EFFECTS OF DIETARY FIBER DURING GESTATION ON SOW REPRODUCTIVE PERFORMANCE

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PERFORMANCE

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Abstract: Although fiber in gestational diets has been reported to be beneficial, there are contradicting results, and to this day there is not a set recommendation on its use. In the first experiment, two levels of total dietary fiber (TDF) with the same insoluble to soluble fiber ratio (ISF:SF) were used. Overall, sows fed the 9% TDF diet were heavier at placement in lactation (306.6 vs. 280.6 kg; $P = 0.012$,). However, sows fed a 18% TDF gestation diet tended to lose less weight during lactation (17.0 vs. 4.0 kg; $P = 0.080$). Consequently, sows fed the low fiber diet had more over-conditioned sows on d 45 and 90 (54.23% vs. 22.92% and 56.38% vs. 21.58% respectively; $P < 0.001$). There were no differences for total born, born alive, stillborn or weaned pigs. In the second experiment, sows received the same TDF, but two different ISF:SF ratios. Results showed that sow BW at placement in the farrowing was not different between diets ($P = 0.747$). On d 45 and 90, BCS were one unit higher for the low ratio diet (12.09 vs. 11.11 and 13.00 vs. 12.15 units respectively; $P < 0.001$). In addition, the low ratio diet group tended to have more fat sows (15.60% vs. 9.10%; $P = 0.080$). Similar to our first experiment, there were no diet effects on total born, stillborn or weaned pigs, but there was an interaction for born alive pigs ($P = 0.046$). Additionally, there was no effect on litter performance. In the third experiment, a diet supplemented with a stimbiotic was compared to a control, with same TDF and ISF: SF. Our data showed that there was a tendency for an interaction between diet and body condition ($P = 0.097$) for farrowing rate. Thin sows fed the stimbiotic supplemented diet had a higher farrowing rate (10% difference, $P = 0.043$). Sow BW and BCS were not different between treatments. Overall, diet had no effect on litter size and performance. Results from these experiments indicated that a 18% TDF fiber with 7.5 ISF:SF was beneficial in controlling body condition in the herd without impacting performance, and a lower ISF:SF or using a stimbiotic did not improve sow or litter performance.

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CHAPTER I

INTRODUCTION

The latest improvements in the maternal genetic lines have led to assessing the nutrient requirement of the sow herd. The increased number of pigs born per litter in the last ten years (13.19 to 15.23 from 2011 - 2021, PigChamp) means that the sow requirements have changed, in both gestation and lactation. Ensuring an optimal nutrition throughout the sow reproductive cycle not only will result in a better gestation outcome, but also improve the sow longevity and profitability.

During gestion nutrients are used for maintenance of the sow, and the development of the litter and its supportive tissues. Hence, the optimal feeding program should be designed to ensure that the sow will be well-conditioned at parturition and optimum litter development. Generally, gestational diets are formulated to be less nutrient dense than a lactation diet, which can be accomplished by adding fibrous byproducts from ethanol and oil production, and flour milling. The purpose of controlling the energy level in the diet is to prevent sows from being over-conditioned, as this is associated with poor reproductive performance as well as negatively affecting sow longevity due to leg problems (Williams et al., 2005; Farmer, 2018). High fiber diets have shown to contribute to satiety and improve overall well-being by reducing stress and behavioral problems associated with restrictive feeding and housing methods, especially in grouped housing (Holt et al., 2006; De Leeuw et al.,2008; Saptoka et al., 2016). Fiber inclusion in gestational diets has shown to improve litter performance by reducing the stillborn piglet rate (Feyera et al., 2017) and decreased pre-wean mortality (Loisel et al., 2013).

