additives. On January 1st, 2017 the Veterinary Feed Directive (VFD) was enacted which made immediate changes in the use of antimicrobial agents in livestock feed and/or water. The VFD was put in place due to increased consumer concern of potential negative effects of antibiotic growth promoters, accompanied with the restriction put in place by the EU and other countries importing pork from the United States. The livestock nutrition industry was forced to find alternatives to replace the antibiotic growth promoters previously used. The research field has since tested many potential alternatives such as acidifiers, minerals, prebiotics, direct-fed microbials, plant extracts or essential oils and other options.

The elimination of antibiotic growth promoters from diets fed to pigs has greater impact on post-weaned pigs as we see a greater increase in diseases and poor growth performance (Liu et al., 2018). The restricted use of antibiotics in nursery diets have the potential for increased diseases and decreased feed intake that is commonly associated with the post-weaning. There is not as many reports of decreased feed intake and diseases in grow-finish phases with the restricted use of antibiotics due to the animal reaching their physiological maturity. This is mostly due to the fact that the physiological challenges on the digestive and immune system have already passed during the weaning phase (Wierup, 2001). As a result, the encounters with reduced growth performance in later stages of commercial swine production is far less than post-weaning with the removal of antibiotics from swine diets (Cromwell, 2013). In order to avoid the negative effects of removing antibiotic growth promoters that have been banned by the VFD the use of feed additives has become heavily researched. Although a trend in commercial swine production is to use feed additives, it is difficult as no required levels are listed in the NRC (2012) like other nutrients.

Essential Oils

The increasing popularity of essential oils has become very popular in use among animal diets due to the potential effects on animal growth performance and health. Essential oils are aromatic, volatile and oily liquids extracted from plant materials such as seeds, flowers, leaves, buds, twigs, herbs, bark, wood, fruit and roots (Brenes and Roura, 2010). The term essential used in this context does not mean indispensable as with the use of the term in relation to essential amino acids and essential fatty acids, which are nutritionally required by animals (Reeds, 2000). Essential oils are generally extracted from plants by distillation but, other processes include expression, solvent extraction, and cold pressing (Simon, 1990; Greathead, 2003). Essential oils used in diets tend to be a mixture of complex compounds which can vary in their individual chemical composition and concentration. However, research has shown that they act as alternative to antibiotics because of their antimicrobial, and antioxidative properties (Dundar et al., 2008). With the potential biological function of essential oils many nutritionists have started to use strategies to incorporate them into swine diets to help improve growth performance and health of the animal. Some of the most common used essential oils derive from garlic, clove, thymol, cinnamaldehyde, and carvacrol (oregano) (NRC, 2012). Among these commonly used essential oils there are two major classes of compounds, terpenes (e.g., carvacrol and thymol) and phenylpropenes (e.g. cinnamaldehyde). Omonijo et al. (2017) reported that there is estimated 4,000 terpenes known to exist while only 50 phenylpropenes have been discovered.

The use of essential oils and their effects are largely dependent on many factors including chemical composition, the climate, seasons, geographical location, time of harvest, part of the plant used, and how the oil is extracted from the plant (Bayder et al., 2004; Màthé, 2009). These variables that effect the chemical composition of essential oils lead to many concerns that need to be further researched. The research that needs to be continued is not only limited to the application in animal diets, but also the advancement in processing of essential oils.

Essential Oils Mode of Action

The mode of action of essential oils have been researched in recent years as their popularity have increased for the use in livestock feeds. Essential oils consist of two major classes of compounds, terpenes (e.g., carvacrol and thymol) and phenylpropenes (e.g. cinnamaldehyde). The most common terpenes, carvacrol and thymol, have several target sites in bacterial cells with the bacterial cell wall being their main target site (Faleiro, 2011; Yap et al., 2014). Carvacrol and thymol have two mode of actions that have been established. One mode of action is that they sensitize the cell walls and cause significant membrane damages that leads to integrity of the cytoplasmic membrane to collapse and eventually death of the bacterial cell. The second mode of action is a result of their lipophilic structure, carvacrol and thymol easily enter the bacterial membranes with the fatty acid chains, this results in the membranes expanding and become more fluid (Omonijo et al., 2017). These properties make carvacrol and thymol possible alternatives to antibiotics in swine production (Kim et al., 1995; Lambert et al., 2001; Delquis et al., 2002). Cinnamaldehyde, a member of the phenylpropenes class is another commonly used essential oil compound in livestock diets. Cinnamaldehyde's antimicrobial activities are related to membrane effects and energy generation (Gill and Holley, 2004; Gill and Holley, 2006). The primary mode of action for carvacrol, thymol, and cinnamaldehyde is related to their effect on the cytoplasmic membrane and energy metabolism (Omonijo et al., 2017).

The gut has several important functions that include absorption of nutrients, secretion of immunoglobulin, cytokines, mucin, and selective barrier protection against harmful antigens, toxins, and pathogens (Lalles et al., 2004). Gut epithelial cells play an important role in immune response as they can detect the onset of inflammation through cytokines. Cytokines are vital for recruitment and activation of different immune cells that include neutrophils, macrophages, T cells, B cells and dendritic cells (Eckmann et al., 1995; Pitman and Blumberg, 2000). Intestinal inflammation is associated with compromised growth, intestinal development, and reduced efficiency of nutrient utilization. Generally, 3 types of intestinal inflammation have been observed in pigs related to pathogens, nutrition, and management (Yang et al., 2015a). As a result of intestinal inflammation reduced growth performance can be observed. Essential oils have been researched to see if they can offer potential benefits that mitigate the effect of intestinal inflammation. Two studies have demonstrated that essential oils can reduce inflammation, a potential improvement in growth performance and health could be observed when feeding essential oils to pigs (Wondrak et al., 2010; Zou et al., 2016). Yang et al. (2015b) observed the supplementation of cinnamon oil reduced the effect of a lipopolysaccharide induced challenged by suppressing inflammation. Essential oils have demonstrated that they can influence immune response and enhance pig health which can lead to increased growth performance.

The mode of action that has been established in essential oils makes it a potential natural alternative to antibiotics. The immune response and reduction of intestinal inflammation observed in studies that utilized essential oils have increased interest in essential oils to promote overall health and growth performance.

Effect of Essential Oils on Nursery Pig Performance

In recent years, researchers have documented the effect of essential oils on growth performance of swine, but the results have been very inconsistent. The use of essential oils in the nursery phase has been an area of interest because it is one of the critical time periods for growth. Li et al. (2012) evaluated the effect of adding essential oils to the diets of weaned pigs and found that over the entire experiment, average daily gain was improved for pigs fed the diets containing essential oils. Likewise, Sads and Bilkei (2013) found that nursery phase pigs fed essential oils had increased weight gain. A study done by Meanner et al. (2011) looked at the effect of two different essential oils on weaned pigs and found no effect on feed intake or body weight but an improvement in gain to feed ratio. While some studies show the use of essential oils in nursery phase pigs can improve weight gain, average daily gain, and gain to feed ratio, other studies contradict the findings. Three studies investigated the effect of essential oils on nursery pig performance found no benefits related to average daily gain, feed intake, and feed conversion ratio (Manzanilla et al., 2004; Neill et al., 2006; Nofrarías et al., 2006). While findings are inconsistent with the use of essential oils in nursery phase growth performance, there is evidence that essential oils can have a positive impact growth performance and makes them a potential alternative to previously used antibiotic growth promoters.

Effect of Essential Oils on Grow-Finish Pig Performance

In the grow-finish stage of pork production, essential oils have been looked at to improve growth performance. While literature and results are very limited on the use of essential oils in grow-finish diets there are a few studies that show a potential for improved growth performance. Two studies reported that pigs fed a garlic treated diet had higher average daily gain, average daily feed intake and gain to feed conversion ratio compared to pigs fed the control diets (Cullen et al., 2005; Janz et al., 2007). Grela et al. (1998) observed a significant improvement in average daily gain and gain to feed conversion ratio with the use of an herb mixture in diets of pigs fed from 25 to 105 kg.

Including essential oils in grow-finish stage diets have shown positives result on growth performance. It is believed the result of these finding is related to the preference of essential oil diets, hence a greater consumption and boost in growth performance can be associated to essential oil inclusion in grow-finish diets. While the limited findings show positive benefits on growth performance when including essential oils in grow-finish diets more research is required to validate these findings.

Effect of Essential Oils on Carcass Composition

Essential oils can be used in swine diets for improving growth performance and health. Although many of these strategies are used in pigs designated for protein production, very little information is available on the effect of essential oils in regard to meat quality and carcass composition. In a study conducted by Janz et al. (2007) found that the dietary supplementation of essential oils had no effect on carcass weight, dressing percentage, or backfat thickness. Likewise, three other studies demonstrated no effect on carcass traits of pigs fed essential oils (Grela, 2000; Paschma, 2000; Paschma and Wawrzynski, 2003).

In monogastric species, fatty acid profiles of tissues are readily influenced by the composition of the feeds they consume (Ellis et al., 1999; Enser et al., 2000). Several studies failed to show an effect on the fatty acid profile of pork longissimus muscle harvested from pigs fed essential oils (Grela, 2000; Paschma and Wawrzynski, 2003; Janz et al., 2007). It is believed because essential oils used in diets only make up a small part of the total diet, they may have no effect on fatty acid profile. In summary, while there are limited findings on the effects of essential oils in regard to meat quality and carcass composition, there is no reports of negative effects on carcass traits. More research is needed to confirm the overall effect of including essential oils can have on carcass traits.

