Nutrient Digestibility, Growth Performance, and Carcass Characteristics of Broilers Fed Diets Formulated with Low Oligosaccharide Soybean Meals

by

Kurt Richard Perryman

A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
August 4, 2012

Keywords: soybean meal, oligosaccharide, apparent metabolizable energy, amino acid digestibility, broiler

Approved by

William A. Dozier, III, Chair, Associate Professor of Poultry Science
Joseph B. Hess, Professor of Poultry Science
Wallace D. Berry, Associate Professor of Poultry Science

ABSTRACT

The objective of this research was to evaluate nutrient digestibility, growth performance, and processing yields of Ross × Ross 708 male broilers fed diets formulated with low oligosaccharide soybean meal (LOSBM) and ultra-low oligosaccharide soybean meal (ULSBM). Experiments 1 through 4 determined the AME_n and digestible amino acid (AA) composition of a control soybean meal (CSBM), LOSBM, and ULSBM from 27 to 31 d of age. In experiments 1 and 3, LOSBM had increased ($P = 0.011$) AME_n and higher ($P = 0.002$) digestible AA concentrations compared with CSBM. Experiments 2 and 4 were expanded to evaluate ULSBM. Low oligosaccharide SBM had greater ($P = 0.012$) AME_n compared with CSBM and ULSBM. Both LOSBM and ULSBM had higher ($P < 0.001$) digestible AA concentrations compared with CSBM, while ULSBM had greater ($P < 0.05$) concentrations of digestible AA compared with LOSBM. Experiments 5 and 6 evaluated feeding diets formulated with CSBM, LOSBM, or ULSBM during a 6 wk production period using nutrient values determined in experiments 1 through 4. In experiment 5, broilers fed diets containing LOSBM or CSBM had similar growth and carcass characteristics. Dietary fat inclusions were reduced over 50% in all feeding phases in diets formulated with LOSBM. In experiment 6, diets were formulated with CSBM, LOSBM, or ULSBM and moderate or reduced (-25 kcal of AME_n/kg) energy concentrations. No negative effects on growth performance or carcass characteristics were observed for broilers fed diets formulated with the 3 SBM types or moderate or reduced energy concentrations. Diets formulated with LOSBM and ULSBM contained up to 70% less supplemental fat compared with CSBM-based diets. Formulating diets using LOSBM and ULSBM compared with CSBM reduced the

amount of supplemental fat inclusion with no adverse effects on broiler performance and processing yields.

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to Dr. Bill Dozier for sharing his extensive knowledge of the poultry industry and for being an excellent mentor. I would like to thank my graduate committee, Drs. Joe Hess and Wallace Berry for their assistance and support. I would also like to extend appreciation to Schillinger Genetics for providing the experimental soybean meals and the United Soybean Board for funding this research.

This research would not have been possible without the efforts of Dr. Dozier's entire lab group, consisting of Leslie Speegle, Matilda Bryant, Curran Gehring, Sam Rochell, Kate Meloche, Laura Thomas, and Andy Goldman. All of these individuals were instrumental in helping me obtain my Masters degree. I would also like to thank Drs. James Usry and Paul Tillman who were the first to encourage me to enroll in graduate school and their continued assistance and valuable advice.

Most importantly, I would like to offer my dearest thanks to my friends and family. Without the continued support and encouragement of my parents Kim and Kevin Perryman or my fiancée Tara Leaderbrand, this work would not have been possible.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

Dietary energy sources represent a significant portion of diet costs in the poultry industry (Donohue and Cunningham, 2009). Due to government mandates for the use of renewable fuels, like biodiesel, the cost of energy-providing ingredients have increased dramatically over the past decade (Donohue and Cunningham, 2009). Demand and prices for fat/oil are predicted to remain high, creating further financial strain for the poultry industry. As a result, it is of upmost importance for nutritionists to maximize the energy utilization of the primary ingredients in poultry diets in order to reduce dependence on supplemental fat. Increasing energy utilization of primary ingredients instead of relying on energy provided by supplemental fat to meet dietary energy recommendations can translate to lower dietary costs.

While the gross energy of soybean meal (**SBM**) is greater than corn, poultry metabolize 28% less energy from SBM compared with corn (NRC, 1994, 1998). Poor energy utilization of SBM is related to its carbohydrate fraction (Choct et al., 2010). The carbohydrate fraction of SBM is variable, and is composed of approximately 10% free sugars and 20 to 30% non-starch polysaccharides (Choct et al., 2010). Both the galactooligosaccharides and non-starch polysaccharides contain carbohydrates that are poorly digested by poultry (Choct et al., 2010). The free sugar segment consists of 5% sucrose, and 5% galactooligosaccharides (4% stachyose and 1% raffinose) on an as-is basis (Bach Knudsen, 1997; Grieshop et al., 2003). While sucrose is highly digestible, raffinose and stachyose have been reported to have ileal digestibilities of less than 1% in poultry (Coon et al., 1990). These small molecular weight galactooligosaccharides (**GAL**) cannot be digested and absorbed due to monogastric animals lacking endogenous α-1,6 galactosidase activity (Gitzelmann and Auricchio, 1965; Cristofaro et al., 1974). Furthermore,

stachyose and raffinose have been reported to act as anti-nutritional factors when fed to poultry. Researchers have reported poor performance in broilers fed raffinose and stachyose, which was attributed to increased osmotic pressure in the lumen. Increased osmotic pressure decreased transit time and diluted digestive enzymes and substrates in poultry (Irish and Balnave, 1993; Leske et al., 1993).

Previous research has reported that removal of raffinose and stachyose from SBM can increase the energy utilization of SBM by broilers (Coon et al., 1990; Leske and Coon, 1999; Parsons et al., 2000). Several strategies have been implemented to ameliorate the adverse effects of raffinose and stachyose on nutrient utilization, which include ethanol extraction of SBM, galactosidase supplementation, and developing new varieties of low galactooligosaccharide SBM. However, results showing increased energy utilization of low GAL SBM by poultry utilizing either of the 3 strategies have been inconsistent (Irish et al., 1995; Kidd et al., 2001; Baker et al., 2011).

Soybean meals stemming from novel genetic varieties of soybeans have been developed to contain either a 75% (low oligosaccharide SBM [**LOSBM**]) or 90% (ultra-low oligosaccharide SBM [**ULSBM**]) reduction in GAL concentrations. Research is limited on the nutrient digestibility of these SBM types, specifically AME_n and AA digestibility. Therefore, the proposed research determined the AME_n and AA digestibility of LOSBM and ULSBM compared with a control SBM over 4 experiments. Then, using the AME_n and digestible AA concentrations determined in the first 4 experiments, 2 growth experiments were conducted emulating commercial conditions. These experiments assessed growth performance, carcass yields, and physiological variables of broilers consuming diets formulated with LOSBM or ULSBM compared with a control SBM.

II. LITERATURE REVIEW

SUPPLY AND DEMAND OF FAT

Fat is an excellent source of energy and linoleic acid for poultry (Leeson and Summers, 2001). Dietary fat supplementation has been reported to decrease feed conversion in broilers (Hidalgo et al., 2004, Dozier et al., 2006, 2011). The benefit of fat may be related to a lower heat increment following absorption and during metabolism (Leeson and Summers, 2001) and a slower rate of feed passage (Mateos et al., 1982). Diets fed to broilers typically contain added fat from 1 to 3% with inclusion concentrations varying with the phase of production.

In addition to their use in livestock and poultry diets, animal fats and vegetable oils are being utilized as inputs for biodiesel production. Rising petroleum costs and the Renewable Fuel Mandate have led to a dramatic increase in biodiesel production since 2000 (National Biodiesel Board, 2012). The United States produced over 4.2 billion liters of biodiesel in 2011(National Biodiesel Board, 2012), resulting in increased demand for animal fats and vegetable oils. As a result, the price of poultry oil has increased from $0.25 to $1.00 per kg during the past 7 yr, and prices may continue to increase with demand for animal fat and vegetable oils (Donohue and Cunningham, 2009).

The majority of the energy in poultry diets is provided by cereal grains and oilseed meals with supplemental fat added to meet the desired energy density of the diet. Energy utilization of corn is relatively high, but gross energy (**GE**) of SBM is poorly utilized by poultry (Hill et al., 1960). By increasing the energy utilization of SBM in poultry, less supplemental fat could be used in dietary formulations, translating into lower dietary costs.

FACTORS INFLUCING METABOLIZABLE ENERGY OF SOYBEAN MEAL

Gross energy of SBM is greater than in corn, but it has 42% less metabolizable energy (**ME**) (Hill et al., 1960; Sibbald and Slinger, 1962). These differences in ME can be attributed to the differences in nutrient composition between corn and SBM. Annison and Choct (1993) reported that carbohydrates are more complex in SBM than cereal grains. The carbohydrate fraction of corn is primarily composed of starch, while the carbohydrate fraction of SBM contains variable concentrations of non-starch polysaccharides (**NSP**) and poorly digested sugars (Potter and Potchanakorn, 1985). Variability in the carbohydrate fraction of SBM can occur depending on soybean variety, agronomic conditions, and processing techniques (Grieshop et al., 2003; Karr-Lilienthal et al., 2005). Moreover, differences in the ratio of starch and sugars to dietary fiber can have a pronounced effect on the nutritive value of the carbohydrate fraction and affect nutrient digestibility of various feed ingredients (Pettersson and Lindberg, 1996).

Differences in the ME of SBM have also been reported between species. National Research Council (1994, 1998) published values for ME of SBM for poultry as 2,440 kcal of ME/kg, while the value for swine approximates 3,380 kcal ME/kg. Energy utilization of SBM in poultry is 27% lower compared with pigs due to anatomical differences between animals. Poultry have 2 large ceca and a short colon, while swine have a single short cecum and a long colon (Moran, 1982). The larger hind gut of the pig provides a greater fermentative capacity due to an increased microflora population. The larger microflora population metabolizes indigestible SBM carbohydrates more efficiently. Furthermore, the greater length of the porcine alimentary tract allows for more complete SBM carbohydrate digestion compared with poultry due to increased retention time (Choct and Cadogan, 2001). This fermentative process converts relatively indigestible carbohydrates into short chained fatty acids, which can supply a source of energy in swine (Bach Knudsen and Hansen, 1991; Carré and Chagneau, 1995).

SOYBEAN MEAL CARBOHYDRATE COMPOSITION

Soybean meal is considered the "gold standard" protein source for monogastric animals (Cromwell, 1999). While SBM is primarily used as a protein source because of a favorable amino acid (**AA**) profile, SBM contains high concentrations of both protein and carbohydrates (Potter and Potchanakorn, 1985). Once soybeans have been processed into meal, the resulting dehulled SBM is typically 48% crude protein, 35% carbohydrates, 10% water, 5% minerals, 1% oil, and <1% other (Choct et al., 2010). Published research has reported high (85 to 95%) digestibility values for the protein fraction of SBM fed to chickens (Ivy et al., 1971; Parsons et al., 1981), but studies are limited on evaluating the digestibility of the carbohydrate fraction of SBM in poultry. Carbohydrate digestibility of SBM has been reported at 35% in rats (Karimzadegan et al., 1979), 61% in turkeys (Potter and Potchanakorn, 1985), and 40% in broiler chicks (Lodhi et al., 1969). A possible explanation for the low digestibility is the complex nature of SBM carbohydrates (Annison and Choct, 1993). The carbohydrate fraction of SBM is composed of approximately 20 to 30% non-starch polysaccharides (**NSP**) (Choct, 1997) and 10% free sugars, including oligosaccharides (Macrae et al., 1993).

Non-Starch Polysaccharides

Non-starch polysaccharides in SBM are a variable mixture of approximately 8% cellulose and 17% pectic polysaccharides such as type I and II rhamnogalacturonans, arabinogalactan I, and xylogalacturonan (Fransen, 1999). Due to the complexity of SBM carbohydrates, fermentative capacity and gastrointestinal tract adaptation are the primary factors influencing NSP digestibility in monogastric animals (Choct et al., 2010). Pectic polysaccharides are highly complex carbohydrates, which are partially water soluble, whereas cellulose is insoluble and has limited digestibility in poultry (Carré et al., 1990; Smits and Annison, 1996). Insoluble NSP are partially resistant to microbial fermentation, while soluble NSP can be metabolized by

gastrointestinal microflora producing short chain fatty acids. These short chain fatty acids are absorbed and utilized by poultry for energy (Carré and Chagneau, 1995). However, due to the limited fermentative capacity of the chicken, the contribution of short chain fatty acids to the ME of the bird is limited to 2 to 3% of total dietary ME (Jørgensen et al., 1996). In swine, ME provided through microbial fermentation of complex carbohydrates can provide up to 24% of dietary ME (Bach Knudsen and Hansen, 1991), however, net efficiency of energy utilization of complex carbohydrate fermentation is low (Yen et al., 1991).

Researchers have also suggested that NSP may lead to decreased digestibility of other nutrients (Antoniou et al., 1981; Choct and Annison, 1990). Soluble NSP are able to bind water in the lumen of the small intestine, which increases the viscosity of the digesta, leading to changes in the physiology and microbial ecosystem of the alimentary tract (Angkanaporn et al., 1994). A more viscous digesta transits more slowly through the gastrointestinal tract and can lead to lower O_2 concentrations, providing a favorable environment for the establishment of fermentative bacteria (Wagner and Thomas, 1978). This finding was supported by researchers who reported an increase in microbial fermentation in the small intestine when soluble soy NSP were added to broiler diets (Choct et al., 1996). Furthermore, viscous digesta stemming from large concentrations of dietary NSP has been attributed to increased losses of endogenous nutrients in broilers.

Angkanaporn et al. (1994) reported increased endogenous losses of protein, including digestive enzymes and AA, in roosters precision fed diets high in soluble NSP. Viscous digesta caused by high dietary NSP concentrations have been reported to increase bile acid secretion and loss of endogenous products in the feces of rats (Ide et al., 1989). Furthermore, it has been reported that NSP can bind bile salts, lipids, and cholesterol leading to further nutrient losses in the excreta (Vahouny et al., 1981). Sequestration and increased fecal loss of enzymes, bile acids, lipids, and cholesterol could lead to major changes in the digestive and absorptive dynamics of

the alimentary tract with poor overall efficiency of nutrient absorption as a consequence (Choct et al., 2010).

Free Sugars and Galactooligosaccharides

The free sugar component of the carbohydrate fraction of SBM is composed of about 5% sucrose and 6% galactooligosaccharides (**GAL**) (5% stachyose and 1% raffinose) (Kuriyama and Mendel, 1917; Bach Knudsen, 1997; Grieshop et al., 2003). Sucrose is highly digestible when consumed by poultry, while GAL have poor digestibility (Waldroup et al., 2006). Concentrations of the carbohydrates of SBM, specifically raffinose and stachyose, have been reported to vary depending on the location where the soybeans were grown and specific soybean genotype (Greishop et al., 2003).

Limited digestibility of GAL is related to the structure of these molecules and the lack of endogenous enzymes in poultry necessary to hydrolyze and absorb these carbohydrates. Raffinose is a trisaccharide with a galactose bonded to the glucose of a sucrose molecule via an α-1-6 linkage. Stachyose is a tetrasaccharide that is analogous to raffinose with an additional galactose bonded to the galactose molecule of raffinose via an additional α-1-6 linkage (Choct et al., 2010). Digestibility of raffinose and stachyose is low in monogastric animals because non-ruminants do not produce α-1-6-galactosidase in the intestinal mucosa, which is necessary to hydrolyze the α-1-6-galactosidic bonds (Gitzelmann and Auricchio, 1965). Hydrolysis of the bonds produces 2 free galactose molecules and a sucrose molecule. If these bonds cannot be hydrolyzed, raffinose and stachyose are unable to cross cell membranes and remain in the lumen of the gastrointestinal tract. Coon et al. (1990) reported ileal digestibility values of raffinose and stachyose to be less than 1% in roosters. The poor ileal digestibility of raffinose and stachyose has led researchers to investigate the negative impact of undigested GAL present in the lumen of the small intestine on nutrient digestibility and intestinal characteristics.

Veldman et al. (1993) reported a 25% reduction in CP and organic matter digestibility when pigs were fed diets containing high concentrations of raffinose and stachyose (2.8 and 15.2%, respectively). This finding was attributed to an increase in osmolality in the lumen of the small intestine. Increased osmolality of the gastrointestinal tract can be attributed to the small molecular weight of raffinose and stachyose, which results in water passing through the permeable epithelial cells into the lumen. A higher volume of water in the lumen leads to a dilution of digestive enzymes and substrates, reducing nutrient breakdown and digestibility. Smiricky et al. (2002) reported reduced N and AA digestibility in growing pigs corresponding with higher concentrations of raffinose and stachyose in the diet. Furthermore, Leske et al. (1993) reported a negative dose-dependent response (0.61 to 5.41% GAL) on TME_n when raffinose and stachyose were added to soy protein concentrate. Poor energy utilization of GAL in poultry has been attributed to the ability of raffinose and stachyose present in the diet to increase fluid retention, hydrogen production, and cause diarrhea (Coon et al., 1990). Irish and Balnave (1993) reported negative correlations of stachyose concentrations in the distal ileum with BW gain (r^2 = 0.90, $P < 0.05$) and feed intake ($r^2 = 0.74$, $P < 0.05$). Furthermore, feed conversion was positively correlated with stachyose concentration ($r^2 = 0.81$, $P < 0.05$). The poor performance was attributed to increased osmotic pressure resulting in increased fluid retention and a faster rate of passage resulting in poor nutrient digestibility.

Because raffinose and stachyose are primarily metabolized by microbiota in the small intestine, GAL present in the diet may result in a prebiotic effect attributed to the growth of beneficial microorganisms. Spring et al. (2000) reported a change in the composition of microbiome of small intestine, indicative of a beneficial effect, when indigestible oligosaccharides were added to poultry diets. Beneficial effects have been credited to an increase in the number of *Lactobacilli* and *Bifidobacteria,* and a decrease in *Clostridia* and *Enterobaceteria* due to oligosaccharide digestion (Nemcova et al., 1999). However, the overall

effect of changes to the microflora attributed to the presence of undigested GAL is not well understood, and it is still generally accepted that GAL can lead to intestinal disorders and poor performance in broilers (Choct et al., 2010).

REDUCTION OF GALACTOLIGOSACCHARIDES OF SOYBEAN MEAL

Due to the relative inability of monogastric animals to digest GAL in SBM, and the potential anti-nutritional effects of GAL, researchers have developed strategies to reduce or hydrolyzed the GAL of SBM. Further processing of SBM via ethanol extraction has been reported to remove over 90% of GAL content (Coon et al., 1990; Leske et al., 1991, 1993; Veldman et al., 1993). Researchers have also utilized exogenous α-1-6 galactosidase in vivo or in vitro to hydrolyze α-1-6 galactosidic bonds present in raffinose and stachyose to increase nutrient digestibility (Irish et al., 1995; Ghazi et al., 1997, 2003; Kidd et al., 2001; Graham et al., 2002; Waldroup et al., 2006). Furthermore, plant geneticists have developed new genetic varieties of soybeans that yield SBM with dramatically less GAL. While each of these methods were effective at limiting the concentration of GAL in SBM, most studies have published inconsistent results on the effects of less GAL in SBM-based diets improving nutrient digestibility and growth performance of broilers.

Ethanol Extraction

Ethanol extraction of SBM results in a 90% reduction of raffinose and stachyose concentrations (Veldman et al., 1993). When ethanol-extracted SBM was precision fed to roosters, TME_n, DM digestibility, and apparent digestibilities of hemicellulose and cellulose were increased compared with roosters fed a control SBM (Coon et al., 1990). These researchers attributed the increase in nutrient digestibility and energy utilization to a 50% slower rate of passage for chickens consuming ethanol-extracted SBM compared with roosters fed the control SBM. Moreover, other researchers reported that feeding roosters ethanol-extracted SBM resulted

in greater TME_n concentrations compared with a control SBM (Leske et al., 1991, 1993). When raffinose and stachyose were added to ethanol-extracted SBM, these authors observed a decrease in TME_n compared with ethanol-extracted SBM. In addition to GAL, ethanol extraction of SBM removes a large percentage of soluble NSP. Because NSP have been reported to decrease nutrient digestibility, this could explain the positive effects ethanol extraction has on nutrient utilization (Coon et al., 1990). Conversely, Irish et al. (1995) did not observe increases in TME_n, weight gain, feed efficiency, or protein digestibility when an ethanol-extracted SBM was fed to chickens. These authors attributed the results to the ethanol extraction process altering the nutrient composition of the SBM and the low palatability of the experimental diet.