Although fiber inclusion has been reported to be beneficial, there are contradicting results on its benefits, and to date there is not a set recommendation on how much fiber should be added. The discrepancies on litter size and piglet weight may be attributed to the different analytic methods used to measure fiber at the time of formulation. The most frequently used analyses are crude fiber (CF) and neutral detergent fiber (NDF), but these may underestimate the dietary fiber in the diet because they only recover insoluble fiber. Total dietary fiber (TDF) is the most accurate, as it measures both soluble and insoluble dietary fibers (Fahey et al., 2019). Prior research has shown that fiber physicochemical characteristics should be considered when formulating, as the results from adding insoluble or soluble fibers leads to different outcomes due to their solubility, viscosity and water holding capacity (Renteria-Flores, 2003; De Leeuw et al., 2008). Therefore, understanding the role of TDF and its fractions on sow reproductive performance could demonstrate the benefits of its application in gestational diets and lead to a better use of fibrous ingredients.

CHAPTER II

REVIEW OF LITERATURE

1. Fiber and its use in animal nutrition

a. Feed ingredients and the use of fiber in swine diet formulations

New market trends and demands affect how food is produced. Recently, consumers have become more interested in where and how their food is produced. In the case of animal protein, housing conditions for pigs and poultry, and the use of antibiotics have been influenced by consumers' concerns about animal welfare, and some producers have adapted their production system in order to keep up with current trends (Alonso et al., 2020). Using available resources as efficiently as possible is essential when thinking about sustainable agriculture. The use of grain and biofuel byproducts, and sourcing feed ingredients more locally, is key when the target is to keep producing animal protein in a world that demands sustainability, but where the land and resources are becoming less available.

One of the major costs associated with animal protein production is feed cost, which accounts for approximately two thirds of total production costs, from which corn and soybean meal are the major components (Lammers et al., 2007; Langemeier, 2021). Feed costs vary based on ingredient availability, seasonality, and the availability of feedstuff that can be used as replacement in formulations. A nutritional strategy used to reduce costs in diets for pigs has been the inclusion of co-products from ethanol, biofuel production and flour milling (Zijlstra and

Beltranena, 2013). These ingredients contain high levels of fiber and in some cases high variability in nutrient content. Fiber is often overlooked in feed formulation. Primarily because its physicochemical effects in the gastrointestinal tract and performance traits are poorly understood. In addition, fiber content, characterization, composition, and variation in some feed ingredients is not accurate, or available.

The most common grains used as energy sources in pig diets are corn, wheat, barley, oat, sorghum, and rye (Jha and Berrocoso, 2015). However, byproducts from grain processing and ethanol and biofuel industries are becoming progressively available and represent an opportunity for livestock production in terms of reducing feeding cost, developing or modifying feeding strategies, and to accommodate the newer customer demands for a more sustainable livestock production.

It is important to note that in general, fibrous feedstuffs contain a lower energy density than corn or soybean meal, which results in a dilution of dietary energy when they are included in the diet (Aherne and Kenelly, 1985). The inclusion of high fiber ingredients in the diet decreases bulk density of the diet and impacts the time spent eating (Renteria-Flores, 2003). A diet that has less bulk density might be beneficial when the purpose is to feed a higher amount of feed to control stereotypies (Robert et al., 1993), and increase satiety without affecting body weight gain or reproductive performance.

The use of fibrous ingredients will depend on the availability, cost, characteristics, and stage of production at which they will be used. For example, DDGS are mainly used in the finishing stage of pig production (Agyekum and Nyachoti, 2017), whereas sugar beet pulp has been used in sow and gilt diet formulations as a source of fermentable fiber, and to delay gastric emptying (De Leeuw et al., 2008). Table 2.1 compiles total dietary fiber (TDF) and the soluble and insoluble fractions from the most commonly used ingredients in swine diets.

Table 2.1
Fiber composition of common ingredients used in swine diets[1]

	Type of fiber,%			
Ingredient	Insoluble	Soluble	Insol:Sol ratio	Total Dietary Fiber
Barley	9.7	5.4	1.8	15.1
Canola meal	15.8	3.2	4.9	19.0
Corn	6.0	0.9	6.7	6.9
Corn DDGS	14.1	3.0	4.7	17.1
Oats, whole	9.8	3.6	2.7	13.4
Oat hulls	65.7	4.9	13.4	70.6
Rye	8.4	3.7	2.3	12.1
Rice bran	17.5	1.2	14.6	18.7
Sorghum	5.1	0.6	8.5	5.7
Soybean hulls	45.0	10.0	4.5	55.0
Soybean meal	12.6	3.9	3.2	16.5
Sugar beet pulp	18.0	25.2	0.7	43.2
Sunflower meal	29.4	5.2	5.7	34.6
Wheat	6.8	2.3	3.0	9.1
Wheat bran	23.8	2.5	9.5	26.3
Wheat middlings	20.2	1.1	18.4	21.3