Conclusion

In conclusion government actions have created unique opportunities and challenges for pork producers that provide the world with a safe protein source. The actions taken by President George W. Bush to create an alternative fuel source has created a valuable coproduct in DDGS for the use in livestock feeding. Distillers dried grains with solubles are an excellent source of energy and digestible phosphorus for all phases of pork production. With the ability to include up to 30% DDGS in nursery and grow-finish diets without a negative impact on growth performance has been key in reducing cost associated to feeding pigs. However, there are limitations of using DDGS because of the high fiber content, along with variation in nutritional composition. While strategies are created to overcome these limitations of DDGS as an ingredient in swine diets, other challenges can arise in response to the amount of DDGS found in finisher diets. High levels of DDGS has led to higher levels of linoleic acid in finisher diets that result in a soft fat. This negatively effects iodine levels and decrease the value of the carcass. Research is still being performed to maximize the value of DDGS in all phase of pork production. However, utilization of DDGS can allow pork to be a safe, affordable, and consistent source of protein.

While the government has created opportunities for feeding pigs, they have also created challenges that must be addressed. The enactment of the VFD in 2017 which banned the use of antibiotics as a growth promoter has created an area of interest for producers to find alternative options. One of these options that has been looked into is the use of essential oils. Essential oils have shown to be a unique feed additive that can improve growth performance while having properties similar to antibiotics that can improve health. The use of essential oils has been studied in all phase of production, but there are still varying results. Further research is needed to validate essential oils as a feed additive that can be a viable option in replacing antibiotics as a growth promoter.

Overall, continued research is needed to optimize the value of DDGS and essential oils. Although the research will be influenced by animal husbandry practices, genetic advancements, consumer awareness, and government regulations, nutrition will always be a focus for swine producers. These unique challenges can lead to strategies that utilizes a combination of these factors to keep improving the production of pork, while still maintaining its presence as a safe, affordable, and consistent protein source for the world.

CHAPTER II

EFFECT OF DISTILLERS DRIED GRAINS WITH SOLUBLES AND A FEED ADDITIVE CONTAINING ESSENTIAL OILS ON PERFORMANCE OF WEAN-TO-FINISH PIGS

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Abstract

The objective of this study was to determine the effects of distillers dried grains with solubles (DDGS) and a feed additive containing essential oils (Biolex™; BioMatrix International, Princeton, MN) on growth performance of wean-to-finish pigs. Five hundred twenty-eight crossbred pigs (5.8 kg) were utilized in this experiment, upon arrival pigs were randomly allotted and balanced by source, sex, and BW to three treatments (11 pigs/pen; 16 pens/treatment). The three dietary treatments consisted of fortified corn-soybean meal-DDGS based diet serving as the control, control + high DDGS (high DDGS), and control + high DDGS + essential oils (Biolex™). Pigs were fed utilizing phase feeding with 5 nursery and 6 finishing dietary phases. A common diet was fed for the first phase of the nursery. The high DDGS treatment was provided from phase

2 of the nursery diets through phase 4 of the finisher diets. A common level of DDGS was fed in finisher phases 5 and 6 as not to affect carcass quality. Biolex™ was added to the high DDGS in phase 4 of the nursery diets and included through phase 6 of the finisher diets. Feed disappearance and BW were recorded to calculate ADG, ADFI, and G:F. Upon completion of the study pigs were shipped to Madison, NE for carcass data collection. Data were analyzed using the MIXED procedure in SAS with pen serving as the experimental unit. There was no difference ($P > 0.10$) in d 0-42 ADG for high DDGS vs. control or high DDGS + Biolex™ vs. high DDGS. Day 0-42 ADG tended to improve ($P < 0.10$) when high DDGS + Biolex™ was compared to control (0.412 vs. 0.395 kg/d). High DDGS vs. control d 0-42 ADFI tended ($P < 0.10$) to increase (0.58 vs. 0.56 kg/d) however, there was no difference ($P > 0.10$) in high DDGS + Biolex™ vs. control or high DDGS + Biolex™ vs. high DDGS ADFI. There was no difference ($P > 0.10$) in d 0-42 G:F observed between high DDGS vs. control or high DDGS + Biolex™ vs. control yet, High DDGS + Biolex™ vs. high DDGS G:F tended ($P < 0.10$) to improve (0.706 vs. 0.695).There was no difference in ($P > 0.10$) in d 42 BW for pigs fed high DDGS vs. control or pigs fed high DDGS + Biolex™ vs. high DDGS. There was a tendency ($P < 0.10$) for high DDGS + Biolex™ d 42 BW to improve compared to control. There was no difference in d 42-168 ADG, ADFI, or G:F for pig fed high DDGS + Biolex™ vs. control. High DDGS + Biolex™ vs. high DDGS d 42-168 ADG showed no difference ($P > 0.10$) however, there was a tendency ($P < 0.10$) for ADFI to decrease (2.39 vs. 2.45 kg/d) and G:F to significantly ($P < 0.05$) increase during this period (0.380 vs. 0.367). For the d 42-168 period high DDGS vs. control ADFI showed no difference ($P > 0.10$) but ADG (0.899 vs. 0.918 kg/d) and G:F (0.367 vs. 0.379) significantly decreased ($P <$

0.05) during this time. There was no difference (*P* > 0.10) in the overall period (d 0-168) final BW, ADG, or ADFI among the treatments. There was significant differences in G:F for the overall period between high DDGS vs. control (0.404 vs. 0.414) and high DDGS + Biolex™ vs. high DDGS (0.414 vs. 0.404). There was no difference in G:F for high DDGS + Biolex™ vs. control.

Carcass data collected from the study found no difference among treatments (*P* > 0.10) in HCW, percent yield, or fat depth. There was no difference (*P* > 0.10) in loin depth between high DDGS + Biolex™ vs. control however, loin depth tended (*P* < 0.10) to increase when high DDGS + Biolex™ was compared to high DDGS (6.60 vs. 6.50 cm). There was also a tendency (*P* < 0.10) for loin depth to decrease for high DDGS vs. control (6.50 vs. 6.61 cm). High DDGS vs. control percent lean tended (*P* < 0.10) to decrease (55.91 vs. 56.17), but there was no difference in percent lean when high DDGS + Biolex™ was compared to high DDGS or control treatments.

Results suggest, high DDGS vs. control tended to increase ADFI for d 0-42 however, ADG and G:F for d 42-168 decreased. Overall G:F decreased in pigs fed high DDGS diets compared to those fed control. Loin depth and percent lean tended to decrease when high DDGS vs. control was compared. When high DDGS + Biolex™ vs. high DDGS was compared an increase in d 42-168 and overall G:F was observed. ADFI tended to decrease for the period d 42-168 with loin depth tending to increase in those fed high DDGS + Biolex™ vs. high DDGS. High DDGS + Biolex™ vs. control tended to improve d 42 BW and d 0-42 ADG, but no difference in growth performance observed in d 42-168 or overall. Carcass traits were not affected when comparing high DDGS + Biolex™ to control.

Introduction

Commercial production has evolved over the years as an industry that produces a safe, affordable, consistent protein source for the world. Still producers face many challenges to maintain efficient pork production and all while still looking to improve their strategies implemented in producing pork. In the late 90's, commercial producers incorporated a production strategy called wean-to-finish. Newly weaned pigs are moved into biosecure facilities, and all-in, all-out management practices are utilized to minimize health challenges. This reduced the transportation, time away from feed, and regrouping stressors that can reduce the performance and health of growing pigs. Wean-to-finish research and statistics has shown that the production practice can improve ADG, and ADFI during the critical growing period of pigs at the end of the nursery phase (Brumm et al., 2002). However, nutritional strategies are a key principle to the success of raising efficient pigs that achieve optimal growth performance and carcass characteristics.

An astonishing number of feed ingredients exist today for producers to incorporate into swine diets in order to reduce cost while not sacrificing nutritional requirements needed to obtain proper growth performance. With the implication of the Energy Policy Act of 2005, and the Energy Independence and Security Act of 2007, ethanol production has dramatically increased. The increase in ethanol product that utilizes corn has created an abundance of distillers dried grains with solubles (DDGS), a coproduct of the ethanol process. Distillers dried grains with solubles has become an economical option for an alternative or partial replacement for corn, soybean meal, and di-calcium phosphorus in swine diets (Shurson and Noll, 2005; Belyea et al., 2010). Distillers dried grains with solubles is an excellent source of energy and phosphorus for all stages of production (Stein and Shurson, 2009). However, nutrient concentration, digestibility, and amino acid concentration vary among sources creating challenges for producers to maximize the value of DDGS in swine diets.

DDGS can be included in nursery and grow-finish diets at levels up to 30% while still being able to achieve acceptable growth performance. Cromwell et al. (1983) found that growth performance could be maintained with 20% DDGS inclusion, whereas 40% would reduce performance. However, other findings report that 20% inclusion reduced growth performance (Kim et al., 2012). These findings suggest the optimal inclusion rate to achieve acceptable growth performance is not fully established. It has been found however that the inclusion of DDGS above 20% prior to slaughter results in soft fat and iodine values that are not acceptable (Stein and Shurson, 2009). It is suggested to reduce or withdrawal DDGS 4 weeks prior to slaughter to maintain acceptable carcass quality.