Enzyme Supplementation

Galactooligosaccharides have limited nutrient value when fed to broilers because poultry lack the enzymes required for the hydrolysis and subsequent absorption of these molecules. Research attempting to supplement diets with α-galactosidase has been met with limited success. Ghazi et al. (1997) provided SBM supplemented with gradient concentrations of α-galactosidase (0, 0.025, 0.0625, 0.250 g/kg) to cockerels in a precision fed assay. These authors reported a 10.8% increase in N retention and a 15.6% increase in TME_n when feeding SBM incubated with 0.25 g/kg of α-galactosidase. Moreover, Ghazi et al. (2003) found similar increases in TME_n and true N digestibility when α-galactosidase was supplemented into corn-SBM-based diets, especially when fed in conjunction with various proteases. Graham et al. (2002) reported increased TME_n when SBM was sprayed and incubated with α-galactosidase, but no differences in growth performance were observed when diets containing enzyme-incubated SBM were fed to broiler chicks from 3 to 27 d of age. Additionally, the autolysis of raffinose and stachyose of soy flakes resulted in a 94 % reduction of GAL concentrations (hydrolyzed into their monosaccharide constituents) (Angel et al., 1988). When these soy flakes were fed to chickens, no increases in TME_n, growth rate, or feed efficiency were observed compared with chickens fed water incubated

soy flakes. Due to a lack of response in TME_n or growth rate, these authors hypothesized that energy utilization of SBM may not be exclusively related to GAL concentrations. Furthermore, α-galactosidase or carbohydrase cocktails containing α-galactosidase supplemented in corn-SBM-based diets have not enhanced growth performance of broilers (Irish et al., 1995; Kidd et al., 2001; Waldroup et al., 2006).

Trait Enhanced Soybean Meal

Genetic varieties of soybeans have been developed with low concentrations of raffinose and stachyose. In addition to a reduction in GAL content, these enhanced soybeans contained increased concentrations of CP and sucrose (Parsons et al., 2000; Baker and Stein, 2009; Baker et al., 2011). The altered nutrient composition of SBM produced from low GAL soybeans may influence nutrient digestibility and growth performance of broilers. Parsons et al. (2000) fed 5 types of low GAL SBM to roosters and reported a 7% increase in TME_n compared with a control SBM. The greater TME_n was attributed to a reduction in GAL content and higher concentrations of CP and sucrose in the low GAL SBM. Conversely, Baker et al. (2011) reported no differences in TME_n or AA digestibility of low GAL SBM compared with a control SBM when fed to chickens. These authors also observed higher CP and sucrose concentrations in the low GAL SBM compared with a control SBM. When these SBM were fed to chicks, no differences in BW gain, feed intake, or feed conversion were observed. In agreement with results determined in poultry, low GAL SBM had similar AA digestibility values compared with conventional SBM when fed to pigs (Baker and Stein, 2009).

Novel types of SBM have recently been developed with a 75% (low oligosaccharide SBM [**LOSBM**]) and 90% (ultra-low oligosaccharide SBM [**ULSBM**]) reduction in GAL concentrations. Data are limited on the nutrient digestibility of LOSBM, including AME_n and AA digestibility. In addition, AME_n and AA digestibility have not been reported with broilers fed

diets containing ULSBM. Furthermore, growth performance and meat yield responses of broilers fed LOSBM or ULSBM during a complete production cycle have not been evaluated. The proposed research will address the aforementioned knowledge gaps in the literature by evaluating AME_n and AA digestibility through 4 experiments. Additionally, 2 experiments will examine growth performance and meat yield responses of broilers fed diets formulated with LOSBM, ULSBM, or a control SBM during a 6 wk production period. Apparent ME_n and digestible AA concentrations determined in the first 4 experiments will be used in formulating diets in experiments 5 and 6.

REFERENCES

Angel, C. R., J. L. Sell, and D. R. Zimmerman. 1988. Autolysis of α-galactosides of defatted soy flakes: Influence on nutritive value for chickens. J. Agric. Food Chem. 36:542-546.

Angkanaporn, K., M. Choct, W. L. Bryden, E. F. Annison, and G. Annison. 1994. Effects of wheat pentosans on endogenous amino acid losses in chickens. J. Sci. Food Agric. 66:399-404.

Anninson, G. and M. Choct. 1993. Enzymes in poultry diets. Pages 61-77 in Enzymes in Animal Nutrition. ETH-Zurich, Zurich, Switzerland.

Antoniou, T., R. R. Marquardt, and E. Cansfield. 1981. Isolation partial characterization, and antinutritional activity of a factor (pentosans) in rye grain. J. Agric. Food Chem. 28:1240-1247.

Bach Knudsen, K. E. 1997. Carbohydrate and lignin contents of plant materials used in animal feeding. Anim. Feed Sci. Technol. 67:319-338.

Bach Knudsen, K. E. and I. Hansen. 1991. Gastrointestinal implications in pigs of wheat and oat fractions. Digestibility and bulking properties of polysaccharides and other major constituents. Br. J. Nutr. 65:217-232.

Baker, K. M. and H. H. Stein. 2009. Amino acid digestibility and concentration of digestible and metabolizable energy in soybean meal produced from high protein or low oligosaccharide varieties of soybeans and fed to growing pigs. J. Anim. Sci. 87:2282-2290.

Baker, K. M., P. L. Utterback, C. M. Parsons, and H. H. Stein. 2011. Nutritional value of soybean meal produced from conventional, high-protein, or low-oligosaccharide varieties of soybeans and fed to broiler chicks. Poult. Sci. 90:390-395.

Carré, B., J. Gomez, and A. M. Chagneau. 1995. Contribution of oligosaccharide and polysaccharide digestion, and excreta losses of lactic acid and short chain fatty acids, to dietary metabolizable energy values in broiler chickens and adult cockerels. Br. Poult. Sci. 36:611-629.

Carré, B., L. Derouet, and B. Leclercq. 1990. The digestibility of cell-wall polysaccharides from wheat (bran or whole grain), soybean meal, and white lupin meal in cockerels, muscovy ducks, and rats. Poult. Sci. 69:623-633.

Choct, M. 1997. Feed non-starch polysaccharides: Chemical structures and nutritional significance. Feed Mill. Int. 7:13-26.

Choct, M. and D. J. Cadogan. 2001. How effective are supplemental enzymes in pig diets? Pages 240-247 in Manipulating Pig Production VIII. Adelaide, South Asutralia.

Choct, M. and G. Annison. 1990. Anti-nutritive activity of wheat pentosans in broiler diets. Br. Poult. Sci. 31:811-821.

Choct, M., R. J. Hughes, J. Wang, M. R. Bedford, A. J. Morgan, and G. Annison. 1996. Increased small intestinal fermentation is partly responsible for the anti-nutritive activity of non-starch polysaccharides in chickens. Br. Poult. Sci. 37:609-621.

Choct, M., Y. Dersjant-Li, J. McLeish, and M. Peisker. 2010. Soy oligosaccharides and soluble non-starch polysaccharides: a review of digestion, nutritive and anti-nutritive effects in pigs and poultry. Asian-Aust. J. Anim. Sci. 10:1386-1398.

Coon, C. N., K. L. Leske, O. Akavanichan, and T. K. Cheng. 1990. Effect of oligosaccharide-free soybean meal on true metabolizable energy and fiber digestion in adult roosters. Poult. Sci. 69:787-793.

Cromwell, G. L. 1999. Soybean Meal – The "Gold Standard". The Farmer's Pride, KPPA News, Vol. 11. No 20.

Donohue, M. and D. L. Cunningham. 2009. Effects of grain and oilseed prices on the costs of US poultry production. J. Appl. Poult. Res. 18:325-337.

Dozier, W. A. III, C. J. Price, M. T. Kidd, A. Corzo, J. Anderson, and S. L. Branton. 2006. Growth performance, meat yield, and economics of broilers fed diets varying in metabolizable energy from thirty to fifty-nine days of age. J. Appl. Poult. Res. 15:367-382.

Dozier, W. A. III, C. K. Gehring, A. Corzo, and H. A. Olanrewaju. 2011. Apparent metabolizable energy needs of male and female broilers from 36 to 47 days of age. Poult. Sci. 90:804-814.

Fransen, C. T. M. 1999. Structural analysis of soybean polysaccharides and transgalactosylation of products from lactose. PhD Diss. Univ. of Utrecht. Utrecht, Netherlands.

Ghazi, S., J. A. Rooke, H. Galbraith, and A. Morgan. 1997. Effect of adding protease and alpha-galactosidase enzymes to soybean meal on nitrogen retention and true metabolizable energy in broilers. Br. Poult. Sci. 38:528-531.

Ghazi, S., J. A. Rooke, and H. Galbraith. 2003. Improvements in the nutritive value of soybean meal by protease and αlpha-galactosidase treatment in broiler cockerels and broiler chicks. Br. Poult. Sci. 44:410-418.

Gitzelmann, R. and S. Auricchio. 1965. The handling of soy alpha-galactosidase by a normal and galactosemic child. Pediatrics 36:231-232.

Graham, K. K., M. S. Kerley, J. D. Firman, and G. L. Allee. 2002. The effect of enzyme treatment of soybean meal on oligosaccharide disappearance and chick growth performance. Poult. Sci. 81:1014-1019.

Grieshop, C. M., C. T. Kadzere, G. M. Clapper, E. A. Flickinger, L. L. Bauer, R. L. Frazier, and G. C. Fahey, Jr. 2003. Chemical and nutritional characteristics of United States soybeans and soybean meals. J. Agric. Food Chem. 51:7684-7691.

Hidalgo, M. A., W. A. Dozier III, A. J. Davis, and R. W. Gordon. 2004. Live performance and meat yield responses of broilers to progressive concentrations of dietary energy maintained at a constant metabolizable energy-to-crude protein ratio. J. Appl. Poult. Res. 13:319-327.

Hill, F. W., D. L. Anderson, R. Renner, and L. B. Carew, Jr. 1960. Studies of the metabolizable energy of grain and grain products for chickens. Poult. Sci. 39:573-579.

Ide, T., M. Horii, K. Kawashim, and T. Yamamoto. 1989. Bile acid conjugation and hepatic taurine concentration in rats fed on pectin. Br. J. Nutr. 62:539-550.

Irish, G. G. and D. Balnave. 1993. Non-starch polysaccharides and broiler performance on diets containing soyabean meal as the sole protein concentrate. Aust. J. Agric. Res. 44:1483-1499.

Irish, G. G., G. W. Barbour, H. L. Classen, R. T. Tyler, and M. R. Bedford. 1995. Removal of the α-galactosides of sucrose from soybean meal using either ethanol extraction or exogenous α-galactosidase and broiler performance. Poult. Sci. 74:1484-1494.

Ivy, C. A., D. B. Bragg, and E. L. Stephenson. 1971. The availability of amino acids from soybean meal for the growing chick. Poult. Sci. 50:408-410.

Jørgensen, H., X. Zhao, K. E. Bach Knudsen, and B. O. Eggum. 1996. The influence of dietary fibre source and level on the development of the gastrointestinal tract, digestibility, and energy metabolism in broiler chickens. Br. J. Nutr. 75:379-395.

Karimzadegan, E., A. J. Clifford, and F. W. Hill. 1979. A rat bioassay for measuring the comparative availability of carbohydrates and its application to legume foods, pure carbohydrates, and polyols. J. Nutr. 109:2247-2259.

Karr-Lilienthal, L. K., C. T. Kadzere, C. M. Grieshop, and G. C. Fahey, Jr. 2005. Chemical and nutritional properties of soybean carbohydrates as related to nonruminants: A review. J. Livestock Prod. Sci. 97:1-12.

Kidd, M. T., G. W. Morgan, Jr., C. J. Price, P. A. Welch, and E. A. Fontana. 2001. Enzyme supplementation to corn and soybean meal diets for broilers. J. Appl. Poult. Res. 10:65-70.

Kuriyama, S. and L. B. Mendel. 1917. The physiological behavior of raffinose. J. Biol. Chem. 31:125-147.

Leeson, S. and J. D. Summers. 2001. Pages 64-65 in Scott's Nutrition of the Chicken. 4th ed. M.L Scott and Associates, Ithaca, N.Y.

Leske, K. L., C. J. Jevne, and C. N. Coon. 1993. Effect of oligosaccharide additions on nitrogen corrected true metabolizable energy of soy protein concentrate. Poult. Sci. 72:664-668.

Leske, K. L., O. Akavanichan, T. K. Cheng, and C. N. Coon. 1991. Effect of ethanol extraction on nitrogen-corrected true metabolizable energy for soybean meal with broilers and roosters. Poult. Sci. 70:892-895.

Lodhi, G. N., R. Renner, and D. R. Clandinin. 1969. Available carbohydrate in rapeseed meal and soybean meal as determined by a chemical method and a chick bioassay. J. Nutr. 99:413-418

Macrae, R., R. K. Robinson, and M. J. Sadler. 1993. Soya beans. Pages 4215-4218 in Encyclopedia of Food Science, Food Technology and Nutrition. Academic Press. London.

Moran, E. T., Jr. 1982. Starch digestion in fowl. Poult. Sci. 61:1257-1267.

National Biodiesel Board. 2012. Production Statistics. http://www.biodiesel.org/production/production-statistics Accessed Apr. 2012.

Nemcova, R., A. Bomba, S. Gancarcikova, R. Herich, and P. Guba. 1999. Study of the effect of *Lactobacillus* paracasei and fructooligosaccharides on the fecal microflora in weanling piglets. Berl. Munich Tierarztl Wochenschr 112:225-228.

NRC. 1994. Nutrient Requirements of Poultry. 9th ed. Natl. Acad. Press, Washington, D.C.

NRC. 1998. Nutrient Requirements of Swine. 10th rev. ed. Natl. Acad. Press, Washington, D.C.

Parsons, C. M., L. M. Potter, and R. D. Brown, Jr. 1981. True metabolizable energy and amino acid digestibility of dehulled soybean meal. Poult. Sci. 60:2687-2696.

Parsons, C. M., Y. Zhang, and M. Araba. 2000. Nutritional evaluation of soybean meals varying in oligosaccharide content. Poult. Sci. 79:1127-1131.

Pettersson, A. and J. E. Lindberg. 1996. Ileal and total tract digestibility in pigs of naked and hulled barley with different starch composition. Anim. Feed Sci. Technol. 66:97-109.

Potter, L. M., and M. Potchanakorn. 1985. Digestibility of the carbohydrate fraction of soybean meal by poultry. Pages 218-224 in World Soybean Conf. III Proc. R. Shibles, ed. West View Press, Boulder, CO.

Sibbald, I. R. and S. J. Slinger. 1962. The metabolizable energy of materials fed to growing chicks. Poult. Sci. 41:1612-1613.

Smiricky, M. R., C. M. Grieshop, D. M. Albin, J. E. Wubben, V. M. Gabert, and G. C. Fahey, Jr. 2002. The influence of soy oligosaccharides on apparent and true ileal amino acid digestibilities and fecal consistency in growing pigs. J. Anim. Sci. 80:2433-2441.

Smits, C. H. M. and G. Annison. 1996. Non-starch polysaccharides in broiler nutrition – Towards a physiologically valid approach to their determination. World's Poult. Sci. J. 52:203-221.

Spring, P., C. Wenk, K. A. Dawson, and K. E. Newman. 2000. The effects of dietary mannaoligosaccharides on cecal parameters and the concentrations of enteric bacteria in the ceca of salmonella-challenged broiler chicks. Poult. Sci. 79:205-211.

Vahouny, G. V., R. Tombes, M. M. Cassidy, D. Kritchevsky, and L. L. Gallo. 1981. Dietary fibres. VI: Binding of fatty acids and monolein from mixed micelles containing bile salts and lecithin. Proc. Exp. Biol. Med. 166:12-16.

Veldman, A., W. A. G. Veen, D. Barug, and P. A. van Paridon. 1993. Effect of α-galactosides and α-galactosidase in feed on ileal piglet digestive physiology. J. Anim. Physiol. Anim. Nutr. 69:57-65.

Wagner, D. D. and O. P. Thomas. 1978. Influence of diets containing rye or pectin on the intestinal flora of chicks. Poult. Sci. 57:971-975.

Waldroup, P. W., C. A. Keen, F. Yan, and K. Zhang. 2006. The effect of levels of α-galactosidase enzyme on performance of broilers fed diets based on corn and soybean meal. J. Appl. Poult. Res. 15:48-57.

Yen, J. T., J. A. Nienaber, D. A. Hill, and W. G. Pond. 1991. Potential contribution of absorbed volatile fatty acids to whole animal energy requirement in conscious swine. J. Anim. Sci. 69:2001-2012.

III. APPARENT METABOLIZABLE ENERGY AND APPARENT ILEAL AMINO ACID DIGESTIBILITY OF LOW AND ULTRA-LOW OLIGOSACCHARIDE SOYBEAN MEALS FED TO BROILER CHICKENS

ABSTRACT

Four experiments were conducted using 1,992 Ross × Ross 708 male broilers to determine AME_n and apparent ileal amino acid digestibility (AIAAD) of low oligosaccharide (LOSBM), ultra-low oligosaccharide (ULSBM), and control soybean meal (CSBM) fed to broilers from 20 to 31 d of age. An AME_n assay was conducted in experiments 1 and 2 while AIAAD was determined in experiments 3 and 4. Chicks were randomly assigned to 3, 4, 2, or 3 dietary treatments, respectively, for experiments 1, 2, 3, or 4. The additional treatment in experiments 2 and 4 was to evaluate ULSBM. In the AME_n assays, treatments were fed from 20 to 29 d of age and a 48 h excreta collection period was conducted from 27 to 29 d of age. Treatment 1 consisted of a basal diet and treatments 2, 3, and 4 consisted of 70% of the basal diet plus 30% CSBM, LOSBM, or ULSBM, respectively. The difference method was used to determine AME_n utilizing a N correction factor to account for N retention. To determine AIAAD, broilers were fed semi-purified diets with CSBM, LOSBM, or ULSBM as the sole source of amino acids (AA) from 26 to 31 d of age with digesta collection occurring at 31 d of age.

In experiment 1, LOSBM had 194 kcal/kg more AME_n compared with CSBM (P = 0.011). Apparent ME_n value of LOSBM was 141 and 134 kcal/kg higher (P = 0.012) compared with CSBM and ULSBM, respectively, in experiment 2. In experiment 3, digestible Lys, Met, Ile, and Val concentrations were higher (P < 0.001) for LOSBM vs. CSBM, even though digestibility coefficients were lower (P < 0.001) for LOSBM. In experiment 4, higher (P < 0.001)

concentrations of digestible Met, Lys, Thr, Val, and Ile were observed for ULSBM and LOSBM compared with CSBM. In conclusion, genetically selected soybean meals with reduced stachyose and raffinose concentrations had higher AME_n and AIAAD values compared with CSBM.

INTRODUCTION

Dietary energy sources represent a significant cost of poultry diets (Donohue and Cunningham, 2009). Prices for energy-providing ingredients increased over 250% from 2006 to 2008 due to a portion of the corn and oil supply being diverted away from animal agriculture for the production of ethanol and biodiesel (Donohue and Cunningham, 2009). In the future, a larger proportion of the fat/oil supply may be utilized in biodiesel production creating a need to increase the energy utilization of cereal grains and oilseed meals.