[1] Adapted from NRC (2012), Jha and Berrocoso (2015)

b. Fiber sources in the U.S.

In 2021, fifteen billion bushels of corn were produced by the U.S., representing more than 30% of the total corn produced globally (USDA, 2022). Corn is one of the main ingredients in livestock diets and its use is expected to keep expanding (Figure 2.1). Globally, corn is increasingly used in swine diets, but as with any feed ingredient, it is dependent on price, quality, availability, and accessibility within a region (Popp et al., 2016). As is expected, pig production is concentrated where corn is produced most efficiently.

The price of corn has increased over the last year. The average price per bushel of corn in 2021 was $5.81, and this year (2022) from January to May the average price was $7.19. The increase in corn prices means that feed costs for livestock production will rise, making the revenue decrease, since pork prices are not projected to increase in the following years (USDA, 2022). Nutritionists must find alternative sources to feed animals, while reducing diet costs without affecting productivity. One option is using co-products from grain milling, and ethanol and biofuel production.

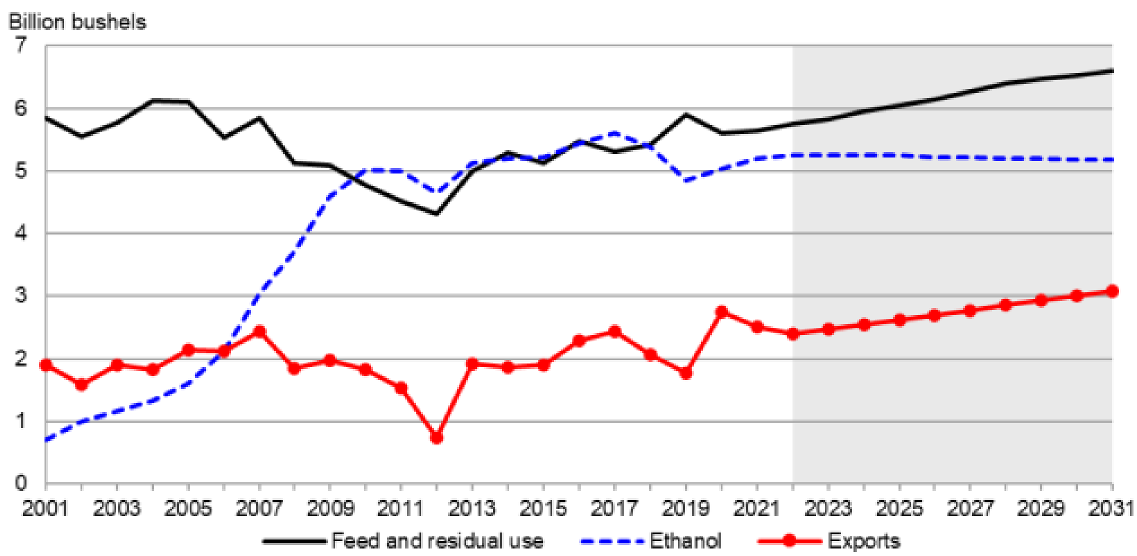

Figure 2.1. U.S. Projections for Corn use in feed and residual use, ethanol, and exports. USDA, Interagency Agricultural Projections Committee. Updated May 2022

