# DIETARY EVALUATION OF LOW-OLIGOSACCHARIDE SOYBEAN MEAL IN PIGS

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**ABSTRACT**

To evaluate the potential benefit of low oligosaccharide soybean meal (LOSBM) in the diets of early-weaned pigs, three experiments were performed by replacing conventional soybean meal (cSBM) with LOSBM. Low oligosaccharide soybean meal has a higher CP content than SBM. The interaction between LOSBM and the use of fishmeal and spray dried porcine plasma (FM/SDPP) was also evaluated during the nursery phase of the study.

The objective of study 1 was to evaluate the effect of LOSBM on growth performance, viscosity of intestinal content, intestinal morphology, organ weights and blood urea nitrogen (BUN) in early-weaned pigs during 14 d post weaning. Four phase 1 diets used were corn-SBM or corn-LOSBM with or without supplementation of FM/SDPP in a 2 × 2 factorial arrangement. There was no interaction between FM/SDPP and the sources of soybean meal for the parameters studied. Treatments had no effect on growth performance, organ weight and intestinal length. No effect of treatment was observed for ileal crypt depth, jejunal crypt depth and ileal villi height. However, jejunal villi height was greater ($P = 0.01$) in pigs with cSBM diet. Levels of BUN were higher ($P = 0.01$) in pigs fed LOSBM diet and replacing cSBM with LOSBM reduced ($P = 0.01$) the viscosity of intestinal content.

The objective of study 2 was to determine the apparent total tract digestibility (ATTD) and apparent ileal digestibility (AID) of DM, energy, N, ADF and NDF by grower pigs fed corn-LOSBM and corn-SBM diets in two different adaptation periods (5d and 7d). Grower pigs cannulated at ileo-cecal junction were randomly allotted to one of two dietary treatments. Treatment 1 consisted of conventional corn-SBM diet and treatment 2 consisted of corn-LOSBM. Replacing SBM with LOSBM improved percent AID of DM ($P < 0.01$), energy ($P < 0.01$) and ADF ($P < 0.01$). Similarly pigs fed LOSBM had improved ATTD of DM ($P < 0.01$), energy ($P < 0.01$) and ADF ($P < 0.01$).

Study 3 was conducted to determine the effect of replacing cSBM with LOSBM on growth performance and carcass characteristics of pigs from wean to finish. Dietary treatments were fed in 6 phases based on a 2 × 3 factorial arrangement with 2 levels of FM/SDPP (none or phases 1 to 3) and 3 levels of LOSBM inclusion (none, phases 1 to 3, or phases 1 to 6). There was no interaction between FM/SDPP in nursery and LOSBM in any phase for ADG, ADFI or G:F. Replacing SBM with LOSBM resulted in gains in piglets feed efficiency (phase 1 and 2, $P< 0.01$) and piglets fed FM/SDPP had improved ADG ($P < 0.01$) and feed efficiency ($P < 0.05$) only in phase 2. Neither treatment factor affected live weight, carcass weight, fat or loin depth, percent lean, percent yield, grade or value. The early improvements did not affect overall performance from wean to finish, nor did they affect the final carcass characteristics. In summary, replacing cSBM with LOSBM did not affect the performance of the pigs. It seems that young pigs can better tolerate LOSBM as it decreased the viscosity of intestinal content. Improved ileal digestibility of nutrients in LOSBM in compared to cSBM may be beneficial for pigs.

**Key words:** blood-urea nitrogen, digestibility, growth, low-oligosaccharide soybean, pigs, viscosity

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# CHAPTER 1

# INTRODUCTION

Soybean is the most widely used protein source for livestock production, and the most cultivated oilseed plant in the world and second most planted crops in the US (Soy Stats, 2011). In the US, the poultry and swine industries together consume 74% of soybean meal (SBM) as the main protein source (Soy Stats, 2011). The popularity of SBM in the swine industry is mainly due to its high protein content, excellent amino acid (AA) composition and relatively higher AA digestibility that can complement high-energy cereal grains (Cromwell, 1999). Dependable supply and inexpensive price of SBM compared to animal source protein provides tremendous opportunity for swine producers.

Modern swine production is intensively focused on increasing sow productivity by way of decreasing the weaning age of pigs that gives an opportunity for multiple breeding and increase litters per year (Cromwell, 2009). Early weaning causes significant stress to the pigs due to transition of diet as well as other environmental stresses after weaning which can negatively affect the growth rate (Bark et al., 1986). In this regard, highly expensive feedstuff of animal origin such as spray dried plasma protein, fishmeal and whey is being used in the ration of nursery swine to meet its protein requirement. Soybean meal is being used as the only source of protein in the diets of sows and grower pigs. However, the use of SBM is limited in early-weaned pigs because of its antinutritional effects (Liener, 1981).

Use of SBM in the diets of early-weaned pigs has been associated with the incidence of various digestive problems subsequently leading to reduced growth performance and related health problems. Oligosaccharides present in SBM such as raffinose and stachyose cannot be digested by endogenous enzyme present in the intestine (Gitzelmann and Auricchio, 1965). Fermentation of these oligosaccharides in the lower gut results in the production of gastrointestinal gases (Steggerda, 1968) causing flatulence, nausea and discomfort (Rackis, 1975; Fleming, 1981; Krause et al., 1994). It has also been reported that SBM oligosaccharide increases the viscosity of intestinal content and the transit time of digesta (Bedford, 1995) which subsequently leads to poor digestion and absorption of nutrients (Mosenthin et al., 1994; Dilger et al., 2004). Lower digestibility of nutrients has been associated with the presence of oligosaccharide in SBM (Veldman, et al., 1993; Smiricky-Tjardes et al., 2003). Soybean meal produced from low oligosaccharide variety of soybean has been shown to have higher percent metabolizable energy (Parsons et al., 2000) and higher apparent ileal and standard ileal digestibility for most AA (Baker and Stein, 2009).

The use of low oligosaccharide soybean meal in nursery and grower pigs may be useful for reducing the negative effects of oligosaccharide and improvement in the performance of pigs. The use of less expensive LOSBM in comparison to proteins of animal origin, which are currently in use for nursery pigs, can be beneficial for the swine industry.

The main objective of this thesis is to assess the benefit of replacing conventional soybean meal (cSBM) with low oligosaccharide soybean meal (LOSBM) in the diets of pigs. The lower oligosaccharide content of LOSBM increases the crude protein (CP) content. Therefore the interaction between LOSBM and the use of fishmeal and spray dried porcine plasma (FM/SDPP) was also evaluated. To achieve this goal three studies were conducted:

Study1. Effect of replacing conventional soybean meal with low oligosaccharide soybean meal in the diet of early-weaned pigs

The objective of this study was to evaluate the effect of LOSBM on growth performance, viscosity of intestinal content, intestinal morphology, organ weights and blood urea nitrogen (BUN) in early-weaned pigs.

Study2. Ileal digestibility of nutrients in low oligosaccharide soybean meal when fed to grower pigs

The objective of this study was to measure and compare the apparent total tract and apparent ileal digestibility of DM, energy, N, acid detergent fiber (ADF) and neutral detergent fiber (NDF) by grower pigs fed corn-LOSBM and corn-SBM diets.

Study3. Effects of replacing conventional soybean meal with low oligosaccharide soybean meal on growth performance and carcass characteristics of pigs from wean to finish.

The objective of this study was to evaluate the effect of LOSBM on growth performance in terms of average daily gain (ADG), average daily feed intake (ADFI), gain-to-feed ratio (G:F) and carcass characteristics of pigs from wean to finish.

# CHAPTER 2

# LITERATURE REVIEW

## I. Oilseed

Oil is obtained from oilseed plants primarily by processing the seeds. Oilseeds that are commonly used for extracting oil for consumption include soybean, canola, coconut, linseed, lupine, safflower, and sesame. These oilseeds vary in their composition of oil, protein, fiber, vitamins and minerals, both between varieties and within a variety. Soybean is the major oilseed produced in the world followed by rapeseed, cottonseed and peanut as shown in Table 1(Soy Stats, 2011).

**Table 1**. World oilseed production

| Oilseeds | 2009 (MMT) | 2010 (MMT) |
|---|---|---|
| Soybeans | 210.9 | 258.4 |
| Rapeseed | 58.2 | 58.4 |
| Cottonseed | 41.3 | 43.3 |
| Peanut | 34.2 | 34.7 |
| Sunflower seed | 33.1 | 30.7 |
| Palm kernel | 11.7 | 12.7 |
| Copra | 5.9 | 6.0 |
| Total | 395.2 | 444.2 |

MMT= million metric Tons (Soy Stats, 2010; 2011)

Different processes like solvent extraction, expeller extraction and hydraulic extraction can be used to extract oil from these seeds. The most common process in modern oil production is solvent extraction. However, the use of extruder-expeller processing of soybean to produce soybean meal (SBM) is growing with an increase in the production of biodiesel fuel (Karr-Lilienthal et al., 2006). Extruder-expeller processing results in SBM with higher (5%) oil content than solvent extracted SBM that contains a lower (1%) oil content (Woodworth et al., 2001). When the oil extraction is completed, a high protein product is obtained beside the primary product oil, which is commonly known as meal. The schematic diagram for the process involved in solvent extraction of oil and soybean meal processing is shown in Figure 1. These meals are the major source of protein for the animal industry. Besides CP content, the quality of meal for animal feed is assessed by the availability and digestibility of amino acids, level of fiber, concentration of minerals, vitamins and antinutrional factors that can affect the performance of the animal (Ensminger et al., 1990).

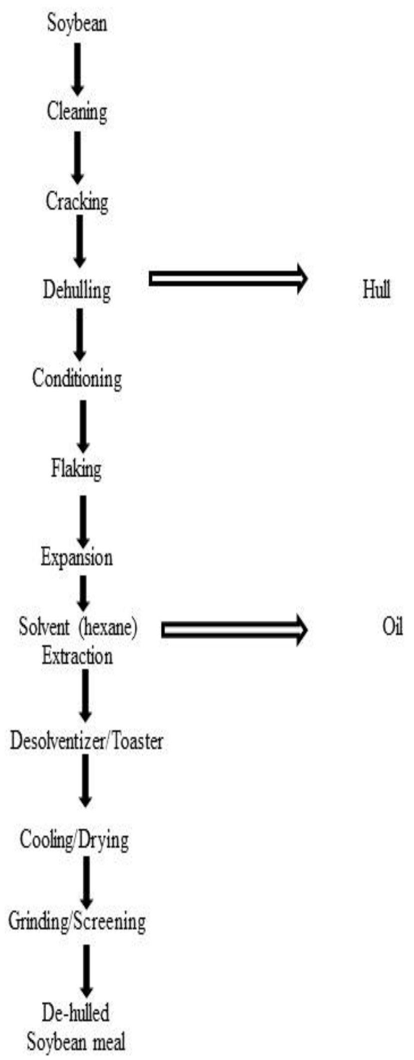


**Fig1**. Process involved in solvent extraction of oil and soybean meal processing (www.soymeal.org, 2011)

## II. Soybean

Soybean is an oilseed crop that falls in the family *Leguminosae,* also known as *Glycine max*. Soybean has been a major nutrition source in East Asia from ancient times (Fukushima, 2001). Soybean is the most cultivated oilseed plant in the world and the second most planted crop in the United States which accounts for 90% of oilseeds produced in United States (Soy Stats, 2011). The United States soybean accounts for 35% of total soybean production in the world (Table 2). Soybean production is concentrated in upper Midwest region, which contributes 80% of total production in US (Soy Stats, 2011; Table 3).

**Table 2**. World Soybean Production

| **Major Producers** | **2010 (MMT)** | | **2009 (MMT)** | | **2008 (MMT)** | |
|---|---|---|---|---|---|---|
| | Production | Export | Production | Export | Production | Export |
| United States | 90.6 | 43.3 | 80.7 | 34.9 | 72.9 | 31.6 |
| Brazil | 70.0 | 32.5 | 57.0 | 30.0 | 61.0 | 25.4 |
| Argentina | 49.5 | 11.0 | 32 | 5.6 | 46.2 | 13.8 |
| China | 15.2 | - | 15.5 | - | 14.0 | - |
| India | 9.6 | - | 9.1 | - | 9.3 | - |
| Canada | 4.3 | 2.8 | 3.9 | 2.0 | 2.7 | 1.8 |
| Others | 11.6 | 3.0 | 9.3 | 1.8 | 8.0 | 1.8 |
| Total | 258.4 | 98.3 | 210.9 | 76.7 | 220.9 | 79.5 |

MMT= Million Metric Tons (Soy Stats, 2009; 2010; 2011)

**Table 3**. Major Soybean Producer States in the United States

| Major Producer States | 2010 (MMT) | 2009 (MMT) | 2008 (MMT) |
|---|---|---|---|
| Iowa | 13.51 | 13.23 | 12.11 |
| Illinois | 12.68 | 11.71 | 11.64 |
| Minnesota | 8.95 | 7.75 | 7.19 |
| Indiana | 7.04 | 7.26 | 6.65 |
| Nebraska | 7.29 | 7.06 | 6.15 |
| Missouri | 5.73 | 6.28 | 5.2 |

MMT= Million Metric Tons (Soy Stats, 2009; 2010; 2011)

**1. Nutrient Composition of Soybean**

Nutritional composition of soybean varies depending upon the genotype, environmental condition, geographical location, harvesting condition and processing (Grieshop et al., 2003; Karr-Lilienthal et al., 2004; 2005). Soybean contains protein, oil, carbohydrates, oligosaccharides, simple sugars and minerals. On average, and at 13% moisture basis, soybean contains approximately 35.35% protein, 19% oil, 4.4 % crude fiber and 4.9-9.5% total sugar (Hammond, et. al., 1993; USDA, 2011).

***Lipids***

Triglycerides constitute 96 % of crude oil from soybean which contains approximately 51% linoleic (C18:2), 25% oleic (C18:1) 11% palmitic (C16) 8% linoleic (C18:3) 4% stearic (C18) and some other minor fatty acids (Synder, 1993).

***Amino acids***

Mature soybean seed before processing contains approximately 3.3%

leucine, 3.1% arginine, 2.7% lysine, 2.1% phenylalanine, 2% valine, 1.9% isoleucine, 1.7% threonine, 1.5% tyrosine, 1% histidine, 0.6% tryptophan, 0.55% methionine and others (USDA, 2011).

***Carbohydrate***

The total sugar concentration of soybean is approximately 14% of DM of which 50% is sucrose, 30% stachyose and 7% raffinose. Total non-structural carbohydrates ranges from 12 to 16% of DM (Grieshop et al., 2003). Starch is the major storage polysaccharides in soybean, which consist of amylopectin and amylose. Free sugars like galactose, glucose, and fructose were found in soybean samples but were destroyed when the soybean was processed for soybean meal (Grieshop et al., 2003).

**2. Anti-nutritional factors in soybean**

Soybean contains many antinutritional factors that can interfere with the normal physiological process of digestion and assimilation. These factors can ultimately affect pig performance. Appropriate processing of soybeans to soybean meal is of utmost importance to achieve the full nutritional potential of soybean meal. Anti-nutritional factors that are of significant importance from the swine nutrition point of view can be categorized into heat labile and heat stable. Trypsin inhibitors, hemagglutinins, goitrogens, phytates and others fall in the heat labile group of anti-nutritional factors whereas saponins, allergens and oligosaccharides such as stachyose and raffinose are heat stable components of soybean (Liener, 1981).

Trypsin inhibitors, a type of protease inhibitor, were among the first anti-nutritional compounds in soybean that have been studied extensively. Protease inhibitors reduces proteolysis by inhibiting digestive enzymes such as trypsin and chymotrypsin (Rackis, 1974), thereby decreasing protein digestibility, feed intake and growth in pigs fed raw soybeans (Yen et al., 1977). However, heat treatment effectively inactivates two types of trypsin inhibitors (Kunitz and Bowman-Birk) and improves the nutritive value of soybean (Liener, 1981). Soybean varieties with low levels of trypsin inhibitor have been developed. However, heat treatment is suggested to maximize AA digestibility for low Kunitz variety of soybean (Goebel, 2010).