Apparent ME_n of soybean meal (**SBM**) is approximately 28% less for poultry when compared with swine (NRC, 1994 and 1998). Poor energy utilization of SBM fed to poultry may relate to its carbohydrate fraction (Choct et al., 2010). Raffinose and stachyose are water soluble galactooligosaccharides (**GAL**) and comprise between 5 and 7% of SBM on a DM basis (Bach Knudsen, 1997; Grieshop et al., 2003). These small molecular weight sugars are not hydrolyzed into smaller mono- and disaccharides necessary to facilitate absorption because poultry lack endogenous α-1,6 galactosidase activity (Gitzelmann and Auricchio, 1965; Cristofaro et al., 1974). As a result, GAL pass through the small intestine undigested (Coon et al., 1990).

Previous research has demonstrated that removal of stachyose and raffinose from SBM increases ME_n in poultry via ethanol extraction or genetic selection (Coon et al., 1990; Leske and Coon, 1999; Parsons et al., 2000). Ethanol extraction of SBM removes more than 90% of GAL content and increases TME_n of SBM (Coon et al., 1990), but increases in ME_n have not been consistently observed in previous research (Irish et al., 1995). Soybeans have been developed with reduced raffinose and stachyose content through genetic selection (Parsons et al., 2000; Baker and Stein, 2009; Baker et al., 2011). Parsons et al. (2000) observed increases of 7 to 9% in

TME_n when several SBM genetically selected for low GAL concentrations and were fed to roosters compared with several commercial SBM sources. Conversely, Baker et al. (2011) reported no difference in TME_n between low GAL SBM and a control SBM.

In addition to low oligosaccharide SBM (**LOSBM**), a new variety of ultra-low oligosaccharide soybean has been developed that when processed yields ultra-low oligosaccharide SBM (**ULSBM**) with over a 90% reduction in GAL content compared with a control SBM (**CSBM**). To our knowledge, published research is unavailable evaluating AME_n and AIAAD of both LOSBM and ULSBM when fed to growing broilers. Therefore, the objective of this research was to determine AME_n and AIAAD of CSBM, LOSBM, and ULSBM fed to broilers.

MATERIALS AND METHODS

General

The Institutional Animal Care and Use Committee at Auburn University approved all experimental protocols involving live birds (PRN 2009-1668; 2010-1699). Four experiments were conducted with broilers from 1 to 31 d of age to determine AME_n (experiments 1 and 2) and AIAAD (experiments 3 and 4) of CSBM, LOSBM, and ULSBM. Experiments 1 and 3 were conducted in March, 2010, whereas experiments 2 and 4 were initiated in March, 2011.

Bird Husbandry

In each experiment, Ross × Ross 708 male broilers (experiment 1 = 576; experiment 2 = 768; experiment 3 = 288; experiment 4 = 360) were obtained from a commercial hatchery and vaccinated for Marek's disease, Newcastle disease, and infectious bronchitis. In each experiment, broilers (12 per cage; 0.04 m^2/bird) were placed into grower battery cages (Petersime, Gettysburg, OH). Each cage (68 cm × 68 cm × 38 cm) was equipped with 1 trough feeder and 1 trough waterer. The experimental facility was a solid-sided house with temperature control. Temperature was set to 33^{o}C at placement, which was decreased gradually to 27^{o}C by the conclusion of the experiment. A 23L:1D lighting schedule was used from 1 to 21 d of age, after which a 12L:12D

lighting schedule was utilized to ensure adequate feed intake for digesta sample collection. Broilers were fed a common corn-soybean meal starter diet (AME_n, 3,075 kcal/kg; digestible Lys, 1.22%; digestible TSAA, 0.92%; digestible Thr, 0.83%; Ca, 0.90%; and non-phytate P, 0.45%) until receiving experimental diets.

Soybean Meals

Five SBM were evaluated throughout the 4 experiments. Two SBM (CSBM and LOSBM) were utilized in 2010, which were produced from soybeans grown in the 2009 crop yr and evaluated in experiments 1 and 3. In 2011, a CSBM, LOSBM, and ULSBM produced from soybeans grown in the 2010 crop yr were evaluated in experiments 2 and 4. Soybeans were obtained from Schillinger Genetics (Schillinger Genetics, West Des Moines, IA) and processed at Zeeland Farm Services' processing plant (Zeeland Farm Services, Zeeland, MI). To avoid agronomic differences (Grieshop et al., 2003), soybeans were grown in the same geographic location in northeast Indiana. Soybeans were processed at the same facility utilizing identical procedures to avoid processing differences.

The 5 resulting SBM were analyzed for CP by determining nitrogen content via the Dumas method (method 990.03; AOAC International, 2006) using a N analyzer (Rapid N Cube, Elementar Analysensyteme GmbH, Hanau, Germany) with CP being calculated by multiplying percent N by a correction factor (6.25). Sucrose, raffinose, and stachyose were estimated (Bhatti et al., 1970), as well as DM (method 934.01; AOAC International, 2006), starch (method 76-13; AACC International, 2006), acid detergent fiber (**ADF**) (method 973.18 (A-D); AOAC International, 2006), neutral detergent fiber (**NDF**) (Holst, 1973), cellulose (method 973.18 (A-D); AOAC International, 2006), and trypsin inhibitors (method 22-40.01; AACC International, 2006). Soybean meals were analyzed for gross energy (**GE**) using bomb calorimetry (Model 6300, Parr Instruments, Moline, IL). Crude fat concentrations were estimated by boiling samples in hexane (method 2003.06; AOAC International, 2006) in a fat extractor (Soxtec model number 2043, Foss North America, Inc., Eden Prarie, MN). Particle size was determined on a 13 half-

height sieve shaker (Tyler RoTap, Mentor, OH) as described by Baker and Herrman (2002). Bulk density was determined by utilizing a standard weight per bushel tester (USDA, 1953).

Dietary Treatments

Birds were randomly assigned to 1 of 3, 4, 2, or 3 dietary treatments for experiments 1 through 4, respectively. For the AME_n assays (experiments 1 and 2), broilers were fed experimental diets from 20 to 29 d of age. Treatment 1 for both experiments was 100% basal diet (Table 3.1), while the remaining treatments were a blend of 70% basal and 30% experimental SBM resulting in 3 dietary treatments for experiment 1 (100% basal; 70% basal and 30% CSBM; 70% basal and 30% LOSBM). In experiment 2, 4 dietary treatments were fed to broilers (100% basal; 70% basal and 30% CSBM; 70% basal and 30% LOSBM; 70% basal and 30% ULSBM). The basal diet was formulated to meet or exceed NRC (1994) nutrient recommendations with corn, peanut meal, distiller's grains, and poultry by-product meal as the primary ingredients. All dietary treatments were fed in pelleted form.

In experiment 3, birds were assigned to 1 of 2 semi-purified diets for AIAAD determination (Table 3.2). Diets were formulated to contain 43% of either the 2 test SBM (CSBM or LOSBM) with the remainder of the diet composed of dextrose, poultry oil, and solkafloc. In experiment 4, broilers were randomly assigned to 1 of 3 semi-purified diets. Diets were formulated to contain 20% CP resulting in SBM inclusion levels of 41.8, 37.3, and 36.2% for CSBM, LOSBM, and ULSBM, respectively. In both experiments, titanium dioxide was included in the experimental diets at 0.50% as an inert marker.

Nitrogen Corrected Apparent Metabolizable Energy Measurements

Following a 7 d acclimation period, a 48 h energy balance assay was conducted from 27 to 29 d of age. Feed disappearance, net excreta weight, and excreta samples were collected after 48 h on d 29 to calculate energy and nitrogen intake and excretion. From each cage, 4 subsamples were collected (free from feed and feather contamination) from the total amount of excreta on the pan. Samples were homogenized, and a representative sample of 500 g was placed in a plastic bag

for analysis. Samples of feed and excreta were then frozen at -20°C until later analysis. Feed and excreta samples were lyophilized (Virtis Genesis Pilot Lyophilizer, SP Industries, Warminster, PA) and ground through a cyclone mill (Cyclotec model number 1093, Foss North America, Inc., Eden Prairie, MN) equipped with a 1 mm screen to ensure a homogeneous mixture. Gross energy of feed and excreta was determined on a 0.8 g sample using an isoperibol oxygen bomb calorimeter (Parr Instruments, Moline, IA), and analysis was performed 8 times for feed or twice for excreta due to the effect these measurements have on AME_n determination. Nitrogen content of feed and excreta was determined on a 0.25 g sample with a combustion analyzer (Rapid N Cube, Elementar Americas, Inc., Mt. Laurel, NJ) in duplicate using a previously established method (method 968.06; AOAC International, 2006). Apparent ME_n for each dietary treatment was calculated using 8,220 (kcal/kg) as the N correction factor (Hill and Anderson, 1958) and using the following equations by Sibbald and Slinger (1963) with units [AME_n (kcal/kg); GE intake (kcal/kg); GE excreted (kcal/kg); 8,220 (kcal/kg); N intake (kg); N excreted (kg); feed intake (kg); SBM AME_n (kcal/kg); basal AME_n (kcal/kg); treatment AME_n (kcal/kg)].

$$AME_n = \frac{(GE\ intake - GE\ excreted) - [8{,}220 * (N\ intake - N\ excreted)]}{feed\ intake}$$

$$SBM\ AME_n = basal\ AME_n - \left(\frac{basal\ AME_n - treatment\ AME_n}{0.30}\right)$$

Apparent Ileal Amino Acid Digestibility Measurements

In experiments 3 and 4, broilers were provided experimental diets at 26 d of age. Following a 5 d acclimation period, an AIAAD assay was conducted at 31 d of age for both experiments. Eight birds per pen were euthanized via CO_2 asphyxiation and digesta were collected by gently flushing out the contents of the terminal ileum (4 to 30 cm proximal to the

ileo-cecal junction) using deionized water. Samples were pooled by pen and kept on ice before being frozen at -20°C for later analysis. After lyophilization, samples were finely ground with an electric coffee grinder to avoid significant loss due to the small sample size of the collected digesta. Complete AA content of the diets and digesta were analyzed by a commercial laboratory (University of Missouri Agricultural Experiment Station Chemical Laboratory, Columbia, MO) in quadruplicates for diets and duplicates for digesta (method 982.30 E (a,b,c); AOAC International, 2006). Performic acid oxidation (method 985.28; AOAC International, 2006) was conducted before acid hydrolysis for the determination of Met and Cys, whereas all other AA were determined after acid hydrolysis. Titanium dioxide concentrations were determined in quadruplicates and duplicates for diets and digesta, respectively, by a method based on that of Leone (1973). Briefly, 0.25 g of digesta or feed were added to threaded glass test tubes and ashed at 580°C for 10 h; 0.8 g of $NaSO_4$ was added to the ashed samples, which were diluted with 5 mL of H_2SO_4 and then heated at 130°C for 72 h; tube contents were diluted to 50 mL with distilled deionized water and held for 12 h at 25°C; 3 mL of feed samples or 1 mL of digesta samples plus 2 mL of 1.8 M H_2SO_4 were added to glass test tubes with 150 µL of H_2O_2; and after allowing 30 min for color development, absorbance was measured on a spectrophotometer (DU 730, Beckman Coulter, Brea, CA) at 410 nm. Apparent ileal AA digestibility was calculated using the following equation (Adedokun et al., 2008):

$$AIAAD = \left[1 - \left(\frac{TiO_{2\ diet,}}{TiO_{2\ digesta}}\right) \times \left(\frac{AA_{digesta}}{AA_{diet}}\right)\right] * 100$$

Statistics

Data were analyzed using a randomized complete block design with cage location as the blocking factor. Experiments 1, 2, 3, and 4 were represented by 16, 16, 12, and 10 replicate cages respectively. Analysis of variance was performed using PROC MIXED (SAS Institute, 2004) by

the following mixed-effects model:

$$Y_{ij} = \mu.. + \rho_i + \tau_j + \varepsilon_{ij}$$

where $\mu..$ is the overall mean; the ρ_i are identically and independently normally distributed random block effects with mean 0 and variance σ^2_ρ; the τ_j are fixed factor level effects corresponding to the j^{th} soybean variety (CSBM, LOSBM, and ULSBM) such that $\Sigma\tau_j = 0$; and the random error ε_{ij} are identically and independently normally distributed with mean 0 and variance σ^2. For experiments 2 and 4, treatment means were separated using Tukey's Honestly Significant Difference test (Tukey, 1953). Statistical significance was considered at $P \leq 0.05$.

RESULTS AND DISCUSSION

Physical and Chemical Characteristics

Quantifying changes in chemical composition is valuable when interpreting nutrient digestibility differences due to SBM types. Low GAL SBM has been reported to have altered sugar, fiber, and CP composition (Baker et al., 2011). Both LOSBM and ULSBM exhibited altered chemical and physical composition compared with a CSBM (Table 3.3). The following chemical and physical characteristics are presented as numerical changes as statistical analysis could not be applied due to a lack of replication. For SBM utilized in experiments 1 and 3 that was grown during the 2009 crop yr, stachyose and raffinose concentrations decreased from 6.79 to 1.56% and 0.71 to 0.21%, respectively, between CSBM and LOSBM. Sucrose and starch concentrations increased by 21% and 39%, respectively, between CSBM and LOSBM. Acid detergent fiber (-36%), NDF (-43%), and cellulose (-32%) had lower concentrations for LOSBM vs. CSBM. Low oligosaccharide SBM had higher CP than CSBM, whereas crude fat content of LOSBM was lower compared with CSBM. Particle size was determined to be 1,300 and 1,166 μm mean diameter for CSBM and LOSBM, respectively, resulting in a 23% higher bulk density for LOSBM compared with CSBM.

Control SBM, LOSBM, and ULSBM utilized in experiments 2 and 4 originated from soybeans grown during the 2010 crop yr. Both LOSBM and ULSBM had lower concentrations of

stachyose (-72 and -90%) and raffinose (-74 and -91%) and higher sucrose (+17 and +4%) and CP (+12 and +16%) concentrations compared with CSBM. Cellulose (-36 and -24%), ADF (-38 and -24%), and NDF (-40 and -27%) concentrations were lower for LOSBM and ULSBM compared with CSBM. Particle size and bulk density were determined as 1,059, 1,279, and 1,106 μm mean diameter and 0.69, 0.75, and 079 g/cc for CSBM, LOSBM, and ULSBM, respectively.

In table 3, the nutrients measured do not account for the total nutrient composition of the different SBM types. Minerals and some soluble carbohydrates were not determined. While concentrations of sucrose, starch, raffinose, stachyose, ADF, NDF, and cellulose were determined, concentrations of soluble NSP (pectins) were not documented. While insoluble NSP remain undigested, digestibility of soluble NSP may be as high as 80 to 90% in poultry and may influence nutrient digestibility (Carré et al., 1995).

Nitrogen Corrected Apparent Metabolizable Energy Assays

In experiment 1, LOSBM had 194 kcal/kg more ($P = 0.011$) AME_n compared with CSBM when fed to growing broilers (Figure 1A). In experiment 2, LOSBM had 141 and 134 kcal/kg more ($P = 0.012$) AME_n compared with CSBM and ULSBM, respectively (Figure 1B). Feed intake between treatments was not different in either experiment (grand means: experiment 1 = 0.121 kg/bird/d; experiment 2 = 0.134 kg/bird/d). The increase in AME_n observed between CSBM and LOSBM was most likely attributed to a reduction of GAL and fiber concentrations and an increase in sucrose concentration for LOSBM vs. CSBM (Table 3.3). Previous research has observed that a reduction of GAL from SBM increases ME_n in poultry (Coon et al., 1990; Parsons et al., 2000). Parsons et al. (2000) also reported that higher sucrose concentrations of low oligosaccharide SBM may lead to better energy utilization of SBM due to the high digestibility of sucrose in poultry.

In experiment 2, ULSBM did not have a higher AME_n than CSBM when fed to broilers even though ULSBM had a 90% reduction in GAL concentrations. The lower AME_n value of ULSBM was due to higher ($P = 0.041$) excreta energy output per bird for broilers consuming

diets containing ULSBM (+4.1%) compared with lower excreta energy output for broilers consuming diets containing LOSBM. The lower AME_n (higher excreta energy output per bird) of ULSBM is most likely due to higher concentrations of ADF, NDF, and cellulose, as well as a lower concentrations of sucrose compared with LOSBM (Table 3.3). While sucrose is highly digestible, fiber is poorly digested by poultry due to a quick digesta transit time and the limited capacity of the gut microbiota to utilize complex carbohydrates, which could translate to higher excreta GE output (Carré et al., 1990; Choct et al., 2010). Furthermore, fiber digestibility varies between bird ages with roosters having higher fiber digestibility than broilers (Carré et al., 1995). This difference in fiber digestibility may explain differences in the present data utilizing broilers and research conducted by Baker et al. (2011), who reported similar TME_n values between a CSBM and LOSBM when precision fed to roosters.

Crude protein of SBM has been reported to influence AME_n among SBM types. Baker et al. (2011) reported a higher TME_n for a high CP SBM (54.9% CP) compared with a control SBM. These authors suggested that increased AME_n of the high CP SBM may have occurred due to excess AA being metabolized for energy utilization, yet no difference was reported in TME_n between a LOSBM (53.6% CP) and a CSBM (47.5% CP). In the current research, LOSBM and ULSBM had higher CP concentrations than CSBM (54.2 and 55.6 vs. 47.8%), but only LOSBM had higher AME_n. A 1.4% difference in CP existed between LOSBM and ULSBM, so differences in AA intake and N excretion influencing AME_n response for LOSBM and ULSBM appears unlikely.

Additionally, previous research has reported that dietary oligosaccharides can influence gut microflora populations (Nemcova et al., 1999). Coon et al. (1990) found ileal digestibility of GAL to be less than 1% in roosters, but total tract digestibility varied from 84 to 90% based on raffinose and stachyose concentrations in the excreta. This finding likely signifies raffinose and stachyose being metabolized via microbial fermentation in the ceca. Fermentation by gut microflora releases volatile fatty acids, which can be utilized by the bird as energy. However, the

effects of raffinose and stachyose utilization by gut microflora on the contribution to AME_n are not well documented.

Apparent ME_n values varied between experiment 1 and 2, but the relative increase of AME_n was similar between the CSBM and LOSBM in both experiments. Differences in AME_n values between experiments 1 and 2 may be attributed to lower crude fat values for SBM utilized in experiment 2. However, crude fat differences between SBM types were small between experiments (Table 3.3). Furthermore, variability in AME_n of SBM has been previously reported in the literature and could contribute to differences observed in this research (Grieshop et al., 2003; Lopez and Leeson, 2008).

Apparent Ileal Amino Acid Digestibility Assays

Apparent ileal AA digestibility coefficients for both indispensable and dispensable AA were greater ($P \leq 0.012$) for CSBM vs. LOSBM in experiment 3 (Table 3.4). Conversely, total digestible AA concentrations were greater ($P \leq 0.003$) for LOSBM vs. CSBM except for Trp. In experiment 4, AIAAD coefficients were higher ($P < 0.05$) for Cys, Gly, and Pro for LOSBM and ULSBM vs. CSBM (Table 3.5). Higher ($P < 0.05$) AIAAD coefficients were observed for Ser for ULSBM vs. CSBM, but CSBM had a higher ($P < 0.05$) Arg digestibility coefficient compared with ULSBM and LOSBM. No differences ($P > 0.05$) were observed for the AIAAD coefficients of Lys, Met, Val, His, Ile, Leu, Phe, Thr, Val, Trp, Asp, Glu, and Tyr between SBM types. Digestible AA concentrations were highest ($P < 0.001$) in ULSBM, followed by LOSBM, with CSBM having the lowest digestible concentrations for both indispensable and dispensable AA. Increased digestible AA concentrations occurred due to higher total AA concentrations in ULSBM and LOSBM vs. CSBM. Baker et al. (2011) reported no differences in AA digestibility coefficients when a low GAL SBM was precision fed to roosters but did observe increased digestible AA concentrations for the low GAL SBM vs. a control SBM due to the higher total AA content of the low GAL SBM.