In 2017, the Veterinary Feed Directive (VFD) was enacted banning the use of antibiotic growth promoters (AGP). As a result, producers face a number of challenges that must be addressed. The development of cost-effective antibiotic alternative is the biggest challenge, which is crucial for the long-term sustainability and profitability of swine production. Essential oils are an alternative being researched because they contain a number of active ingredients and one of the most promising antibiotic alternatives. Interest in essential oils as a potential antibiotic replacement is due to results of in vitro studies showing antimicrobial activity against microflora commonly present in the pig’s gut (Michiels et al., 2009). As a result, research has been conducted to determine whether or not essential oils can improve pig performance when included in swine diets. Li et al. (2012) compared the performance of pigs fed a control diet to that of pigs fed a diet containing antibiotics or essential oils and found that growth performance of pigs fed essential oils was essentially equal to that of pigs fed antibiotics. However, results have shown inconclusive findings with some studies reporting no beneficial effects on growth performance.

The use of DDGS and essential oils has produced varying results in the past. The varying results can be related to quality of ingredients, processing, inclusion rate, along with the effect of the animal that depends on genetics, age, environment, diet, and health status. These factors can make it challenging to determine what is influencing these results. However, producers are always looking for ways to reduce production costs and nutrition accounts for a large portion of cost associated with pork production.

Therefore, the objective of this study was to determine the effects of DDGS levels and a feed additive containing essential oils (Biolex™; BioMatrix International, Princeton, MN) on growth performance of wean-to-finish pigs.

Materials and Methods

Experimental Design, Animal Care, Housing and Diets

All methods and procedures for the live animal research portion of this experiment were reviewed and approved by the Oklahoma State University Institutional Animal Care and Use Committee. All live animal research of this experiment was conducted at the Oklahoma State University Swine Research and Education Center (Stillwater, Ok). At the completion of the experiment animals were shipped and harvested for carcass data collection at the Tyson Foods pork packing plant in Madison, NE.

Five hundred and twenty-eight crossbred piglets (average initial BW = 5.8 kg) were weaned and transported to the Oklahoma State University Swine Research and

Education Center in Stillwater, OK. Upon arrival at the research center, pigs were randomly allotted to one of forty-eight pens consisting of sixteen replicate pens per treatment with eleven pigs per pen. The pigs were balanced among treatments by initial BW, sex, and source.

After allotment, pigs were randomly assigned to one of three dietary treatments. The dietary treatments were a fortified corn-soybean meal-DDGS based diet that served as the control, control + high DDGS, and control + high DDGS + essential oils (Biolex™; BioMatrix International, Princeton, MN). Pigs were fed utilizing phase feeding consisting of 5 nursery diets and 6 finishing diets. All pigs were fed a common diet during phase one of the nursery (N1) before dietary treatments were utilized. Phases two and three of the nursery (N2, N3) utilized control and control + high DDGS, phase 4 of the nursery (N4) utilized all three dietary treatments. Phase five and six of the finisher diets (F5, F6) consisted of similar levels of DDGS (removal of high DDGS) as not to affect carcass quality. Phase six finisher diets (F6) included ractopamine hydrochloride (Paylean®, Elanco Animal Health, Greenfield, IN). Diets contained no antibiotics throughout the entire period. Treatment design and ingredient composition of formulated diets is listed in Table 2.1, 2.2 and 2.3.

The whole trial lasted for 168 days and the pigs were housed in wean-to-finish facilities with control of environmental temperature and ventilation. The barns were set with a starting initial temperature of 31.1°C and reduced until it reached 18.3°C. Each pen was equipped with an adjustable stainless-steel self-feeder and nipple cup waterer to allow for *ad libitum* access to feed and water. Feed wastage was noted and recorded. Health status of the pens were monitored and recorded.

Growth performance was measured through weighing of pens, feeders, and number of pigs on a weekly basis through the nursery phase and upon the completion of the diet phases for the majority of pens during the finisher phase (days 0, 7, 14, 21, 28, 35, 42, 63, 88, 109, 127, 158, and 168). Feed intake was calculated based on feed fed, and total weight of feeder minus the initial feeder weight to measure feed left in the feeder. Growth performance was determined based on average daily gain (ADG), average daily feed intake (ADFI), and feed conversion (G:F).

Pigs were marketed in two groups, on day 158 the three heaviest pigs per pen were shipped to Madison, NE for harvest and on day 168 the remaining pigs in the pen were shipped and harvested. Carcass traits were collected from pigs utilized in the study and reported using live weight, hot carcass weight (HCW), percent yield, fat depth (FD), loin depth (LD), and percent lean.

Statistical Analysis

All data collected were analyzed using the MIXED procedure of SAS (Version 9.4, SAS Institute, Inc., Cray, NC) with pen serving as the experimental unit. Means were reported as Least Square Means (LS Means) and the variability of data was represented as the standard error of means (SE). Significance was declared at $P \leq 0.05$, and a tendency at $P > 0.05$ and $P \leq 0.10$.

Results

The growth performance measures are presented in Table 2.6. Growth performance was collected for periods d 0-42, d 42-168, and overall d 0-168. High DDGS vs. control had no effect ($P > 0.10$) on d 0-42 ADG, G:F, or d 42 BW. There was a tendency ($P = 0.100$) for pigs fed high DDGS vs. control to have increased ADFI during this period. During d 0-42, high DDGS + Biolex™ vs. high DDGS tended (*P* = 0.071) to increase G:F, but had no effect (*P* > 0.10) on ADG, ADFI, or d 42 BW. High DDGS + Biolex™ vs. control ADFI and G:F did not differ (*P* > 0.10); however, ADG for this period tended (*P* = 0.075) to increase with d 42 BW also tending (*P* = 0.094) to increase.

Average daily gain, ADFI, and G:F did not differ (*P* > 0.10) for high DDGS + Biolex™ vs. control throughout out the finisher period (d 42-168). Similarly, high DDGS + Biolex™ vs. high DDGS ADG did not differ (*P* > 0.10) for this time period. There was however a significant improvement in G:F (P = 0.031) and a tendency (P = 0.085) for ADFI to decrease when comparing high DDGS + Biolex™ to high DDGS for this period. While d 42-168 ADFI did not differ between high DDGS vs. control, there was significant decrease in both ADG (*P* = 0.050) and G:F (*P* = 0.036) for this time period.

There was no difference (*P* > 0.10) in the overall (d 0-168) ADG, ADFI, or final BW. High DDGS + Biolex™ vs. control G:F did not differ (*P* > 0.10) overall however, there was significant differences in G:F for high DDGS + Biolex™ vs. high DDGS (*P* = 0.024) and high DDGS vs. control (*P* = 0.034). Gain to feed increased in high DDGS + Biolex™ vs. high DDGS, while G:F decreased when high DDGS was compared to control.

Carcass traits are presented in Table 2.7. There was no effect (*P* > 0.10) in hot carcass weight, yield percentage, and fat depth among treatments. There was however a tendency for pigs fed high DDGS vs. control to have decreased loin depth (*P* = 0.062) along with decreased percent lean (*P* = 0.088). Pigs fed high DDGS + Biolex™ vs. high

DDGS had a tendency for increased loin depth (*P* = 0.085), but there was no difference in percent lean (*P* > 0.10). There was no effect (*P* > 0.10) on loin depth or percent lean when high DDGS + Biolex™ vs. control was compared.

Discussion

Feeding high DDGS inclusion levels during the nursery period (d 0-42) did not have a negative effect on growth performance, there was however a tendency for ADFI to increase compared to pigs fed control diets. Similarly, Jones et al. (2010) found no negative effects on growth performance when nursery pigs were supplied diets with 30% DDGS inclusion rates. However, there was a tendency for G:F to increase in pigs fed high DDGS + Boilex™ compared to pigs fed high DDGS during the d 0-42 period. It was also found that high DDGS + Biolex™ tended to increase average BW on day 42, and ADG over the d 0-42 period compared to control. Two studies conducted found similar results. Li et al. (2012) found adding essential oils to the diets of weaned pigs over the nursery period had improved average daily gain. Sads and Bilkei (2013) found that nursery pigs fed essential oils had increased weight gain during the nursery phase. The findings of past studies looking at the effect of high DDGS inclusion rates and the addition of essential oils in nursery diets reflect similar findings during the nursery time period of this study. The findings suggest producers can incorporate higher levels of DDGS along with the addition of essential oils to maintain or even improve growth performance in the nursery phase.

The grow-finish period (d 42-168) of this study found similar results as a study performed by Kim et al. (2012) that observed reduced growth performance in pigs fed diets with high DDGS inclusion rates. There was a significant decrease in G:F when pigs fed high DDGS were compared to those pigs fed control diets in the d 42-168 period. It was also found that pigs fed high DDGS had significant decrease in ADG compared to control. Hardman (2014) found increasing DDGS inclusion levels linearly reduced ADG, ADFI, but had no effect on feed efficiency. Although the findings in this study are similar to the study performed by Hardman (2014) in relation to the significant decrease in ADG as higher DDGS inclusion levels were compared to control, however it doesn't reflect the significant decrease in G:F. The treatment including high DDGS + Biolex™ vs. high DDGS tended to have lower ADFI, and a significantly improved G:F. Song et al. (2010) conducted a study looking at the effect of high DDGS inclusion level (30%) and the addition of vitamin E in wean-to-finish pigs. The study found that when high DDGS levels are fed to pigs G:F decreased compared to the control diet with no DDGS, and when pigs fed high DDGS were compared to pigs fed high DDGS plus vitamin E, G:F decreased. While the study performed by Song et al. (2010) looked at the inclusion of vitamin E with the use of high levels of DDGS it can be speculated that results are similar due to antioxidant properties that both vitamin E and essential oils have. Antioxidants are critical in stopping or limiting the production of reactive oxygen species (ROS). An increase in ROS can overwhelm the antioxidant system and results in oxidative stress. Oxidative stress can be associated with reduction in performance, compromised immunity, and reduced appetite (Omonijo et al., 2017). It can be speculated that both vitamin E and essential oils antioxidant properties could help protect the linoleic and oleic acids found in DDGS from oxidation. Linoleic and oleic acids are found to be in DDGS at 54% and 26% respectively and are unsaturated fatty acids that contribute to the high energy content of DDGS (Shurson, 2018). It can be speculated that the energy content of diets containing high DDGS will not be affected by free radicals at high levels due to the antioxidative properties of vitamin E and essential oils. This could potentially result in the energy content of the diet being utilized more effectively and as a result greater feed efficiency could be achieved. This could suggest why when feeding high levels of DDGS alone negatively impacts G:F. While the addition of high levels of DDGS in the finisher period offer potential benefits for producers looking to reduce cost of the diet, it could potentially have a negative effect on the efficiency of growth performance during this time.