***Hemagglutinins***

Commonly known as lectins, hemagglutinins are proteins that have specific carbohydrate binding-site that gives them the ability to agglutinate cells (Liener, 1981). Decrease in villus height and increase in crypt depth were observed when the intestine of suckling pigs were exposed to a lectin preparation (Radberg et al., 2001). Temporary declines were also observed in enzyme activities of intestinal brush border and macro nutrient absorption upon lectin treatment (Linderoth et al., 2006). Extrusion as well as heat treatment of soybean has been shown to mitigate the negative effects of raw lectin rich beans on gut function and growth rate (Marzo et al., 2011; Liener 1981).

***Goitrogens***

Soybean and its products have been associated with incidences of diet induced goiter in human and animals, which is caused by the inhibition of thyroid hormone synthesis by soy isoflavones, genistein and diadzein (Divi et al., 1997). Iodine deficiency is another main risk factor that has been shown to cause hypothyroidism in rats (Doerge and Sheehan, 2002).

***Phytate***

Phosphorus is mainly stored as phytate in almost all plant seeds including corn and soybean. The bioavailability of this phytate phosphorus is very low for swine and poultry (Peeler, 1972). The phytate can chelate metal ions of calcium, magnesium, zinc, copper and iron and reduces their bioavailability in the gut (Liener, 1981). Davies and Olpin (1979) experimented with diets based on soybean and egg albumin with similar zinc concentration and found that soybean based diet lowered the growth rate and plasma zinc concentration in rats, unless treated with exogenous supplementation of zinc. Utilization of phytate phosphorus was enhanced by supplementing microbial derived phytase in corn-soybean based diet for growing-finishing pigs (Cromwell, 1993b).

***Allergens***

Beta-Conglycinin is a 7S fraction, storage protein in soybean that contains 3 subunits (Synder, 1993). All 3 subunits of ß-Conglycinin are responsible for allergenicity (Krishnan et al., 2009). Glycinin and ß-Conglycinin are the immunological active compounds in soybean that acts as dietary antigen causing delayed hypersensitivity reaction in piglet’s intestine, which can modify intestinal morphology (Stokes et al., 1987; Li et al., 1990; Freisen et al., 1993; Dreau et al., 1994; Pluske et al., 1997). ß-Conglycinin can cause intestinal damage by decreasing cell proliferation, damaging cytoskeleton, and subsequently causing apoptosis of the epithelial cell in the intestinal lining of the piglets (Chen et al., 2011). Fortunately pigs seem to adapt to soy diets over time resulting in less severe reaction as they get older (Stokes et al., 1987; Li et al., 1990).

***Raffinose saccharides***

Raffinose saccharides (Fig. 2) constitute approximately 4 to 6 % of DM in soybean seed; raffinose is approximately 1%, stachyose 4% and verbascose is found in negligible amount (Karr-Lilienthal et al., 2005). These raffinose saccharides contain α-D galactose which cannot be digested by endogenous enzymes (Kuriyama and Mendel, 1917). D-galactose containing oligosaccharides found commonly in legume seeds are shown in figure 2. Intestinal mucosa of non-ruminant animals lack α-galactosidase activity for stachyose, raffinose or melibiose which can be the cause of fermentation and consequently diarrhea (Gitzelmann and Auricchio, 1965).

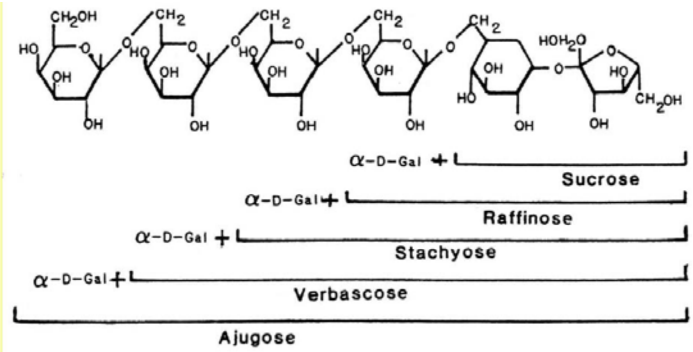


Fig 2. D-galactose containing oligosaccharides (Choct et al., 2010)

These oligosaccharides enter the lower gut where they interact with the microbes and produce gastrointestinal gases (Steggerda, 1968) such as carbon dioxide, methane and hydrogen. These gases can lower the pH and causes flatulence, nausea and discomfort in human and animals (Rackis, 1975, Fleming 1981, Krause et al., 1994). Differences in the number and types of bacteria responsible for anaerobic breakdown of these oligosaccharides in the upper and lower gut of animals might be responsible for individual responses of gas production (Steggerda, 1968). Soy oligosaccharides and other soluble component of soy carbohydrate are at least partially responsible for the anti-nutritional effect of soybean in pigs and poultry (Choct et al. (2010). It is believed that oligosaccharides increase the viscosity in the small intestine, transit time of digesta (Bedford, 1995), which leads to poor digestion and absorption (Mosenthin et al., 1994; Dilger et al., 2004).

Oligosaccharides cannot be eliminated by traditional meal processing (Leske et al., 1993; Grieshop et al., 2003) and are therefore present in the SBM. Efficient use of carbohydrates present in the SBM is vital for achieving better efficiency in feed to gain ratio and reduce the feed cost of the ration (Karr-lilienthal et al., 2005).

**3. Importance of Raffinose and Stachyose in Soybean**

Sucrose and raffinose saccharides are the major soluble carbohydrates in soybean seed (Kuo et al., 1988). Dornbos and McDonald (1986) observed a shift from the synthesis of protein and oil to the production of soluble carbohydrates in the later stage of seed development in maturing soybean seeds. The content of galacto-oligosaccharides in soybean seed increases with the degree of maturity until fully matured (Espinosa-Martos and Ruperez, 2006). Accumulation of these oligosaccharides, specifically stachyose and desiccation tolerance of seed occurs concurrently during soybean seed maturation (Saravitz et al., 1987; Obendorf et al, 1998). This may suggest that stachyose might have a role in desiccation tolerance of seed. Soybean contains α galactosidase that can hydrolyze galactose of raffinose sugars during the germination process that correlates with the loss of desiccation tolerance (Kennedy et al., 1985). Raffinose sugars present in the cotyledons is first broken into sucrose and transported to the embryonic axes for further metabolism (Kuo et al., 1988), and is stimulated by the elimination of sucrose in the seeds (Kennedy et al., 1985). Nishizawa et al. (2008) suggested a protective role of galactinol and raffinose in the seed for scavenging the hydroxyl radical, and preventing the oxidative damage caused by salinity, chilling or drought, in addition to functioning as osmoprotectant and cellular membrane stabilizer. In contrast, Dierking and Bilyeu (2009) found that these galactosyl oligosaccharides such as raffinose and stachyose did not affect the soybean seed germination. This gives an important breakthrough for the incorporation of these traits (low oligosaccharide) into the breeding system without compromising other agronomic characteristics of soybean seeds.

**III. Soybean meal**

Soybean meal is the major source of protein meal consumed that accounts for 69% of all protein meal sources in the world (Soy Stats, 2011). Soybean meal production and export data in U.S is shown in Table 4. In the United States, soybean meal has been a popular feed ingredient for animals because of its dependable supply and inexpensive price compared to animal protein products. In addition, soybean meal is a highly palatable and digestible source of plant protein for poultry and swine diets.  Poultry and swine industry together consume 74% of soybean meal in the United States followed by beef (12%) and dairy (8%) industries (Soy stats, 2011). Chemical composition of common oilseed meal used in livestock production is shown in Table 5. In compare to other common oilseed meal, the energy and protein content is higher in soybean meal.

**Table 4**. The soybean meal production/export in United States by years

| **Year** | **Production (MMT)** | **Export (MMT)** |
|---|---|---|
| 2005 | 37.4 | 5.4 |
| 2006 | 39.0 | 7.9 |
| 2007 | 38.4 | 7.9 |
| 2008 | 35.5 | 8.4 |
| 2009 | 37.8 | 7.7 |
| 2010 | 35.9 | 8.4 |

MMT= Million Metric Tons (Soy Stats, 2006: 2011)

**Table 5**. Chemical composition of oilseed meal (as fed basis) solvent extracted without hulls

| Components | Soybean | Rapeseed | Cottonseed | Peanut | Sunflower | Copra |
|---|---|---|---|---|---|---|
| Dry Matter, % | 90 | 90 | 90 | 92 | 93 | 90 |
| DE, kcal/kg | 3685 | 2885 | 2575 | 3415 | 2840 | 3010 |
| ME, kcal/kg | 3380 | 2640 | 2315 | 3245 | 2735 | 2565 |
| CP, % | 47.50 | 35.60 | 41.40 | 49.10 | 42.2 | 21.90 |
| CF, % | 3.00 | 3.50 | 1.50 | 1.20 | 2.90 | 3.00 |
| NDF, % | 8.90 | 21.20 | 28.40 | 16.20 | 27.80 | 51.30 |
| ADF, % | 5.40 | 17.20 | 19.40 | 12.20 | 18.40 | 25.50 |
| Ca, % | 0.34 | 0.63 | 0.19 | 0.22 | 0.37 | 0.16 |
| P, % | 0.69 | 1.01 | 1.06 | 0.65 | 1.01 | 0.58 |

(NRC, 1998)

**IV. Use of Soybean meal in swine diet**

Soybean meal is considered the best source of supplemental protein for livestock production. Extensive use of corn-SBM diet with the supplementation of commercially available vitamins and minerals became popular after the discovery of vitamin B12 because it is the only essential nutrient unavailable in plant source (Cromwell, 2009). High concentration of protein and excellent blend of AA in SBM compliments high-energy cereal grains, making SBM the perfect supplement to the cereal diets for pigs and poultry (Cromwell, 1999). Easy availability, simplicity in diet formulation, manageable anti-nutritional factors and excellent blend of almost all required amino acid for pigs, soybean meal is often referred as a "gold standard" in swine diets (Cromwell, 1999).

**1. Effect of SBM oligosaccharides on early-weaned pigs**

Swine production in recent years has been intensively focused on increasing sow productivity by decreasing the weaning age of pigs. Most swine producers in the United States have been weaning pigs at the age of 2 to 3 wks that increases the number of litters per year (Cromwell, 2009). Soybean meal is being used as the primary protein supplement in the diets of sows and grower pigs. However, the use of SBM is limited in early-weaned pigs because of its anti-nutritional effect (Liener, 1981). The idea of early weaning became successful only after the introduction of feed ingredients like spray dried plasma protein, milk products and other animal protein such as fishmeal and blood meal (Cromwell, 2009).

The need for superior quality feed ingredient of animal origin for early-weaned pigs is to obtain a smooth transition from the sow's milk to the corn-soybean based diets. Weaning causes significant stress to the pigs not only due to the transition of diet but also due to the change in the pig's environment which can reduce feed consumption and consequent reduction in growth rate (Bark et al., 1986). van Beers-Schreurs et al. (1998) concluded that the level of feeding, composition of diet and separation of pigs from sows to a new environment could affect the post-weaning villus atrophy of small intestine. Pigs on SBM diet had shorter villi and slight increase in crypt depth than pigs on diet with milk protein on d 28 of age and this difference was negligible at the end of 8 wks (Li et al., 1990). Reduced weight gain from 3 to 4wk was observed together with abnormal villus morphology and increased serum titers specific to soybean protein when pigs were fed diet with SBM as a result of transient hypersensitivity (Li et al., 1990; Stokes et al., 1987; Friesen et al., 1993). This hypersensitivity response observed in early weaned piglets fed SBM diets might be responsible for poor post weaning performance (Li et al., 1990). Reduced daily DM intake and body weight gain were observed when young pigs were fed diets rich in raffinose and stachyose (Houdjik et al., 1999). Weaning age, feed intake and feed composition influences the intestinal health in early-weaned pigs (Wijtten et al., 2011). Non-digestible oligosaccharide elevates the viscosity in the small intestine, which affects the rate of digestion, transit time of digesta, and increases gut motility (Bedford, 1995). Increased intestinal viscosity exhibits negative effect on enzyme diffusion, digestion and absorption of nutrients in piglets (Mosenthin et al., 1994; Dilger et al., 2004). Furthermore Zhang et al (2003) and Zhang et al. (2001) related the incidence of intestinal disorder, malabsorption of nutrients, diarrhea and poor growth performance to the inclusion of SBM in the diets of weanling pigs. Thus, it can be deduced that the post-weaning lag in the early weaned pig is partly due to the introduction of SBM in their diets. Houdjik et al. (1999) suggested that early-weaned pigs would take minimum of 2 wks to adapt to the corn-soybean meal based diet.

**2 Effect of SBM oligosaccharides on digestibility and performance in pigs**

Soybean oligosaccharides, raffinose and stachyose are soluble sugars that can resist digestion by pancreatic and brush border enzyme (Gdala et al., 1997). Cecum and the first segment of colon is the site for major degradation of raffinose saccharides (Gdala et al., 1997). Apparent ileal digestibility (AID) of raffinose and stachyose ranges from 62 to 91% and 84 to 97%, the lowest for SBM and highest for SBM with galactosidase (Smiricky et al., 2002). No improvement in AID was observed when the mixture of enzyme was supplemented in SBM diet for 8 to 10 wk-old piglets, but interestingly xylanase supplementation decreased the digestibility of raffinose saccharides (Gdala et al., 1997). Veldman et al. (1993) observed 20% lower ileal digestibility of organic matter (OM), CP and nitrogen free extract when the pig's diet were supplemented with soybean oligosaccharide. Decrease in digestibility with soy oligosaccharides may be because of increase in gut osmolarity, enzyme dilution and substrate concentration (Sauer and Ozimek, 1986). Grower pigs fed diets containing soy solubles and transgalacto-oligosaccharides had lower AID and ATTD for DM, OM and N than pigs fed oligosaccharide free diet (Smiricky-Tjardes et al., 2003).

Baker and Stein (2009) observed higher AID and standard ileal digestibility (SID) values for most AA when grower pigs were fed diets containing SBM produced from low oligosaccharides variety of soybean compared to pigs fed diet containing conventional SBM. Similarly, 7 to 9 % higher metabolizable energy (ME) for LOSBM than with SBM was observed when fed to roosters (Parsons et al., 2000). A reduction in gas production was observed with soy flour from low oligosaccharide variety of soybean compared to soy flour from conventional soybeans in humans (Suarez et al., 1999). Similar results for gas production were observed when substrates with combination of raffinose and stachyose were used (Smircky-Tjardes et al., 2003). Interestingly, in the same study, the fermentation of oligosaccharides in soy solubles with the same concentration of raffinose and stachyose was slower than the pure substrates. This might indicate that oligosaccharides in soybean are not readily available for fermentation as pure substrate. Rate of digesta passage was higher when 2% stachyose was added in pig's diet than for 1% stachyose addition (Zhang et al; 2001). This decrease in transit time may affect the oligosaccharide interaction time with bacteria and affect the fermentation in the lower gut of the pig (Zhang et al., 2003). Decrease in transit time can affect N, energy, electrolyte status, and water metabolism (Wiggins, 1984). Zhang et al. (2003) observed increase in the number of lactobacilli in ileum and bifidobacteria in the cecum and colon with the addition of 1% stachyose. However, when the level of stachyose was increased to 2%, the numbers of these beneficial bacteria were reduced. Similar trend was observed for the level of volatile fatty acid (VFA) and lactic acid in the same experiment.

**3. Effect of lysine and crude protein level on BUN, and carcass characteristics**

Recently, consumer choice for healthy foods has shifted pork production to lean pork with lower fat content. Pork producers are using genetic selection based on lean gain. It is well established that leaner breeds will require more balanced protein and amino acids for maximum gain to their genetic potential. Commercially, available lysine and other amino acids has been the object of choice for some time to meet the requirements in a cost effective way. According to NRC (1998) corn-soybean meal contributes 97.5% of total swine diet in U S. Cereal grains, especially corn, is limiting in tryptophan whereas SBM is limiting in methionine. The first limiting amino acid is lysine followed by tryptophan in corn-SBM based diet for growing pigs (Beeson et al., 1948; Mertz et al., 1949). The order of limiting amino acid in corn-SBM diet for nursery pigs is lysine, tryptophan, threonine, methionine and valine (Mavromichalis et al., 1998). This order of limiting amino acid changes slightly depending on the growth stage of the animals. Valine is important for lactating sows, methionine and tryptophan for young and tryptophan and threonine for growing pigs which can alter the order in the sequence as the percentage of corn and soybean in the diet differs in different growth stages (Cromwell, 2000). An amino acid requirement of gilts for lean gain is higher than barrow (Baker et al., 1967; Cromwell et al., 1993a).