Amino acid digestibility coefficients for LOSBM were lower than the digestibility

coefficients for CSBM in experiment 3 (Table 3.4). Trypsin inhibitor concentrations were 73% higher for LOSBM vs. CSBM (Table 3.3). Previous research has also observed higher trypsin inhibitor values for low GAL SBM vs. a control SBM (Baker and Stein, 2009; Baker et al., 2011). In experiment 4, the trypsin inhibitor concentration difference was less between CSBM and LOSBM, and birds fed diets containing LOSBM did not exhibit lower AA digestibility coefficients. Conversely, no differences in AA digestibility coefficients were observed between ULSBM and CSBM even though ULSBM had a higher trypsin inhibitor concentration. The reason for this result is not known and might indicate that trypsin inhibitor concentrations under 6,000 TIU/g may be adequate for AA digestion. Further supporting adequate SBM processing, the protein solubility index for each of the SBM types were within the range (70 to 85%) of adequate heat treatment during processing (Araba and Dale, 1990).

In conclusion, these data indicated that LOSBM and ULSBM have a better nutrient profile compared with CSBM. Low oligosaccharide SBM had on average (experiments 1 and 2) 168 more kcal of AME_n/kg compared with CSBM. In experiment 3, LOSBM had 5.8% higher AIAAD concentrations vs. CSBM, and in experiment 4, LOSBM and ULSBM had 8.0 and 17.0% greater AIAAD concentrations compared with CSBM, respectively, for the first 5 limiting AA in broilers. Further research is warranted to better understand the changes in chemical composition of ULSBM on AME_n.

REFERENCES

AACC International. 2006. Approved Methods of Analysis, 11th Ed. Method 22-40.01. Measurement of trypsin inhibitor activity of soy products—spectrophotometric method. AACC Int., St. Paul, MN, U.S.A.

Adedokun, S. A., O. Adeola, C. M. Parsons, M. S. Lilburn, and T. J. Applegate. 2008. Standardized ileal amino acid digestibility of plant feedstuffs in broiler chickens and turkey poults using a nitrogen-free or casein diet. Poult. Sci: 87:2535-2548.

Ajinomoto Heartland, LLC. 2004. True Digestibility of Essential Amino Acids for Poultry. Revision 7. Ajinomoto Heartland, LLC. Chicago, IL.

American Society of Agricultural Engineers. 1993. Method of determining and expressing fineness of feed materials by sieving. American Society of Agricultural Engineers Yearbook of Standard. ASAE, St. Joesph, MO.

AOAC International. 2006. Official Methods of Analysis of AOAC International. 18th ed. AOAC Int., Gaithersburg, MD.

Araba, M. and N.M. Dale. 1990. Evaluation of protein solubility as an indicator of overprocessing soybean meal. Poult. Sci. 6976-83.

Bach Knudsen, K. E. 1997. Carbohydrate and lignin contents of plant materials used in animal feeding. Anim. Food Sci. Technol. 67:319-338.

Baker, K. M. and H. H. Stein. 2009. Amino acid digestibility and concentration of digestible and metabolizable energy in soybean meal produced from high protein or low oligosaccharide varieties of soybeans and fed to growing pigs. J. Anim. Sci. 87:2282-2290.

Baker, K. M., P. L. Utterback, C. M. Parsons, and H. H. Stein. 2011. Nutritional value of soybean meal produced from conventional, high-protein, or low-oligosaccharide varieties of soybeans and fed to broiler chicks. Poult. Sci. 90:390-395.

Baker, S. and T. Herrman. 2002. Evaluating feed particle size. Bulletin MF-2051. Kansas State Agricultural Experiment Station and Cooperative Extension Service, Manhattan, KS.

Bhatti, T., R. E. Chambers, and J.R. Clamp. 1970. The gas chromatographic properties of biologically important N-acetylglucosamine derivatives, monosaccharides, disaccharides, trisaccharides, tetrasaccharides and pentasaccharides. Biochim Biophys Acta. 222:339-347.

Carré, B., L. Derouet, and B. Leclercq. 1990. The digestibility of cell-wall polysaccharides from wheat (bran or whole grain), soybean meal, and white lupin meal in cockerels, muscovy ducks, and rats. Poult. Sci. 69:623-633.

Carré, B., J. Gomez, and A. M. Chagneau. 1995. Contribution of oligosaccharide and polysaccharide digestion, and excreta losses of lactic acid and short chain fatty acids, to dietary metabolizable energy values in broiler chickens and adult cockerels. Br. Poult. Sci. 36:611-629.

Choct, M., Y. Dersjant-Li, J. McLeish, and M. Peisker. 2010. Soy oligosaccharides and soluble non-starch polysaccharides: a review of digestion, nutritive and anti-nutritive effects in pigs and poultry. Asian-Aust. J. Anim. Sci. 10:1386-1398.

Coon, C. N., K. L. Leske, O. Akavanichan, and T. K. Cheng. 1990. Effect of oligosaccharide-free soybean meal on true metabolizable energy and fiber digestion in adult roosters. Poult. Sci. 69:787-793.

Cristofaro, E., F. Mottu, and J. J. Wuhrmann. 1974. Involvement of the raffinose family of oligosaccharides in flatulence. Pages 313-336 in Sugars in Nutrition. H. Sipple and K. McNutt, ed. Academic Press. New York, NY.

Donohue, M. and D. L. Cunningham. 2009. Effects of grain and oilseed prices on the costs of US poultry production. J. Appl. Poult. Res. 18:325-337.

Gitzelmann, R. and S. Auricchio. 1965. The handling of soy alpha-galactosidase by a normal and galactosemic child. Pediatrics 36:231-238.

Grieshop, C. M., C. T. Kadzere, G. M. Clapper, E. A. Flickinger, L. L. Bauer, R. L. Frazier, and G. C. Fahey Jr. 2003. Chemical and nutritional characteristics of United States soybeans and soybean meals. J. Agric. Food Chem. 51:7684-7691.

Hill, F. W. and L. Anderson. 1958. Comparison of metabolizable energy and productive energy determinations with growing chicks. J. Nutr. 64:587-603.

Holst, D. O. 1973. Holst filtration apparatus for Van Soest detergent fiber analysis. J. AOAC 56:1352–1356.

Irish, G. G., G. W. Barbour, H. L. Classen, R. T. Tyler, and M. R. Bedford. 1995. Removal of the α-galactosides of sucrose from soybean meal using either ethanol extraction or exogenous α-galactosidase and broiler performance. Poult. Sci. 74:1484-1494.

Leone, J. L. 1973. Collaborative study of the quantitative determination of titanium dioxide in cheese. J. Assoc. Off. Anal. Chem. 56:535-537.

Leske, K. L. and C. N. Coon. 1999. Nutrient content and protein and energy digestibilities of ethanol extracted, low α-galactoside soybean meal as compared to intact soybean meal. Poult. Sci. 78:1177–1183.

Lopez, G. and S. Leeson. 2008. Assessment of the nitrogen correction factor in evaluating metabolizable energy of corn and soybean meal in diets for broilers. Poult. Sci. 87:298-306.

Nemcova, R., A. Bomba, S. Gancarcikova, R. Herich, and P. Guba. 1999. Study of the effect of *Lactobacillus* paracasei and fructooligosaccharides on the fecal microflora in weanling piglets. Berl. Munich Tierarztl Wochenschr 112:225-228.

NRC. 1994. Nutrient Requirements of Poultry. 9th ed. Natl. Acad. Press, Washington, D.C.

NRC. 1998. Nutrient Requirements of Swine. 10th rev. ed. Natl. Acad. Press, Washington, D.C.

Parsons, C. M., K. Hashimoto, K. J. Wedekind, and D. H. Baker. 1991. Soybean protein solubility in potassium hydroxide: an in vitro test of in vivo protein quality. J. Anim. Sci. 69:2918-2924.

Parsons, C. M., Y. Zhang, and M. Araba. 2000. Nutritional evaluation of soybean meals varying in oligosaccharide content. Poult. Sci. 79:1127-1131.

SAS Institute. 2004. SAS User's Guide. Statistics. Version 9.1 ed. SAS Inst. Inc., Cary, NC.

Sibbald, I. R. and S. J. Slinger. 1963. A biological assay for metabolizable energy in poultry feed ingredients together with findings which demonstrate some of the problems associated with the evaluation of fats. Poult. Sci. 42:313–325.

Tukey, J. W. 1953. The problem of multiple comparisons. Pages 1948-1983 in The Collected Works of John W. Tukey VIII. Multiple Comparisons. Chapman and Hall, New York.

USDA. 1953. The test weight per bushel of grain: Method of use and calibration of the apparatus. Circular No.921. U.S. Government Printing Office, Washington, D.C.

Table 3.1 Ingredient and calculated nutrient composition of the basal diets fed from 20 to 29 d of age for AME_n determination (experiments 1 and 2)

Item	Basal
Ingredient, % "as-fed"	
Ground corn	64.24
Distillers dried grains with solubles	12.06
Peanut meal (41% CP)	10.05
Poultry by-product meal	10.05
Poultry oil	1.00
Limestone	0.85
Sodium chloride	0.32
Dicalcium phosphate	0.23
DL-Met	0.19
L-Lys·HCl	0.38
L-Thr	0.11
L-Trp	0.02
Vitamin Premix[1]	0.25
Mineral premix[2]	0.25
Calculated Analysis (%)[3]	
AME_n (kcal/kg)	3,213
CP	19.50
digestible TSAA	0.74
digestible Lys	0.98
digestible Thr	0.66
digestible Ile	0.63
digestible Val	0.78
digestible Trp	0.16
digestible Arg	1.19
Ca	0.81
Non-phytate P	0.40
Na	0.21

[1]Vitamin premix includes per kg of diet: Vitamin A (Vitamin A acetate), 8,000 IU; Vitamin D (cholecalciferol), 2,000 IU; Vitamin E (DL-alpha tocopherol acetate), 8 IU; menadione (menadione sodium bisulfate complex), 2 mg; Vitamin B12 (cyanocobalamin), 0.02 mg; folacin (folic acid), 0.5 mg: D-pantothenic acid (calcium pantothenate), 15 mg; riboflavin (riboflavin), 5.4 mg; niacin (niacinamide), 45 mg; thiamin (thiamin mononitrate), 1 mg; D-biotin (biotin), 0.05 mg; and pyridoxine (pyridoxine hydrochloride), 2.2 mg; choline (choline chloride), 500 mg.

[2]Mineral premix include per kg of diet: Mn (manganous oxide), 65 mg; Zn (zinc oxide), 55 mg; Fe (iron sulfate monohydrate), 55 mg; Cu (copper sulfate pentahydrate), 6 mg; I (calcium iodate), 1 mg; Se (sodium selenite), 0.3 mg.

[3]Values reported as percentages unless noted otherwise. Digestible amino acid values were determined from digestibility coefficients and calculated total amino acid content of the ingredients (Ajinomoto Heartland, LLC. 2004).

Table 3.2 Ingredient composition of semi-purified diets fed from 26 to 31 d of age for apparent ileal amino acid digestibility of control (CSBM), low oligosaccharide (LOSBM), and ultra-low oligosaccharide (ULSBM) soybean meal fed to broiler chickens (experiments 3 and 4)

	Experiment 3		Experiment 4		
	CSBM	LOSBM	CSBM	LOSBM	ULSBM
Ingredient, % "as-fed"					
Soybean meal	43.00	43.00	41.80	37.30	36.20
Dextrose	41.85	41.85	43.05	47.55	48.65
Poultry oil	5.00	5.00	5.00	5.00	5.00
Solkafloc	5.00	5.00	5.00	5.00	5.00
Titanium dioxide	0.50	0.50	0.50	0.50	0.50
Dicalcium phosphate	1.90	1.90	1.90	1.90	1.90
Limestone	1.00	1.00	1.00	1.00	1.00
Choline chloride	0.25	0.25	0.25	0.25	0.25
Sodium chloride	0.20	0.20	0.20	0.20	0.20
Sodium bicarbonate	0.55	0.55	0.55	0.55	0.55
Vitamin premix[1]	0.50	0.50	0.50	0.50	0.50
Mineral premix[2]	0.25	0.25	0.25	0.25	0.25

[1]Vitamin premix includes per kg of diet: Vitamin A (Vitamin A acetate), 8,000 IU; Vitamin D (cholecalciferol), 2,000 IU; Vitamin E (DL-alpha tocopherol acetate), 8 IU; menadione (menadione sodium bisulfate complex), 2 mg; Vitamin B12 (cyanocobalamin), 0.02 mg; folacin (folic acid), 0.5 mg: D-pantothenic acid (calcium pantothenate), 15 mg; riboflavin (riboflavin), 5.4 mg; niacin (niacinamide), 45 mg; thiamin (thiamin mononitrate), 1 mg; D-biotin (biotin), 0.05 mg; and pyridoxine (pyridoxine hydrochloride), 2.2 mg; choline (choline chloride), 500 mg.

[2]Mineral premix include per kg of diet: Mn (manganous oxide), 65 mg; Zn (zinc oxide), 55 mg; Fe (iron sulfate monohydrate), 55 mg; Cu (copper sulfate pentahydrate), 6 mg; I (calcium iodate), 1 mg; Se (sodium selenite), 0.3 mg.

Table 3.3 Physical and chemical characteristic of control (CSBM), low oligosaccharide (LOSBM), and ultra-low oligosaccharide (ULSBM) soybean meals on an as-is basis[1]

Item (%), unless otherwise noted	Experiments 1 and 3		Experiments 2 and 4			Analytical Method
	CSBM	LOSBM	CSBM	LOSBM	ULSBM	
Dry Matter	91.16	91.69	90.70	91.50	91.90	AOAC[5] 934.01. 2006
Crude Protein	47.60	54.59	47.86	53.73	55.63	AOAC 990.03. 2006
Crude Fat	1.71	1.12	1.24	0.79	0.77	AOAC 2003.06. 2006
Sucrose	6.95	8.38	7.47	8.71	7.78	Bhatti et al., 1970
Raffinose	0.71	0.21	0.82	0.21	0.07	Bhatti et al., 1970
Stachyose	6.79	1.56	5.08	1.44	0.50	Bhatti et al., 1970
Starch	0.89	1.24	0.81	0.61	0.40	AACC[6] 76-13. 2006[7]
ADF	5.54	3.52	5.50	3.39	4.19	AOAC 973.18 (A-D). 2006
NDF	8.09	4.60	8.07	4.84	5.91	Holst, 1973
Cellulose	5.53	3.74	5.71	3.68	4.36	AOAC 973.18 (A-D). 2006
Gross Energy (kcal/kg)	4,226	4,287	3,998	4,037	4,149	Isoperibol bomb calorimeter[7]
Particle Size (Dgw)[2]	1,300	1,166	1,059	1,279	1,106	ASAE[8] S319.4. 1993
Bulk Density (g/cc)[3]	0.53	0.65	0.69	0.75	0.79	USDA, 1953
KOH Solubility	82.24	83.44	78.93	84.31	82.58	Parsons et al., 1991
Trypsin Inhibitor (TIU/g)[4]	3,429	5,924	3,183	4,323	5,677	AACC 22-40. 2006

[1]Unless otherwise noted, all methods of analysis were determined by the University of Missouri Experimental Station Chemical Laboratories, Columbia, MO.
[2]Dgw = geometric mean diameter in µm, determined by Iowa State University.
[3](g/cc) = grams per cubic centimeter, determined by Iowa State University.
[4]TIU = Trypsin inhibitor units.
[5]AOAC = Association of Official Analytical Chemists.
[6]AACC = Association of American Cereal Chemists.
[7]Modified Starch Assay Kit (product code STA-20, Sigma, St. Louis, MO).
[7]Isoperibol bomb calorimeter (Parr model no. 6300) determined by Auburn University Laboratory (Auburn, AL).
[8]ASAE = American Society of Agricultural Engineers

Table 3.4 Apparent ileal amino acid digestibility (AIAAD) coefficients and concentrations of digestible amino acids (AA) of control (CSBM) and low-oligosaccharide (LOSBM) soybean meals[1] (experiment 3)

	AIAAD Coefficients (%)				Digestible AA Concentrations (%)			
Source[2]	CSBM	LOSBM	SEM[3]	*P*-Value	CSBM	LOSBM	SEM[3]	*P*-Value
Indispensable Amino Acids								
Arginine	91.7	90.6	0.2	<0.001	3.32	4.08	0.010	<0.001
Histidine	91.4	89.7	0.3	<0.001	1.20	1.29	0.004	<0.001
Isoleucine	87.6	85.3	0.3	<0.001	2.06	2.14	0.008	<0.001
Leucine	88.9	86.8	0.3	<0.001	3.45	3.63	0.012	<0.001
Lysine	91.8	90.1	0.2	<0.001	2.83	2.97	0.008	<0.001
Methionine	92.0	90.4	0.3	<0.001	0.59	0.61	0.002	<0.001
Phenylalanine	89.4	87.0	0.3	<0.001	2.29	2.41	0.008	<0.001
Threonine	86.5	84.0	0.3	<0.001	1.76	1.79	0.007	0.003
Valine	87.9	85.8	0.3	<0.001	2.14	2.21	0.008	<0.001
Tryptophan	88.7	86.9	0.3	<0.001	0.59	0.59	0.002	0.176
Dispensable Amino Acids								
Alanine	89.1	86.0	0.3	<0.001	1.95	1.86	0.006	<0.001
Aspartic Acid	90.9	88.4	0.3	<0.001	4.79	5.19	0.017	<0.001
Cystine	85.4	84.0	0.4	0.012	0.60	0.65	0.003	<0.001
Glutamic Acid	90.9	88.4	0.3	<0.001	7.77	8.38	0.026	<0.001
Glycine	87.2	85.3	0.3	<0.001	1.84	1.90	0.007	<0.001
Proline	90.0	87.2	0.3	<0.001	2.58	2.64	0.009	<0.001
Serine	88.1	86.1	0.3	<0.001	2.18	2.29	0.008	<0.001
Tyrosine	88.6	85.3	0.3	<0.001	1.07	1.05	0.004	0.002

[1]Values were least-square means of 12 replicate cages with each cage containing 12 birds from 26 to 31 d of age.
[2]CSBM = control soybean meal; LO-SBM = low oligosaccharide soybean meal.
[3]Pooled standard error.

Table 3.5 Apparent ileal amino acid digestibility (AIAAD) coefficients and concentrations of digestible amino acids (AA) of control (CSBM), low-oligosaccharide (LOSBM), and ultra-low oligosaccharide (ULSBM) soybean meals[1] (experiment 4)

	AIAAD Coefficients (%)					Digestible AA Concentrations(%)				
Source[2]	CSBM	LOSBM	ULSBM	SEM[3]	*P*-Value[4]	CSBM	LOSBM	ULSBM	SEM[3]	*P*-Value[4]
Indispensable Amino Acids										
Arginine	94.2[a]	93.1[b]	93.0[b]	0.4	0.022	3.49[c]	3.88[b]	4.26[a]	0.015	<0.001
Histidine	87.9	89.2	88.9	0.4	0.085	1.18[c]	1.28[b]	1.39[a]	0.006	<0.001
Isoleucine	85.8	87.0	86.2	0.5	0.213	1.85[c]	2.03[b]	2.23[a]	0.012	<0.001
Leucine	85.9	87.3	86.8	0.5	0.139	3.30[c]	3.58[b]	3.85[a]	0.020	<0.001
Lysine	88.4	89.4	89.2	0.4	0.182	2.78[c]	2.96[b]	3.21[a]	0.014	<0.001
Methionine	90.1	90.9	90.5	0.4	0.421	0.62[c]	0.66[b]	0.71[a]	0.003	<0.001
Phenylalanine	86.6	88.0	87.6	0.5	0.117	2.16[c]	2.34[b]	2.55[a]	0.013	<0.001
Threonine	80.6	82.3	82.1	0.6	0.074	1.57[c]	1.69[b]	1.78[a]	0.012	<0.001
Valine	83.1	84.7	83.6	0.5	0.110	1.90[c]	2.08[b]	2.27[a]	0.014	<0.001
Tryptophan	90.8	91.4	91.2	0.3	0.381	0.59[c]	0.66[b]	0.68[a]	0.002	<0.001
Dispensable Amino Acids										
Alanine	84.8	86.3	86.1	0.5	0.072	1.79[c]	1.92[b]	2.05[a]	0.011	<0.001
Aspartic Acid	84.9	86.2	86.1	0.4	0.119	4.80[c]	5.33[b]	5.72[a]	0.030	<0.001
Cystine	74.4[b]	77.6[a]	79.1[a]	0.7	<0.001	0.51[c]	0.58[b]	0.66[a]	0.005	<0.001
Glutamic Acid	88.9	89.8	89.5	0.4	0.302	7.55[c]	8.39[b]	8.89[a]	0.039	<0.001
Glycine	82.4[b]	84.7[a]	84.2[a]	0.5	0.009	1.71[c]	1.86[b]	2.00[a]	0.012	<0.001
Proline	84.3[b]	86.2[a]	85.9[a]	0.5	0.015	2.07[c]	2.28[b]	2.49[a]	0.013	<0.001
Serine	84.4[b]	85.8[ab]	86.1[a]	0.5	0.048	1.99[b]	2.24[a]	2.25[a]	0.013	<0.001
Tyrosine	86.7	87.8	87.9	0.4	0.115	1.57[c]	1.69[b]	1.80[a]	0.008	<0.001

[1]Values were least-square means of 10 replicate cages with each cage containing 12 birds from 26 to 31 d of age.
[2]CSBM = control soybean meal; LOSBM = low oligosaccharide soybean meal; ULSBM = ultra low oligosaccharide soybean meal.
[3]Pooled standard error.
[4]Least-square means within the same row with different superscripts are different at ($P < 0.05$).