Overall, there was no difference among the dietary treatments on final average BW, overall ADG, or ADFI, but there was a significant increase in G:F when pigs fed high DDGS + Biolex™ were compared to high DDGS. Gain to feed significantly decreased when pigs fed high DDGS were compared to control. Gaines et al. (2007ab) also reported a reduction in G:F for pigs fed diets with high DDGS inclusion. Gain to feed is a ratio of ADG divided by ADFI and even though there were no statistical differences between treatments there was a lower numerical value for ADG and higher numerical value for ADFI for those pigs fed high DDGS. These results suggest that feeding high DDGS for long durations can negatively impact the efficiency of a pig in regard to growth performance however, the addition of Biolex™ to diets containing high DDGS can improve feed efficiency if fed for a long time period. While the potential economic value of DDGS can persuade producers to include them into finisher diets, the savings acquired with including DDGS must be able to offset the potential cost occurred for less efficient pigs.

Carcass traits collected from pigs utilized in the study showed no difference in HCW, yield percentage, or FD among treatments. There was also no effect on percent lean for high DDGS + Biolex™ vs. high DDGS or high DDGS + Biolex™ vs. control however, there tended to be a decrease in percent lean in pigs fed high DDGS vs. control. High DDGS + Biolex™ vs. control had no effect on loin depth. There was a tendency for pigs fed high DDGS + Biolex™ vs. high DDGS to increase loin depth, but high DDGS vs. control tended to decrease loin depth. Rojo et al. (2016) found that increasing dietary levels of DDGS resulted in a linear reduction in loin depth. This is similar to the results found in this study that higher DDGS vs. control tended to reduce loin depth. Even though high DDGS included in diets can have potential negative effect on loin depth and percent lean other negative effect of including DDGS must be accounted for in order to maintain acceptable carcass quality. The inclusion of DDGS in finishing diets increases dietary unsaturated fatty acids resulting in higher carcass fat iodine level (Madsen et al., 1992). Carcass fat iodine values are important measures of carcass quality because higher values result in softer less valuable bellies and loins. However, producers can use conjugated linoleic acid (CLA) in finisher diets to reduce iodine levels in carcass fat (Stein and Shurson, 2009). The addition of CLA into diets can result in increased cost associated to the diet, but producers have another strategy they can use to limit the negative effect of DDGS on iodine values. Removal of DDGS from the diet during the final 3 to 4 weeks before slaughter will also reduce the negative impact of DDGS on carcass fat iodine values and will result in acceptable iodine values (Hill et al., 2008; Xu et al., 2008). There is limited research on the effect essential oils has on carcass traits, but it is believed that due to the low levels found in diets it has no effect on carcass traits.

The use of high levels of DDGS have potential to reduce cost associated with feeding nursery and finisher pigs, however the negative effects must be considered to optimize growth performance and carcass traits. Further research is needed to understand the effect essential oils have when included with high levels of DDGS.

Conclusion

Further research is required to determine if essential oils can help mitigate the negative effects of feeding high DDGS in both nursery and finishing production stages. Management systems and health status of pigs may also have an effect on the ability of essential oils to reduce the negative impact of feeding high DDGS. The inclusion levels, essential oil combination, and best time to included essential oils to optimize growth performance and carcass traits still needs to be looked at.

The results of this study suggest that the inclusion of high levels of DDGS does have a negative effect growth performance and carcass traits. However, the addition of Biolex™ can mitigate or even improve these effects on growth performance and carcass traits.

Table 2.1 DDGS Inclusion Levels in Wean-to-Finish Experiment[abcd]			
Phase	Control	High DDGS	High DDGS + Biolex™
N1		Common diet	
N2	-	5.00	5.00
N3	7.50	11.25	11.25
N4	11.25	15.00	15.00 + 0.05%
N5	15.00	20.00	20.00 + 0.05%
F1	22.50	25.00	25.00 + 0.05%
F2	22.50	30.00	30.00 + 0.05%
F3	22.50	30.00	30.00 + 0.05%
F4	22.50	30.00	30.00 + 0.05%
F5	17.50	17.50	17.50 + 0.05%
F6	10.00	10.00	10.00 + 0.05%

[a] DDGS inclusion shown as percent of diet.

[b] Pigs fed during N2 and N3 were fed dietary treatments control and control + high DDGS. Pigs fed during F5 and F6 were fed dietary treatments control and control + Biolex™.

[c] High DDGS +Biolex™ was included in N4 through F5. Resulting in three dietary treatments.

[d] Similar levels of DDGS were fed in F5 and F6 to not affect carcass quality.

Table 2.2 Ingredient Composition of Wean-to-Finish Nursery Diets[a]									
Ingredients, %	N1	N2 Control	N2 High DDGS	N3 Control	N3 High DGGS	N4 Control	N4 High DDGS	N5 Control	N5 High DDGS
Pre-formulated N1 pellet	100	-	-	-	-	-	-	-	-
Corn	-	41.78	39.09	49.48	47.54	54.33	52.01	54.43	51.34
Distillers dried grains w/solubles	-	-	5.00	7.50	11.25	11.25	15.00	15.00	20.00
Soybean meal	-	26.88	24.51	30.34	28.55	29.99	28.26	25.55	23.24
Nursery Premix	-	30.00	30.00	10.00	10.00	-	-	-	-
Soybean oil	-	-	-	-	-	1.24	1.56	2.04	2.46
Limestone, ground	-	0.38	0.42	0.71	0.78	0.87	0.94	0.93	1.02
Salt	-	0.26	0.25	0.49	0.48	0.61	0.60	0.60	0.60
L-Lysine HCL	-	0.26	0.31	0.41	0.45	0.48	0.52	0.52	0.56
Vitamin Trace Mineral Premix	-	0.07	0.07	0.16	0.16	0.20	0.20	0.20	0.20
L-Threonine	-	0.07	0.07	0.11	0.11	0.12	0.12	0.12	0.12
Dicalcium Phosphate	-	0.01	-	0.42	0.30	0.58	0.47	0.32	0.16
DL-Methionine	-	0.06	0.04	0.13	0.12	0.15	0.14	0.13	0.12
L-Tryptophan	-	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.03
Tribasic Copper Chloride	-	0.02	0.02	0.03	0.03	0.04	0.04	0.04	0.04
Natuphos E 2500	-	0.07	0.07	0.07	0.07	0.06	0.07	0.07	0.07
DFM[1]	-	0.02	0.02	0.04	0.04	0.05	0.05	0.05	0.05
Zinc Oxide	-	0.11	0.11	0.10	0.10	-	-	-	-
Biolex™[b]	-	-	-	-	-	-	-/+	-	-/+

[a] All diets formulated to the same concentration of ME, digestible lysine, calcium, and available phosphorus.
[b] Biolex™ was added in high DDGS diets in place of corn in N4 and N5 diets at 0.05%.
[1] Direct Fed Microbial

Table 2.3 Ingredient Composition of Wean-to-Finish Finisher Diets[ab]						
Ingredients, %	F1 Control	F1 High DDGS	F2 Control	F2 High DDGS	F3 Control	F3 High DDGS
Corn	53.97	52.34	59.30	53.74	65.77	59.27
Distillers dried grains w/solubles	22.50	25.00	22.50	30.00	22.50	30.00
Soybean meal	18.07	16.93	12.35	9.63	6.11	4.36
Soybean oil	2.57	2.81	3.10	3.84	2.97	3.72
Limestone, ground	1.17	1.18	1.15	1.18	1.11	1.13
Salt	0.59	0.59	0.59	0.58	0.59	0.58
L-Lysine HCL	0.59	0.61	0.53	0.59	0.51	0.54
Vitamin Trace Mineral Premix	0.20	0.20	0.20	0.20	0.20	0.20
L-Threonine	0.13	0.13	0.10	0.10	0.09	0.07
Dicalcium Phosphate	-	-	-	-	-	-
DL-Methionine	0.09	0.09	0.04	0.02	-	-
L-Tryptophan	0.04	0.04	0.04	0.04	0.04	0.04
Tribasic Copper Chloride	0.03	0.03	0.03	0.03	0.03	0.03
Natuphos E 2500	0.07	0.07	0.07	0.07	0.07	0.06
Biolex™[cd]	-	-/+	-	-/+	-	-/+
Paylean®	-	-	-	-	-	-

[a] All diets formulated to the similar concentration of ME, digestible lysine, calcium, and available phosphorus.
[b] Biolex™ was added in high DDGS diets in place of corn in F1, F2, and F3 diets at 0.05%.