Protein is required not only for supplying essential amino acids but also for providing nitrogen to synthesize other non-essential amino acids (Lehninger et al., 2005). Requirements can be met by feeding excess protein. However, protein in excess can affect pig growth performance, contributes to environmental pollution and increase the cost of production (NRC, 1998). Macleod (1997) found no correlation between total protein intake and protein deposition in muscle but increasing the concentration of lysine increases the protein deposition in muscle. The author suggested that excess AA in the form of unbalanced protein supplied in the diet upsets the kinetics of metabolism as the energy cost of urea formation and excretion in the form of uric acid is higher than the energy required incorporating amino acid in protein (Macleod, 1997). Therefore feeding excess protein, lacking limiting amino acids is non-productive, deleterious to the animal's health and performance, and costly for producers as well the environment.

Performance of pigs in terms of protein and fat deposition in the body is the function of its nutrient intake, primarily protein and energy (Carr et al. 1977; Close et al., 1983). This is why it is important to understand the metabolism of nutrients and the response of the pig body. Liver is a major organ in AA metabolism with high protein turnover to maintain its function, synthesis of plasma protein and detoxification/ metabolism of excess amino acids in the body (Lehninger et al., 2005). Excess AA relative to that required by the body for protein synthesis is metabolized in mammalian liver by transamination and deamination process (Krebs, 1942). During this process the carbon skeleton of AA is used for energy production whereas the ammonia is converted to urea, which contributes to BUN (Lehninger et al., 2005). Reeds et al. (1980) found a close correlation between the daily urinary excretion of urea and ammonia with total AA catabolism in the body. An inverse relationship between the BUN and the biological value of the diet was suggested by Eggum (1970). Time of measurement is important, as the plasma urea nitrogen (PUN) concentration increases 3 to 4 h after feeding before reaching a uniform PUN value (Eggum, 1970). It was suggested that the measurement of plasma urea concentration would give a rapid, efficient and practical approach to evaluate the protein quality and as well to determine the protein and AA acid requirement of pig (Eggum, 1970; Brown and Cline 1974; Coma et al., 1995; Chen et al., 1995). Orok and Bowland (1975) remarked that the method described by these authors is not feasible as the feed intake of individual pigs differs in the practical pig production system. Orok and Bowland (1975) suggested the use of “increase in plasma urea to grams of nitrogen ingested expressed as percentage over the period of 0 to 7h after feeding for evaluating the protein quality in feedstuff”. Cai and Zimmerman (1995) observed lower values for PUN when pigs were allowed water intake 1.5 or 3 times feed intake per day. Kerr et al., (2003) observed lower concentration of serum urea and ammonia nitrogen when barrows were fed 12% CP corn-SBM diet with supplemented AA than barrows fed the same or higher CP corn-SBM diet. However, the response seems to be different based on the magnitude of the CP reduction. Heo et al. (2008) fed a 17% CP diet with supplemental AA and a diet with 24% CP to weanling pigs and observed that the low CP diet decreased PUN and fecal ammonia nitrogen, without affecting the performance of the pigs. Feeding diets with higher CP level increases the PUN (Fonnesbeck and Symons, 1969; Chen et al., 1999). Decreasing the CP level decreases the plasma urea concentration and urinary nitrogen excretion (Browne and Cline, 1974; Newport, 1979) and is correlated with nitrogen intake, absorption and nitrogen excretion (Fonnesbeck and Symons, 1969). Increases in plasma urea concentration due to imbalance AA in diets can be corrected by supplementing the limiting AA, which causes a decrease in the breakdown of other amino acids and instead increases their utilization for protein synthesis. This condition is further explained by Kumta and Harper (1961) in which they found lack of enzyme activities (for example tryptophan pyrrolase) responsible for protein synthesis when the diets were not balanced for AA. Lysine supplementation has been shown to decrease the PUN (Browne and Cline, 1974). Similarly, decrease in PUN was observed as the ratio of lysine and digestible energy (DE) was increased and the decrease peaked at 0.9g lysine/MJ of DE for weaned pigs (Nam and Aherne, 1994). Kerr et al. (1995)

correlated the weight of metabolically active organs such as the liver, kidney and heart with the CP content of the diet, higher the CP in diet heavier are these organs (Chen et al., 1999). This heavier weight of metabolically active organs can be due to the increased level of activity to be performed by these organs when feed intake is high (Koong et al., 1985).

Whang and Easter (2000) demonstrated a positive relationship between the PUN values and muscle gain. Increasing CP in the diet resulted in a decreased lipid proportion and an increase in protein deposition and whole body protein concentration (Newport, 1979; Close et al.; 1983, Chen et al., 1995; Gomez et al., 2002), increase in carcass weight gain, decrease back fat depth and increase longissimus muscle area (Chen et al., 1995; 1999). Corn-SBM diet formulated for lower CP than control diet without supplementing AA resulted in the carcass of high fat deposition, reduction in longissimus muscle area and poor yield grades when compared to diets with high CP. However, longissimus muscle area increased after the supplementation of AA (Kerr et al., 1995). Easter and Baker (1980) and Kerr et al. (1995 and 2003) suggested that the carcass composition can be maintained by a small (2%) reduction in CP with supplemental lysine replacing SBM for growing pigs on corn-SBM diet. An increase in protein deposition, decrease in fat deposition and an improvement in growth were observed when dietary lysine concentration was increased for growing pigs (Batterham et al., 1990). Protein deposition in the body correlates with protein intake and ME (Reeds et al., 1980; Close et al., 1983). However, excessive nitrogen intake can cause decrease in the rate and efficiency of gain, and reduced growth performance (Chen et al., 1999). Improved carcass leanness and feed efficiency was observed when dietary CP concentration was increased (Baker et al., 1967). Digestion in the lower gut is inefficient in terms of utilizing ME, and hence the site of nutrient metabolism is important (Just et al., 1983). Soy oligosaccharides are fermented in the hindgut by bacteria to produce VFA, which can reduce ME. Removing oligosaccharides in SBM has been shown to increase ME (Coon et al., 1990; Parsons et al., 2000). When high protein-SBM was fed to broilers, greater performance was observed in terms of ADG, feed efficiency and nutrient retention. In the same study increasing the lysine: ME ratio further increased ADG, feed efficiency (de Coca-sinova et al., 2010).

From this review it can be deduced that SBM provides better quality of AA blending for pigs than its replacement by supplementing AA. Relatively higher energy content, higher CP and higher amount of lysine and other essential amino acids in LOSBM than conventional SBM may provide a better blend of AA and benefit through efficient N retention and improved carcass characteristic in pigs.

**V. Processing to improve SBM quality**

Heat treatment can denature the proteinaceous antinutritional factors in SBM like trypsin inhibitors and lectins, which improve the nutritive quality of soybean meal (Liener, 1981; van der Poel, 1990). However, duration and temperature of heating, particle size and moisture content is vital in processing for maximum retention of nutrition (van der Poel, 1990). Overheating can decrease the nutritional value of feedstuff by decreasing the amount of available and digestible lysine (Carpenter, 1960) and other important amino acids (Parsons, 1996).

Raffinose saccharides are heat stable and soluble carbohydrate component in legumes (Liener, 1981). Normal meal processing cannot eliminate these saccharides (Leske et al., 1993; Grieshop et al., 2003). Qin et al., (1996) suggested steam toasting of soybean at temperature of 102 ˚C for 40 min., 120 ˚C for 7.5 min. and 134 ˚C for 1.5 min. to reduce the trypsin inhibitor activity, urease activity, lectins and protein dispersibility index. This treatment improved DM and N digestibility in piglets. Reduction in the level of alpha-galactosides content and complete elimination of trypsin inhibitor activity was observed when chickpea was cooked after soaking (Frias et al., 2000).

Many attempts were made to reduce raffinose saccharides by aqueous extraction due to its soluble nature. Ku et al. (1976) boiled soybean in water with the addition of sodium bicarbonate or hydrochloric acid. This treatment reduced the raffinose and stachyose concentration, at the expense of protein because some amount of protein was also dissolved in the solution. In a similar attempt Barampana and Simard (1994) used a combination of soaking, cooking and fermentation that reduced stachyose concentration up to 95% and raffinose concentration up to 97%. Coon et al. (1990) reduced the oligosaccharides in SBM using ethanol extraction process to a level that resulted in 20% higher metabolizable energy for roosters. Ultrafiltration process has been shown to reduce the undesirable oligosaccharide from aqueous extract of soybean (Omosaiye et al., 1978).

Other attempts include the use of carbohydrase enzymes to reduce oligosaccharides contents or to minimize its antinutritional effect, but no improvement in performance was observed when supplemented to nursery diets (Kim et al., 2003). Use of antibiotics and organic acids is capable of inhibiting the flatus activity (Rackis, 1974); but the continued use of antibiotic in the food chain is not promising. Benefits of enzyme supplementation in diets containing SBM for reducing the effect of oligosaccharides are inconsistent (Kim and Baker, 2003).

**VI. Application of biotechnology to improve SBM quality**

Plant biotechnology seems promising as it can modify specific traits (e.g. oligosaccharide content) without affecting other important quality traits. Scientists had suggested that breeding soybean for removal of oligosaccharides holds the possibility (Rackis, 1975; Parsons et al., 2000) or even the final solution for flatulence and other related problems (Clarke and Wiseman, 2000). Genetically modified crop technology is being extensively used to improve soybean meal as protein supplement for livestock. As of 2010, The United States has been using biotech enhanced soybean seed stocks for 93% of total land acreage used for soybean production (Soy Stats, 2011). Argentina and Brazil plant biotech seed stock in 100% and 75% of total land acreage used respectively for soybean production (Soy Stats, 2011). Biotechnologically enhanced soybeans have been developed for agronomic traits like herbicide-tolerance, insect resistance and disease resistance (Coon, 1998). A similar approach for improving the quality traits has resulted in such product as high-oleic soybeans (oil with 80% oleic acid) and high-oil corn, which is suggested to improve stability of the oil in feedstuffs (Coon, 1998). Germplasm related to raffinose saccharides synthesis in soybean seeds was identified and with the technique of mutation breeding a novel variety of soybean containing low amount of oligosaccharides has been developed (Sebastian et al., 2000). Decreasing oligosaccharides would increase other constituent of soybean meal such as protein and carbohydrates increasing its nutritional value and this variety of soybean meal can be fed in lower inclusion level without compromising performance (Baker et al., 2011).

**Table 6**. Comparison of nutritional composition of conventional soybean meal (SBM) and low oligosaccharide soybean meal (LOSBM)

| Criteria | SBM[1] | LOSBM[2] | LOSBM-SBM (% change) |
|---|---|---|---|
| Dry matter, (%) | 88.66 | 88.46 | -0.20 |
| Crude protein, (%) | 46.55 | 53.16 | +6.61 |
| Crude fat, (%) | 1.23 | 1.09 | -0.14 |
| Crude fiber, (%) | 2.61 | 1.83 | -0.78 |
| Ash, (%) | 6.82 | 6.01 | -0.81 |
| Gross energy, (kcal/kg) | 4124.50 | 4187.50 | +63.00 |
| Amino acids, (%) | | | |
| Lysine | 3.08 | 3.35 | +0.27 |
| Methionine | 0.66 | 0.69 | +0.03 |
| Threonine | 1.75 | 1.92 | +0.17 |
| Tryptophan | 0.61 | 0.65 | +0.04 |
| Leucine | 3.71 | 4.16 | +0.45 |
| Isoleucine | 2.27 | 2.49 | +0.22 |
| Valine | 2.39 | 2.60 | +0.21 |
| Raffinose, % | 0.58 | 0.08 | -0.50 |
| Stachyose, % | 3.23 | 0.42 | -2.81 |

[1]SBM= conventional soybean meal
[2] LOSBM= low oligosaccharide soybean meal, Schlillinger Seeds Inc., Des Moines, IA.

The nutritional comparison (Table 6) shows that the oligosaccharides in LOSBM is significantly decreased, however there is also increase in gross energy (GE), concentration of important AA (leucine, isoleucine, lysine and valine) and subsequently CP content.

**VII. Conclusion**

It has been established that conventional soybean meal contributes to weaning related stress in early-weaned pigs. Soybean oligosaccharides, raffinose and stachyose have been associated with the negative effect on digestibility, performance and general health in pigs. Attempts made to reduce raffinose saccharides in SBM have not proven effective. The cost of using expensive feedstuffs of animal origin for weanling pigs is high. Breeding of soybean with low oligosaccharide and higher protein and amino acid content has been successful. The use of LOSBM for early-weaned and grower pigs holds the possibility to mitigate the negative effect of oligosaccharides, improve the performance, nitrogen retention, carcass characteristics and to reduce the cost of feed by replacing expensive feedstuff currently in use.

# CHAPTER 3

## Effect of replacing conventional soybean meal with low oligosaccharide soybean meal in the diets of early weaned pigs

**Summary**

An experiment was conducted to determine the effect of replacing conventional soybean meal (cSBM) with low oligosaccharide soybean meal (LOSBM) on growth performance, blood urea nitrogen (BUN), intestinal morphology and viscosity of intestinal content of early-weaned pigs. The lower oligosaccharide content of LOSBM resulted in a commensurate increase in the crude protein (CP) content of LOSBM. Therefore, a comparative study was performed with fishmeal and spray dried plasma (FM/SDPP). Thirty-two 19-d old pigs (6.9 ± 0.4 kg BW) were individually assigned to a pen and used in randomized complete block design with 8 blocks (wt. group) of four dietary treatments. Four nursery diets were used in 2 × 2 factorial arrangement with factors consisting of cSBM (cSBM vs. LOSBM) and with or without FM/SDPP. Pigs were fed ad libitum through the entire experimental period of 14 d. Pigs were weighed and blood was collected via jugular vena puncture before they were euthanized by overdose of sodium pentobarbital for organs (intestine, pancreas, liver, heart, kidney and spleen) harvest. No interaction of FM/SDPP and the source of soybean meal were observed for the response criteria studied. Average daily gain and average daily feed intake were not affected by treatment diets. However, inclusion of FM/SDPP improved (*P* = 0.03) gain to feed ratio. Treatments had no effect on organ weights and intestinal length. No effect of dietary treatment was observed for ileal crypt depth, jejunal crypt depth, and ileal villi height. However, jejunal villi height was greater (*P* = 0.01) in cSBM diet. Concentration of BUN was higher (*P* = 0.01) in pigs fed LOSBM diet than in pigs fed diets containing SBM. Replacing cSBM with LOSBM reduced (*P* = 0.01) the viscosity of intestinal content.

**Keywords:** blood urea nitrogen, growth, intestinal morphology, low oligosaccharide soybean meal, swine, viscosity

## Introduction

The ability to wean pigs at an early age allowed the swine industry to increase sow productivity. However, weaning causes significant stress to young pigs due to the separation from sows, handling, changes in form of the diet and environment (van Beers-Schreurs et al., 1998). This can lead to feed consumption below the maintenance requirement (Bark et al., 1986) and changes in the gut morphology such as villus atrophy and increased crypt depth (van Beers-Schreurs et al., 1998). Feeding early weaned pigs with diets containing superior quality ingredients that can provide readily available and highly digestible nutrients is most important for a smooth transition from milk diet to grain based diets. For this purpose, expensive feedstuff of animal origin such as fishmeal spray dried plasma protein and whey are used in early-weaned pig diets.

Soybean meal (SBM) is frequently used as the main protein supplement in the diets of sows and grower pigs. However, the use of SBM in early-weaned pigs is limited due to the presence of anti-nutritional factors such as raffinose and stachyose oligosaccharides (Liener, 1981). Inclusion of SBM in the diets of early-weaned pigs has been shown to reduce weight gain, decrease villus height and increase crypt death (Li et al., 1990) leading to transient hypersensitivity and subsequently poor growth performance (Stokes et al.; 1987; Li et al., 1990; Friesen et al., 1993). Non-digestible oligosaccharides such as raffinose and stachyose present in SBM increases the viscosity in the small intestine which affects the rate of digestion, transit time of digesta by increasing the gut motility (Bedford, 1995), digestion and absorption of nutrients when fed to weanling pigs (Mosenthin et al., 1994; Dilger et al., 2004; Zhang et al., 2003).