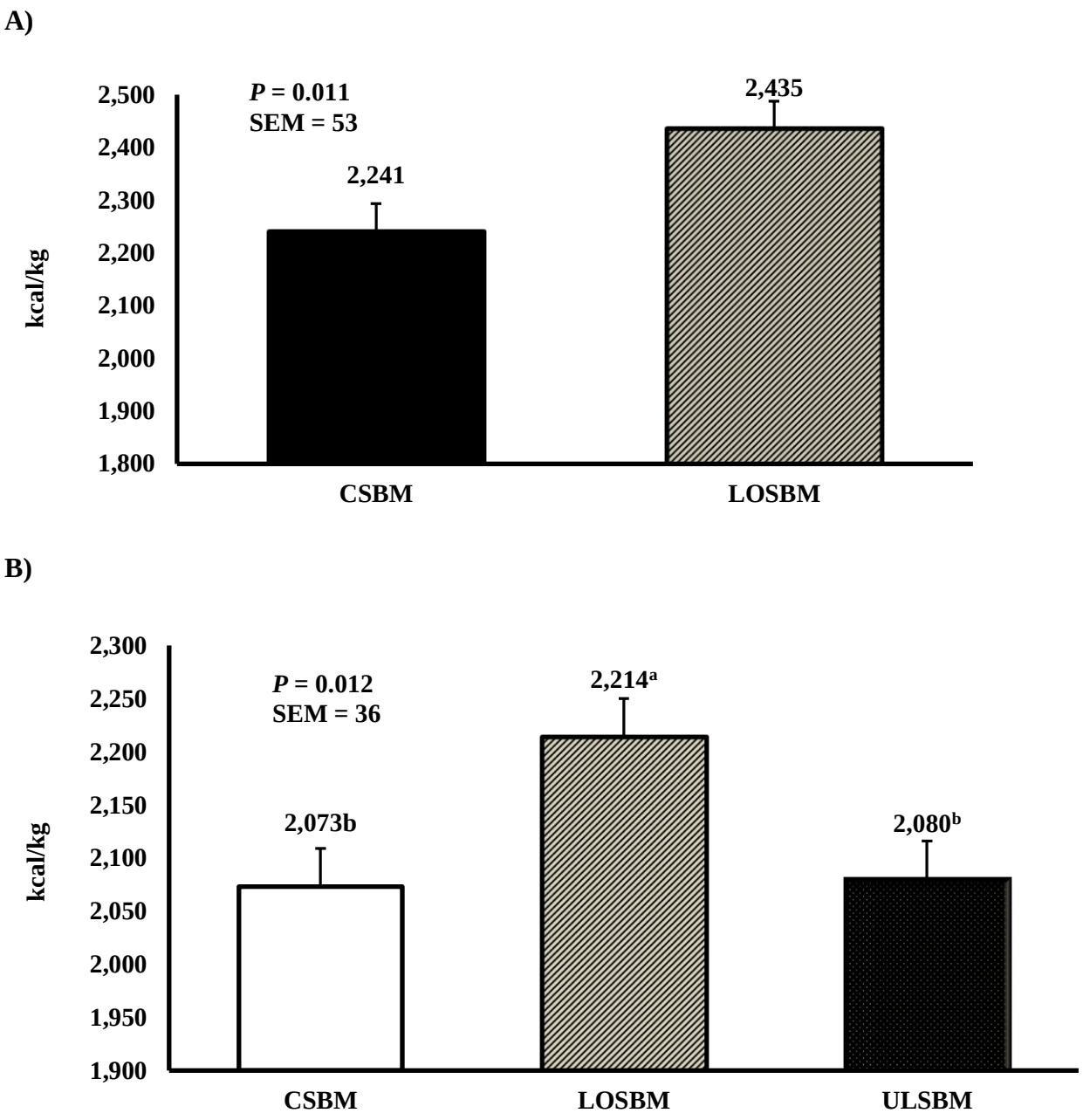

Figure 3.1 Apparent ME_n of low oligosaccharide soybean meals fed to Ross × Ross 708 broilers. A) Apparent ME_n of a control SBM (CSBM) and low oligosaccharide SBM (LOSBM) determined in experiment 1. B) Apparent ME_n of CSBM, LOSBM, and ultra-low oligosaccharide SBM (ULSBM) determined in experiment 2. The soybean meals were fed as part of a complete diet from 20 to 29 d of age for both experiments. Apparent ME_n of soybean meals were determined using the substitution method developed by Sibbald and Slinger (1963). Means were separated using Tukey's Honestly Significant Difference multiple comparison test.

IV. GROWTH PERFORMANCE AND MEAT YIELDS OF BROILER CHICKENS FED DIETS CONTAINING LOW AND ULTRA-LOW OLIGOSACCHARIDE SOYBEAN MEAL DURING A SIX WEEK PRODUCTION PERIOD

ABSTRACT

Two experiments were conducted to determine the effects of broilers fed diets containing low oligosaccharide soybean meals (SBM) on growth performance, meat yields, and physiological variables during a 6 wk production period. In experiment 5, 600 Ross × Ross 708 male chicks were randomly distributed to 24 floor pens (25 birds per pen; 0.09 m^2 per bird at 1 d of age). Birds were fed corn-soybean meal-poultry by-product meal-based diets with either low oligosaccharide (LOSBM) or control SBM (CSBM) from 1 to 40 d of age. In experiment 6, 1,500 Ross × Ross 708 male chicks were randomly distributed to 60 floor pens (25 birds per pen; 0.09 m^2 per bird at 1 d of age). Broilers were fed corn-soybean meal-poultry by-product meal-based diets containing 1 of 3 SBM sources (CSBM, LOSBM, or ultra-low oligosaccharide SBM [ULSBM]) and formulated with moderate or reduced AME_n concentrations (25 kcal/kg reduction) resulting in a 3 × 2 factorial design. Diets were formulated using AME_n and digestible amino acid (AA) values determined from previous research utilizing the same SBM types. Variables measured consisted of BW gain, feed intake, feed conversion ratio (FCR), mortality, carcass weight and yield, abdominal fat percentage, total breast meat weight and yield, digesta viscosities and pH, plasma nonesterfied fatty acids, plasma glucose, and plasma triglycerides. In experiment 5, broilers fed diets containing LOSBM grew faster ($P = 0.02$) and had decreased ($P < 0.001$) feed conversion from 1 to 14 d of age. Abdominal fat percentage was higher ($P < 0.001$) for birds fed LOSBM vs. CSBM. In experiment 6, no differences were observed for interaction

effects or main effects of energy concentration. Feed conversion ratio was lower ($P < 0.001$) for broilers fed diets containing ULSBM vs. LOSBM and CSBM from 1 to 28 and 1 to 42 d of age. Broilers fed diets formulated with ULSBM had higher ($P < 0.05$) carcass yield vs. birds fed diets with CSBM. Total breast yield was higher ($P = 0.021$) for birds fed diets containing LOSBM and ULSBM vs. CSBM. Abdominal fat percentage was higher ($P = 0.027$) for broilers fed diets containing LOSBM vs. CSBM. Diets formulated with LOSBM and ULSBM required approximately 45% less supplemental fat, and broilers fed these diets exhibited no adverse effects on growth performance and meat yields compared with broilers fed diets containing CSBM.

INTRODUCTION

Dietary energy sources represent a significant cost of poultry diets (Donohue and Cunningham, 2009). Since 2006, prices for energy-providing ingredients have increased dramatically due to a large portion of the corn and oil supply being diverted away from animal agriculture to satisfy production demands for ethanol and biodiesel (Donohue and Cunningham, 2009). In the future, a larger proportion of animal fats and vegetable oils may be utilized for biodiesel production leading to further increases in cost for these products, hence creating a need to identify strategies to enhance energy utilization of cereal grains and oilseed meals. Optimizing energy utilization of these primary ingredients will allow nutritionists to formulate diets with lower inclusions of supplemental fat.

Apparent ME_n of SBM is approximately 28% less for poultry compared with swine (NRC, 1994, 1998). Lower AME_n values for SBM may be attributed to its carbohydrate fraction, which is primarily composed of cellulose, non-starch polysaccharides, and galactooligosaccharides (**GAL**) (Choct et al., 2010). Besides sucrose, the carbohydrate fraction of SBM is poorly utilized by poultry due to a lack of endogenous galactosidase and low fermentative capacity of the gastrointestinal tract (Gitzelmann and Auricchio, 1965; Carré et al., 1995). Galactooligosaccharides (raffinose and stachyose) comprise between 5 and 7% of SBM on

a DM basis (Bach Knudsen, 1997; Grieshop et al., 2003) and are poorly digested because monogastric animals do not produce endogenous α-1,6 galactosidase necessary for GAL hydrolysis into its constituent monosaccharides (Gitzelmann and Auricchio, 1965; Cristofaro et al., 1974). Several strategies have been implemented to reduce the concentration of raffinose and stachyose of SBM to enhance dietary energy utilization with poultry (Coon et al., 1990; Parsons et al., 2000; Ghazi et al., 2003).

Novel soybean varieties have been genetically selected for reduced raffinose and stachyose content, which may lead to increased AME_n and higher concentrations of digestible AA when fed to broilers (Parsons et al., 2000; Baker et al., 2011; Perryman and Dozier, 2012). Baker et al. (2011) reported higher true digestible AA concentrations for a low GAL SBM vs. a control SBM, but did not observe differences in TME_n or growth performance in broilers from 8 to 22 d of age. Perryman and Dozier (2012) reported a 7 to 9% increase in AME_n for LOSBM vs. CSBM and observed 8.0 and 17% greater apparent ileal AA digestibility (**AIAAD**) concentrations for Met, Lys, Thr, Val, and Ile for LOSBM and ULSBM, respectively, compared with CSBM.

To our knowledge, growth and meat yield responses of broilers fed diets formulated with LOSBM or ULSBM have not been reported on in the literature. Therefore, the objective of this research was to evaluate growth and meat yield responses of broilers fed diets formulated with LOSBM, ULSBM, or CSBM during a 6 wk production period. In experiment 6, diets were also formulated to contain either moderate or reduced AME_n concentrations. Feeding broilers a reduced AME_n diet may accentuate growth and meat yield responses with diets containing LOSBM and ULSBM compared with CSBM.

MATERIALS AND METHODS

The Institutional Animal Care and Use Committee at Auburn University approved all experimental protocols involving live birds (PRN 2009-1668).

Soybean Meals

In experiment 5, 2 SBM (CSBM and LOSBM) were produced from soybeans grown in the 2009 crop yr. In experiment 6, CSBM, LOSBM, and ULSBM produced from soybeans grown during the 2010 crop yr were evaluated. Soybeans were obtained from Schillinger Genetics (Schillinger Genetics, West Des Moines, IA) and processed at Zeeland Farm Services' processing plant (Zeeland Farm Services, Zeeland, MI). Nutrient composition of SBM has been reported to be influenced by production location, fertilization rate, and rainfall (Greishop et al., 2003; Karr-Lilienthal et al., 2005). To avoid agronomic differences, soybeans were grown in the same geographic location in northeast Indiana. The resulting soybeans were processed at the same facility, utilizing identical procedures to avoid processing differences.

The 5 SBM types were analyzed for CP by determining nitrogen content via the Dumas method (method 990.03; AOAC International, 2006) using a N analyzer (Rapid N Cube, Elementar Analysensyteme GmbH, Hanau, Germany), and CP was calculated by multiplying percent N by a factor of 6.25 (Table 4.1). Sucrose, raffinose, and stachyose were determined (Bhatti et al., 1970), as well as starch (method 76-13; AACC International, 2006), acid detergent fiber (**ADF**) (method 973.18 (A-D); AOAC International, 2006), neutral detergent fiber (**NDF**) (Holst, 1973), cellulose (method 973.18 (A-D); AOAC International, 2006), and trypsin inhibitor concentration (method 22-40.01; AACC International, 2006). Soybean meals were dried to determine DM (method 934.01; AOAC International, 2006) and were analyzed for gross energy (**GE**) using bomb calorimetry (Model 6300, Parr Instruments, Moline, IL). Crude fat concentrations were estimated by boiling samples in hexane (method 2003.06; AOAC International, 2006) in a fat extractor (Soxtec model number 2043, Foss North America, Inc., Eden Prairie, MN). Particle size was determined on a 13 half-height sieve shaker (Tyler RoTap, Mentor, OH) as described by Baker and Herrman (2002). Bulk density was determined utilizing a standard weight per bushel tester (USDA, 1953).

Dietary Treatments

In each experiment, broilers were fed diets using a 3-phase feeding program: starter (1 to 14 d of age), grower (15 to 28 d of age), and finisher (29 to 40 or 42 d of age for experiments 5 and 6, respectively) feeding phases. Starter diets were provided as crumbles, and subsequent feeds were provided as whole pellets. All diets were formulated to meet or exceed NRC (1994) nutrient recommendations and were formulated utilizing AME_n and AIAAD concentrations for CSBM, LOSBM, and ULSBM determined from previous research (Perryman and Dozier, 2012; Table 4.2).

In experiment 5, broilers were fed 1 of 2 dietary treatments formulated to contain either LOSBM or CSBM (Table 4.3). In experiment 6, 6 dietary treatments were implemented utilizing a 3 × 2 factorial design consisting of 3 types of SBM (CSBM, LOSBM, or ULSBM) and 2 AME_n concentrations (moderate or reduced) (Tables 4.4-4.6). Diets with moderate AME_n were formulated to contain 3,025, 3,115, and 3,160 kcal AME_n/kg in the starter, grower, and finisher phases, respectively. Diets with reduced AME_n were formulated to contain a 25 kcal/kg reduction in AME_n compared with the moderate AME_n diets.

Common Procedures

Ross × Ross 708 male broiler chicks (experiment 5 = 600; experiment 6 = 1,500) were obtained from a commercial hatchery at 1 d of age and distributed randomly to 24 (experiment 5) or 60 (experiment 6) floor pens (0.09 m^2/bird; 25 birds per pen). At the hatchery, chicks received vaccinations for Marek's disease, Newcastle disease, and infectious bronchitis. The experimental facility was solid-sided with a negative-pressure ventilation system equipped with an electronic controller, vent boards, exhaust fans, and evaporative cooling pads. Ambient temperature set points consisted of 33°C from placement until 4 d of age, 32°C from 5 to 8 d of age, 31°C from 9 to 13 d of age, 29°C from 14 to 22 d of age, 26°C from 23 to 27 d of age, 25°C from 28 to 32 d of age, 23°C from 33 to 38 d of age, and 21°C from 39 to 42 d of age. Actual average ambient temperatures during experimentation were 26.2°C ± 1.9 SD for experiment 5 and 24.9°C ± 2.3

SD for experiment 6. The lighting schedule followed the primary breeder recommendation with a 23L:1D photoperiod at a light intensity of 30 lux, which was implemented from placement to 7 d of age, then, a 20L:4D photoperiod with an intensity of 3 lux was utilized until 40 or 42 d of age. Light intensity was verified at bird level using a photometric sensor (LI-250A Light Meter, LI-COR Bioscience, Lincoln, NE) with National Institute of Standards and Technology traceable calibration for each intensity adjustment. Each pen had fresh pine shavings, a hanging feeder, and a nipple drinker line, and birds were offered feed and water ad libitum. Birds and feed were weighed on a per pen basis at 1, 14, 28, and 40 or 42 d of age for the determination of growth rate, feed intake, and FCR (ratio of feed intake to BW gain). Mortality was recorded daily.

At 37 d of age, 3 birds per pen were randomly selected for blood collection. Blood was collected via the ulnar vein using a 10 mL non-heparinized syringe equipped with an 18-gauge needle. An 8 mL sample of blood per bird was obtained for the determination of plasma glucose, triglyceride, and nonesterfied fatty acid concentrations. Samples were centrifuged using a Sorvall Legend 23R centrifuge (ThermoFisher Scientific Inc., Waltham, MA) at 2000 × *g* for 5 min and 1.5 mL of plasma was obtained and stored at -20°C for later analysis. Plasma glucose (Kunst et al., 1986) and triglyceride (Wahlefeld and Bergmeyer, 1974) concentrations were determined using a Cobas C 311 analyzer (Roche Diagnostics, Indianapolis, IN). Plasma nonesterfied fatty acid concentrations were determined using the method described by Tripathy et al. (2003). Concentrations of plasma nonesterfied fatty acids were measured using a universal microplate spectrophotometer (Bio-Tek Instrument Inc., Winooski, VT) with reagent assay test kits (Wako Diagnostics, Richmond, VA) according to the manufacturer's instructions. Five µL of sample, standard, or blank were added to the appropriate wells and analyzed utilizing enzymatic procedures described by Hintz (2000). All samples were evaluated in triplicate during the same assay in order to avoid inter-assay variability. The amount of nonesterfied fatty acid in the sample was determined using standard curves from the optical density measured at 550 nm.

At 40 (experiment 5) and 42 d of age (experiment 6), 14 birds per pen were individually weighed and selected for processing based on having a BW within ±15% of the mean pen weight. In addition to BW determination, all birds were evaluated for pododermatitis (**PD**) by trained personnel assigning a score of 0, 1, or 2 based on the severity of footpad lesions via the method describe by Nagaraj et al. (2007). Feed was removed 12 h prior to processing, after which, pre-selected birds were placed in coops and transported to the Auburn University Processing Plant. Broilers were electrically stunned, exsanguinated, scalded, mechanically picked, mechanically eviscerated, and then placed on ice. Whole carcass (without abdominal fat) and abdominal fat were weighed, and carcasses were split into front and back halves and then placed on ice for 18 h. The front halves were then deboned to obtain total breast weights, which were composed of the pectoralis major and minor muscles. Carcass, abdominal fat percentage, and total breast meat yields were determined from individual BW of broilers selected for processing at 40 (experiment 5) and 42 d of age (experiment 6).