The most abundant and widely utilized by-product are distiller's dried grains with solubles (DDGS) (Stein and Shurson, 2009). Distiller's dried grains are the result of fermentation of cereal grains (corn, wheat, etc.) to produce fuel, ethanol, and carbon dioxide. In swine production, growing pigs are fed approximately 10% of the corn DDGS produced annually (Jayasinghe, 2017). However, one disadvantage of formulating diets containing DDGS, and other co-products is that they have a high fiber content, and in some cases, it is highly variable, DDGS have a CV% between 7% and 12.5% in their NDF content (Pedersen et al., 2014; Caldas et al., 2020). Recently, ethanol plants have improved the process with which they extract oil from the solubles fraction, so that swine producers are now using more reduced oil DDGS (Petry et al., 2020a). Reduced oil DDGS contain less fat and greater non-soluble polysaccharides (NSP) than conventional DDGS, and as a result, contain less dietary energy (Li et al., 2017).

Soybeans are the second most important crop in the U.S., in 2021 4.4 billion bushels were produced (USDA, 2022). Soybeans are used for soybean oil extraction and its major coproduct, soybean meal. A byproduct of soybean processing are soybean hulls, often referred as soyhulls or soybean husks, and the yield is approximately 8% of what is processed (Poore et al., 2002). Thus, in 2021, there were approximately 4.4 million tons of soybean hulls available for animal feed. Soyhull's composition is variable and depends on the source of soybeans. Nevertheless, soybean hulls are composed primarily of fiber, with 57% TDF, and 2.4% lignin. The use of soyhulls in monogastric diets is not popular, due to the high fiber content. However, the fiber in soybean hulls is low in lignin and has high potential digestibility for ruminant animals (Poore et al., 2002).

Wheat is one of the most important crops in the U.S., and ranks third behind corn and soybeans, with 1.6 billion bushels produced, and 24 MT exported (USDA, 2022). Most wheat is milled for flour. An estimated 25% ends up as flour mill byproducts, meaning that approximately 5 million tons of wheat byproducts were available for feeding animals in the U.S. in 2021. Wheat middlings or wheat midds are a fraction that results from processing wheat flour. It is a combination of several mill feed fractions, including bran, shorts and screenings (Poore et al., 2002). Wheat middlings are defined by AAFCO (2000) as fine particles of wheat bran, wheat shorts, wheat germ, wheat flour and some of the offal from the "tail of the mill". Wheat middlings contain a higher total dietary fiber (TDF) than wheat, between 23% and 28% of DM, with most of it being insoluble fiber (87% of TDF).

Sugar beet pulp is a source of soluble dietary fiber and highly fermentable compared to other fiber sources. It is high in pectin, a non-starch polysaccharide with the ability to increase viscosity, reducing the rate of diffusion of digestive enzymes into the digesta, and consequently, reducing nutrient absorption (Jiménez-Moreno et al., 2009). The TDF of sugar beet pulp and wheat straw is similar (65.57% vs. 71.54% in beet pulp and wheat straw, respectively) but sugar beet pulp contains a higher percent of soluble dietary fiber than wheat straw (11.7% vs. 0.54% in beet pulp and wheat straw, respectively) while wheat straw contains mainly insoluble fiber (71%) (Renteria-Flores, 2003).

2. Fiber analytical methods

a. Analytical methods to measure fiber

Fiber is defined as non-starch polysaccharides that are not digested or poorly digested by enzymes in the small intestine but are fermented by microbes in the large intestine (ALINORM, 2008). Plant carbohydrates are divided into cell wall components and non-cell wall components (NRC,2012) (Figure 2.2). Various analytical techniques that measure different fiber fractions are available. Among the different methods used to quantify fiber, crude fiber (CF), neutral detergent fiber (NDF), acid detergent fiber (ADF) and total dietary fiber (TDF) are the most common ones.