Soybean varieties with significantly lower concentrations of oligosaccharides have been developed. Soybean meals containing reduced level of oligosaccharides have been used in grower and nursery pigs with varied results in terms of performance (Zhang et al., 2003; Hinson et al., 2009). Replacing SBM with LOSBM showed higher apparent ileal digestibility (AID) and standard ileal digestibility (SID) values for most amino acid (AA) (Baker and Stein, 2009). Higher percent metabolizable energy for roosters (ME) (Coon et al., 1990; Parsons et al., 2000) and reduction in gas production in human observed when oligosaccharide content of SBM was lowered (Suarez et al., 1999). Reducing oligosaccharides increases the crude protein (CP) and lysine content of SBM. Replacing conventional SBM with LOSBM may help to mitigate the negative effect of oligosaccharides and provide better blend of AA with its relatively higher nutritional content and benefit through efficient nitrogen retention and performance of early weaned pigs. With a goal of assessing the benefits of using LOSBM in early-weaned pigs, the objective of this study was to determine the effect of replacing SBM with LOSBM and its interaction with the use of fishmeal and spray dried porcine plasma (FM/SDPP) on (1) growth performance; (2) intestinal morphology and organ weights; (3) blood urea nitrogen (BUN) and (4) viscosity of intestinal contents.

## Materials and Methods

The University of Minnesota Institutional Animal Care and Use Committee approved all experimental protocols.

### *Animal and Housing*

Early weaned pigs [(Landrace × Yorkshire (Topigs, Winnipeg, Canada)) × Duroc (Comparts, Nicollet, MN), (n = 32, 6.9 ± 0.4 kg BW)] were housed in an environmentally controlled nursery facility at The University of Minnesota, Southern Research Outreach Center, Waseca, MN. Pigs were identified by ear tags at weaning and were individually housed in 32 pens equipped with a feeder and a nipple drinker. Pigs were grouped in a randomized complete block design with 8 blocks (wt. group) of 4 treatments. Four nursery diets were formulated to meet or exceed NRC (1998) requirement of nursery pigs (Table 2). Treatment 1 consisted of a conventional corn soy diet, including the use of FM/SDPP. Treatment 2 was based on treatment 1 except that no FM/SDPP was included. Treatments 3 and 4 differed from treatments 1 and 2, respectively, by their replacement of SBM with LOSBM. The experimental period lasted for 14 d and pigs were weighed at d 1 and d14. Average daily gain (ADG), average daily feed intake (ADFI) and gain to feed ratio (G: F) were calculated. All pigs were allowed ad libitum access to feed and water. Diets were fed in meal form and formulated to provide 1.5% total lysine, 0.9% calcium and 0.7% phosphorus.

***Sampling***

Blood samples were collected from each pig on d 14 before they were euthanized by intra-cardiac injection of sodium pentobarbital. After euthanasia, the abdominal cavity was exposed and the organs were harvested. The total length of the small intestine and the organ weights (liver, kidney, heart and pancreas) were recorded. The two ends of the small intestine were located and the intestinal luminal contents were emptied into a sterile plastic container for viscosity measurement. A small portion (approximately 5 cm) of jejunum, and ileum was cut, flushed with phosphate buffer, tied at both ends after filling with buffer solution and placed in a plastic container filled with buffer solution. The sampled portions were sent to the Cancer Center

Histopathology Core (University of Minnesota, MN) for intestinal morphology measurements.

***Analysis***

Diet, SBM and LOSBM samples were analyzed for dry matter (DM), gross energy (GE), CP, crude fat (CF), neutral detergent fiber (NDF), acid detergent fiber (ADF) and ash content. All the analyses were done in duplicate and averaged. Feed samples were dried at 102 ˚C for 4 h in an oven (Thermo Scientific Precision, Thermo Fisher Scientific Inc., Hampton, New Hampshire) to determine DM (AOAC, 2000 method 939.01). The CP in the feed samples was determined using Kjeldahl method (method 976.05, AOAC, 2000; Kjeltec 2300 Analyzer, Foss, Höganäs, Sweden). Gross energy was determined by bomb calorimeter using IKA WERKE c2000 basic bomb calorimeter (IKA Werke GmbH & Co. KG**,** Staufen, Germany). Crude fat was analyzed by ether extract method (AOCS, 2009 method Am 5-04) using an ANKOM XT15 extraction system (ANKOM Technology, Macedon, NY). Samples were analyzed for NDF and ADF using filter bag technique (ANKOM 2000 fiber analyzer, method 12 and 13; ANKOM Technology, Macedon, NY). To determine the total ash content, the samples were weighed before and after ashing in a high temperature muffle furnace at 600 ˚C for 6 h (Isotemp Muffle Furnace, Thermo Fisher Scientific Inc. Hampton, New Hampshire).

Digesta samples were centrifuged in Hermile z300 (Labnet international, Inc., Edison, NJ, USA) at 1,400 *g* for 15 minutes immediately after the collection. The supernatant fluid was used in a Brookfield DV-E viscometer (Brookfield Engineering Laboratories Inc., Middleboro U.S) to determine the viscosity of intestinal content at a shear rate of 12.25 $s^{-1}$ at 37 °C. Viscosity was measured in centipoises (cP) following the procedure of McDonald et al (2001).

***Blood Urea Nitrogen***

Blood urea nitrogen was measured using Stanbio Urea Nitrogen kit (BUN) Liqui-UV^R (Stanbio laboratory, Boerne, Texas) using the method described by Sampson et al. (1980). Thermo scientific Genesys 20 was the spectrophotometer used to read the absorbance. Spectrophotometer was calibrated at 340 nm with distilled water at zero absorbance. Absorbance was recorded in the spectrophotometer after 30 s and at exactly 60 s after first reading. Changes in the absorbance were recorded at these times to calculate the BUN.

Calculation

Serum blood urea nitrogen was calculated by using the equation:

$$Serum\ BUN\ (mg/dL)\ =\ \frac{\Delta A\ Serum}{\Delta A\ standard} \times\ 30$$

where ΔA serum is the change/decrease in the absorbance of the serum sample, ΔA standard is the change/decrease in the absorbance of the standard and30 was the concentration of the standard (mg/dL) used.

***Intestinal morphology***

Ileum and jejunum samples were fixed in 10% neutral buffered formalin. Tissues were processed separately; paraffin-embedded tissue blocks were made and serial sectioned at 5 microns.  The slides were then stained with hematoxylin and eosin. The stained slides were scanned using an Aperio ScanScope CS digital slide scanner (Aperio Technologies, Inc. Vista, CA). The cross-sections of both ileum and jejunum were examined histologically to determine villus height (μm) and crypt depth (μm). Approximately twenty-five linear measurements of both villus height and crypt depth were taken per pig using the Aperio image analysis algorithm framework software (Aperio Technologies, Inc. Vista, CA). These measurements were then averaged for each section respectively.

### *Statistical Analysis*

Data were analyzed as a 2 × 2 factorial arrangement with 2 levels of LOSBM (with or without) and 2 levels of FM/SDPP (with or without) inclusion. Individual animals served as the experimental unit. Statistical analysis was performed using JMP (version 9, SAS Inst. Inc., Cary, NC). Statistical differences were considered significant at $P < 0.05$.

## Results

### *Diet*

Raffinose and Stachyose contents of cSBM were 0.58 and 3.23% respectively and those of LOSBM were 0.08 and 0.42%, respectively. The CP and AA concentration were greater in LOSBM than cSBM. The comparison table of nutrient composition of cSBM and LOSBM is shown in Table 1.

### *Growth Performance*

No differences were detected between treatment diets for growth performance of piglets (Table 3). However, inclusion of FM/ SDPP with cSBM and LOSBM resulted in a better G: F ratio ($P$ = 0.03). There was no interaction effect for inclusion of LOSBM and FM/SDPP among the treatments for growth performance.

### *Intestinal morphology and viscosity*

Intestinal length did not differ between treatments. Replacing SBM with LOSBM decreased viscosity of intestinal content ($P$ = 0.01; Table 4). Inclusion of FM/SDPP had no effect on intestinal morphology. Treatment diets had no effect on intestinal villi height (IVH), intestinal crypt depth (ICD) and jejunal crypt depth (JCD) but

SBM fed pigs had greater ($P$ = 0.01) jejunal villi height (JVH) compared to LOSBM fed pig . No interaction was detected for types of soybean meal and FM/SDPP for intestinal morphology. Viscosity of intestinal content was lower ($P$ = 0.01) in pigs fed LOSBM diet than pigs fed SBM.

***Blood urea nitrogen and organ weights***

Treatments had no effect on organ (heart, kidney, liver, pancreas, spleen) weights. However, there was a trend for the increased liver weight for the pigs on SBM diet ($P$ = 0.08). Replacing SBM with LOSBM increased BUN ($P$ = 0.01; Table 5).

**Discussion**

The nutrient composition of SBM used in the current study is in agreement with the values published previously (NRC, 1998). The LOSBM used in the study contained lower concentration of oligosaccharides and higher concentration of CP and AA than SBM. This was expected because LOSBM was processed from a new variety of soybeans bred for lower oligosaccharide content. The oligosaccharide content of SBM and LOSBM used in this study were in agreement with the data reported by Parsons et al. (2000). However, the concentration of raffinose and stachyose in SBM used in this study was lower than reported by Karr-Lilienthal et al. (2005).

Inclusion of SBM in the diet of nursery pigs is thought to affect negatively growth performance (Li et al., 1990; Freisen et al; 1993; Veldman, 1993; Pluske et al., 1997). However, there was no difference in growth performance between SBM and LOSBM fed pigs in our study which might indicate that treatment diets contained excess digestible nutrient.

Soluble oligosaccharides that cannot be digested by the pigs gut increases the viscosity in the small intestine (Bedford, 1995), which can affect digestion and absorption of nutrients in piglets (Mosenthin et al., 1994; Zhang et al., 2001; Dilger et al., 2004). Replacing SBM with LOSBM was effective in reducing the viscosity of intestinal content in early-weaned pigs which clearly relates to the oligosaccharides intake and the elevation of viscosity particularly in the small intestine.

The small intestine is the major site of digestion and absorption in pigs where most of the DM, energy and proteins are digested (Keys and DeBarthe, 1974). The small intestine exhibits a dynamic process of cell turnover, which is characterized by crypt cell proliferation, migration to villus axis and cell extrusion from villus apex via sloughing (Ziegler et al., 1999). Poor growth performance and the health of pigs are associated with changes in the small intestine such as villus atrophy and crypt elongation (Pluske, 2001). It is considered that the composition of diet can affect the functionality as well as the morphology of the intestine (Stanogias and Pearce, 1985). No data has been published on the effect of LOSBM on intestinal morphology of early-weaned pigs. However, inclusion of SBM in the diets of early-weaned pigs has been associated with many digestive ailments such as transient hypersensitivity reactions which can modify intestinal morphology (Li et al., 1990; Dreau et al., 1994). McDonald et al (2001) increased the viscosity of pig the intestinal content with the addition of sodium carboxymethyl cellulose and observed villus atrophy and an increase in crypt depth in the small intestine.  However, in the present study we did not observe altered intestinal morphology due to a SBM oligosaccharide-induced increase in viscosity. This may be partly due to the difference in the nature of the ingredients used in these studies. Compounds other than soybean oligosaccharides such as Glycinin and β-Conglycinin may be responsible for negative effect on intestinal morphology (Stokes et al., 1987; Li et al., 1990). Glycinin and β-Conglycinin can cause hypersensitivity in the small intestine of nursery pigs which might negatively affect its morphology (Cromwell, 2000). Further studies need to be done to explore the effects of SBM oligosaccharides on intestinal morphology.

The weight of metabolically active organs such as liver, kidney and heart has been found to be positively correlated with the CP content of the diet (Kerr et al., 1995; Chen et al., 1999). Increases in the weight of these organs can be explained by the extra metabolic load to be performed by them as a result of higher protein intake (Koong et al., 1985). Treatment diets fed to pigs in the present study were formulated to be iso-nitrogenous which might explain the similarity in the visceral mass.

Amino acids absorbed in excess of that required for protein synthesis in the body are metabolized by the liver through transamination and deamination process (Krebs, 1942). Deamination process in the liver yields ammonia which is toxic and needs to get excreted from the liver through the blood in the form of urea, which contributes to BUN (Lehninger et al., 2005). Blood urea nitrogen can be used as the indicator of quality, quantity and the biological value of protein in feed (Eggum, 1970). However, increased viscosity in the gut lumen decreases the absorptive capacity. Furthermore, fermentable substrates in the lower gut increase the ammonia demand of intestinal bacteria for de novo synthesis of bacterial protein (Mosenthin et al., 1992). The ammonia absorption from the intestine is reduced, allowing less urea to be formed and thus decreasing BUN (Mosenthin et al., 1992). Blood urea nitrogen concentrations for the pigs fed LOSBM diet were significantly higher than those fed SBM diet, which might be due to the presence of oligosaccharides in SBM. As the diets were formulated to be isonitrogenous, the differences in BUN values are due to better absorption of LOSBM protein.

**Conclusion**

Soybean meal processed from a low oligosaccharide variety of soybean contained lower amounts of oligosaccharides (raffinose and stachyose) and higher amounts of CP and AA. Replacing SBM with LOSBM decreased the viscosity of intestinal content. The LOSBM did not have any negative effect for the responses measured in the present study. However, similar research with less digestible starter diet is required to see if LOSBM can promote pig performance in general. Low oligosaccharides soybean meal can possibly replace feedstuff like FM and SDPP in the diet of early-weaned pigs.

**Table1.** Comparison of nutritional composition of conventional soybean meal and low oligosaccharide soybean meal

| Criteria | SBM[1] | LOSBM[2] | LOSBM-SBM (% change) |
|---|---|---|---|
| Dry matter , % | 88.66 | 88.46 | -0.2 |
| Crude protein ,% | 46.55 | 53.16 | +6.61 |
| Crude fat, % | 1.23 | 1.09 | -0.14 |
| Crude fiber, % | 2.61 | 1.83 | -0.78 |
| Ash, % | 6.82 | 6.01 | -0.81 |
| Gross energy, kcal/g | 4124.50 | 4187.50 | +63.0 |
| Amino acids | | | |
| Lysine, % | 3.08 | 3.35 | +0.27 |
| Methionine, % | 0.66 | 0.69 | +0.03 |
| Threonine, % | 1.75 | 1.92 | +0.17 |
| Tryptophan, % | 0.61 | 0.65 | +0.04 |
| Leucine, % | 3.71 | 4.16 | +0.45 |
| Isoleucine, % | 2.27 | 2.49 | +0.22 |
| Valine, % | 2.39 | 2.60 | +0.21 |
| Raffinose, % | 0.58 | 0.08 | -0.50 |
| Stachyose, % | 3.23 | 0.42 | -2.81 |

[1]SBM= conventional soybean meal

[2] LOSBM= low oligosaccharide soybean meal, Schlillinger Seeds Inc., Des Moines, IA.

**Table 2**. Ingredient and composition of (% as fed basis) experimental diets fed to pigs[1]

| Ingredients | Dietary treatment | | | |
|---|---|---|---|---|
| | Diet 1 (+SBM) | Diet 2 (-SBM) | Diet 3 (+LOSBM) | Diet 4 (-LOSBM) |
| Corn | 44.0 | 46.9 | 48.0 | 50.9 |
| SDPP | 5 | 0 | 5 | 0 |
| Whey powder | 15 | 15 | 15 | 15 |
| SBM, 47.7% | 24 | 32 | 0 | 0 |
| LOSBM[2], 53.3% | 0 | 0 | 20 | 28 |
| Oil | 2 | 2 | 2 | 2 |
| Fishmeal | 6 | 0 | 6 | 0 |
| Limestone | 1 | 1 | 1 | 1 |
| Dicalcium phosphate | 1.20 | 1.20 | 1.20 | 1.20 |
| Lysine HCl | 0.27 | 0.4 | 0.3 | 0.41 |
| DL-Methionine | 0.16 | 0.14 | 0.18 | 0.18 |
| L-Threonine | 0.18 | 0.18 | 0.18 | 0.18 |
| L-Tryptophan | 0 | 0.01 | 0 | 0.01 |
| Salt | 0.4 | 0.4 | 0.4 | 0.4 |
| Nursery premix[3] | 0.5 | 0.5 | 0.5 | 0.5 |
| Zinc oxide | 0.25 | 0.25 | 0.25 | 0.25 |
| Analyzed composition | | | | |
| DM % | 91 | 91 | 91 | 91 |
| GE, kcal/kg | 3,977 | 3,938 | 4,000 | 3,972 |
| Protein, % | 20.3 | 18.6 | 21.2 | 19.7 |
| Fat, % | 4.4 | 4.9 | 5.2 | 5.3 |
| NDF, % | 6.7 | 6.7 | 6.9 | 7.7 |
| ADF, % | 2.9 | 3.7 | 2.5 | 3.3 |
| Ash, % | 7.2 | 6.3 | 6.5 | 6.1 |

[1]Dietary treatments are as follows: +SBM = conventional soybean meal (SBM) diet containing fishmeal and spray dried plasma (FM/SDPP); -SBM = SBM diet without FM/SDPP; +LOSBM = low oligosaccharide soybean meal (LOSBM) diet containing FM/SDPP; -LOSBM = LOSBM diet without FM/SDPP.
[2]LOSBM, Schlillinger Seeds Inc., Des Moines, IA.
[3]Vitamin-mineral premix supplied the following micronutrients (per kilogram of diet): 11,000 IU of vitamin A; 2,756 IU of vitamin $D_3$; 55 IU of vitamin E; 55µg of vitamin $B_{12}$; 16,000 mg of riboflavin; 44.1 mg of pantothenic acid; 82.7 mg of niacin; Zn, 150 mg; 175 mg of Fe; 60 mg of Mn; 17.5 mg of Cu; 2 mg of I; and 0.3 mg of Se.