At 41 (experiment 5) or 43 d of age (experiment 6), 3 birds per pen were euthanized via CO_2 asphyxiation to collect foregut (proximal duodenum to Meckel's diverticulum) and hindgut (Meckel's diverticulum to ileocecocolic junction) segments of the intestine to determine digesta pH and viscosity. Digesta were gently expressed from each segment into a 50 mL tube, and pH values were recorded before the samples were placed on ice and transferred to a -20°C freezer until later analysis. For viscosity determination, samples were centrifuged at 1,500 × *g* for 5 min, and the supernatant was transferred to 15 mL tubes for further analysis. Samples were centrifuged at 12,500 × *g* for 5 min and 8 mL of supernatant was collected and stored at -20°C until later analysis. Viscosities were measured in centipoises (**cP**) using a Brookfield DV-E viscometer (Brookfield Engineering Laboratories Inc., Midddleboro, MA) following the manufacturer's recommended procedure. Briefly, an 8 mL sample was heated to 40°C and placed in the viscometer. Using the S18 spindle and a rotational speed of 12 rpm, the spindle was submerged

completely in sample using the sample guard as a guide. The viscometer was activated and a viscosity (cP) value was recorded after 10 s.

Statistical Analyses

Data were analyzed using a randomized complete block design with pen location as the blocking factor. Experiment 5 was represented by 12 replicate pens per treatment. Analysis of variance was performed using PROC MIXED (SAS Institute, 2004) by the following mixed-effects model:

$$Y_{ij} = \mu.. + \rho_i + \tau_j + \varepsilon_{ij}$$

where $\mu..$ is the overall mean; the ρ_i are identically and independently normally distributed random block effects with mean 0 and variance σ^2_ρ; the τ_j are fixed factor level effects corresponding to the j^{th} soybean variety (CSBM or LOSBM) such that $\Sigma\tau_j = 0$; and the random error ε_{ij} are identically and independently normally distributed with mean 0 and variance σ^2.

Experiment 6 was designed as a 3 × 2 factorial with 3 SBM types (CSBM, LOSBM, or ULSBM) and 2 AME_n concentrations (moderate or reduced) and each treatment was represented by 10 replicate pens. Interaction and main effects were evaluated using PROC MIXED (SAS Institute, 2004) by the following mixed-effects model:

$$Y_{ijk} = \mu... + \rho_i + \alpha_j + \beta_k + (\alpha\beta)_{jk} + \varepsilon_{ijk}$$

where $\mu...$ is the overall mean; the ρ_i are identically and independently normally distributed random block effects with mean 0 and variance σ^2_ρ; the α_j are fixed factor level effects corresponding to the j^{th} soybean variety (CSBM, LOSBM, or ULSBM) such that $\Sigma\alpha_j = 0$; the β_k are fixed factor level effects corresponding to the k^{th} AME_n concentration (moderate or reduced) such that $\Sigma\beta_k = 0$; the $(\alpha\beta)_{jk}$ are interaction level effects corresponding to either the j^{th} soybean and the k^{th} AME_n concentration such that $\Sigma_j(\alpha\beta)_{jk} = 0$ and $\Sigma_k(\alpha\beta)_{jk} = 0$; and the random error ε_{ijk} are identically and independently normally distributed with mean 0 and variance σ^2. Statistical significance was established at $P \leq 0.05$, and significantly different treatment means were separated using Tukey's Honestly Significant Difference test (Tukey, 1953).

RESULTS AND DISCUSSION

Physical and Chemical Characteristics

Soybean meal genetically selected for low concentrations of GAL contained altered sugar, fiber, and CP composition compared with commodity SBM (Baker and Stein, 2009; Baker et al., 2011). Quantifying changes in chemical composition of trait enhanced SBM is valuable when interpreting growth responses and carcass characteristic differences. Both LOSBM and ULSBM exhibited altered chemical and physical composition compared with CSBM (Table 4.1). The resulting chemical and physical characteristics are presented as numerical diferences because statistical analysis could not be applied due to a lack of replication. In experiment 5, LOSBM had less stachyose (-77%), raffinose (-70%), ADF (-36%), NDF (-43%), and cellulose (-32%), and more CP (+15%), sucrose (+21%), and starch (+39%) compared with CSBM. Particle size was determined to be 1,300 and 1,166 μm mean diameter for CSBM and LOSBM, respectively, and bulk density was greater (+23%) for LOSBM vs. CSBM.

In experiment 6, both LOSBM and ULSBM had lower concentrations of stachyose (-72 and -90%) and raffinose (-74 and -91%), and higher sucrose (+17 and +4%) and CP (+12 and +16%) concentrations compared with CSBM. Moreover, cellulose (-36 and -24%), ADF (-38 and -24%), and NDF (-40 and -27%) concentrations were lower for LOSBM and ULSBM vs. CSBM. Particle size was determined as 1,059, 1,279, and 1,106 μm mean diameter for CSBM, LOSBM, and ULSBM, respectively, and bulk density was greater (+9 and +15%) for LOSBM and ULSBM compared with CSBM.

Growth Performance, Physiological Variables, and Pododermatitis

In experiment 5, broilers consuming diets formulated with LOSBM had increased (P = 0.020) BW gain and decreased ($P < 0.001$) FCR compared with broilers fed diets formulated with CSBM from 1 to 14 d of age (Table 4.7). Feed intake and mortality were without change between broilers consuming either CSBM- and LOSBM-based diets from 1 to 14 d of age. Additionally,

BW gain, feed intake, FCR, and mortality were not different between broilers fed diets formulated with CSBM and LOSBM from 1 to 28 and 1 to 40 d of age. No differences were observed between broilers consuming diets formulated with CSBM or LOSBM for the physiological variables measured (data not shown; grand means for foregut viscosity = 35.8 cPa, hindgut viscosity = 39.8 cPa, foregut pH = 5.95, hindgut pH = 5.33, NEFA = 451 mEq/L, plasma glucose = 220 mg/dL, and plasma triglycerides = 131 mg/dL).

In experiment 6, interaction effects were not significant between AME_n concentration and SBM type. Thus, data are presented as main effects of SBM type and AME_n concentration (Table 4.8). Body weight gain, feed intake, and mortality were similar between broilers fed the 3 SBM types throughout the experimental period. Feed conversion was decreased ($P < 0.001$) for broilers fed diets containing ULSBM from 1 to 28 and 1 to 42 d of age compared with birds receiving CSBM- or LOSBM-based diets. Feeding broilers diets with moderate or reduced AME_n concentration did not elicit differences in growth performance. Additionally, broilers consuming diets with either of the 3 SBM types and moderate or reduced AME_n had similar viscosity, pH, and blood plasma profile (data not shown; grand means forforegut viscosity = 30.7 cPa, hindgut viscosity = 37.2 cPa, foregut pH = 5.91, hindgut pH = 5.33, NEFA = 279 mEq/L, plasma glucose = 253 mg/dL, and plasma triglycerides = 48 mg/dL).

In experiment 5, broilers fed diets formulated with LOSBM had higher BW gain and lower FCR than birds fed diets formulated with CSBM from 1 to 14 d of age. These advantages of growth performance with broilers fed diets formulated with LOSBM may be attributed to the inability of young broilers to metabolize the complex carbohydrates of SBM due to the immature gastrointestinal tract of the young chick (Carré et al., 1995). Soybean meal genetically selected for low concentrations of GAL had reduced concentrations of ADF, NDF, and cellulose compared with CSBM. Increased amounts of complex carbohydrates in the diet have been reported to be detrimental to nutrient digestibility due to their possible anti-nutritive effect and the limited fermentative capacity of the poultry gastrointestinal tract (Choct and Annison, 1990).

In contrast to experiment 5, a reduction in feed conversion was not observed among broilers fed either of the 3 SBM types from 1 to 14 d of age in experiment 6. In agreement, Baker et al. (2011) observed no differences in BW gain, feed intake, FCR, or mortality when comparing chicks fed diets formulated with low GAL SBM vs. a control SBM from 8 to 22 d of age. However, in the present research, FCR was reduced from 1 to 28 and 1 to 42 d of age for broilers consuming diets formulated with ULSBM compared with CSBM and LOSBM. The basis for this decrease in FCR is elusive, but may have been attributed to an underestimation of the predetermined AME_n and digestible AA content of ULSBM utilized in diet formulation (Perryman and Dozier, 2012). Higher concentrations of dietary AME_n have been reported to decrease FCR in broilers compared with diets formulated with lower AME_n concentrations (Hidalgo et al., 2004; Dozier et al., 2006, 2011). Similarly, previous research has reported that broilers consuming diets with increased AA density have reduced FCR in modern genetic strains (Kidd et al., 2005; Dozier et al., 2006, 2007; Corzo et al., 2010).

Feeding broilers diets with reduced AME_n density did not elicit any differences in BW gain, feed intake, FCR, or mortality compared with broilers that consumed diets formulated with moderate AME_n concentrations (Table 4.8). Similarly, Hidalgo et al. (2004) reported no differences in cumulative BW gain, feed intake, or FCR of broilers fed diets with weighted energy concentrations of 3,100 or 3,144 kcal of ME/kg from 1 to 38 d of age. However, broilers fed diets containing a weighted average of 3,233 kcal of ME/kg were 0.066 kg heavier than broilers consuming diets with a weighted average of 3,056 kcal of ME/kg from 1 to 38 d of age. Similarly, FCR was decreased by 6% (1.40 vs. 1.49 kg:kg) for broilers consuming diets formulated with 3,153 vs. 3,020 kcal of ME/kg from 18 to 30 d of age and decreased by 8% (2.07 vs. 2.24 kg:kg) for broilers consuming diets with 3,175 vs. 3,086 kcal of ME/kg from 31 to 38 d of age. Poor growth was related to diets being formulated to a constant ME:CP ratio. Broilers did not compensate for the low ME concentration of the diet, so intake of essential AA was also lower for birds consuming diets formulating with low ME. In agreement, Saleh et al. (2004)

reported no differences in BW gain, feed intake, or FCR for broilers consuming diets with weighted average energy concentrations of 3,101 or 3,140 kcal of ME/kg from 1 to 42 d of age. Broilers fed diets with a weighted energy concentration of 3,227 kcal of ME/kg grew faster than birds fed diets formulated with a weighted average ME concentration of 3,023 kcal of ME/kg from 1 to 42 d of age. Poor feed conversion in both studies was attributed to reduced BW gain with broilers fed diets with low energy concentrations. Broilers did not increase feed intake to compensate for the low energy concentrations of the diets. Feed consumption was not different between broilers consuming diets varying in ME concentrations by less than 132 kcal of ME/kg during a 5 or 6 wk production period (Hidalgo et al., 2004; Saleh et al., 2004). These data provide evidence that birds younger than 42 d of age may not adjust feed intake to compensate for differences in energy concentrations of the diet. These findings could explain the lack of growth responses observed in experiment 6 due to broilers consuming diets differing in AME_n by only 25 kcal/kg.

Broilers fed diets formulated with LOSBM or ULSBM had a lower incidence ($P = 0.002$) of PD compared with broilers that consumed diets formulated with CSBM, which may have been due to decreased GAL concentrations of the LOSBM and ULSBM (Figure 1). Bedford (1995) reported that GAL causes excreta to have hydroscopic properties resulting in increased litter moisture, and elevated litter moisture has been reported to influence incidences of PD (Martland 1984, 1985; Mayne et al., 2007). Additionally, reduced incidences of PD may be attributed to lower concentrations of SBM in diets formulated with LOSBM and ULSBM. Soybean meal is relatively high in K (1.98%) compared with corn (0.30%) (NRC, 1994), so reducing the concentration of SBM in the diet could lead to lower concentrations of K in the diet. High dietary K concentrations have been implicated in causing an increase in water intake translating to elevated litter moisture (Eichner et al., 2007). While litter moisture was not measured in this experiment, diets formulated with LOSBM and ULSBM had on average 16% less SBM compared with diets formulated with CSBM. Therefore, diets formulated with LOSBM and

ULSBM had less GAL and lower K concentrations due to less SBM formulated into the diet, which may have had a synergetic effect contributing to a reduction in PD.

Processing Characteristics

In experiment 5, broilers fed diets formulated with CSBM or LOSBM had similar weights and yields of the whole carcass and total breast meat (Table 4.9). Broilers consuming diets formulated with LOSBM had increased ($P < 0.001$) abdominal fat percentage compared with broilers consuming diets formulated with CSBM. In experiment 6, neither interaction effects nor main effects of AME_n were observed for carcass yield, but carcass and breast yields were different among broilers consuming the 3 SBM types (Table 4.10). Broilers fed diets formulated with ULSBM had greater ($P < 0.05$) carcass yield compared with birds consuming CSBM-based diets. Additionally, total breast meat yield was increased ($P = 0.021$) for broilers fed diets containing LOSBM and ULSBM vs. CSBM. Increased breast and carcass yields in birds fed diets formulated with LOSBM or ULSBM may be attributed to better AA utilization of these diets compared with diets formulated with CSBM. Researchers have reported that increasing concentrations of complex carbohydrates in poultry diets may negatively influence AA digestibility (Antoniou et al., 1981; Choct and Annison, 1990). Both LOSBM and ULSBM had less ADF, NDF, and cellulose compared with CSBM. Furthermore, a possible underestimation of the digestible AA content of ULSBM and LOSBM determined in previous research could have been responsible for the greater lean tissue deposition reported herein (Perryman and Dozier, 2012). Previous research has reported that higher concentrations of dietary AA resulted in increased deposition of lean tissue resulting in higher carcass and total breast weights in broilers (Bartov et al., 1998; Kidd et al., 2004; Corzo et al., 2005, 2010; Dozier et al., 2008b; Lilly et al., 2011).

In agreement with experiment 5, broilers fed diets containing LOSBM had higher ($P = 0.027$) abdominal fat percentage compared with birds consuming CSBM-based diets in experiment 6 (Table 4.10). Increased abdominal fat percentage could be attributed to the higher

AME_n of LOSBM compared with CSBM. Diets in both experiments were formulated to meet the recommended requirements for the first 5 limiting AA in poultry. Due to higher concentrations of less limiting AA in LOSBM compared with CSBM, excess AA may have been catabolized for energy, increasing AME_n and translating to a higher abdominal fat percentage. Parsons et al. (2000) partially attributed the higher TME_n of several low GAL SBM types to the higher concentrations of AA of these SBM types, which may have provided a source of energy via their carbon skeletons. Furthermore, ratios of AME_n:CP were not kept constant between treatments, and the AME_n:CP ratio was highest for diets formulated with LOSBM compared with CSBM- and ULSBM-based diets. Additionally, underestimating AME_n of LOSBM would lead to experimental diets with higher AME_n:CP ratios. Broilers fed diets with progressively higher AME_n:CP ratio have been reported to have increased abdominal fat percentage with increasing energy concentrations (Bartov et al., 1974).

In experiment 6, broilers fed diets with varying AME_n concentrations had similar carcass characteristics (Table 4.10). In agreement, Hidalgo et al. (2004) reported no differences in carcass and breast weights with broilers fed 6 diets varying in energy density from 1 to 38 d of age. Similarly, Leeson et al. (1996) reported no differences in breast or carcass weights with broilers fed diets ranging from 2,700 to 3,100 kcal of ME/kg from 0 to 49 d of age. Conversely, carcass weights and breast weights were different between broilers fed diets formulated with weighted dietary energy concentrations of 3,054 or 3,214 kcal of ME/kg from 0 to 63 d of age (Saleh et al., 2004). These authors attributed this response to the ability of older broilers to increase feed intake to compensate for the low energy density of the diet. The increase in feed intake resulted in an increased consumption of essential AA, translating to greater lean tissue deposition. In the present research, a lack of differences in carcass characteristics may be due to broilers not increasing feed intake to compensate for lower dietary AME_n concentrations. This finding agrees with previous research, which reported broilers younger than 42 d of age may not have the ability

to increase feed intake to compensate for lower dietary AME_n concentrations (Hidalgo et al., 2004; Saleh et al., 2004; Dozier et al., 2008a).

Diets formulated with LOSBM or ULSBM contained lower concentrations of poultry oil compared with diets formulated with CSBM. Less oil supplementation occurred as a result of the better nutrient profiles of LOSBM and ULSBM (Perryman and Dozier, 2012). Due to higher digestible AA content, less LOSBM and ULSBM were necessary to satisfy dietary AA specifications compared with diets formulated with CSBM. With lower inclusions of LOSBM and ULSBM, higher concentrations of corn entered into diet formulation, which resulted in lower supplementation of poultry oil. Additionally, LOSBM had a higher AME_n compared with ULSBM. Therefore, diets formulated with LOSBM required the lowest inclusions of poultry oil to satisfy dietary energy specifications.

In conclusion, due to the better nutrient profiles of ULSBM and LOSBM, diets formulated with these SBM types had between 28 and 71% less supplemental oil compared with diets formulated with CSBM. Broilers consuming diets formulated with either LOSBM or ULSBM resulted in acceptable growth performance and meat yield responses compared with birds consuming diets formulated with CSBM. Feeding broilers diets formulated with LOSBM and ULSBM compared with CSBM also resulted in a 58% reduction in incidences of pododermatitis during a 6 wk production period. These data support that nutrient utilization of LOSBM and ULSBM is increased in broilers compared with CSBM. Due to better nutrient utilization, less supplemental fat is required in diets formulated with LOSBM or ULSBM, which can translate to a reduction in dietary costs.

ACKNOWLEDGEMENTS

The authors would like to express appreciation to Schillinger Genetics for providing the experimental soybean meals and to the United Soybean Board for funding this research.

REFERENCES

AACC International. 2006. Approved Methods of Analysis, 11th Ed. Method 22-40.01. Measurement of trypsin inhibitor activity of soy products-spectrophotometric method. AACC International, St. Paul, MN, U.S.A.

American Society of Agricultural Engineers. 1993. S319.2. Method of determining and expressing fineness of feed materials by sieving. American Society of Agricultural Engineers Yearbook of Standard. ASAE, St. Joseph, MO.

Antoniou, T., R. R. Marquardt, and E. Cansfield. 1981. Isolation partial characterization, and antinutritional activity of a factor (pentosans) in rye grain. J. Agric. Food Chem. 28:1240-1247.

AOAC International. 2006. Official Methods of Analysis of AOAC International. 18th ed. AOAC International, Gaithersburg, MD.

Bach Knudsen, K. E. 1997. Carbohydrate and lignin contents of plant materials used in animal feeding. Anim. Feed Sci. Technol. 67:319-338.

Baker, K. M. and H. H. Stein. 2009. Amino acid digestibility and concentration of digestible and metabolizable energy in soybean meal produced from high protein or low oligosaccharide varieties of soybeans and fed to growing pigs. J. Anim. Sci. 87:2282-2290.

Baker, K. M., P. L. Utterback, C. M. Parsons, and H. H. Stein. 2011. Nutritional value of soybean meal produced from conventional, high-protein, or low-oligosaccharide varieties of soybeans and fed to broiler chicks. Poult. Sci. 90:390-395.

Baker, S. and T. Herrman. 2002. Evaluating feed particle size. Bulletin MF-2051. Kansas State Agricultural Experiment Station and Cooperative Extension Service, Manhattan, KS.

Bartov, I. and I. Plavnik. 1998. Moderate excesss of dietary protein increases breast meat yield of broiler chicks. Poult. Sci. 77:680-688.

Bartov, I., S. Bornstein, and B. Lipstein. 1974. Effect of calorie to CP ratio on the degree of fatness in broilers fed on practical diets. Br. Poult. Sci. 15:107-117.

Bedford, M. R. 1995. Mechanism of action and potential environmental benefits from the use of feed enzymes. Anim Feed Sci. Technol. 53:145-155.

Bhatti, T., R. E. Chambers, and J.R. Clamp. 1970. The gas chromatographic properties of biologically important N-acetylglucosamine derivatives, monosaccharides, disaccharides, trisaccharides, tetrasaccharides and pentasaccharides. Biochim Biophys Acta. 222:339-347.

Carré, B., J. Gomez, and A. M. Chagneau. 1995. Contribution of oligosaccharide and polysaccharide digestion, and excreta losses of lactic acid and short chain fatty acids, to dietary metabolisable energy values in broiler chickens and adult cockerels. Br. Poult. Sci. 36:611-629.

Choct, M. and G. Annison. 1990. Anti-nutritive activity of wheat pentosans in broiler diets. Br. Poult. Sci. 31:811-821.