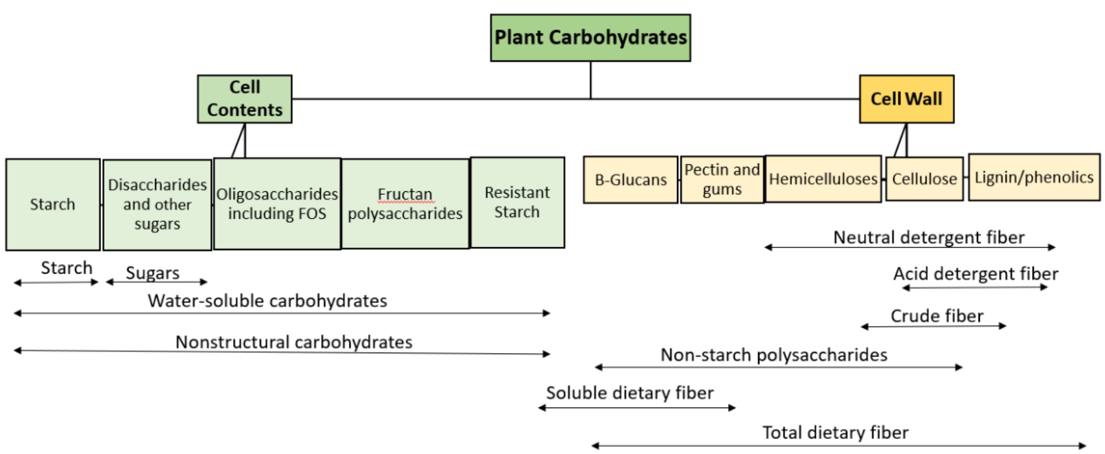

Figure 2.2. Plant carbohydrate fractions. Source: NRC 2012.

The oldest and still frequently used analysis is crude fiber (CF). This is obtained using the Weende method (AOAC 978.10). This technique puts samples through a sequential extraction with petroleum ether, sulfuric acid, and alkali, followed by a gravimetric determination of the residue after drying the sample (Renteria-Flores, 2003). The residue left is a combination of cellulose, hemicelluloses, and lignin (Van Soest and McQueen, 1973). When using this method only an incomplete fraction of the fibrous carbohydrate components is recovered. The proportion of cellulose recovered by the CF analysis is on average 50–90% of the total cellulose content (Cummings, 1976; Kienzle et al., 2001a). The hemicellulose recovered is approximately 20% of the total hemicellulose, and the lignin recovered is between 10% and 50% of the total content (Cummings et al., 1976).

Later, in the 1970's, methods using detergents (NDF and ADF) were developed by Goering and Van Soest (Goering and Van Soest, 1970). Van Soest objective was to develop a method that could analyze cellulose, lignin, and hemicellulose. The NDF method uses a neutral-detergent solution and heat. The sample is boiled, filtered, rinsed, and dried. The residue, which contains hemicellulose, cellulose, lignin and insoluble ash, is weighed and expressed as a percent of the initial sample (Van Soest and McQueen, 1973). The ADF is determined gravimetrically as the residue remaining after using an acid-detergent solution. It is used for the determination of cellulose, lignin, acid-insoluble ash, acid detergent insoluble nitrogen (ADIN) and silica (Van Soest et al 1991). Hence, hemicellulose content in a sample can be calculated by the difference between NDF and ADF.

The TDF analysis is an enzymatic-gravimetric method developed by Prosky et al. (1985). First, the samples are gelatinized with heat stable α-amylase, followed by digestion with proteases and amyloglucosidase to remove protein and starch from the sample (Prosky et al, 1985). After, ethanol is added to precipitate soluble fiber. Then, samples are rinsed and dried. Half of the residues are used for protein analysis and the other half is analyzed for ash. The TDF value is the weight of the residue minus the weight of proteins and ash, divided by the sample weight and expressed as a percent.

The Association of Official and Analytical Chemists (AOAC) has more than ten methods to analyze dietary fiber, which makes it difficult to choose the most appropriate method to quantify fiber. These methods are summarized in table 2.2. From all these, two are the classical procedures, AOAC 985.29 and AOAC 991.43, and two are the most recent ones (AOAC 2009.01 and 2011.25).