**Table 3**. Main effect of low oligosaccharide soybean meal (LOSBM[1]) and fishmeal/spray dried plasma (FM/SDPP) on growth performance of early-weaned pigs

| | LOSBM | | | FM | | | *P*-value | | |
|---|---|---|---|---|---|---|---|---|---|
| | cSBM[2] | LOSBM | SEM[3] | No | Yes | SEM[3] | cSBM | FM | cSBM X FM |
| Growth performance | | | | | | | | | |
| Average daily gain, g/d | 225 | 206 | 32 | 208 | 224 | 32 | 0.40 | 0.47 | 0.62 |
| Average daily feed intake, g/d | 272 | 251 | 43 | 270 | 253 | 43 | 0.48 | 0.57 | 0.83 |
| Gain to feed ratio | 0.836 | 0.846 | 0.061 | 0.793 | 0.889 | 0.0061 | 0.82 | 0.03 | 0.46 |

[1]LOSBM, Schlillinger Seeds Inc., Des Moines, IA.
[2]cSBM = conventional soybean meal
[3]SEM = Standard error of means

**Table 4**. Main effect of low oligosaccharide soybean meal (LOSBM[1]) and fishmeal/spray dried plasma (FM/SDPP) intestinal length, viscosity and morphology of early weaned pigs

| | LOSBM | | | FM | | | *P*-value | | |
|---|---|---|---|---|---|---|---|---|---|
| | cSBM[2] | LOSBM | SEM[3] | No | Yes | SEM[3] | SBM | FM | SBM X FM |
| Intestinal length, cm | 1105 | 1041 | 33.53 | 1012 | 1151 | 33.53 | 0.72 | 0.22 | 0.62 |
| Intestinal viscosity, cP | 2.01 | 1.57 | 0.22 | 1.83 | 1.75 | 0.22 | 0.01 | 0.60 | 0.13 |
| Intestinal morphology, µm | | | | | | | | | |
| Ileal crypt depth | 202 | 203 | 11 | 206 | 200 | 11 | 0.90 | 0.46 | 0.68 |
| Jejunal crypt depth | 266 | 255 | 11 | 264 | 257 | 11 | 0.15 | 0.40 | 0.90 |
| Ileal villi height | 310 | 306 | 34 | 310 | 305 | 34 | 0.86 | 0.83 | 0.11 |
| Jejunal villi height | 522 | 426 | 45 | 476 | 473 | 45 | 0.01 | 0.93 | 0.78 |

[1]LOSBM, Schlillinger Seeds Inc., Des Moines, IA.
[2]cSBM = conventional soybean meal
[3]SEM = Standard error of means

**Table 5**. Main effect of low oligosaccharide soybean meal (LOSBM[1]) and fishmeal/spray dried plasma (FM/SDPP) on blood urea nitrogen (BUN) and organ weights of early-weaned pigs

| | LOSBM | | | FM | | | *P*-value | | |
|---|---|---|---|---|---|---|---|---|---|
| | cSBM[2] | LOSBM | SEM[3] | No | Yes | SEM[3] | cSBM | FM | SBM X FM |
| Organ weights, g | | | | | | | | | |
| Heart | 55.01 | 55.69 | 2.69 | 53.88 | 56.82 | 2.69 | 0.71 | 0.12 | 0.45 |
| Kidney | 54.27 | 52.23 | 3.71 | 51.99 | 54.51 | 3.71 | 0.43 | 0.33 | 0.23 |
| Pancreas | 23.59 | 21.91 | 2.34 | 22.49 | 23.01 | 2.34 | 0.31 | 0.75 | 0.88 |
| Liver | 292.70 | 268.30 | 19.33 | 271.17 | 289.29 | 19.33 | 0.08 | 0.20 | 0.96 |
| Spleen | 18.51 | 17.48 | 1.69 | 18.08 | 17.91 | 1.69 | 0.39 | 0.88 | 0.83 |
| BUN[4], mg/dL | 8.54 | 11.45 | 1.34 | 9.20 | 10.79 | 1.34 | 0.01 | 0.10 | 0.37 |

[1]LOSBM, Schlillinger Seeds Inc., Des Moines, IA.
[2]cSBM = conventional soybean meal
[3]SEM = Standard error of means
[4]BUN = blood urea nitrogen

# CHAPTER 4

## Ileal digestibility of nutrients in low oligosaccharide soybean meal when fed to grower pigs

**Summary**

An experiment was conducted to measure and compare the effect of replacing conventional soybean meal (cSBM) with low oligosaccharide soybean meal (LOSBM) on apparent ileal digestibility (AID) and apparent total tract digestibility (ATTD) of DM, energy, N, ADF and NDF by grower pigs fed corn-LOSBM or corn-SBM based diets in two different adaptation periods (5 d and 7 d). Sixteen barrows (24.5 ± 1.4 kg BW) fitted with simple T-cannulas at the distal ileum were assigned to one of two treatments containing corn-SBM or corn-LOSBM based diet. Celite was included in both dietary treatments as an inert marker. Pigs were fed 650 g twice daily for a 5d adaptation period. Fresh fecal grab samples were collected 2 times on d 6 (morning and afternoon) and once on the morning of d 7, and ileal digesta was collected for 4 h in the morning and 4 h in the evening on each of d 7 and d 8 . A month later, the same animals were fed their previously assigned treatments with a longer 7 d adaptation period, 3 d fecal collection (twice a day), and 2 d ileal collection period on each of d 11 and d 12. Results of the experiment showed that the percentage of ATTD of DM, energy and NDF was greater ($P < 0.05$) in corn-LOSBM diet than in corn-SBM diet. Longer adaptation showed improvement ($P < 0.05$) in ADF and NDF digestibility ($P < 0.05$). However, increasing the adaptation period from 5d to 7d did not improve ($P < 0.05$) nutrient and energy ATTD and AID values. Replacing SBM with LOSBM in the diets of growing pigs showed greater ($P < 0.001$) percent AID of DM, energy and NDF.

**Key words**: adaptation, ileal digestibility, low-oligosaccharide soybean meal, pig

## Introduction

Soybean seed contains raffinose saccharides such as raffinose, stachyose and verbascose, which constitute 4 to 6 % of DM and remain in SBM after meal processing (Leske et al., 1993; Grieshop et al., 2003). These oligosaccharides cannot be digested by the endogenous enzyme (Kurimaya and Mendel, 1917) due to the lack of alpha-galactosidase enzyme in the monogastric animal (Gitzelmann and Auricchio, 1965). Fermentation of these soluble sugars in the lower gut produces gastrointestinal gases (Steggerda, 1968) resulting in flatulence and discomfort (Rackis, 1975; Fleming, 1981; Krause et al., 1994). It is also believed that these oligosaccharides can increase the viscosity of intestinal (Bedford, 1995) content leading to poor digestion and absorption (Mosenthin et al., 1994; Dilger et al., 2004). There are numerous studies suggesting the negative effect of soy oligosaccharides on nutrients and energy digestibility. In those studies the authors reduced the oligosaccharides content of the soybean meal and showed improvements in digestibility of DM, energy, CP and essential amino acids (Leske et al., 1993; Leske and Coon, 1999; Parsons et al., 2000). Studies with addition of soy oligosaccharides to purified swine diets had been shown to decrease ileal DM and N digestibility (Veldman et al., 1993; Smiricky-Tjardes, 2003). However, it is important to note that the level of oligosaccharides used in the treatments and the magnitude of their effect on the digestibility of nutrients vary with the studies. Some researcher argues that the reduction in digestibility values when SBM is included in the pigs' diet is not solely because of the presence of oligosaccharides (Zhang et al., 2001; Smiricky et al., 2002). Raffinose saccharides in SBM are poorly digested in the pig's intestine, which can decrease the efficiency of energy utilization (Sebastian et al., 2000). It is therefore potentially valuable to reduce the level of these oligosaccharides to maximize nutrient digestibility (van Kempen et al., 1996). There are limited benefits of enzyme supplementation to reduce the negative effect of soybean oligosaccharides (Kim and Baker, 2003). New varieties of low oligosaccharide soybean that contain reduced amount of oligosaccharide have been used recently in pigs and poultry diet. Those studies had shown positive effect on AA digestibility when fed to grower pigs (Baker and Stein, 2009) as well higher values of nitrogen corrected metabolizable energy value when fed to roosters (Parsons et al., 2000). It is therefore the objective of this study is to measure and compare the apparent total tract and apparent ileal digestibility of DM, energy, N, ADF and NDF by grower pigs fed corn-LOSBM and corn-SBM diets for two different adaptation period (5 d and 7 d).

## Materials and Methods

### *Animal and housing*

Crossbred pigs [(Landrace × Yorkshire (Topigs, Winnipeg, Canada)) × Duroc (Comparts, Nicollet, MN), (n = 16, 24.5 ± 1.4 kg BW)] were surgically fitted with T-cannula in distal ileum. Pigs were individually housed in metabolism crates (2.0 m × 0.7 m) in an environmentally controlled metabolism facility and surgery was performed at the surgical facility at University of Minnesota, Southern Research and Outreach center, Waseca, MN.

### *Pre surgical preparation*

Pigs were fasted for 24 h prior to pre-surgical anesthesia. However, the pigs had access to water. Surgical instruments, gowns, drapes were sterilized prior to surgery in an autoclave (Midmark M9D, Midmark Corporations, Versailles, OH). Cannulas were kept in a solution of Nolvasan (Chlorhexidine diacetate 2%, Fort Dodge Animal Health, Fort Dodge, IA) for sterilization. Pigs were injected with Penicillin an hour prior to surgeries as pre-surgical preparation. Dose was calculated on the basis of body weight as described in Appendix 1.

***Surgical Procedure***

Pigs were sedated by an intramuscular injection of a cocktail mixture of 2.5 mL Ketamine, 2.5 mL Xylazine injected into a vial of lyophilized Telazol (Tiletamine and Zolazepam). This cocktail contained 50 mg/mL each of Tiletamine, Zolazepam, Ketamine and Xylazine. The dosage of sedative agents was calculated according to the body weight of the animal as described in Appendix 1.

After sedation the pig was placed on the left lateral recumbency with right lateral view for the surgical procedure. The limbs were restrained to an adjustable surgical table. Surgical lamp was adjusted to assist in the visibility. A gas mask of appropriate size was placed on the snout of the pig. Anesthesia was maintained by using Isoflurane in oxygen. The anesthetic machine (Moduflex Coaxial, Dispomed ltd., Joliette, Quebec, Canada) was used to regulate the amount of oxygen and isoflurane administered to the pig during surgery. Initially isoflurane was turned to 5% and oxygen to 1-1.2 L/min. This dose was maintained for 1-2 min before attaching ECG sensors. Relaxed muscle tone, relaxed jaw tone and absence of eye reflex were used as indicators of proper anesthesia. After establishing proper anesthesia, the level of isoflurane was decreased to 2.5% and towards the end of the surgery the level was gradually reduced to 0%. Body temperature, blood pressure, heart rate and respirations were monitored using ECG (Midray PM-900 vet, Mindray DS USA Inc., Redmond, WA). Temperature probe was fitted rectally, Pulse oximeter was fixed on dewclaw/tongue/inner part of ear, BP cuff was attached to right hind leg while ECG leads were also positioned in their respective position (White lead- right side of the chest just under the arm, Black lead- same location but on left side, Red lead- left side of the body down by the left leg). Surgical site was prepared by shaving with an electric razor from the dorsal midline to the ventral midline and from the fourth rib past the hind leg, cleaned and scrubbed with Betadine scrub (Povidone-Iodine 7.5%, Purdue Products L.P., Stamford, CT). The site was rinsed using isopropyl alcohol and sterile drapes were placed and attached using the towel clamps.

A small incision 5 to 7 cm parallel and caudal to the last rib was made on the skin using a scalpel blade (No.10 blade and No.3 handle). Remaining muscle layer was exposed by a blunt dissection of tissue forceps. Scissors were used to ease the dissection if necessary. Tissue forceps were used to identify different muscle layers and keep them exposed. A small cut through the peritoneum was made using scissor to expose the abdominal cavity. The caecum was located and a vertical incision of 4 cm along the length of the intestine was made at approximately 5 cm anterior to the ileocecal junction. A sterilized cannula was inserted and anchored by a surgeons knot around the barrel using 3-0 PDS suture (Ethicon Inc., Johnson and Johnson, New Brunswick, NJ). A simple continuous stitch was placed to tighten and secure the cannula. An additional mattress stitch was applied to keep the tissue snug against the cannula.

Another small (2 cm) incision on the skin was made in between the last $2^{nd}$ and $3^{rd}$ ribs on the pigs left side. The barrel of cannula was exteriorized outside through this incision between the ribs by holding cannula with forceps. After ensuring the position of the cannula and intestine the locking nuts and cap was screwed in place.

Peritoneum was incorporated into each stitch of first muscle layer during closure using a continuous suture using 3-0 PDS suture. The remaining muscle layers were sutured using simple continuous suture with 2-0 PDS suture (Ethicon Inc., Johnson and Johnson, New Brunswick, NJ). Similarly the subcuticular muscle layer and skin were closed using subcuticular stitch with 2-0 PDS. The incision sites were treated with Chlorhexidine ointment (Chlorhexidine acetate 2%, Phoenix Pharmalabs, Providence, Utah) and liquid bandage was applied.

Anesthesia was discontinued and an injection of Benamine (Flunixin Meglumine 50mg/mL, Intervet Inc., Merck Animal Health, Summit, NJ) and long acting Penicillin was administered intramuscularly. The doses were calculated on the basis of body weight as shown in Appendix 1. Animals were transferred to the metabolic crates immediately after the surgery for individual care.

***Post-operative care***

The temperature of metabolism crate was maintained at 22 ˚C with sufficient ventilation. Water was continuously supplied from d 0 of surgery but the feed was allowed from d 1 after the surgery twice daily. The post-operative drug protocol and the feeding regimen are shown in Appendix 2 and 3 respectively.

Pigs were monitored for general appearance, body temperature, feed disappearance and evidence of feces or vomit twice daily. The incision site was monitored and cleaned twice daily with luke warm water, dried with clean towels and treated with iodine and petroleum jelly (Vaseline, Unilever, London, UK) or Desitin (Zinc Oxide 40%, Johnson and Johnson, New Brunswick, NJ). Individual crates and the metabolism room were also cleaned twice daily. Pigs were allowed minimum of 10 days for post-surgery recovery before the start of the experimental period.

***Feed and feeding***

Pigs were randomly allotted to one of two dietary treatments. Diets were formulated to meet or exceed NRC (1998) requirements for growing pigs. Treatment 1 consisted of conventional corn-soybean meal diet and treatment 2 consisted of corn-LOSBM. Celite was included in both diets as an inert marker at 0.5%. Diets were similar to the diets used in the balance study. The composition of treatment diets is shown in the Table 1.

Pigs were fed two equal feeding at 0800 h and 1600 h for entire experimental period. Each pig was fed 650 g of feed in each feeding.