Choct, M., Y. Dersjant-Li, J. McLeish, and M. Peisker. 2010. Soy oligosaccharides and soluble non-starch polysaccharides: a review of digestion, nutritive and anti-nutritive effects in pigs and poultry. Asian-Aust. J. Anim. Sci. 10:1386-1398.

Coon, C. N., K. L. Leske, O. Akavanichan, and T. K. Cheng. 1990. Effect of oligosaccharide-free soybean meal on true metabolizable energy and fiber digestion in adult roosters. Poult. Sci. 69:787-793.

Corzo, A., M. T. Kidd, D. J. Burnham, E. R. Miller, S. L. Branton, and R. Gonzalez-Esquerra. 2005. Dietary amino acid density effects on growth and carcass of broilers differing in strain cross and sex. J. Appl. Poult. Res.14:1-9.

Corzo, A., M. W. Schilling, R. E. Loar II, L. Mejia, L. C. G. S. Barbosa, and M. T. Kidd. 2010. Responses of Cobb × Cobb 500 broilers to dietary amino acid density regimens. J. Appl. Poult. Res. 19:227-236.

Cristofaro, E., F. Mottu, and J. J. Wuhrmann. 1974. Involvement of the raffinose family of oligosaccharides in flatulence. Pages 313-336 in Sugars in Nutrition. H. Sipple and K. McNutt, ed. Academic Press. New York, NY.

Donohue, M. and D. L. Cunningham. 2009. Effects of grain and oilseed prices on the costs of US poultry production. J. Appl. Poult. Res. 18:325-337.

Dozier, W. A. III, A. Corzo, and M. T. Kidd. 2008a. Apparent metabolizable energy needs of broiler chicks subjected to diverse ambient temperature regimens. J. Appl. Poult. Res. 17:134-140.

Dozier, W. A. III, C. K. Gehring, A. Corzo, and H. A. Olanrewaju. 2011. Apparent metabolizable energy needs of male and female broilers from 36 to 47 days of age. Poult. Sci. 90:804-814.

Dozier, W. A. III, M. T. Kidd, and A. Corzo. 2008b. Dietary amino acid responses of broiler chickens. J. Appl. Poult. Res. 17:157-167.

Dozier, W. A. III, C. J. Price, M. T. Kidd, A. Corzo, J. Anderson, and S. L. Branton. 2006. Growth performance, meat yield, and economics of broilers fed diets varying in metabolizable energy from thirty to fifty-nine days of age. J. Appl. Poult. Res. 15:367-382.

Dozier, W. A., III, J. L. Purswell, M. T. Kidd, A. Corzo, and S. L. Branton. 2007. Dietary apparent metabolizable energy and amino acid density effects on growth and carcass traits of heavy broilers. J. Appl. Poult. Res. 16:192-205.

Eichner, G., S. L. Vieira, C. A. Torres, J. L. B. Coneglian, D. M. Freitas, and O. A. Oyarzabal. 2007. Litter moisture and footpad dermatitis as affected by diets formulated on an all-vegetable basis or having the inclusion of poultry by-product. J. Appl. Poult. Res. 16:344-350.

Ghazi, S., J. A. Rooke, and H. Galbraith. 2003. Improvements in the nutritive value of soybean meal by protease and α-galactosidase treatment in broiler cockerels and broiler chicks. Br. Poult. Sci. 44:410-418.

Gitzelmann, R. and S. Auricchio, 1965. The handling of soy alpha-galactosidase by a normal and galactosemic child. Pediatrics 36:231-238.

Grieshop, C. M., C. T. Kadzere, G. M. Clapper, E. A. Flickinger, L. L. Bauer, R. L. Frazier, and G. C. Fahey, Jr. 2003. Chemical and nutritional characteristics of United States soybeans and soybean meals. J. Agric. Food Chem. 51:7684-7691.

Hidalgo, M. A., W. A. Dozier III, A. J. Davis, and R. W. Gordon. 2004. Live performance and meat yield responses of broilers to progressive concentrations of dietary energy maintained at a constant metabolizable energy-to-crude protein ratio. J. Appl. Poult. Res. 13:319-327.

Hintz, J. V. 2000. The hormonal regulation of premigratory fat deposition and winter fattening in red-winged blackbirds. Comp. Biochem. Physiol. 125:239-249.

Holst, D. O. 1973. Holst filtration apparatus for Van Soest detergent fiber analysis. J. AOAC 56:1352-1356.

Karr-Lilienthal, L. K., C. T. Kadzere, C. M. Grieshop, and G. C. Fahey, Jr. 2005. Chemical and nutritional properties of soybean carbohydrates as related to nonruminants: A review. J. Livestock Prod. Sci. 97:1-12.

Kidd, M. T., A. Corzo, D. Hoehler, E. R. Miller, and W. A. Dozier, III. 2005. Broiler responsiveness (Ross × 708) to diets varying in amino acid density. Poult. Sci. 84:1389-1396.

Kidd, M. T., C. D. McDaniel, S. L. Branton, E. R. Miller, B. B. Boren, and B. L. Francher. 2004. Increasing amino acid density improves live performance and carcass yields of commercial broilers. J. Appl. Poult. Res. 13:593-604.

Kunst, A., B. Draeger, and J. Ziegenhorn. 1984. Metabolites 1: Carbohydrates. Pages 163-172 in Methods of Enzymatic Analysis, 3rd ed. Volume VI.

Leeson, S., L. Caston, and J. D. Summers. 1996. Broiler responses to diet energy. Poult. Sci. 75:529-535.

Lilly, R. A., M. W. Schilling, J. L. Silva, J. M. Martin, and A. Corzo. 2011. The effects of dietary amino acid density in broiler feed on carcass characteristics and meat quality. J. Appl. Poult. Res. 20:56-67.

Martland, M. F. 1985. Ulcerative dermatitis in broiler chickens. The effects of wet litter. Avian Pathol. 14:353-364.

Martland, M. F. 1984. Wet litter as a cause of plantar pododermatitis, leading to foot ulceration and lameness in fattening turkeys. Avain Pathol. 12:241-252.

Mayne, R. K., R. W. Else, and P. M. Hocking. 2007. High litter moisture alone is sufficient to cause foot pad dermatitis in growing turkeys. Brit. Poult. Sci. 48:538-545.

Nagaraj, M., J. B. Hess, and S. F. Bilgili. 2007. Evaluation of a feed-grade enzyme in broiler diets to reduce pododermatitis. J. Appl. Poult. Res. 16:52-61.

NRC. 1998. Nutrient Requirements of Swine. 10th rev. ed. Natl. Acad. Press, Washington, D.C.

NRC. 1994. Nutrient Requirements of Poultry. 9th ed. Natl. Acad. Press, Washington, D.C.

Parsons, C. M., Y. Zhang, and M. Araba. 2000. Nutritional evaluation of soybean meals varying in oligosaccharide content. Poult. Sci. 79:1127-1131.

Perryman, K. R. and W. A. Dozier, III. 2012. Apparent metabolizable energy and apparent ileal amino acid digestibility of low and ultra-low oligosaccharide soybean meals fed to broiler chickens. Poult. Sci. (submitted April, 2012).

Saleh, E. A., S. E. Watkins, A. L. Waldroup, and P. W. Waldroup. 2004. Effects of dietary nutrient density on performance and carcass quality of male broilers grown for further processing. Int. J. Poult. Sci. 3:1-10.

SAS Institute. 2004. SAS User's Guide. Statistics. Version 9.1 ed. SAS Inst. Inc., Cary, NC.

Tripathy, D., P. Mohanty, S. Dhindsa, T. Syed, H. Ghanim, A. Aljada, and P. Dandona. 2003. Elevation of free fatty acids induces inflammation and impairs vascular reactivity in healthy subjects. Diabetes 52:2882-2887.

Tukey, J. W. 1953. The problem of multiple comparisons. Pages 1948-1983 in The Collected Works of John W. Tukey VIII. Multiple Comparisons. Chapman and Hall, New York, NY.

USDA. 1953. The test weight per bushel of grain: Method of use and calibration of the apparatus. Circular No.921. U.S. Government Printing Office, Washington, D.C.

Wahlefeld, A. W. and H. U. Bergmeyer. 1974. Page 1831 in Methods of Enzymatic Analysis. 2nd ed. Acad. Press Inc, New York, NY.

Table 4.1 Physical and chemical characteristic of control (CSBM), low oligosaccharide (LOSBM), and ultra-low oligosaccharide (ULSBM) soybean meals on an as-is basis[1]

Item (%), unless otherwise noted	Experiment 5		Experiments 6			Analytical Method
	CSBM	LOSBM	CSBM	LOSBM	ULSBM	
Dry Matter	91.16	91.69	90.70	91.50	91.90	AOAC[5] 934.01. 2006
Crude Protein	47.60	54.59	47.86	53.73	55.63	AOAC 990.03. 2006
Crude Fat	1.71	1.12	1.24	0.79	0.77	AOAC 2003.06. 2006
Sucrose	6.95	8.38	7.47	8.71	7.78	Bhatti et al., 1970
Raffinose	0.71	0.21	0.82	0.21	0.07	Bhatti et al., 1970
Stachyose	6.79	1.56	5.08	1.44	0.50	Bhatti et al., 1970
Starch	0.89	1.24	0.81	0.61	0.40	AACC[6] 76-13. 2006[7]
ADF	5.54	3.52	5.50	3.39	4.19	AOAC 973.18 (A-D). 2006
NDF	8.09	4.60	8.07	4.84	5.91	Holst, 1973
Cellulose	5.53	3.74	5.71	3.68	4.36	AOAC 973.18 (A-D). 2006
Gross Energy (kcal/kg)	4,226	4,287	3,998	4,037	4,149	Isoperibol bomb calorimeter[7]
Particle Size (Dgw)[2]	1,300	1,166	1,059	1,279	1,106	ASAE[8] S319.4. 1993
Bulk Density (g/cc)[3]	0.53	0.65	0.69	0.75	0.79	USDA, 1953
KOH Solubility	82.24	83.44	78.93	84.31	82.58	Parsons et al., 1991
Trypsin Inhibitor (TIU/g)[4]	3,429	5,924	3,183	4,323	5,677	AACC 22-40. 2006

[1]Unless otherwise noted, all methods of analysis were determined by the University of Missouri Experimental Station Chemical Laboratories, Columbia, MO.
[2]Dgw = geometric mean diameter in µm, determined at Iowa State University.
[3](g/cc) = grams per cubic centimeter, determined at Iowa State University.
[4]TIU = Trypsin inhibitor units.
[5]AOAC = Association of Official Analytical Chemists.
[6]AACC = Association of American Cereal Chemists.
[7]Modified Starch Assay Kit (product code STA-20, Sigma, St. Louis, MO).
[7]Isoperibol bomb calorimeter (Parr model no. 6300) determined by Auburn University Laboratory (Auburn, AL).
[8]ASAE = American Society of Agricultural Engineers.

Table 4.2 Apparent metabolizable energy and total concentrations of digestible amino acids for the first 5 limiting amino acids in Ross × Ross 708 male broilers for control soybean meal, low oligosaccharide soybean meal, and ultra-low oligosaccharide soybean meal fed to growing broilers used in diet formulations[1]

Soybean Meal		Digestible Amino Acid Concentrations, %[3]				
	AME_n, kcal/kg[2]	Met	Lys	Thr	Ile	Val
2010						
Control	2,241	0.59	2.83	1.76	2.06	2.14
Low Oligosaccharide	2,435	0.61	2.97	1.79	2.14	2.21
2011						
Control	2,073	0.62	2.78	1.57	1.85	1.90
Low Oligosaccharide	2,214	0.66	2.96	1.69	2.03	2.08
Ultra-Low Oligosaccharide	2,080	0.71	3.21	1.78	2.23	2.27

[1]Values were determined by Perryman and Dozier (2012).

[2]Values are least-square means of 16 replicate cages with each cage containing 12 broilers at placement from 27 to 29 d of age.

[3]Values were least-square means of 12 replicate cages (2010) or 10 replicate cages (2011) with each cage containing 12 birds from 26 to 31 d of age during an apparent ileal amino acid digestibility assay.

Table 4.3 Ingredient and calculated composition of diets formulated with control soybean meal (CSBM) or low oligosaccharide soybean meal (LOSBM) fed to Ross × Ross 708 male broilers from 1 to 40 d of age (experiment 5)

	1 to 14 d of age		15 to 28 d of age		29 to 40 d of age	
Ingredient, % "as-fed"	CSBM	LOSBM	CSBM	LOSBM	CSBM	LOSBM
Ground corn	58.20	65.36	67.30	72.56	71.50	75.95
CSBM	32.00	-	23.47	-	19.83	-
LOSBM	-	26.66	-	19.55	-	16.52
Poultry by-product meal	4.00	4.00	4.00	4.00	4.00	4.00
Poultry oil	2.84	0.82	2.38	0.89	2.24	0.98
Limestone	0.88	0.89	0.86	0.87	0.83	0.84
Sodium Chloride	0.37	0.36	0.41	0.40	0.44	0.44
Defluorinated Phosphate	0.65	0.69	0.35	0.38	0.07	0.09
DL-Met	0.26	0.28	0.26	0.27	0.20	0.21
L-Lys·HCl	-	0.10	0.15	0.23	0.12	0.18
L-Thr	0.04	0.08	0.11	0.14	0.08	0.10
Builders Sand	0.19	0.19	0.14	0.14	0.12	0.12
Vitamin premix[1]	0.25	0.25	0.25	0.25	0.25	0.25
Mineral premix[2]	0.25	0.25	0.25	0.25	0.25	0.25
Phytase[3]	0.02	0.02	0.02	0.02	0.02	0.02
Salinomycin[4]	0.05	0.05	0.05	0.05	0.05	0.05
Calculated Analysis						
AME_n, kcal/kg	3,025	3,025	3,115	3,115	3,160	3,160
CP, %	22.67	22.67	19.50	19.50	18.00	18.00
digestible Lys, %	1.17	1.17	1.07	1.07	0.95	0.95
digestible TSAA, %	0.88	0.88	0.80	0.80	0.71	0.71
digestible Thr, %	0.76	0.76	0.72	0.72	0.64	0.64
digestible Ile, %	0.92	0.88	0.76	0.73	0.70	0.67
digestible Val, %	1.02	0.98	0.86	0.83	0.80	0.77
digestible Trp, %	0.19	0.18	0.15	0.15	0.14	0.14
digestible Arg, %	1.44	1.49	1.18	1.22	1.07	1.11
Ca, %	0.92	0.92	0.80	0.80	0.69	0.69
Non-phytate P, %	0.44	0.44	0.38	0.38	0.33	0.33
Na, %	0.21	0.21	0.21	0.21	0.21	0.21

[1]Vitamin premix include per kg of diet: Vitamin A (Vitamin A acetate), 8,000 IU; Vitamin D (cholecalciferol), 2,000 IU; Vitamin E (DL-alpha tocopherol acetate), 8 IU; menadione (menadione sodium bisulfate complex), 2 mg; Vitamin B12 (cyanocobalamin),0.02 mg; folacin (folic acid), 0.5 mg: D-pantothenic acid (calcium pantothenate) 15 mg; riboflavin (riboflavin), 5.4 mg; niacin (niacinamide), 45 mg; thiamin (thiamin mononitrate), 1 mg; D-biotin (biotin), 0.05 mg; and pyridoxine (pyridoxine hydrochloride), 2.2 mg; choline (choline chloride), 500 mg.

[2]Mineral premix include per kg of diet: Mn (manganous oxide), 65 mg; Zn (zinc oxide), 55 mg; Fe (iron sulfate monohydrate), 55 mg; Cu (copper sulfate pentahydrate), 6 mg; I (calcium iodate), 1 mg; Se (sodium selenite), 0.3 mg.

[3]Quantum phytase from ABVista, Marlborough, Wiltshire, UK.

[4]BioCox 60 provided 60 g/907 kg of salinomycin (Alpharma, Fort Lee, NJ).

Table 4.4 Ingredient and calculated composition of diets formulated with moderate or reduced AME_n concentrations and either control soybean meal (CSBM), low-oligosaccharide soybean meal (LOSBM), or ultra-low oligosaccharide soybean meal (ULSBM) fed to Ross × Ross 708 male broilers from 1 to 14 d of age (experiment 6)

	Moderate AME_n			Reduced AME_n		
Ingredient, % "as-fed"	CSBM	LOSBM	ULSBM	CSBM	LOSBM	ULSBM
Ground corn	57.74	63.65	64.27	58.31	64.20	64.86
Soybean Meal	32.25	28.13	26.97	32.16	28.06	26.88
Poultry by-product meal	4.00	4.00	4.00	4.00	4.00	4.00
Poultry oil	3.15	1.45	1.88	2.66	0.96	1.39
Limestone	0.74	0.77	0.77	0.75	0.77	0.77
Defluorinated Phosphate	0.65	0.67	0.69	0.65	0.67	0.68
Sodium Chloride	0.37	0.37	0.36	0.37	0.37	0.36
DL-Met	0.32	0.28	0.29	0.32	0.28	0.29
L-Lys·HCl	0.11	0.05	0.12	0.11	0.06	0.12
L-Thr	0.10	0.06	0.08	0.10	0.06	0.08
Vitamin Premix[1]	0.25	0.25	0.25	0.25	0.25	0.25
Mineral Premix[2]	0.25	0.25	0.25	0.25	0.25	0.25
Phytase[3]	0.02	0.02	0.02	0.02	0.02	0.02
Salinomycin[4]	0.05	0.05	0.05	0.05	0.05	0.05
Calculated Analysis						
AME_n, kcal/kg	3,025	3,025	3,025	3,000	3,000	3,000
CP, %	22.67	22.67	22.68	22.67	22.67	22.68
digestible Lys, %	1.17	1.17	1.17	1.17	1.17	1.17
digestible TSAA, %	0.88	0.88	0.88	0.88	0.88	0.88
digestible Thr, %	0.76	0.76	0.76	0.76	0.76	0.76
digestible Ile, %	0.82	0.86	0.81	0.82	0.87	0.81
digestible Val, %	0.91	0.97	0.90	0.91	0.97	0.90
digestible Trp, %	0.23	0.24	0.22	0.23	0.24	0.23
digestible Arg, %	1.37	1.49	1.45	1.37	1.49	1.45
Ca, %	0.92	0.92	0.92	0.92	0.92	0.92
Non-phytate P, %	0.44	0.44	0.44	0.44	0.44	0.44
Na, %	0.21	0.21	0.21	0.21	0.21	0.21

[1]Vitamin premix included per kg of diet: Vitamin A (Vitamin A acetate), 8,000 IU; Vitamin D (cholecalciferol), 2,000 IU; Vitamin E (DL-alpha tocopherol acetate), 8 IU; menadione (menadione sodium bisulfate complex), 2 mg; Vitamin B12 (cyanocobalamin), 0.02 mg; folacin (folic acid), 0.5 mg: D-pantothenic acid (calcium pantothenate) 15 mg; riboflavin (riboflavin), 5.4 mg; niacin (niacinamide), 45 mg; thiamin (thiamin mononitrate), 1 mg; D-biotin (biotin), 0.05 mg; and pyridoxine (pyridoxine hydrochloride), 2.2 mg; choline (choline chloride), 500 mg.

[2]Mineral premix include per kg of diet: Mn (manganous oxide), 65 mg; Zn (zinc oxide), 55 mg; Fe (iron sulfate monohydrate), 55 mg; Cu (copper sulfate pentahydrate), 6 mg; I (calcium iodate), 1 mg; Se (sodium selenite), 0.3 mg.

[3]Quantum phytase from ABVista, Marlborough, Wiltshire, UK.

[4]BioCox 60 provided 60 g/907 kg of salinomycin (Alpharma, Fort Lee, NJ).