Table 2.3 Ingredient Composition of Wean-to-Finish Finisher Diets[abcd]						
Ingredients, %	F4 Control	F4 High DDGS	F5 Control	F5 C + Biolex™	F6 Control	F6 C + Biolex™
Corn	68.54	61.33	70.33	70.28	67.44	67.39
Distillers dried grains w/solubles	22.50	30.00	17.50	17.50	10.00	10.00
Soybean meal	3.20	2.36	6.14	6.14	15.92	15.92
Soybean oil	3.19	3.77	3.63	3.63	4.06	4.06
Limestone, ground	1.09	1.10	0.99	0.99	0.85	0.85
Salt	0.59	0.57	0.60	0.60	0.61	0.61
L-Lysine HCL	0.47	0.48	0.42	0.42	0.44	0.44
Vitamin Trace Mineral Premix	0.20	0.20	0.18	0.18	0.18	0.18
L-Threonine	0.09	0.06	0.09	0.09	0.14	0.14
Dicalcium Phosphate	-	-	-	-	0.08	0.08
DL-Methionine	-	-	-	-	0.07	0.07
L-Tryptophan	0.04	0.04	0.03	0.03	0.03	0.03
Tribasic Copper Chloride	0.03	0.03	0.03	0.03	0.03	0.03
Natuphos E 2500	0.07	0.07	0.07	0.07	0.07	0.07
Biolex™[cd]	-	-/+	-	0.05	-	0.05
Paylean®	-	-	-	-	0.1	0.1

[a] All diets formulated to the similar concentration of ME, digestible lysine, calcium, and available phosphorus.
[b] High DDGS + Biolex™ was added in high DDGS diets in place of corn in F4 diets at 0.05%.
[c] Similar levels of DDGS (removal of high DDGS) were included in F5 and F6 diets as not to effect carcass quality.
[d] Biolex™ was added in control diets in place of corn in F5 and F6 diets at 0.05%.

Table 2.4 Chemical Composition of Wean-to-Finish Nursery Diets[ab]								
Item	N2 Control	N2 Hi DDGS	N3 Control	N3 Hi DDGS	N4 Control	N4 Hi DDGS	N5 Control	N5 Hi DDGS
ME, kcal/kg	3232	3207	3159	3143	3197	3197	3230	3230
Crude Protein, %	21.10	21.30	22.30	22.40	22.00	22.10	21.00	21.20
Crude Fat, %	3.70	3.80	3.50	3.70	4.70	5.10	5.60	6.20
Crude Fiber, %	2.00	2.20	2.50	2.60	2.70	2.80	2.70	2.90
Lysine, Dig. %	1.35	1.35	1.35	1.35	1.30	1.30	1.23	1.23
Calcium, Total %	0.78	0.78	0.71	0.70	0.65	0.64	0.60	0.59
Phosphorous, Total %	0.65	0.67	0.59	0.59	0.54	0.54	0.50	0.49
Zinc, ppm	229	229	225	225	216	216	215	215
Copper, ppm	2800	2800	1500	1500	132	133	132	133

[a] High DDGS and High DDGS + Biolex™ treatments have identical values.

[b] Biolex™ was added in N4 and N5 to Hi DDGS.

Table 2.5 Chemical Composition of Wean-to-Finsh Finisher Diets[abc]						
Item	F1 Control	F1 Hi DDGS	F2 Control	F2 Hi DDGS	F3 Control	F3 Hi DDGS
ME, kcal/kg	3230	3330	3263	3263	3263	3263
Crude Protein, %	19.8	19.9	17.5	18	15	15.9
Crude Fat, %	6.5	6.8	7.1	8.1	7.2	8.1
Crude Fiber, %	2.9	3	2.8	3.1	2.6	2.9
Lysine, Dig. %	1.13	1.13	0.95	0.95	0.79	0.79
Calcium, Total %	0.57	0.57	0.54	0.54	0.5	0.5
Phosphorous, Total %	0.46	0.47	0.43	0.47	0.41	0.45
Zinc, ppm	133	134	132	134	131	133
Copper, ppm	164	163	163	163	162	162

[a] High DDGS and High DDGS + Biolex™ treatments have identical values.
[b] Biolex™ was added in F1-F3 to Hi DDGS.

Item	F4 Control	F4 Hi DDGS	F5 Control	F5 BL	F6 Control	F6 BL
ME, kcal/kg	3307	3307	3351	3351	3395	3395
Crude Protein, %	13.60	14.70	13.60	14.80	15.90	17.20
Crude Fat, %	8.00	8.90	8.10	9.70	7.90	10.40
Crude Fiber, %	2.60	2.90	2.40	2.90	2.20	3.00
Lysine, Dig. %	0.69	0.69	0.69	0.69	0.92	0.92
Calcium, Total %	0.48	0.48	0.45	0.45	0.45	0.45
Phosphorous, Total %	0.39	0.43	0.37	0.43	0.36	0.46
Zinc, ppm	130	132	116	120	115	121
Copper, ppm	162	162	161	160	162	161

Table 2.5 Chemical Composition of Wean-to-Finish Finisher Diets[abcd]

[a] High DDGS treatment and High DDGS + Biolex™ treatment have identical values.
[b] Biolex™ was added in F4 to High DDGS.
[c] Phase F5 and F6 had similar DDGS levels resulting in removal of High DDGS.
[d] Biolex™ remained in F5 and F6.

Table 2.6 Effect of Treatments on Wean-to-Finish Growth Performance[a]							
	Dietary Treatments[b]				P <:		
Item	C	Hi DDGS	BL	SE	C vs. Hi DDGS	Hi DDGS vs. BL	C vs. BL
No. of Pigs	176	176	176	--	--	--	--
Rep.	16	16	16	--	--	--	--
D 0-42							
D 0 BW[1], kg	5.8	5.8	5.8	0.304	0.849	0.924	0.924
ADG[2], kg/d	0.395	0.406	0.412	0.014	0.229	0.538	0.075
ADFI[3] kg/d	0.56	0.58	0.58	0.021	0.100	0.955	0.111
G:F[4]	0.704	0.695	0.706	0.008	0.144	0.071	0.706
D 42 BW, kg	22.4	22.8	23.1	0.073	0.275	0.535	0.095
D 42-168							
ADG[2], kg/d	0.918	0.899	0.906	0.017	0.050	0.442	0.200
ADFI[3] kg/d	2.24	2.45	2.39	0.061	0.492	0.085	0.275
G:F[4]	0.379	0.367	0.38	0.028	0.036	0.031	0.933
D 0-168							
ADG[2], kg/d	0.800	0.793	0.799	0.012	0.306	0.400	0.850
ADFI[3] kg/d	1.93	1.96	1.93	0.043	0.219	0.140	0.787
G:F[4]	0.415	0.403	0.415	0.019	0.034	0.024	0.868
D 168 BW[1], kg	137.8	136.7	137.7	2.02	0.327	0.388	0.903

[a] Least Square Means for 16 pens/trt
[b] C, Hi DDGS, and BL = Control, High DDGS, and High DDGS + Biolex™ respectively
[1] Body Weight
[2] Average Daily Gain
[3] Average Daily Feed Intake
[4] Gain to Feed Ratio

Table 2.7 Effect of Wean-to-Finish Treatments on Carcass Characteristics[a]							
	Dietary Treatments[b]				P <:		
Item	C	Hi DDGS	BL	SE	C vs. Hi DDGS	Hi DDGS vs. BL	C vs. BL
Live Wt, kg	137.82	136.69	137.68	2.02	0.327	0.388	0.903
Hot Carcass Wt, kg	98.91	98.93	99.20	1.48	0.978	0.784	0.762
% Yield	74.62	74.82	74.43	0.631	0.813	0.645	0.822
FD[1], cm	1.31	1.34	1.31	0.011	0.407	0.531	0.835
LD[2], cm	6.61	6.50	6.60	0.017	0.062	0.085	0.867
% Lean	56.17	55.91	56.14	0.111	0.088	0.123	0.849

[a] Least Square Means for 16 pens/trt

[b] C, Hi DDGS, and BL = Control, High DDGS, and High DDGS + Biolex™ respectively

[1] Fat Depth

[2] Loin Depth

CHAPTER III

EFFECT OF A FEED ADDITIVE CONTAINING ESSENTIAL OILS ON PERFORMANCE OF NURSERY PIGS

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Abstract

Recently, we reported that the addition of Biolex™ in diets containing high levels of DDGS vs. control (standard corn-soybean meal-DDGS based diets) in a wean-to-finish study tended to improve d 42 BW and ADG for the d 0-42 period. The objective of this study was to determine if adding Biolex™ in standard corn-soybean meal-DDGS based nursery diets would effect growth performance of nursery pigs. Two hundred eighty crossbred pigs (5.4 kg) were utilized in this experiment that lasted 42 days. Upon arrival pigs were randomly allotted and balanced by source, sex, and BW to two dietary treatments (10 pigs/pen; 14 pens/treatment). The dietary treatment consisted of fortified corn-soybean meal-DDGS based diet serving as the control and control + Biolex™. Pigs were fed utilizing phase feeding with 5 nursery dietary phases. A common diet was fed for the first two phases of the study. Biolex™ was added to the control diets in nursery

diets phase 3 thru 5. Pigs and feeders were weighed weekly to calculate feed disappearance, ADG, ADFI, and G:F. Data were analyzed using GLM procedure in SAS with pen serving as the experimental unit. There was no difference (P > 0.10) in d 14-42 growth performance when Biolex™ was added to the diet. Similarly, there was no statistical differences ($P > 0.10$) for overall growth performance. The results suggest adding Biolex™ to standard nursery diets had no effect on growth performance.