***Sample Collection***

For the first trial 5 d of adaptation period was provided. Fresh fecal grab samples were collected 2 times on d 6 (morning and afternoon) and once on the morning of d 7. Ileal digesta was collected for 4 h in the morning and 4 h in the evening on each of d 7 and d 8. Later, the same animals were fed their previously assigned treatments with a longer 7 d adaptation period, 3 d fecal collection (twice a day), and 2 d ileal collection period on each of d 11 and d 12. A small plastic bag with 10 ml of 10% formaldehyde was attached to the cannula barrel using cable tie to collect the ileal digesta. Digesta collection bags were changed whenever full or at least once every hour. All samples were immediately stored at -20 ˚C before preparation and analysis.

***Sample preparation***

Fecal samples were thawed and pooled for each animal. Samples were dried in an Oven at 60 ˚C (Thermo Scientific Precision, Thermo Fisher Scientific Inc., Hampton, New Hampshire) for 3 h to take the excess moisture out. Ileal digesta samples were lyophilized using FreeZone 6 (Labconco Corp., Kansas City, MO). Dried ileal digesta, feed and fecal samples were ground using a sample grinder to a particle size of 1 mm.

***Analysis***

All four treatment diets, SBM and LOSBM samples were analyzed for DM, GE, CP, NDF, ADF and acid insoluble ash (AIA) content. All the analysis was done in duplicates.

Samples were dried at 102 ˚C for 4 h in an oven (Thermo Scientific Precision, Thermo Fisher Scientific Inc., Hampton, New Hampshire) for DM (AOAC 2000 method 939.01). The N in the feed samples was determined using the Kjeldahl method (method 976.05, AOAC, 2000; Kjeltec 2300 Analyzer, Foss, Höganäs, Sweden). Gross energy was determined using the Bomb calorimeter method using an IKA$^{R}$-WERKE c2000 basic bomb calorimeter (IKA Werke GmbH & Co. KG, Staufen, Germany). Crude fat of the diet samples was analyzed using ether extract method (AOCS Am 5-04) using ANKOM $^{XT15}$ Extraction system (ANKOM Technology, Macedon, NY). Samples were analyzed for NDF and ADF using filter bag technique (ANKOM$^{2000}$ fiber analyzer, method 12 and 13, respectively; ANKOM Technology, Macedon, NY). Samples were ashed in a high temperature muffle furnace at 600 ˚C for 6 h. Acid insoluble ash (AIA) content of feed, ileal digesta and feces was determined (McCarthy et al., 1974). Five gram of samples was weighed in duplicates into a digestion tubes with 100 ml of 4 N HCL along with 2 Kjeltabs (FOSS Analytical, Denmark). The tubes were digested for 30 minutes at 150 ˚C in the using FOSS Tecator™ digestion system (FOSS Analytical, Denmark). The content of the tubes were filtered through ash less filter paper (Whattman no.4) through a funnel. The filtrate was washed with boiling distilled water until the residue was free of acid. The pH of the residue was measured using litmus paper. Neutral filtrates were subjected to ashing in a muffle furnace at 600 ˚C for 6 h (Isotemp Muffle Furnace, Thermo Fisher Scientific Inc., Hampton, New Hampshire) and the ash was weighed and AIA was calculated.

***Digestibility Calculations***

Apparent Nutrient Digestibility (AND) for Nutrients was calculated by using the formula:

$$AND_{nutrients} = 1 - \{(Nutrient_{feces} / Nutrient_{diet}) \times (Ce_{diet} / Ce_{feces})\}$$

where Nutrient and Ce represents the concentration of Nutrients or Ce in either feces or diet.

Similarly, Apparent Ileal Digestibility (AID) for Nutrients was calculated by:

$$AID_{nutrients} = 1 - \{(Nutrient_{ileal} / Nutrient_{diet}) \times (Ce_{diet} / Ce_{ileal})\}$$

where, Nutrient and Ce represents the concentration of Nutrient or Celite in either ileal digesta or diet.

***Statistical Analysis***

The ATTD and AID data were analyzed as a 2 × 2 factorial arrangement with 2 levels of LOSBM (with or without) and 2 adaptations period lengths (5 d and 7 d). Individual animals served as the experimental unit. Statistical analysis was performed using JMP (version 9, SAS Inst. Inc., Cary, NC). Statistical differences were considered significant at $P < 0.05$.

**Results**

In general all pigs remained healthy and consumed their designated diet. No feed refusal was observed for any of the treatment diets used in the study. The analyzed nutrient compositions of the tested ingredients are presented in Table 1 and the composition and analysis of the test diets are presented in Table 2.

The AID values for DM, gross energy, N, ADF and NDF in corn-SBM and corn-LOSBM diets fed to growing pigs are presented in Table 4. The AID values for DM, gross energy and NDF in corn-LOSBM diet were greater than that of corn-SBM diet ($P < 0.05$). However, replacing SBM with LOSBM in the diets of growing pigs did not affect AID values for N and ADF. Longer adaptation period did not improve the AID values for nutrients and energy in the present study.

The ATTD values for DM, gross energy, N, ADF and NDF in corn-SBM and corn-LOSBM diets fed to growing pigs are presented in Table 3. The ATTD values for DM, gross energy and NDF in corn-LOSBM diet were greater than in corn-SBM diet fed to grower pigs ($P < 0.05$). Replacing SBM with LOSBM did not affect ATTD values for N and ADF. Longer adaptation period did improve ATTD values for ADF and NDF when fed to grower pigs ($P < 0.05$).

**Discussion**

The nutritional composition of LOSBM used in this study is similar to the soybean meal produced from reduced oligosaccharide variety of soybean as described by Parsons et al (2000) and the nutrient composition of SBM is in agreement with published values (NRC, 1998). As expected, raffinose and stachyose concentration was less in LOSBM than SBM. The CP concentration of LOSBM was higher than in SBM.

There are a number of studies performed to determine the AID and ATTD values of individual feed ingredients (NRC 1998), but, there are very few studies performed in mixed diet using corn-SBM or corn-LOSBM. The measured AID value for N in corn-SBM based diet in this study agrees with previously measured values (Stein et al., 2005). Addition of soy solubles to soy protein concentrate diet had been shown to decrease the AID of N and DM in growing pigs, while addition of soy oligosaccharide to SBM diet had no effect N and DM digestibility (Smiricky, et al., 2002). Using LOSBM instead of SBM did not affect the AID or ATTD value for N and ADF in the present study. The ATTD and AID value for GE and NDF in corn-LOSBM diet was greater than that in corn-SBM diet when fed to grower pigs. The negative digestibility coefficient for NDF in this study may be partly due to endogenous loss of carbohydrate or laboratory error in analyzing the ileal digesta samples for NDF.

Reducing oligosaccharide can increase the energy value of SBM (Coon et al., 1990, Parsons et al., 2000) and the lower efficiency of energy utilization in corn-SBM diet is due to poor digestion of oligosaccharides in SBM (Sebastian et al., 2000). Young growing pig in this study responded to the adaptation period by improved ATTD value of NDF and ADF with the longer adaptation period.

**Conclusion**

Data from these experiments would suggest that ATTD and AID value of DM, GE and NDF in corn-LOSBM is greater than that of corn-SBM for young growing pigs.

**Table 1**. Comparison of nutritional composition of conventional soybean meal and low oligosaccharide soybean meal

| Criteria | SBM[1] | LOSBM[2] | LOSBM-SBM (% change) |
|---|---|---|---|
| Dry matter, % | 88.66 | 88.46 | -0.2 |
| Crude protein,% | 46.55 | 53.16 | +6.61 |
| Crude fat, % | 1.23 | 1.09 | -0.14 |
| Crude fiber, % | 2.61 | 1.83 | -0.78 |
| Ash, % | 6.82 | 6.01 | -0.81 |
| Gross energy, kcal/g | 4124.50 | 4187.50 | +63.0 |
| Amino acids, (%) | | | |
| Lysine, % | 3.08 | 3.35 | +0.27 |
| Methionine, % | 0.66 | 0.69 | +0.03 |
| Threonine, % | 1.75 | 1.92 | +0.17 |
| Tryptophan, % | 0.61 | 0.65 | +0.04 |
| Leucine, % | 3.71 | 4.16 | +0.45 |
| Isoleucine, % | 2.27 | 2.49 | +0.22 |
| Valine, % | 2.39 | 2.60 | +0.21 |
| Raffinose, % | 0.58 | 0.08 | -0.50 |
| Stachyose, % | 3.23 | 0.42 | -2.81 |

[1]SBM, conventional soybean meal

[2] LOSBM, Schlillinger Seeds Inc., Des Moines, IA.

**Table 2**. Ingredient and analyzed composition of Experimental diets on as fed basis

| Treatment: | Corn-SBM[1] | Corn-LOSBM[2] |
|---|---|---|
| Ingredients, % | | |
| Corn | 68.83 | 72.23 |
| SBM, (47.5% CP) | 25 | - |
| LOSBM, (53.3% CP) | - | 21.53 |
| Tallow | 3 | 3 |
| Choice White Grease | - | - |
| Limestone | 1 | 1 |
| Dicalcium phosphate | 1 | 1 |
| Lysine HCL | 0.2 | 0.28 |
| DL-Methionine | 0.02 | 0.01 |
| L-Threonine | 0.09 | 0.09 |
| L-Tryptophan | 0.01 | 0.01 |
| Salt | 0.35 | 0.35 |
| Vitamin-mineral premix[a] | 0.5 | 0.5 |
| Celite | 0.5 | 0.5 |
| Analyzed Composition | | |
| DM, % | 88 | 88.4 |
| GE, kcal/kg | 3984.5 | 3941.5 |
| Protein, % | 14.89 | 14.15 |
| Fat, % | 6.54 | 7.16 |
| NDF, % | 6.08 | 7.25 |
| ADF, % | 3.91 | 3.25 |
| Ash, % | 4.67 | 4.50 |

[1]SBM = conventional soybean meal (SBM).
[2]LOSBM= low oligosaccharide soybean meal, Schlillinger Seeds Inc., Des Moines, IA.
[3]Vitamin-mineral premix supplied the following micronutrients (per kilogram of diet): 11,000 IU of vitamin A; 2,756 IU of vitamin $D_3$; 55 IU of vitamin E; 55µg of vitamin $B_{12}$; 16,000 mg of riboflavin; 44.1 mg of pantothenic acid; 82.7 mg of niacin; Zn, 150 mg; 175 mg of Fe; 60 mg of Mn; 17.5 mg of Cu; 2 mg of I; and 0.3 mg of Se.

**Table 3**. Simple and main effects of soybean meal (SBM) type and length of adaptation period on percent apparent total tract digestibility in grower pigs[¶]

| | | Dry matter | Gross energy | Nitrogen | Acid detergent fiber | Neutral detergent fiber |
|---|---|---|---|---|---|---|
| | | | | Main Effects | | |
| Adaptation | | | | | | |
| 5 d | | 89.65 ± 0.26 | 86.86 ± 0.38 | 87.56 ± 0.46 | 55.91 ± 2.47 | 47.31 ± 1.59 |
| 7 d | | 90.21 ± 0.25 | 87.87 ± 0.37 | 88.71 ± 0.45 | 65.15 ± 2.47 | 58.51 ± 1.59 |
| SBM | | | | | | |
| Conv.[1] | | 89.20 ± 0.26 | 86.58 ± 0.38 | 87.81 ± 0.46 | 59.97 ± 2.55 | 45.28 ± 1.64 |
| LOSBM[2] | | 90.65 ± 0.25 | 88.16 ± 0.37 | 88.47 ± 0.45 | 61.09 ± 2.38 | 60.54 ± 1.54 |
| | | | | Simple Effects | | |
| Adaptation | SBM | | | | | |
| 5 d | Conv. | 89.42[b] ± 0.38 | 86.63[b] ± 0.56 | 88.01[ab] ± 0.68 | 54.98 ± 3.61 | 41.03 ± 2.32 |
| 5 d | LOSBM | 89.87[b] ± 0.35 | 87.10[b] ± 0.52 | 87.11[b] ± 0.63 | 56.83 ± 3.37 | 53.59 ± 2.17 |
| 7 d | Conv. | 88.98[b] ± 0.35 | 86.52[b] ± 0.52 | 87.60[ab] ± 0.63 | 64.95 ± 3.61 | 49.53 ± 2.32 |
| 7 d | LOSBM | 91.44[a] ± 0.35 | 89.23[a] ± 0.52 | 89.83[a] ± 0.63 | 65.35 ± 3.37 | 67.49 ± 2.17 |
| *P*-value | | | | | | |
| Adaptation | | 0.133 | 0.069 | 0.085 | 0.014 | < 0.001 |
| SBM | | < 0.001 | 0.006 | 0.315 | 0.750 | < 0.001 |
| Adaptation × SBM | | 0.010 | 0.046 | 0.022 | 0.837 | 0.241 |

[1]Conv. = conventional soybean meal
[2]LOSBM = low oligosaccharide soybean meal, Schlillinger Seeds Inc., Des Moines, IA.
[¶]Values are Mean ± SEM(Standard error of means)

**Table 4.** Simple and main effects of soybean meal type and length of adaptation period on percent apparent ileal digestibility in young pigs[¶]

| | | Dry matter | Gross energy | Nitrogen | Acid detergent fiber | Neutral detergent fiber |
|---|---|---|---|---|---|---|
| | | | | Main Effects | | |
| Adaptation | | | | | | |
| 5 d | | 74.60 ± 0.71 | 76.04 ± 0.75 | 81.02 ± 1.17 | 23.81 ± 5.80 | -6.12 ± 3.69 |
| 7 d | | 71.67 ± 0.75 | 72.65 ± 0.79 | 76.78 ± 1.32 | -1.94 ± 5.88 | -23.81 ± 4.01 |
| SBM | | | | | | |
| Conv.[1] | | 70.04 ± 0.75 | 71.49 ± 0.79 | 77.51 ± 1.32 | 8.77 ± 6.08 | -37.75 ± 4.13 |
| LOSBM[2] | | 76.23 ± 0.71 | 77.19 ± 0.75 | 80.29 ± 1.17 | 13.09 ± 5.59 | 7.82 ± 3.56 |
| | | | | Simple Effects | | |
| Adaptation | SBM | | | | | |
| 5 d | Conv. | 72.07 ± 0.96 | 73.70 ± 1.02 | 79.34 ± 1.59 | 18.06 ± 8.20 | -25.57 ± 5.22 |
| 5 d | LOSBM | 77.13 ± 1.04 | 78.38 ± 1.10 | 82.70 ± 1.71 | 29.56 ± 8.20 | 13.33 ± 5.22 |
| 7 d | Conv. | 68.01 ± 1.14 | 69.28 ± 1.21 | 75.68 ± 2.10 | -0.51 ± 8.98 | -49.93 ± 6.39 |
| 7 d | LOSBM | 75.33 ± 0.96 | 76.01 ± 1.02 | 77.87 ± 1.59 | -3.37 ± 7.59 | 2.32 ± 4.83 |
| *P*-value | | | | | | |
| Adaptation | | 0.010 | 0.005 | 0.025 | 0.005 | 0.004 |
| SBM | | < 0.001 | < 0.001 | 0.130 | 0.607 | < 0.001 |
| Adaptation × SBM | | 0.286 | 0.358 | 0.742 | 0.395 | 0.236 |

[1]Conv. = conventional soybean meal
[2]LOSBM = low oligosaccharide soybean meal, Schlillinger Seeds Inc., Des Moines, IA.
[¶]Values are Mean ± SEM (Standard error of means)

# CHAPTER 5

## Effect of replacing conventional soybean meal with low oligosaccharide soybean meal on growth performance and carcass characteristics of pigs from wean to finish.