Table 2.2 Summary of the Official Methods to Analyze Dietary Fiber by the Association of Official and Analytical Chemists (AOAC)

AOAC Method	Compounds measured
985.29	Total dietary fiber (high molecular weight)
991.42	Insoluble dietary fiber in food
991.43	Total dietary fiber (high molecular weight: soluble and insoluble)
993.19	High-molecular-weight dietary fiber (when >10% fiber and <2% starch)
993.21	High-molecular-weight soluble dietary fiber in foods
994.13	High-molecular-weight dietary fiber, provides sugar composition and Klason lignin
995.16	β-Glucan in cereals, feeds, and foods
997.08	Fructans and fructooligosaccharides
999.03	Fructans and fructooligosaccharides (underestimates highly depolymerized compounds)
2000.11	Polydextrose
2001.02	Trans galactooligosaccharides
2001.03	High- and low-molecular-weight dietary fiber (if no resistant starch is present)
2002.02	Resistant starch (2 and 3)
2009.01	Total high- and low-molecular-weight dietary fiber in all foods
2011.25	Insoluble and soluble dietary fiber of high- and low molecular weight in all foods

*(*Adapted from Garcia-Vaquero M., 2019.Analytical Methods and Advances to Evaluate Dietary Fiber*)*

b. Total Dietary Fiber (TDF)

Total dietary fiber (TDF) is the most encompassing and arguably the most accurate measurement of fiber, as it measures both soluble and insoluble dietary fibers (Fahey et al., 2019). Dietary fiber includes non-starch polysaccharides, resistant starch, and resistant oligosaccharides (Blackwood et al., 2000). The advances in nutritional research have led to many definitions used to describe dietary fiber. An accepted definition was that dietary fiber (DF) comprises the edible parts of a plant that are not hydrolyzed by the endogenous enzymes in the mammalian digestive tract (Trowell ,1976). However, in 2009 the dietary fiber definition was revised by the CODEX Alimentarius Commission, and after review they defined it as carbohydrate polymers with ten or more monomeric units, which are not hydrolyzed by the endogenous enzymes in the small intestine (ALINORM , 2008).

Prosky et al. (1985) developed a procedure that used three digestive enzymes to analyze fiber. This methodology quantified the undigested residue as total dietary fiber (TDF) content. The residue from the TDF method includes both soluble and insoluble fiber. Years later, in 1992 Lee et al. published a modified version of TDF quantification. This modification separated dietary fiber (DF) into two fractions based on the water solubility of DF, these fractions were identified as soluble (SF) and insoluble dietary fiber (ISF) (Figure 2.3). Most fiber-containing foods have about one-third soluble and two-thirds insoluble fiber (Cummings, 1981). Moreover, fiber can be classified based on its physicochemical characteristics: viscosity, and fermentability, which have been recognized as producing beneficial physiological responses (Roberfroid, 1993).

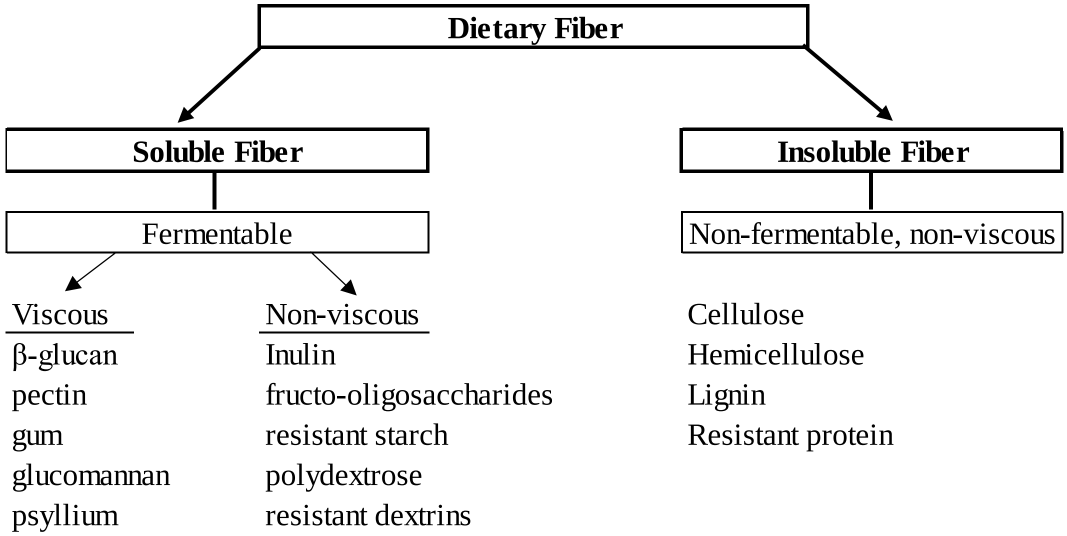

Figure 2.3. Fiber classification according to chemical properties. Adapted from Jha and Berrocoso, 2015