Introduction

Nursery pigs face several challenges immediately following weaning that ultimately impact growth performance. Factors such as, change in diet, social stress, disease challenges, and fasting during transit from sow to nursery facilities can all have an impact on nursery pig growth performance (Pluske et al 1997). Pluske and Williams (1996) hypothesize that psychological stressors pigs tend to encounter as a result of weaning have a greater negative impact due to maintained low levels of voluntary feed intake during the first several days post-weaning. The transition from a highly digestible liquid diet to a more complex diet is an additional challenge that these pigs face (Lalles at al., 2007). As a result, pre-weaning ME intake is not achieved until the end of the second week post-weaning (Le Dividich and Herpin, 1994). This time period termed post-weaning lag is known to have a negative impact on growth performance of nursery pigs. This has increased the interest for finding ingredients that could potential increase feed intake post-weaning.

Prior to January 2017, sub-therapeutic levels of antibiotics could be added to nursery diets to limit some of the negative effects associated with weaning that impacts growth performance. Doyle (2001) reported that the addition of antibiotics could increase

ADG up to 8% and G:F by 3% when included in nursery diets. However, increased consumer concern about the effects of antibiotics potentially in protein sources, antibiotic resistance, and actions taken by the EU regarding trade the VFD was enacted. Producers have since looked for alternatives to maintain the growth performance antibiotics offered when incorporated into diets.

Essential oils have become a popular alternative in swine diets because of the observed ability to fight pathogens, and improve gut integrity, as a result increasing pig performance (Sad and Bilkei, 2003; Manzanilla et al., 2004; Michiels et al., 2010). The mode of action associated with essential oils has been observed to have an effect on the cytoplasmic membrane and energy metabolism (Omonijo et al., 2017). Likewise, essential oils have been researched to determine if they can offer potential benefits to combat the effect of intestinal inflammation. Yang et al. (2015) observed that supplementation of cinnamon oil in feed suppressed the inflammation that resulted from a lipopolysaccharide induced challenge. The results of two studies that used cinnamaldehyde and oregano oils observed reduced inflammation, suggesting that essential oils could potentially improve health and growth performance (Wondrak et al., 2010; Zou et al., 2016). It has been demonstrated that essential oils mode of action can influence pig immune response, reduce inflammation, improve gut integrity, and as a result improve the health of pigs while potentially improving growth performance. These findings have made essential oils a popular alternative to antibiotic growth promoters.

Therefore, the objective of this study was to evaluate the effect of Biolex™, proprietary blends of coated essential oils, on pig growth performance during the nursery phase.

Materials and Methods

Two hundred eighty pigs were used to evaluate the effect of Biolex™ feed additive on nursery pig performance. Pigs were weaned and transported to Oklahoma State University Swine Research and Education Center where they were housed in an environmentally controlled building for the duration of the 42-day experiment. On d 0, pigs were randomly allotted to 1 of 28 pens (10 pigs/pen), and pens were randomly allotted to 1 of 2 dietary treatments. Dietary treatments included 1) Control, a fortified corn-soybean meal-DDGS diet, or 2) Biolex™, control diet plus Biolex™. Biolex™ was added to the diet at 0.05% in place of corn during phases 3-5. A common diet was fed during phase 1 and 2 of the study. All diets contained no antibiotics throughout the duration of the study. Pigs and feeders were weighed weekly (d 0, 7, 14, 21, 28, 35, and 42) to calculate feed disappearance, ADG, ADFI, and G:F. Each pen was equipped with a stainless-steel feeder and cup water. Feed and water were offered *ad libitum* throughout the 42-d study.

Statistical Analysis

All data was analyzed in a randomized complete block design using the GLM procedure of SAS (Version 9.4, SAS Institute, Inc., Cray, NC) with pen serving as the experimental unit. Means were reported as the Least Square Means (LS Means). Variability of the data is presented as the Standard Error (SE). Differences between treatments were considered significant at $P \leq 0.05$ and a tendency at $P > 0.05$ and $P \leq 0.10$.

Results

Performance results are presented in Table 3.1. Dietary treatment did not have an effect on ADG, ADFI, or G:F from d 0-14. There was no effect on d 14 BW between the treatments. Statistical analysis showed no effect on d 14-42 BW, ADG, ADFI, or G:F when comparing Biolex™ vs. control. Overall, comparing the 2 dietary treatments found no difference in D 42 BW, or ADG, ADFI, and G:F.

Discussion

Addition of Biolex™ to standard nursery diets showed no effect on nursery pig performance. Similar results were found in a study performed by Kroismayr et al. (2008) that found no significant effects of essential oils on growth performance parameters of weaned piglets. Likewise, Tian and Piao (2019) found that including a blend of essential oils in weaned pig diets had no effect on growth performance. However, other studies contradict these findings and suggest the use of essential oils in nursery diets can improve growth performance. Franz et al. (2010) reviewed 8 reports that utilized essential oils on nursery pigs and found the average improvement in weight gain, feed intake, and feed conversion were 2.0, 0.9, and 3.0% respectively.

While no differences were observed on growth performance parameters measured in this study there was, a numerical improvement in ADG and numerical decrease in ADFI for those pigs fed dietary treatment Biolex™ compared to control from d 14-42. Biolex™ had an ADG of 472.45 vs. 462.89 g/d, resulting in a 2.23% numerical improvement in ADG. ADFI also showed a numerical difference between Biolex™ and control during d 14-42 of 672.93 vs. 674.19 g/d as a result G:F ratio improved 2.16% numerically when feeding Biolex™ vs. control. While these are only numerical difference and not statistical differences there is potential for Biolex™ to improve growth performance and maintain feed efficiency when include in diets.

It was previously reported by our lab that the addition of Biolex™ to diets with high DDGS inclusion rates showed a tendency to improve ADG from d 0-42 and d 42 BW when compared to control. It was also noted that Biolex™ included with high DDGS tended to improve G:F compared to those fed high DDGS containing diets from d 0-42. However, upon completion of this study it was noted that including Biolex™ in a standard nursery had no effect on growth performance when compared to control.

Further research should be conducted to look at the time of inclusion, and rate of inclusion as this could affect the potential outcome of including Biolex™ on nursery pig performance. While pigs remained relatively healthy throughout the trial and were administered no deliberate health challenges it may prove beneficial to include Biolex™ to pigs that are health challenged. There have been studies that indicate that essential oils can improve performance of pigs under an immune challenge (Liu et al., 2013). The potential for essential oils to improve performance under an immune challenge is one reason why it has been considered as a potential alternative to antibiotic growth promoters.

Conclusion

The inclusion of Biolex™ in standard nursery diets had no effect on growth performance. Further research is needed to evaluate and validate the potential benefits of including Biolex™ in nursery diets.

Table 3.1 Ingredient Composition of Nursery Experiment Diets[ab]

Ingredients, %	N1	N2	N3 Control	N3 Biolex™	N4 Control	N4 Biolex™	N5 Control	N5 Biolex™
Pre-formulated N1 pellet	100	-	-	-	-	-	-	-
Corn	-	41.78	49.48	49.43	54.33	54.28	54.43	54.38
Distillers dried grains w/solubles	-	-	7.50	7.50	11.25	11.25	15.00	15.00
Soybean meal	-	26.88	30.34	30.34	29.99	29.99	25.55	25.55
Nursery Premix	-	30.00	10.00	10.00	-	-	-	-
Soybean oil	-	-	-	-	1.24	1.24	2.04	2.04
Limestone, ground	-	0.38	0.71	0.71	0.87	0.87	0.93	0.93
Salt	-	0.26	0.49	0.49	0.61	0.61	0.60	0.60
L-Lysine HCL	-	0.26	0.41	0.41	0.48	0.48	0.52	0.52
Vitamin Trace Mineral Premix	-	0.07	0.16	0.16	0.20	0.20	0.20	0.20
L-Threonine	-	0.07	0.11	0.11	0.12	0.12	0.12	0.12
Dicalcium Phosphate	-	0.01	0.42	0.42	0.58	0.58	0.32	0.32
DL-Methionine	-	0.06	0.13	0.13	0.15	0.15	0.13	0.13
L-Tryptophan	-	0.01	0.01	0.01	0.02	0.02	0.02	0.02
Tribasic Copper Chloride	-	0.02	0.03	0.03	0.04	0.04	0.04	0.04
Natuphos E 2500	-	0.07	0.07	0.07	0.06	0.06	0.07	0.07
DFM[1]	-	0.02	0.04	0.04	0.05	0.05	0.05	0.05
Zinc Oxide	-	0.11	0.10	0.10	-	-	-	-
Biolex™	-	-	-	0.05	-	0.05	-	0.05

[a] All diets formulated to the same concentration of ME, digestible lysine, calcium, and available phosphorus.
[b] Common diets were fed for N1 and N2 before dietary treatments.
[1] Direct Fed Microbial

Table 3.2 Chemical Composition of Nursery Experiment Diets[a]

Item	N2	N3	N4	N5
ME, kcal/kg	3208	3144	3197	3230
Crude Protein, %	21.3	22.4	22.1	21.2
Crude Fat, %	3.8	3.7	5.1	6.2
Lysine, Dig. %	1.35	1.35	1.30	1.23
Calcium, Total %	0.78	0.70	0.64	0.59
Phosphorous, Total %	0.53	0.42	0.37	0.34
Zinc, ppm	229	225	216	215
Copper, ppm	2800	1500	133	133

[a] Control and Biolex™ treatments have similar values.