**Summary**

A trial was conducted to determine the effect of replacing conventional soybean meal (SBM) with low oligosaccharide soybean meal (LOSBM) on growth performance and carcass characteristics of pigs from wean to finish. The lower fiber content of LOSBM increases the CP content, so the interaction between LOSBM and the use of fishmeal (FM) and spray dried plasma (SDPP) was also evaluated. There were 9 pigs per pen, 6 treatments, and 8 blocks. The 432 pigs were assigned to pens in a randomized complete block design by body weight. Treatments were fed in 6 phases and based on a 2 × 3 factorial arrangement with 2 levels of FM/SDPP (none or phases 1 to 3) and 3 levels of LOSBM inclusion (none, phases 1 to 3, or phases 1 to 6). Body weights and feed intake were recorded at the beginning and end of each phase. Pigs were slaughtered at an average BW of 115kg, and carcass characteristics were measured. There was no interaction between FM/SDPP in the nursery and LOSBM in any phase for ADG, ADFI or G: F. Average daily gain was not affected by LOSBM in any phase, but was improved by FM/SDPP in phase 2 ($P < 0.01$). Feed intake was reduced only in phase 5 by LOSBM ($P < 0.05$), and was not affected by FM/SDPP. Feed efficiency was improved by replacing SBM with LOSBM in phases 1 and 2 ($P < 0.01$) and by the inclusion of FM/SDPP in phase 2 ($P < 0.05$). However these gains did not persist into the later phases and did not affect overall performance at market weight. Neither treatment factor affected live weight, carcass weight, fat or loin depth, percent lean, percent yield, grade or value. In conclusion, using LOSBM instead of conventional SBM results in minor gains in piglet feed efficiency by way of reduced feed intake, and piglets fed FM/SDPP only had slightly improved ADG. These early

improvements did not affect overall performance from wean to finish, nor did they affect the final carcass.

**Keywords:** swine; low oligosaccharide soybean; growth; carcass; blood urea nitrogen

## Introduction

Soybean meal (SBM) is used as the major source of supplemental protein in livestock industry (Soy Stats, 2011) mainly due to its excellent nutrient profile, dependable supply and lower cost. However, the oligosaccharide content of SBM is believed to affect the performance of early-weaned pigs in terms of growth and health. These oligosaccharides, namely raffinose and stachyose are heat stable components of soybean (Liener, 1981) and cannot be removed by meal processing (Leske et al., 1993; Grieshop et al., 2003). Raffinose and stachyose can resist digestion in monogastric animals due to the lack of enzyme alpha-galactosidase (Kuriyama and Mendel, 1917; Gitzelmann and Auricchio, 1965). Fermentation of raffinose and stachyose in the lower gut produces gastrointestinal gases such as carbon dioxide, methane and hydrogen (Steggerda, 1968) which can result in flatulence, nausea and discomfort in human and animals (Rackis, 1975; Fleming 1981; Krause et al., 1994). It is also believed that these oligosaccharides increase the viscosity of intestinal content and digesta transit time (Bedford, 1995), which subsequently leads to poor digestion and absorption of nutrients (Mosenthin et al., 1994; Dilger et al., 2004).

A new variety of soybean containing low amount of oligosaccharide has been developed. Soybean meal produced from this variety of soybean has been reviewed in a number of studies with varied results. The low oligosaccharide content of low oligosaccharide soybean meal (LOSBM) increases the CP, lysine and other essential AA content. Removal of oligosaccharides from SBM increases the ME content in roosters (Coon et al., 1990; Parsons et al., 2000). These changes in the composition of LOSBM may assert a positive impact on growth performance as well the carcass characteristics of pig when fed from wean to finish.

The objective of this study therefore, was to evaluate the effect of LOSBM on growth performance in terms of average daily gain (ADG), average daily feed intake (ADFI), gain-to-feed ratio (G:F) and carcass characteristics of pigs from the wean to finish stage. The CP and AA acid content of LOSBM was higher. Therefore, the interaction between LOSBM and the use of fishmeal and spray dried porcine plasma (FM/SDPP) was also evaluated.

**Materials and Methods**

The University of Minnesota Institutional Animal Care and Use Committee approved all experimental protocols.

Crossbred pigs [(Landrace × Yorkshire (Topigs, Winnipeg, Canada)) × Duroc (Comparts, Nicollet, MN), (n = 432, 19 d, 6.6 ± 1.2 kg BW)] were housed in 3 environmentally controlled rooms in wean to finish research facility at the University of Minnesota Southern Research and Outreach Center, Waseca, MN. Each room consisted of 16 pens and each pen was 2.0 m × 3.0 m in dimension with totally slatted floor equipped with a nipple drinker and one self-feeder. Nine pigs were housed per pen and 8 pens per dietary treatment were used in the study. All pigs were allowed ad libitum access to feed and water. The pig's environment (temperature) and health were monitored daily.

A 6 phase wean to finish feeding program was used with a 2 × 3 factorial arrangement of treatments with 2 levels of FM/SDPP (with or without) and three levels of LOSBM inclusion (none, phases 1-3, or phases 1-6). Treatment 1 contained conventional corn-soybean meal in all phases and FM/SDPP in the 3 nursery phases.

Treatment 2 was based on treatment 1, but with no FM/SDPP. Treatments 3 and 5 differed from Treatment 1 by the replacement of conventional SBM with LOSBM in the first 3 or all 6 phases, respectively. Treatments 4 and 6 differed from Treatment 2 by the replacement of conventional SBM with LOSBM in the first 3 or all 6 phases. All diets were formulated to meet or exceed the nutrient requirements as established by NRC 1998. The dietary composition is shown in Tables 2 and 3.

***Growth Performance***

All pigs were ear tagged for identification and weighed at weaning. Phases 1and 2 were 15 d each, phases 3 through 5 was 30 d each, and phase 6 was 15 d. Pigs were weighed and feed disappearance was calculated at the start and at the end of each phase to determine ADG, ADFI and G: F. Pigs were marketed at the average body weight of 115 kg.

***Carcass measurements***

At the end of phase 6, pigs (n = 256) were shipped to commercial abattoir and standard carcass measurements were obtained, which included carcass weight (kg), carcass yield (%), fat depth (mm), loin depth (mm), lean percentage, carcass premium scores (grade index) and carcass value (USD).

***Chemical analyses***

All diets, SBM and LOSBM samples were analyzed for dry matter (DM), gross energy (GE), CP, crude fat (CF), neutral detergent fiber (NDF), acid detergent fiber (ADF) and ash content. All the analyses were done in duplicate and averaged. Samples were dried at 102 ˚C for 4 h in an oven (Thermo Scientific Precision, Thermo Fisher Scientific Inc., Hampton, New Hampshire) to determine DM% (AOAC, 2000 method 939.01. The CP in the feed samples was determined using Kjeldahl method (method 976.05, AOAC, 2000; Kjeltec 2300 Analyzer, Foss, Höganäs, Sweden). Gross energy was determined by bomb calorimeter using IKA$^{R}$-WERKE c2000 basic bomb calorimeter (IKA Werke GmbH & Co. KG**,** Staufen, Germany). CF of the diet samples was analyzed by ether extract method (AOCS, 2009 method Am 5-04) using ANKOM $^{XT15}$ extraction system (ANKOM Technology, Macedon, NY). Samples were analyzed for NDF and ADF using filter bag technique (ANKOM$^{2000}$ fiber analyzer, method 12 and 13, respectively; ANKOM Technology, Macedon, NY). To determine the total ash content, the samples were weighed before and after ashing in high temperature muffle furnace at 600 ˚C for 6 h (Isotemp Muffle Furnace, Thermo Fisher Scientific Inc., Hampton, New Hampshire).

***Statistical Analysis***

All the data were analyzed as 2 × 3 factorial arrangement with 2 levels of FM/SDPP (with or without) and 3 levels of LOSBM (none, phases 1 to 3, or phases 1 to 6) inclusion. The pen served as the experimental unit for the growth performance, and individual animal for the carcass data. Results for growth performance and carcass traits are presented in Tables 3 and 4, respectively.

All statistical analysis was performed using JMP (version 9, SAS Inst. Inc., Cary, NC). Simple effect means were compared using Tukey's HSD pairwise comparisons test in the event of significant interaction between the main effects. Statistical differences were considered significant at $P < 0.05$.

**Results**

Nutritional composition of SBM and LOSBM used in the present study is shown in Table 1. As expected the concentration of raffinose and stachyose is lower in LOSBM than SBM. Due to the removal of these oligosaccharides, the CP and AA content in LOSBM are higher compared to SBM. There was no interaction between FM/SDPP in the nursery and LOSBM in any phase for ADG, ADFI or G: F as shown in Table 4. Average daily gain was not affected by LOSBM in any phase, but was improved by FM/SDPP in phase 2 ($P < 0.01$). Feed intake was reduced only in phase 5 by LOSBM ($P < 0.05$), was not affected by FM/SDPP. Feed efficiency was improved by replacing SBM with LOSBM in phases 1 and 2 ($P < 0.01$) and by the inclusion of FM/SDPP in phase 2 ($P < 0.05$). However these effects did not persist into the later phases and did not affect overall growth performance at market weight. There was no treatment difference in final live weight, carcass weight, fat or loin depth, percent lean, percent yield, grade or value as presented in Table 5.

**Discussion**

Removal of oligosaccharides from SBM by ethanol extraction has been shown to increase ME content of SBM when fed to roosters (Coon et al., 1990). Soybean carbohydrates mainly raffinose saccharides are poorly digested which decreases the efficiency of energy utilization in SBM (Sebastian et al., 2000) which may explain the increased ME value in SBM with reduced oligosaccharide content. It is also believed that these oligosaccharides increase the acidity of the lower intestine, alter the gut osmolarity and increases the viscosity of digesta thereby decreasing digesta transit time (Coon et al, 1990; van Kempen et al., 2006). This change in gut physiology due to the presence of oligosaccharides might reduce energy digestibility (Coon et al, 1990; van Kempen et al., 2006). Similarly, reductions in CP and AA digestibility have been associated with the presence of raffinose and stachyose in SBM (Smiricky et al., 2002; van Kempen et al., 2006). In a recent study, Hinson (2009) observed the NE content of LOSBM to be numerically greater than SBM when fed to grower and finisher pigs. Replacing 25% of conventional SBM with LOSBM did not show any difference in terms of ADG and G:F when fed to grower pigs. These results were consistent with the present study which showed no difference in the overall ADG and

G:F from the wean to finish stage of production. Growing pigs fed diets containing either SBM or LOSBM had reduced lipid accretion and increased protein accretion than pigs fed corn-FM-casein based basal diet (Hinson, 2009). Similarly, protein accretion is higher in pigs consuming diets containing LOSBM than that of pigs on SBM diet (Hinson, 2009). There was no effect of replacing SBM with LOSBM on carcass characteristic in terms of carcass weight, fat depth, loin depth, lean, grade, and percent yield for which the present study was unable to find any difference.

**Conclusion**

Replacing SBM for the entire wean to finish or/and FM/SDPP for the nursery period with LOSBM had no deleterious effect on growth performance or carcass characteristics of wean to finish pigs. Earlier gains in the nursery stage for feed efficiency did not affect overall performance and carcass characteristics of wean to finish pigs.

**Table 1.** Comparison of nutritional composition of conventional soybean meal (SBM) and low oligosaccharide soybean meal (LOSBM)

| Criteria | SBM[1] | LOSBM[2] | LOSBM-SBM (% change) |
|---|---|---|---|
| Dry matter, % | 88.66 | 88.46 | -0.2 |
| Crude protein,% | 46.55 | 53.16 | +6.61 |
| Crude fat, % | 1.23 | 1.09 | -0.14 |
| Crude fiber, % | 2.61 | 1.83 | -0.78 |
| Ash, % | 6.82 | 6.01 | -0.81 |
| Gross energy, kcal/g | 4124.50 | 4187.50 | +63.0 |
| Amino acids, (%) | | | |
| Lysine, % | 3.08 | 3.35 | +0.27 |
| Methionine, % | 0.66 | 0.69 | +0.03 |
| Threonine, % | 1.75 | 1.92 | +0.17 |
| Tryptophan, % | 0.61 | 0.65 | +0.04 |
| Leucine, % | 3.71 | 4.16 | +0.45 |
| Isoleucine, % | 2.27 | 2.49 | +0.22 |
| Valine, % | 2.39 | 2.60 | +0.21 |
| Raffinose, % | 0.58 | 0.08 | -0.50 |
| Stachyose, % | 3.23 | 0.42 | -2.81 |

[1]SBM=conventional soybean meal

[2] LOSBM= low oligosaccharide soybean meal, Schlillinger Seeds Inc., Des Moines, IA.

**Table 2**. Ingredients and analyzed composition of experimental diets (as-fed) in phases 1-3

| | Phase 1 diets | | | | Phase 2 diets | | | | Phase 3 diets | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatment: | 1 | 2 | 3 & 5 | 4 & 6 | 1 | 2 | 3 & 5 | 4 & 6 | 1 | 2 | 3 & 5 | 4 & 6 |
| FM/SDPP[1]: | + | - | + | - | + | - | + | - | + | - | + | - |
| LOSBM[2]: | - | - | + | + | - | - | + | + | - | - | + | + |
| Ingredients, % | | | | | | | | | | | | |
| Corn | 44.04 | 46.92 | 47.99 | 50.87 | 53.11 | 55.48 | 52.10 | 59.45 | 55.61 | 55.71 | 58.63 | 59.60 |
| Spray dried porcine plasma | 5 | - | 5 | - | 1.5 | - | 1.5 | - | - | - | - | - |
| Whey powder | 15 | 15 | 15 | 15 | 8 | 8 | 8 | 8 | 5 | 5 | 5 | 5 |
| SBM[3], (47.5% CP) | 24 | 32 | 0 | - | 28 | 30 | - | - | 32 | 33 | - | - |
| LOSBM, (53.3% CP) | - | - | 20 | 28 | - | - | 26 | 26 | - | - | 29 | 29 |
| Oil | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Fishmeal | 6 | - | 6 | - | 3 | - | 6 | - | 1 | - | 1 | - |
| Limestone | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Dicalcium-phosphate | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| Lysine HCl | 0.27 | 0.4 | 0.3 | 0.41 | 0.3 | 0.4 | 0.3 | 0.41 | 0.3 | 0.25 | 0.28 | 0.28 |
| DL-Methionine | 0.16 | 0.14 | 0.18 | 0.18 | 0.1 | 0.08 | 0.08 | 0.08 | 0.1 | 0.06 | 0.07 | 0.08 |
| L-Threonine | 0.18 | 0.18 | 0.18 | 0.18 | 0.14 | 0.18 | 0.17 | 0.19 | 0.14 | 0.12 | 0.17 | 0.17 |
| L-Tryptophan | - | 0.01 | - | 0.01 | - | 0.01 | - | 0.02 | - | 0.01 | - | 0.02 |
| Salt | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| Vitamin-mix[4] | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Zinc oxide | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| Mecadox | - | - | - | - | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Analyzed Composition | | | | | | | | | | | | |
| Dry matter, % | 92.6 | 92.0 | 92.9 | 92.1 | 92.1 | 92.2 | 92.4 | 91.6 | 89.7 | 89.8 | 90.0 | 89.6 |
| Crude protein, % | 22.25 | 18.25 | 20.83 | 19.36 | 17.74 | 17.05 | 22.18 | 19.07 | 17.06 | 16.96 | 18.5 | 18.73 |
| Crude fat, % | 4.25 | 4.18 | 5.25 | 4.42 | 5.44 | 5.30 | 4.66 | 4.69 | 4.86 | 4.68 | 4.67 | 4.47 |
| Gross energy, kcal/g | 3948.5 | 3897.0 | 4000.5 | 3936.5 | 3940.0 | 3920.5 | 3953.0 | 3944.0 | 3923.0 | 3932.5 | 3967.5 | 3922.0 |
| Neutral detergent fiber, % | 7.64 | 6.67 | 5.63 | 8.00 | 7.61 | 7.73 | 7.83 | 6.85 | 9.10 | 7.24 | 9.97 | 6.46 |
| Acid detergent fiber, % | 3.80 | 3.53 | 2.26 | 3.04 | 3.39 | 3.82 | 2.89 | 3.61 | 4.24 | 3.86 | 3.92 | 4.41 |
| Ash, % | 7.20 | 6.80 | 7.01 | 6.05 | 6.95 | 6.28 | 6.69 | 6.16 | 5.96 | 5.70 | 5.46 | 5.94 |

[1]FM/SDPP= fish meal and spray dried porcine plasma

[2] LOSBM= low oligosaccharide soybean meal, Schlillinger Seeds Inc., Des Moines, IA.

[3]SBM=conventional soybean meal

[4]Vitamin-mineral premix supplied the following micronutrients (per kilogram of diet): 11,000 IU of vitamin A; 2,756 IU of vitamin $D_3$; 55 IU of vitamin E; 55µg of vitamin $B_{12}$; 16,000 mg of riboflavin; 44.1 mg of pantothenic acid; 82.7 mg of niacin; Zn, 150 mg; 175 mg of Fe; 60 mg of Mn; 17.5 mg of Cu; 2 mg of I; and 0.3 mg of Se.