Table 4.5 Ingredient and calculated composition of diets formulated with moderate or reduced AME_n concentrations and either control soybean meal (CSBM), low-oligosaccharide soybean meal (LOSBM), or ultra-low oligosaccharide soybean meal (ULSBM) fed to Ross × Ross 708 male broilers from 15 to 28 d of age (experiment 6)

	Moderate AME_n			Reduced AME_n		
Ingredient, % "as-fed"	CSBM	LOSBM	ULSBM	CSBM	LOSBM	ULSBM
Ground corn	63.29	70.79	68.13	63.87	71.35	68.70
Soybean Meal	26.75	21.05	22.86	26.66	20.98	22.77
Poultry by-product meal	4.00	4.00	4.00	4.00	4.00	4.00
Poultry oil	3.36	1.45	2.42	2.86	0.96	1.93
Limestone	0.75	0.79	0.77	0.76	0.79	0.78
Deflourinated Phosphate	0.32	0.36	0.35	0.32	0.36	0.35
Sodium Chloride	0.41	0.40	0.41	0.41	0.40	0.41
DL-Met	0.28	0.27	0.25	0.28	0.27	0.25
L-Lys·HCl	0.15	0.19	0.14	0.15	0.19	0.14
L-Thr	0.12	0.13	0.10	0.12	0.13	0.10
Vitamin Premix[1]	0.25	0.25	0.25	0.25	0.25	0.25
Mineral Premix[2]	0.25	0.25	0.25	0.25	0.25	0.25
Phytase[3]	0.02	0.02	0.02	0.02	0.02	0.02
Salinomycin[4]	0.05	0.05	0.05	0.05	0.05	0.05
Calculated Analysis						
AME_n, kcal/kg	3,115	3,115	3,115	3,090	3,090	3,090
CP, %	20.47	19.55	20.69	20.47	19.55	20.69
digestible Lys, %	1.07	1.07	1.07	1.07	1.07	1.07
digestible TSAA, %	0.80	0.80	0.80	0.80	0.80	0.80
digestible Thr, %	0.72	0.72	0.72	0.72	0.72	0.72
digestible Ile, %	0.73	0.72	0.73	0.73	0.72	0.73
digestible Val, %	0.82	0.82	0.82	0.82	0.82	0.82
digestible Trp, %	0.19	0.20	0.20	0.20	0.20	0.20
digestible Arg, %	1.22	1.24	1.30	1.22	1.24	1.30
Ca, %	0.80	0.80	0.80	0.80	0.80	0.80
Non-phytate P, %	0.38	0.38	0.38	0.38	0.38	0.38
Na, %	0.21	0.21	0.21	0.21	0.21	0.21

[1]Vitamin premix include per kg of diet: Vitamin A (Vitamin A acetate), 8,000 IU; Vitamin D (cholecalciferol), 2,000 IU; Vitamin E (DL-alpha tocopherol acetate), 8 IU; menadione (menadione sodium bisulfate complex), 2 mg; Vitamin B12 (cyanocobalamin), 0.02 mg; folacin (folic acid), 0.5 mg: D-pantothenic acid (calcium pantothenate) 15 mg; riboflavin (riboflavin), 5.4 mg; niacin (niacinamide), 45 mg; thiamin (thiamin mononitrate), 1 mg; D-biotin (biotin), 0.05 mg; and pyridoxine (pyridoxine hydrochloride), 2.2 mg; choline (choline chloride), 500 mg.

[2]Mineral premix include per kg of diet: Mn (manganous oxide), 65 mg; Zn (zinc oxide), 55 mg; Fe (iron sulfate monohydrate), 55 mg; Cu (copper sulfate pentahydrate), 6 mg; I (calcium iodate), 1 mg; Se (sodium selenite), 0.3 mg.

[3]Quantum phytase from ABVista, Marlborough, Wiltshire, UK.

[4]BioCox 60 provided 60 g/907 kg of salinomycin (Alpharma, Fort Lee, NJ).

Table 4.6 Ingredient and calculated composition of diets formulated with moderate or reduced AME_n concentrations and either control soybean meal (CSBM), low-oligosaccharide soybean meal (LOSBM), or ultra-low oligosaccharide soybean meal (ULSBM) fed to Ross × Ross 708 male broilers from 29 to 42 d of age (experiment 6)

	Moderate AME_n			Reduced AME_n		
Ingredient, % "as-fed"	CSBM	LOSBM	ULSBM	CSBM	LOSBM	ULSBM
Ground corn	70.05	74.36	73.88	70.61	74.92	74.42
Soybean Meal	20.95	17.86	17.86	20.88	17.78	17.81
Poultry by-product meal	4.00	4.00	4.00	4.00	4.00	4.00
Poultry oil	2.67	1.47	1.93	2.18	0.98	1.44
Limestone	0.75	0.77	0.77	0.75	0.77	0.77
Deflourinated Phosphate	0.06	0.08	0.08	0.06	0.08	0.08
Sodium Chloride	0.44	0.44	0.44	0.44	0.44	0.44
DL-Met	0.23	0.21	0.21	0.23	0.21	0.21
L-Lys·HCl	0.17	0.15	0.17	0.17	0.16	0.17
L-Thr	0.11	0.09	0.09	0.11	0.09	0.09
Vitamin Premix[1]	0.25	0.25	0.25	0.25	0.25	0.25
Mineral Premix[2]	0.25	0.25	0.25	0.25	0.25	0.25
Phytase[3]	0.02	0.02	0.02	0.02	0.02	0.02
Salinomycin[4]	0.05	0.05	0.05	0.05	0.05	0.05
Calculated Analysis						
AME_n, kcal/kg	3,160	3,160	3,160	3,135	3,135	3,135
CP, %	18.17	18.00	18.32	18.17	18.00	18.32
digestible Lys, %	0.95	0.95	0.95	0.95	0.95	0.95
digestible TSAA, %	0.71	0.71	0.71	0.71	0.71	0.71
digestible Thr, %	0.64	0.64	0.64	0.64	0.64	0.64
digestible Ile, %	0.64	0.66	0.64	0.64	0.66	0.64
digestible Val, %	0.73	0.76	0.73	0.73	0.76	0.73
digestible Trp, %	0.17	0.18	0.17	0.17	0.18	0.17
digestible Arg, %	1.06	1.12	1.12	1.06	1.12	1.12
Ca, %	0.69	0.69	0.69	0.69	0.69	0.69
Non-phytate P, %	0.33	0.33	0.33	0.33	0.33	0.33
Na, %	0.21	0.21	0.21	0.21	0.21	0.21

[1]Vitamin premix included per kg of diet: Vitamin A (Vitamin A acetate), 8,000 IU; Vitamin D (cholecalciferol), 2,000 IU; Vitamin E (DL-alpha tocopherol acetate), 8 IU; menadione (menadione sodium bisulfate complex), 2 mg; Vitamin B12 (cyanocobalamin), 0.02 mg; folacin (folic acid), 0.5 mg: D-pantothenic acid (calcium pantothenate) 15 mg; riboflavin (riboflavin), 5.4 mg; niacin (niacinamide), 45 mg; thiamin (thiamin mononitrate), 1 mg; D-biotin (biotin), 0.05 mg; and pyridoxine (pyridoxine hydrochloride), 2.2 mg; choline (choline chloride), 500 mg.

[2]Mineral premix include per kg of diet: Mn (manganous oxide), 65 mg; Zn (zinc oxide), 55 mg; Fe (iron sulfate monohydrate), 55 mg; Cu (copper sulfate pentahydrate), 6 mg; I (calcium iodate), 1 mg; Se (sodium selenite), 0.3 mg.

[3]Quantum phytase from ABVista, Marlborough, Wiltshire, UK.

[4]BioCox 60 provided 60 g/907 kg of salinomycin (Alpharma, Fort Lee, NJ).

Table 4.7 Growth performance of Ross × Ross 708 male broilers fed control soybean meal (CSBM) or low oligosaccharide soybean meal (LOSBM) diets from 1 to 40 d of age[1] (experiment 5)

Item	BW Gain (kg)	Feed Intake (kg)	FCR[2] (kg:kg)	Mortality (%)
1 to 14 d of age				
CSBM	0.330	0.417	1.263	0.0
LOSBM	0.341	0.418	1.226	0.7
SEM	0.003	0.003	0.007	0.3
Analysis of Variance		Probabilities		
SBM	0.020	0.696	<0.001	0.166
1 to 28 d of age				
CSBM	1.448	2.113	1.467	0.7
LOSBM	1.417	2.073	1.467	1.7
SEM	0.018	0.014	0.007	0.6
Analysis of Variance		Probabilities		
SBM	0.199	0.052	0.972	0.275
1 to 40 d of age				
CSBM	2.681	4.280	1.595	0.7
LOSBM	2.624	4.218	1.594	3.3
SEM	0.021	0.035	0.007	1.0
Analysis of Variance		Probabilities		
SBM	0.071	0.213	0.973	0.079

[1]Vaules are least-square means of 12 replicate pens with 25 broilers per pen at 1 d of age.

[2]FCR = Feed conversion ratio was a ratio of feed intake to BW gain.

Table 4.8 Growth performance of Ross × Ross 708 male broilers fed control soybean meal (CSBM), low oligosaccharide soybean meal (LOSBM), or ultra-low oligosaccharide soybean meal (ULSBM) diets with moderate or reduced levels of AME_n during a 42 d production period (experiment 6)[1,2]

Item	BW Gain (kg)	Feed Intake (kg)	FCR[3] (kg:kg)	Mortality (%)
1 to 14 d of age				
CSBM	0.351	0.410	1.166	0.4
LOSBM	0.354	0.411	1.162	0.2
ULSBM	0.357	0.413	1.158	0.4
SEM	0.003	0.003	0.004	0.3
Moderate AME_n	0.354	0.412	1.165	0.5
Reduced AME_n	0.354	0.411	1.159	0.1
SEM	0.002	0.002	0.003	0.2
Analysis of Variance		Probabilities		
SBM	0.126	0.742	0.143	0.810
AME_n	0.534	0.639	0.230	0.175
1 to 28 d of age				
CSBM	1.522	2.052	1.353[a]	0.6
LOSBM	1.505	2.057	1.366[a]	0.2
ULSBM	1.551	2.035	1.317[b]	0.1
SEM	0.021	0.028	0.007	0.3
Moderate AME_n	1.513	2.040	1.349	0.5
Reduced AME_n	1.538	2.057	1.342	0.0
SEM	0.017	0.024	0.007	0.2
Analysis of Variance		Probabilities		
SBM	0.474	0.826	<0.001	0.435
AME_n	0.429	0.593	0.194	0.118
1 to 42 d of age				
CSBM	3.008	4.755	1.581[a]	3.5
LOSBM	2.984	4.687	1.571[a]	2.1
ULSBM	3.036	4.692	1.544[b]	0.8
SEM	0.021	0.036	0.005	0.8
Moderate AME_n	2.996	4.657	1.563	2.8
Reduced AME_n	3.023	4.735	1.567	1.5
SEM	0.019	0.045	0.005	0.6
Analysis of Variance		Probabilities		
SBM	0.096	0.127	<0.001	0.054
AME_n	0.184	0.114	0.425	0.140

[1]Vaules are least-square means of 10 replicate pens with 25 broilers per pen from 1 to 42 d of age.
[2]Apparent ME_n concentrations reduced by 25 kcal/kg from moderate concentration. (Moderate: 3,025, 3,115, and 3,160 kcal of AME_n/kg for starter, grower and finisher, respectively).
[3]FCR = Feed conversion ratio was a ratio of feed intake to BW gain.
[ab]Means within a column for a given measurement not sharing a common superscript differ ($P \leq 0.05$).

Table 4.9 Processing characteristics of Ross × Ross 708 broilers fed diets containing control (CSBM) or low oligosaccharide soybean meal (LOSBM) at 40 d of age[1] (experiment 5)

Item	Live Weight (kg)	Carcass Weight (kg)	Breast Weight[2] (kg)	Carcass Yield[3] (%)	Breast Yield[2,3] (%)	Abdominal Fat Percentage[3] (%)
CSBM	2.782	1.960	0.641	70.5	23.0	1.54
LOSBM	2.748	1.951	0.623	71.0	22.7	1.86
SEM	0.017	0.015	0.009	0.4	0.2	0.05
Analysis of Variance	Probabilities					
SBM	0.170	0.669	0.118	0.322	0.259	<0.001

[1]Vaules are least-square means of 12 replicate pens with 14 broilers per pen at 40 d of age.

[2]Breast is composed of pectoralis major and minor muscles.

[3]Yield or percentage represents grams of tissue per 100 g of tissue per grams live weight.

Table 4.10 Processing characteristics of Ross × Ross 708 broilers fed control (CSBM), low oligosaccharide (LOSBM), or ultra-low oligosaccharide (ULSBM) soybean meal based diets with moderate or reduced AME_n values at 42 d of age[1] (experiment 6)

SBM	AME_n [2]	Live Weight (kg)	Carcass Weight (kg)	Breast Weight[3] (kg)	Carcass Yield[4] (%)	Breast Yield[3,4] (%)	Abdominal Fat Percentage[4] (%)
CSBM		3.134	2.248	0.725	71.7[b]	23.1[b]	1.50[b]
LOSBM		3.119	2.245	0.732	72.0[ab]	23.5[a]	1.60[a]
ULSBM		3.145	2.273	0.739	72.3[a]	23.5[a]	1.58[ab]
SEM		0.022	0.017	0.007	0.1	0.1	0.03
	Moderate	3.128	2.250	0.729	71.9	23.3	1.57
	Reduced	3.137	2.260	0.735	72.1	23.4	1.56
	SEM	0.019	0.015	0.006	0.1	0.1	0.02
Analysis of Variance		Probabilities					
SBM		0.623	0.288	0.256	0.010	0.021	0.027
Energy		0.690	0.522	0.362	0.395	0.251	0.789

[1]Vaules are least-square means of 12 replicate pens with 14 broilers per pen at 40 d of age.

[2]AME_n was reduced by 25 kcal/kg from moderate concentrations (Moderate: 3,025, 3,115, and 3,160 kcal/kg, respectively, for starter, grower, and finisher phases).

[3]Breast is composed of pectoralis major and minor muscles.

[4]Yield or percentage represents grams of tissue per 100 grams of live weight.

[ab]Means within a column for a given measurement not sharing a common superscript differ ($P \leq 0.05$).

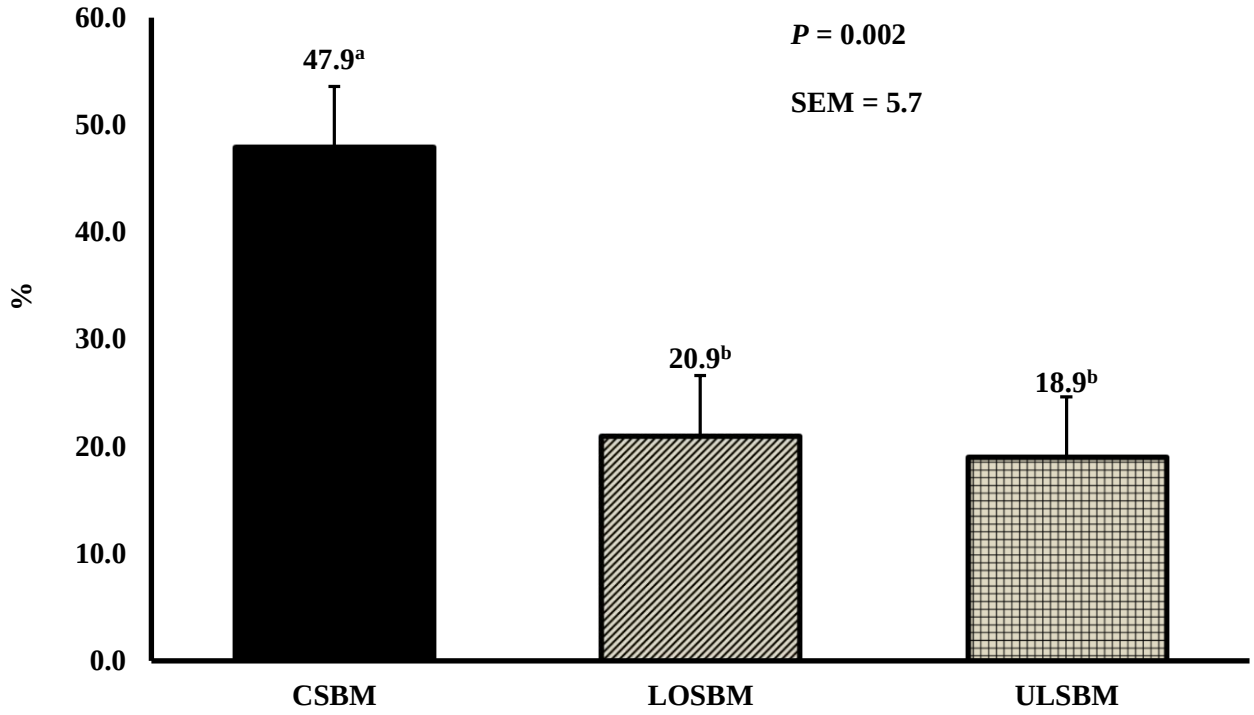

Figure 4.1 Incidence of pododermatitis in Ross × Ross male broilers fed diets containing control SBM (CSBM), low oligosaccharide SBM (LOSBM), or ultra-low oligosaccharide SBM (ULSBM) at 42 d of age (experiment 6). Birds were evaluated for pododermatitis by assigning a score of 0, 1, or 2 based on the severity of footpad lesions via the method describe by Nagaraj et al. (2007). Values represent least-square means of 20 replications per treatment, with each pen having 25 birds at 1 d of age. Means not sharing a common superscript differ ($P \leq 0.05$).

V. CONCLUSIONS

Soybean meal is an excellent source of dietary AA for poultry, but its energy content is not efficiently utilized due to the poorly digestible nature of its carbohydrate fraction. Over the past decade, the prices of energy-providing ingredients have increased dramatically. Because feed costs represent over 70% of live production cost for broilers, strategies should be developed to maximize energy utilization of the primary ingredients in order to minimize feed costs. Soybeans have been developed with reduced raffinose and stachyose concentrations through genetic selection. The research presented herein evaluated nutrient digestibility, growth performance, and meat yield responses of broilers fed diets formulated with either LOSBM, ULSBM, or CSBM.

The first 4 experiments were conducted to determine the nutrient digestibility of a LOSBM and ULSBM compared with a CSBM. It was concluded that LOSBM had higher AME_n compared with CSBM and ULSBM. This finding was attributed to nutrient composition changes due to genetic selection. Low oligosaccharide SBM had over a 70% reduction in GAL content, lower concentrations of ADF, NDF, and cellulose, and higher concentrations of sucrose compared with CSBM. Furthermore, LOSBM and ULSBM were determined to have greater concentrations of digestible AA compared with CSBM.

In experiments 5 and 6, growth performance and carcass yields of broilers fed diets formulated with CSBM, LOSBM, or ULSBM were evaluated during a 6 wk production period. In experiment 5, cumulative growth and carcass characteristics were similar for broilers fed diets formulated with either LOSBM or CSBM. Experiment 6 was expanded to evaluate ULSBM in conjunction with CSBM and LOSBM. Additionally, diets were formulated with moderate or reduced concentrations of AME_n to determine whether birds fed diets containing LOSBM or ULSBM with reduced AME_n might accentuate growth and meat yield responses. However, main

effects of SBM type and AME_n concentration did not negatively impact growth rate, carcass yields, or physiological variables. Broilers fed diets containing ULSBM had more efficient growth from 1 to 28 and 1 to 42 d of age than birds fed diets formulated with the 2 other SBM. Due to the enhanced nutrient profile of LOSBM and ULSBM, diets were formulated with 28 to 71% less fat compared with CSBM-based diets. Moreover, broilers that consumed ULSBM- and LOSBM-based diets had less incidence of PD compared with broilers fed CSBM-based diets. Research is necessary to further evaluate the effect of diets containing LOSBM or ULSBM on incidences of PD.

Overall, these findings provide evidence that nutrient utilization of LOSBM and ULSBM is greater than CSBM when fed to poultry. Due to higher digestible AA and AME_n concentrations, less supplemental fat can be used in diets formulated with LOSBM or ULSBM, which can translate to a reduction in dietary costs.