Table 3.3 Effect of Biolex™ and Control Diets on Growth Performance[a]				
	Dietary treatment			P <:
Item	Control	Biolex™	SE	
No. of Pigs	140	140	--	--
Rep.	14	14	--	--
BW[1], kg				
d 0	5.4	5.4	0.027	1.000
d 14	7.6	7.5	0.063	0.391
d 42	20.5	20.7	0.49	0.461
ADG[2], g/d				
d 0-14	151.51	148.46	0.005	0.394
d 14-42	462.89	472.45	0.018	0.396
d 0-42	367.80	373.53	0.012	0.466
ADFI[3] g/d				
d 0-14	190.74	194.21	0.009	0.547
d 14-42	674.19	672.93	0.018	0.910
d 0-42	507.73	506.93	0.013	0.922
G:F[4]				
d 0-14	0.794	0.764	0.03	0.190
d 14-42	0.687	0.702	0.024	0.340
d 0-42	0.724	0.737	0.024	0.509

[a] Least Square Means for 14 pens/trt
[1] Body Weight
[2] Average Daily Gain
[3] Average Daily Feed Intake
[4] Gain to Feed Ratio

CHAPTER IV

SUMMARY

Commercial swine producers are constantly looking for ways to produce pork in a safe and cost-effective way. Producers utilize many strategies to overcome challenges such as increased regulation, consumer concern, increased feed ingredient cost, and feed ingredient availability. As a result, researchers are looking at new feed technologies, feed ingredients, and reviewing old technologies and ingredients to provide information to best utilize these products to producers. Distillers dried grains with solubles have been researched and utilized in swine diets for more than half a century. Distillers dried grains with solubles offer an economic opportunity for reducing feed cost, however increased levels have shown to negatively impact performance.

In 2017, the Veterinary Feed Directive was enacted banning the use of antibiotic growth promoters resulting in scientist and producers looking for alternatives. One alternative is the use of essential oils due to its potential effects on animal growth performance and health. All of these considerations are the reason behind the objective of the study to determine the effect of distillers dried grains with solubles and a feed additive contain essential oils on performance of wean-to-finish pigs. This study helped to conclude that the inclusion of high DDGS in wean-to-finish diets can have negative effects on growth performance and carcass traits. Pig fed diets with high DDGS had lower G:F ratio resulting in a less efficient pig overall. The less efficient pig also tended to have a smaller loin depth measurement. These results show that the advantage of DDGS being an economical option to partially replace feed ingredients can result in a less efficient pig that ultimately can increase production cost due to the lack of efficiency in growth performance. Furthermore, there is potential for a decrease in loin depth when feeding pigs higher levels of DDGS that could affect carcass value.

Biolex™, a feed additive that contains proprietary blends of coated essential oils, can be added to wean-to-finish diets that contains high DDGS levels to effectively manage feed efficiency. Feed efficiency is important area in modern swine production, due to the regulations put in place that limit the use of antibiotics to improve performance. Biolex™ is a viable product to replace antibiotics and maintain feed efficiency in wean-to-finish production that utilizes high levels of DDGS.

However, the study looking at the effect of essential oils on nursery pig performance found no effect on growth performance. This study found that the inclusion of Biolex™ in standard nursery diets will not have a negative impact on performance, however it did not offer improvement in growth performance. Further research is needed to find if the use of Biolex™ could be beneficial when included into nursery diets. A potential area that Biolex™ could have an impact on nursery performance is during times of immune challenges.

Overall, these studies suggest that including Biolex™ in standard nursery diets has no effect on growth performance. However, including Biolex™ in diets containing high DDGS levels in wean-to-finish diets can maintain acceptable growth performance while improving feed efficiency with no negative effect on carcass quality. Making it a viable option that can be utilized by producers and nutritionist in wean-to-finish production to maintain a safe, consistent, protein source for consumers.

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APPENDICES

Appendix 1

Experiment 1

Appendix 1. Table 1. Pen means for Body Weight and Average Daily Gain							
		BW, kg			ADG, kg/d		
Pen	Trt[a]	d 0	d 42	d 168	d 0-42	d 42-168	d 0-168
1	C	5.85	22.02	142.25	0.385	0.956	0.828
2	A	6.10	23.54	141.04	0.415	0.953	0.816
3	B	6.06	23.50	135.01	0.415	0.882	0.782
4	B	5.94	23.99	143.81	0.430	0.949	0.836
5	A	5.85	22.02	143.31	0.385	0.984	0.832
6	C	5.36	22.51	134.41	0.408	0.883	0.781
7	C	6.31	26.44	142.63	0.479	0.920	0.826
8	A	5.77	20.41	133.88	0.348	0.923	0.776
9	B	5.81	21.23	132.34	0.367	0.876	0.766
10	A	5.73	21.36	139.76	0.372	0.961	0.811
11	C	6.14	23.87	139.35	0.422	0.912	0.806
12	B	5.73	24.24	146.59	0.441	0.973	0.855
13	B	6.06	23.71	131.25	0.420	0.849	0.759
14	A	5.24	20.74	136.84	0.369	0.917	0.796
15	C	5.73	23.62	137.25	0.426	0.897	0.796
16	B	6.18	22.26	133.70	0.383	0.879	0.772
17	A	5.94	22.26	138.27	0.389	0.921	0.804
18	C	5.77	21.73	134.57	0.380	0.890	0.779
19	B	5.65	22.55	138.46	0.402	0.917	0.805
20	A	6.14	21.93	139.37	0.376	0.917	0.807
21	C	6.64	24.04	145.49	0.414	0.963	0.842
22	A	6.23	22.30	142.91	0.383	0.959	0.830
23	B	5.81	21.23	138.65	0.367	0.927	0.804
24	C	5.28	22.51	136.01	0.410	0.898	0.792
25	B	5.94	23.95	137.64	0.429	0.899	0.798
26	A	5.44	22.47	136.87	0.405	0.905	0.797
27	C	5.40	22.68	132.59	0.411	0.867	0.770
28	A	6.10	24.12	137.17	0.429	0.892	0.793
29	B	5.77	21.97	135.10	0.386	0.895	0.784
30	C	6.51	23.29	137.33	0.400	0.900	0.792
31	A	6.47	22.76	137.91	0.388	0.909	0.795
32	C	6.06	23.75	139.41	0.421	0.915	0.808
33	B	6.18	24.53	136.47	0.437	0.883	0.788
34	A	5.90	22.80	137.74	0.402	0.907	0.798
35	C	5.77	22.90	142.30	0.408	0.949	0.829
36	B	5.77	24.24	134.24	0.440	0.867	0.777
37	C	5.65	22.47	138.32	0.401	0.915	0.803

38	B	5.03	22.88	136.76	0.425	0.899	0.797
39	A	5.36	23.58	129.71	0.434	0.840	0.755
40	A	5.61	22.54	136.33	0.403	0.900	0.792
41	B	5.81	22.59	138.64	0.400	0.914	0.805
42	C	5.61	24.04	137.87	0.439	0.901	0.802
43	A	5.52	22.26	137.59	0.399	0.919	0.804
44	C	5.48	21.65	129.95	0.385	0.854	0.753
45	B	5.77	21.65	132.80	0.378	0.877	0.769
46	A	5.44	23.27	136.05	0.424	0.895	0.793
47	B	4.99	20.94	135.27	0.380	0.902	0.788
48	C	5.11	21.97	132.80	0.401	0.874	0.773

[a] Treatment A, B, and C = Control, Control + High DDGS, and Control + High DDGS + Biolex™ respectively.

Appendix 1. Table 2. Pen means for Average Daily Feed Intake and Gain to Feed Ratio							
		ADFI, kg/d			G:F		
Pen	Trt	d 0-42	d 42-168	d 0-168	d 0-42	d 42-168	d 0-168
1	C	0.57	2.44	1.94	0.679	0.392	0.417
2	A	0.61	2.38	1.93	0.678	0.400	0.422
3	B	0.60	2.28	1.85	0.696	0.387	0.412
4	B	0.61	2.61	2.08	0.699	0.364	0.393
5	A	0.54	2.41	1.94	0.711	0.408	0.430
6	C	0.58	2.31	1.87	0.705	0.382	0.407
7	C	0.66	2.43	1.97	0.723	0.379	0.410
8	A	0.50	2.31	1.85	0.695	0.400	0.420
9	B	0.55	2.36	1.90	0.669	0.371	0.393
10	A	0.53	2.58	2.06	0.702	0.372	0.394
11	C	0.62	2.38	1.93	0.685	0.383	0.408
12	B	0.64	2.59	2.07	0.692	0.376	0.405
13	B	0.61	2.36	1.91	0.690	0.360	0.387
14	A	0.53	2.29	1.85	0.695	0.400	0.421
15	C	0.61	2.37	1.92	0.702	0.379	0.405
16	B	0.56	2.40	1.93	0.688	0.367	0.391
17	A	0.57	2.48	1.97	0.683	0.371	0.400
18	C	0.56	2.33	1.88	0.683	0.382	0.404
19	B	0.57	2.43	1.95	0.701	0.378	0.403
20	A	0.57	2.63	2.07	0.660	0.348	0.381
21	C	0.55	2.59	2.05	0.747	0.372	0.401
22	A	0.55	2.53	2.00	0.697	0.380	0.405
23	B	0.51	2.45	1.96	0.718	0.379	0.401
24	C	0.60	2.34	1.90	0.689	0.383	0.408
25	B	0.59	2.44	1.95	0.722	0.368	0.400
26	A	0.57	2.32	1.86	0.716	0.391	0.418
27	C	0.56	2.16	1.75	0.734	0.401	0.429
28	A	0.62	2.34	1.90	0.689	0.381	0.407
29	B	0.54	2.28	1.82	0.714	0.393	0.420
30	C	0.56	2.37	1.91	0.711	0.379	0.404
31	A	0.54	2.53	2.02	0.715	0.359	0.384
32	C	0.60	2.51	2.00	0.704	0.364	0.394
33	B	0.63	2.47	2.00	0.697	0.358	0.385
34	A	0.55	2.35	1.89	0.736	0.386	0.412
35	C	0.56	2.53	1.99	0.722	0.374	0.407
36	B	0.63	2.57	2.08	0.696	0.338	0.365

37	C	0.57	2.35	1.89	0.699	0.389	0.415
38	B	0.58	2.35	1.90	0.730	0.383	0.410
39	A	0.59	2.32	1.85	0.734	0.363	0.398
40	A	0.56	2.45	1.94	0.722	0.368	0.399
41	B	0.59	2.64	2.08	0.678	0.347	0.378
42	C	0.62	2.47	2.00	0.709	0.365	0.392
43	A	0.57	2.36	1.85	0.705	0.390	0.425
44	C	0.56	2.28	1.85	0.687	0.374	0.398
45	B	0.56	2.41	1.94	0.673	0.363	0.386
46	A	0.59	2.47	1.95	0.725	0.363	0.397
47	B	0.57	2.50	2.01	0.663	0.361	0.383
48	C	0.56	2.29	1.85	0.717	0.381	0.407

[a] Treatment A, B, and C = Control, Control + High DDGS, and Control + High DDGS + Biolex™ respectively.