**Table 3.** Ingredients and analyzed composition of experimental diets (as-fed) in phases 4-6

| | Phase 4 diets | | Phase 5 diets | | Phase 6 diets | |
|---|---|---|---|---|---|---|
| Treatment: | 1,3,5 | 2,4 & 6 | 1,3,5 | 2,4 & 6 | 1,3,5 | 2,4 & 6 |
| LOSBM[1]: | - | + | - | + | - | + |
| Ingredients, % | | | | | | |
| Corn | 68.83 | 72.23 | 71.50 | 74.12 | 72.80 | 77.10 |
| SBM[2], (47.5% CP) | 25 | - | 23.5 | - | 22 | - |
| LOSBM, (53.3% CP) | - | 21.53 | - | 20.8 | - | 18.5 |
| Tallow | 3 | 3 | 2 | 2 | - | - |
| Choice white grease | - | - | - | - | 2 | 1 |
| Limestone | 1 | 1 | 0.5 | 0.6 | 0.4 | 0.6 |
| Dicalcium-phosphate | 1 | 1 | 1.4 | 1.4 | 2 | 2 |
| Lysine HCl | 0.2 | 0.28 | 0.2 | 0.15 | - | - |
| DL-Methionine | 0.02 | 0.01 | 0.02 | 0.03 | - | - |
| L-Threonine | 0.09 | 0.09 | 0.03 | 0.05 | - | - |
| L-Tryptophan | 0.01 | 0.01 | - | - | - | - |
| Salt | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| Vitamin-mix[3] | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 |
| Analyzed Composition | | | | | | |
| DM, % | 90.4 | 90.2 | 88.3 | 88.6 | 91.4 | 91.4 |
| CP, % | 12.96 | 14.14 | 13.30 | 14.42 | 11.01 | 13.31 |
| Crude fat, % | 5.71 | 5.26 | 5.21 | 5.57 | 4.77 | 4.46 |
| GE, kcal/g | 3911.5 | 3928.5 | 3912.5 | 4000.0 | 3943.0 | 3839.0 |
| NDF, % | 9.00 | 9.24 | 9.70 | 7.97 | 7.84 | 6.96 |
| ADF, % | 5.71 | 4.25 | 3.37 | 3.25 | 4.95 | 3.26 |
| Ash, % | 4.91 | 5.52 | 4.38 | 4.12 | 4.73 | 4.76 |

[1] LOSBM= low oligosaccharide soybean meal, Schlillinger Seeds Inc., Des Moines, IA.
[2]SBM=conventional soybean meal
[3]Vitamin-mineral premix supplied the following micronutrients (per kilogram of diet): 11,000 IU of vitamin A; 2,756 IU of vitamin $D_3$; 55 IU of vitamin E; 55µg of vitamin $B_{12}$; 16,000 mg of riboflavin; 44.1 mg of pantothenic acid; 82.7 mg of niacin; Zn, 150 mg; 175 mg of Fe; 60 mg of Mn; 17.5 mg of Cu; 2 mg of I; and 0.3 mg of Se.

**Table 4.** Growth performance effect of feeding low oligosaccharide soybean meal (LOSBM) and fishmeal/spray dried plasma (FM/SDPP) from wean to finish[¶]

| | | Average daily gain, g/d | | | Average daily feed intake, g/d | | | Gain to feed ratio | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Phases: | 1-3 | 4-6 | 1-6 | 1-3 | 4-6 | 1-6 | 1-3 | 4-6 | 1-6 |
| | | | | | Main effects | | | | | |
| LOSBM[1] | | | | | | | | | | |
| None | | 634 | 927 | 792 | 1,162 | 2,546 | 1,907 | 0.546 | 0.364 | 0.416 |
| Phases 1-3 | | 645 | 913 | 790 | 1,171 | 2,479 | 1,875 | 0.552 | 0.369 | 0.422 |
| Phases 1-6 | | 627 | 917 | 784 | 1,135 | 2,501 | 1,871 | 0.553 | 0.367 | 0.419 |
| SEM | | 8.5 | 8.2 | 5.3 | 20.0 | 26.6 | 17.4 | 0.006 | 0.002 | 0.002 |
| FM/SDPP | | | | | | | | | | |
| None | | 634 | 922 | 790 | 1,170 | 2,516 | 1,895 | 0.543 | 0.367 | 0.417 |
| Phases 1-3 | | 637 | 916 | 788 | 1,142 | 2,502 | 1,874 | 0.558 | 0.366 | 0.421 |
| SEM | | 7.1 | 6.8 | 4.4 | 16.5 | 22.0 | 14.4 | 0.005 | 0.002 | 0.002 |
| | | | | | Simple effects | | | | | |
| LOSBM | FM/SDPP | | | | | | | | | |
| None | None | 630 | 929 | 791 | 1,147 | 2,570 | 1,913 | 0.551[a] | 0.362 | 0.414 |
| Phases 1-3 | None | 645 | 911 | 789 | 1,200 | 2,458 | 1,878 | 0.539[a] | 0.371 | 0.420 |
| Phases 1-6 | None | 628 | 926 | 790 | 1,164 | 2,519 | 1,894 | 0.540[a] | 0.368 | 0.417 |
| None | Phases 1-3 | 638 | 925 | 793 | 1,178 | 2,523 | 1,902 | 0.542[a] | 0.367 | 0.418 |
| Phases 1-3 | Phases 1-3 | 646 | 916 | 792 | 1,142 | 2,499 | 1,873 | 0.566[a] | 0.367 | 0.423 |
| Phases 1-6 | Phases 1-3 | 627 | 907 | 778 | 1,107 | 2,483 | 1,848 | 0.567[a] | 0.366 | 0.421 |
| SEM[3] | | 12.0 | 11.5 | 7.4 | 28.0 | 37.3 | 24.4 | 0.008[a] | 0.003 | 0.003 |
| *P*-value | | | | | | | | | | |
| FM/SDPP | | 0.81 | 0.54 | 0.75 | 0.23 | 0.65 | 0.31 | 0.02 | 0.89 | 0.18 |
| LOSBM | | 0.33 | 0.48 | 0.51 | 0.42 | 0.20 | 0.27 | 0.59 | 0.41 | 0.17 |
| FM/SDPP × LOSBM | | 0.92 | 0.92 | 0.56 | 0.53 | 0.21 | 0.45 | 0.04 | 0.33 | 0.98 |

[1] LOSBM= low oligosaccharide soybean meal, Schlillinger Seeds Inc., Des Moines, IA.
[2]FM/SDPP= fish meal and spray dried porcine plasma
[3]SEM= standard error of means
[¶] Values are Mean ± SEM (standard error of means)

**Table 5.** Carcass effect of feeding low oligosaccharide soybean meal (LOSBM) and fishmeal/spray dried plasma (FM/SDPP) from wean to finish[¶]

| | | Slaughter Wt., kg | Carcass wt., kg | Fat Depth | Loin Depth | Lean, % | Grade | Value, $ | Yield, % |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Main Effects | | | | |
| LOSBM[1] | | | | | | | | | |
| None | | 119.07 ± 1.14 | 89.33 ± 0.73 | 0.70 ± 0.02 | 2.74 ± 0.03 | 55.47 ± 0.20 | 5.64 ± 0.23 | 160.57 ± 1.57 | 75.15 ± 0.47 |
| Phases 1-3 | | 119.30 ± 1.14 | 89.51 ± 0.73 | 0.68 ± 0.02 | 2.73 ± 0.03 | 55.56 ± 0.20 | 5.87 ± 0.23 | 161.11 ± 1.57 | 75.17 ± 0.47 |
| Phases 1-6 | | 119.67 ± 1.16 | 89.24 ± 0.73 | 0.68 ± 0.02 | 2.77 ± 0.03 | 55.76 ± 0.20 | 5.78 ± 0.23 | 160.53 ± 1.58 | 75.93 ± 0.48 |
| FM/SDPP[2] | | | | | | | | | |
| None | | 119.90 ± 0.96 | 89.52 ± 0.61 | 0.68 ± 0.01 | 2.77 ± 0.03 | 55.72 ± 0.17 | 5.88 ± 0.19 | 161.24 ± 1.31 | 75.62 ± 0.39 |
| Phases 1-3 | | 118.79 ± 0.93 | 89.20 ± 0.59 | 0.69 ± 0.01 | 2.72 ± 0.03 | 55.47 ± 0.16 | 5.65 ± 0.19 | 160.24 ± 1.28 | 75.21 ± 0.38 |
| | | | | | Simple Effects | | | | |
| LOSBM | FM/SDPP | | | | | | | | |
| None | None | 118.85 ± 1.54 | 89.45 ± 0.98 | 0.72 ± 0.02 | 2.73 ± 0.04 | 55.35 ± 0.27 | 5.58 ± 0.31 | 160.79 ± 2.11 | 75.38 ± 0.63 |
| Phases 1-3 | None | 118.73 ± 1.65 | 88.68 ± 1.05 | 0.66 ± 0.02 | 2.78 ± 0.05 | 55.93 ± 0.29 | 6.08 ± 0.33 | 159.90 ± 2.25 | 74.83 ± 0.68 |
| Phases 1-6 | None | 122.12 ± 1.65 | 90.43 ± 1.05 | 0.67 ± 0.02 | 2.79 ± 0.05 | 55.86 ± 0.29 | 5.98 ± 0.33 | 163.03 ± 2.25 | 76.65 ± 0.68 |
| None | Phases 1-3 | 119.28 ± 1.65 | 89.21 ± 1.05 | 0.69 ± 0.02 | 2.75 ± 0.05 | 55.58 ± 0.29 | 5.71 ± 0.33 | 160.36 ± 2.25 | 74.92 ± 0.68 |
| Phases 1-3 | Phases 1-3 | 119.88 ± 1.54 | 90.33 ± 0.98 | 0.70 ± 0.02 | 2.67 ± 0.04 | 55.18 ± 0.27 | 5.67 ± 0.31 | 162.32 ± 2.11 | 75.51 ± 0.63 |
| Phases 1-6 | Phases 1-3 | 117.22 ± 1.62 | 88.04 ± 1.03 | 0.68 ± 0.02 | 2.74 ± 0.05 | 55.66 ± 0.28 | 5.59 ± 0.32 | 158.03 ± 2.22 | 75.21 ± 0.68 |
| *P*-value | | | | | | | | | |
| FM/SDPP | | 0.400 | 0.698 | 0.795 | 0.212 | 0.286 | 0.391 | 0.576 | 0.449 |
| LOSBM | | 0.931 | 0.964 | 0.379 | 0.641 | 0.568 | 0.763 | 0.956 | 0.413 |
| FM/SDPP × LOSBM | | 0.138 | 0.154 | 0.327 | 0.327 | 0.218 | 0.631 | 0.248 | 0.285 |

[1] LOSBM= low oligosaccharide soybean meal, Schlillinger Seeds Inc., Des Moines, IA.
[2]FM/SDPP= fish meal and spray dried porcine plasma
[¶] Values are Mean ± SEM (standard error of means)

# CHAPTER 6

## Overall Summary

Feed cost is a major factor in the swine industry determining the cost of pork production. Although the use of expensive feed ingredients such as fish meal, spray dried plasma protein and whey has been shown to improve the pig's performance, the cost of these feedstuffs is ever increasing and so is its demand in the swine industry. Researchers have been trying to find alternative feedstuffs without affecting the performance of pigs to keep up with the growing demand of pork and cost effectiveness in production.

Swine producers are weaning pigs at an early age to increase sow productivity and to reduce disease transmission from sow to the piglet. Early weaned pigs experience significant stress due to the transition of diet and the change in environment. Feedstuff of animal origin is being routinely used in nursery swine diet. These ingredients are generally used to meet the protein and amino acids requirements of nursery pigs and achieve smooth transitioning. Studies have shown that early use of conventional soybean meal in nursery swine diet has negative effect on growth performance and the health of these pigs. Oligosaccharides such as raffinose and stachyose found in conventional soybean meal (SBM) have been attributed to be the cause of these effects. A soybean variety with reduced level of these sugars has been developed and used in the production of soybean meal (LOSBM). Some studies in pigs and poultry have shown positive to mixed effect for the use of LOSBM in terms of nutrient digestibility and growth performance. However, our studies showed that replacing SBM with LOSBM in the diet of nursery swine has no negative effects on performance. The first study showed that replacing SBM with LOSBM in nursery swine diet could help to lower the viscosity of intestinal content, which might be helpful to mitigate digestive problems associated with ingestion of soybean oligosaccharide from SBM by young pigs. Previous researchers have shown that soybean oligosaccharides hinder nutrient digestion and absorption due to their viscous nature. Absorption of ammonia in the blood circulation is reduced with the presence of fermentable substrates in the diet of pigs which leads to lesser urea formation and ultimately lowers the level of blood urea nitrogen (Mosenthin et al., 1992). We observed a higher level of blood urea nitrogen (BUN) in nursery pigs fed LOSBM diet, which may be due to higher digestibility, and absorption of AA from the gut. Increasing the viscosity of intestinal content in the diet of weanling pigs have been shown to decrease villi height and increase crypt depth of the small intestine when compared to the same product of low viscosity (McDonald et al., 2001). However, higher viscosity associated with feeding SBM compared to LOSBM did not influence the morphology of the small intestine in our study. The substrate used by the authors was non-fermentable compared to fermentable oligosaccharides present in the SBM. In addition, the mean value of intestinal viscosity was higher for that substrate than for SBM in our study, which may explain the difference. On the other hand, it is also believed that dietary fiber may stimulate cell proliferation and growth of the small intestine through SCFA production in the lower intestine (Sakata and Inagaki, 2001). However, there is limited evidence to validate this complex interaction of soybean oligosaccharides, viscosity and intestinal morphology in young pigs.

The digestibility study showed that LOSBM has better ATTD and AID values for DM, energy and NDF compared to SBM in corn-soybean meal based diet for growing pigs, which further emphasizes the benefit of replacing SBM with LOSBM. Apparent ileal digestibility of DM, energy, N, ADF and NDF was improved when the same pigs were used for 7 d adaptation period compared to 5 d adaptation after a month of rest period which indicates that as pig grows older they acquire adaptive characteristics for digestion in the upper intestine due to the development in enzyme production and secretion. However, longer adaptation periods improved ATTD of NDF and ADF compared to 5 d adaptation period. From the growth performance study, it was concluded that removal of FM/SDPP during first three phases and replacing SBM with LOSBM during wean to finish period did not have any negative effect on growth performance as well the carcass characteristics of pigs.

In summary, our results indicate that it may be beneficial to include LOSBM in the diet of early-weaned pigs to reduce negative effect of oligosaccharides without compromising the growth performance and possibly replace FM/SDPP to reduce the cost of feed.

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# Appendices

**Appendix 1**. Telazol/Ketamine/Xylazine (TKX) dosing based on body weight.

| Body Weight | | Cocktail Dose |
|---|---|---|
| Lbs | Kg | mL |
| 44.0 | 20 | 0.9 |
| 48.4 | 22 | 1.0 |
| 52.8 | 24 | 1.1 |
| 57.2 | 26 | 1.1 |
| 61.6 | 28 | 1.2 |
| 66.0 | 30 | 1.3 |
| 70.4 | 32 | 1.4 |
| 74.8 | 34 | 1.5 |

**Appendix 2.** Excede, Penicillin and Banamine dosing based on body weight.

| Body Weight | | Excede | Penicillin | Banamine |
|---|---|---|---|---|
| Lbs | Kg | mL | mL | mL |
| 44.0 | 20 | 1.0 | 0.4 | 0.9 |
| 48.4 | 22 | 1.1 | 0.5 | 1.0 |
| 52.8 | 24 | 1.2 | 0.5 | 1.1 |
| 57.2 | 26 | 1.3 | 0.6 | 1.1 |
| 61.6 | 28 | 1.4 | 0.6 | 1.2 |
| 66.0 | 30 | 1.5 | 0.7 | 1.3 |
| 70.4 | 32 | 1.6 | 0.7 | 1.4 |
| 74.8 | 34 | 1.7 | 0.7 | 1.5 |

**Appendix 3.** Course of feed reintroduction for 25kg pigs following ileal cannulation surgery

| Day | Quantity of feed |
|---|---|
| 1 | No feed on day of surgery |
| 2 | 75g per meal 2x a day |
| 3 | 150g per meal 2x a day |
| 4 | 300g per meal 2x a day |
| 5 | 450g per meal 2x a day |
| 6 | 600g per meal 2x a day |
| 7 | Normal allowance |