Appendix 1. Table 3. Pen means for average live weight, hot carcass weight, percent yield, fat depth, loin depth, and percent lean.							
Pen	Trt	Live Wt, kg	HCW, kg	% Yield	FD, cm	LD, cm	% Lean
1	C	142.25	102.90	76.82	1.56	6.67	55.66
2	A	141.04	100.45	75.06	1.24	6.76	56.59
3	B	135.01	98.46	73.57	1.28	6.30	55.72
4	B	143.81	103.49	77.33	1.47	6.56	55.65
5	A	143.31	99.15	74.14	1.27	6.50	56.09
6	C	134.41	96.80	72.38	1.25	6.68	56.46
7	C	142.63	102.49	76.58	1.20	6.85	56.83
8	A	133.88	94.01	70.25	1.24	6.71	56.48
9	B	132.34	96.35	72.04	1.27	6.23	55.59
10	A	139.76	97.59	72.97	1.35	6.60	56.03
11	C	139.35	99.81	74.63	1.25	6.72	56.49
12	B	146.59	105.06	78.44	1.25	6.82	56.66
13	B	131.25	94.29	70.45	1.24	6.08	55.43
14	A	136.84	99.20	74.17	1.24	6.88	56.78
15	C	137.25	98.58	73.71	1.22	6.83	56.74
16	B	133.70	95.90	71.70	1.38	6.27	55.40
17	A	138.27	98.82	73.94	1.30	6.42	55.84
18	C	134.57	98.21	73.61	1.39	6.59	55.94
19	B	138.46	101.04	75.68	1.33	6.51	55.92
20	A	139.37	99.64	74.63	1.61	6.51	55.24
21	C	145.49	101.36	75.92	1.28	7.05	56.99
22	A	142.91	104.06	77.87	1.53	6.71	55.77
23	B	138.65	99.77	74.78	1.34	6.78	56.41
24	C	136.01	99.37	74.42	1.49	6.27	55.17
25	B	137.64	100.48	75.42	1.37	6.73	56.20
26	A	136.87	97.88	73.36	1.35	6.53	55.91
27	C	132.59	95.03	71.23	1.15	6.26	55.97
28	A	137.17	99.07	74.26	1.19	6.59	56.44
29	B	135.10	97.64	73.13	1.36	6.42	55.73
30	C	137.33	96.72	72.50	1.30	6.51	56.03
31	A	137.91	98.04	73.49	1.32	6.42	55.82
32	C	139.41	99.68	74.66	1.31	6.43	55.84
33	B	136.47	98.54	75.92	1.30	6.55	56.09
34	A	137.74	100.27	77.26	1.19	6.62	56.46
35	C	142.30	101.99	78.27	1.38	6.38	55.61
36	B	134.24	97.55	75.16	1.44	6.40	55.46
37	C	138.32	100.06	77.10	1.14	6.92	57.10

38	B	136.76	99.28	76.49	1.40	6.64	55.97
39	A	129.71	95.74	73.47	1.19	6.71	56.63
40	A	136.33	98.68	75.90	1.32	6.66	56.22
41	B	138.64	100.73	77.47	1.44	6.60	55.85
42	C	137.87	101.59	78.54	1.54	6.77	55.84
43	A	137.59	97.76	75.02	1.13	6.35	56.16
44	C	129.95	96.65	66.90	1.36	6.27	55.48
45	B	132.80	95.94	73.92	1.25	6.55	56.25
46	A	136.05	101.89	78.19	1.41	6.80	56.21
47	B	135.27	98.17	75.64	1.27	6.57	56.23
48	C	132.80	95.65	73.70	1.21	6.38	56.07

[a] Treatment A, B, and C = Control, Control + High DDGS, and Control + High DDGS + Biolex™ respectively.

Appendix 2

Experiment 2

Appendix 2. Table 1. Pen means for Body Weight and Average Daily Gain							
		BW, kg			ADG, g/d		
Pen	Trt[a]	d 0	d 14	d 42	d 0-14	d 14-42	d 0-42
1	A	5.4	7.9	20.4	178.26	447.11	366.19
2	B	5.4	8.0	21.9	181.44	497.33	401.59
3	B	5.4	7.5	20.0	145.60	445.49	354.02
4	A	5.5	7.6	21.0	152.41	478.43	378.73
5	B	5.5	7.1	20.4	113.40	476.27	363.98
6	B	5.4	7.7	19.8	158.76	434.15	350.70
7	A	5.5	8.0	21.2	181.44	471.41	383.89
8	B	5.4	7.8	20.8	165.11	464.93	373.94
9	A	5.5	7.8	20.7	168.28	458.45	370.62
10	A	5.5	7.3	20.4	129.73	464.93	361.77
11	B	5.4	7.7	20.7	158.76	464.93	371.72
12	A	5.5	7.3	20.6	129.73	474.65	368.41
13	A	5.4	7.6	21.6	152.41	501.65	394.59
14	B	5.5	8.1	22.3	184.61	509.48	411.00
15	B	5.6	7.4	19.9	129.73	447.11	349.60
16	B	5.6	7.4	19.7	129.73	439.01	344.07
17	A	5.4	7.7	20.0	158.76	439.01	354.02
18	B	-	-	-	-	-	-
19	B	5.5	7.1	20.6	113.40	481.67	367.67
20	A	5.3	7.3	19.6	142.43	439.01	348.49
21	B	5.5	7.2	20.6	122.92	479.51	369.51
22	A	5.5	7.5	20.8	142.43	474.47	372.71
23	A	5.4	7.6	20.2	152.41	451.97	360.66
24	B	5.4	7.7	22.1	165.11	514.61	407.86
25	A	5.3	7.6	20.9	165.11	474.65	380.57
26	A	5.4	7.3	19.0	129.73	421.19	331.90
27	B	5.3	7.4	20.6	152.41	469.79	372.83
28	A	5.5	7.4	20.8	136.08	477.53	372.58

[a] Treatment A and B = Control and Control + Biolex™ respectively.

Appendix 2. Table 1. Pen means for Average Daily Feed Intake and Gain to Feed Ratio							
		ADFI, g/d			G:F		
Pen	Trt[a]	d 0-14	d 14-42	d 0-42	d 0-14	d 14-42	d 0-42
1	A	200.94	677.70	514.88	0.887	0.660	0.711
2	B	190.06	729.61	545.42	0.955	0.682	0.736
3	B	201.39	641.58	491.32	0.723	0.694	0.721
4	A	206.84	667.15	504.89	0.737	0.717	0.750
5	B	175.54	630.62	470.16	0.646	0.755	0.774
6	B	213.64	655.52	504.59	0.743	0.662	0.695
7	A	181.89	706.93	527.72	0.998	0.667	0.727
8	B	175.54	654.85	491.21	0.941	0.710	0.761
9	A	198.67	663.42	504.70	0.847	0.691	0.734
10	A	196.86	708.95	534.02	0.659	0.656	0.677
11	B	195.95	674.51	511.12	0.810	0.689	0.727
12	A	185.52	698.87	523.62	0.699	0.679	0.704
13	A	172.36	682.45	505.69	0.884	0.735	0.780
14	B	212.73	730.08	528.81	0.868	0.698	0.777
15	B	208.20	676.19	516.32	0.623	0.661	0.677
16	B	180.53	620.25	470.08	0.719	0.708	0.732
17	A	202.30	670.31	510.46	0.785	0.655	0.694
18	B	-	-	-	-	-	-
19	B	158.76	632.56	465.47	0.714	0.761	0.790
20	A	181.89	647.96	488.77	0.783	0.678	0.713
21	B	208.20	695.84	529.26	0.590	0.689	0.698
22	A	179.17	643.28	482.45	0.795	0.738	0.773
23	A	181.44	644.27	486.23	0.840	0.702	0.742
24	B	206.84	677.74	511.75	0.798	0.759	0.797
25	A	206.84	721.04	545.53	0.798	0.658	0.698
26	A	183.25	628.14	476.16	0.708	0.671	0.697
27	B	197.77	673.16	510.79	0.771	0.698	0.730
28	A	190.06	668.41	496.63	0.716	0.714	0.750

[a] Treatment A and B = Control and Control + Biolex™ respectively

VITA

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Candidate for the Degree of

Master of Science

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