c. Soluble Dietary Fiber (SF)

The soluble fiber fraction includes pectins, gums, and inulin, among others. Soluble fiber can be distinguished by its ability to form viscous gels and it generally increases the time through the digestive tract, which results in delayed gastric emptying and delayed absorption of nutrients (Scheeman, 1998; Leeuw et al., 2008). Delayed gastric emptying promotes satiety and reduces hunger (Davidson and McDonald, 1998). Diets containing fiber with high water-holding capacity may result in an increase in gastric distension and intestinal fill, limiting the voluntary intake (Lepionka et al., 1997). Soluble fibers are usually completely fermented by intestinal microbiota, predominantly in the large intestine, and have little effect on fecal bulk volume (Wong and Jenkins, 2007).

d. Insoluble Dietary Fiber (ISF)

The insoluble fiber fraction includes mainly cellulose and lignin. Opposite to soluble fibers, insoluble fibers such as wheat bran tend to decrease intestinal transit time, which limits nutrient digestion and absorption (Mroz et al., 1986), and increase fecal bulk (Renteria-Flores, 2003). Insoluble fiber does not retain water and is less likely to be fermented by intestinal microbiota. Additionally, research in sows showed that insoluble fiber decreases energy digestibility (Chabeauti et al, 1991; Renteria- Flores, 2003).

e. Physicochemical properties of fiber

The physiological effects of dietary fiber depend on its physicochemical properties, solubility, viscosity. fermentability, water absorption and water-holding capacity. The physicochemical properties are determined by the polymer subunits, linkages, structures, and side chains (Li et al., 2022), and have a direct impact on nutrient digestion and absorption, as they will affect intestinal transit time, satiety, intestinal microbiome, and overall intestinal health.

Fiber viscosity or gel formation is associated with dietary soluble fiber and its ability to absorb water, which results in a gelatinous mass that resists the effects of gastrointestinal motility (Renteria-Flores, 2003). Pectins, gums, psyllium, and β-glucan can form viscous solutions when they interact with an aqueous phase, and these can increase the volume and viscosity of the digesta (Mudgil, 2017). Additionally, viscosity has close association with short chain fatty acid (SCFA) production, as viscosity is closely related with fiber solubility, and soluble fiber is highly fermentable (Agyekum, and Nyachoti, 2017). Viscosity also alters the intestinal transit time and slows the gastric emptying rate (Schroeder et al. 2013; Müller et al., 2018). For example, β-glucan, a soluble viscous fiber, through fermentation and production of butyrate stimulates the secretion of the hormone glucagon-like peptide 1 (**GLP-1**), which signals fullness and can inhibit appetite, as a result feed intake is decreased (Adam et al., 2014; Deleu et al., 2021).

Fermentability is the most important characteristic of dietary fiber. It is known that fermentable fiber is associated with solubility (Williams et al., 2017). Thus, the more soluble, the more fermentable. (Agyekum, and Nyachoti, 2017). The process of fermentation allows colonic bacteria to use fiber as an energy source, and results in SCFA production, mainly acetate, propionate and butyrate. Butyrate is used as an energy source by colonocytes, contributing to the intestinal epithelial health (Serena et al., 2008; Priester et al., 2020). Acetate and propionate are transported to the liver and peripheral tissues, regulating biological processes in the host (Koh et al. 2016). For example, propionate diffuses into the hepatic portal vein to be used for hepatic gluconeogenesis (Ashaolu et al., 2021).

Water absorption and water holding capacity (WHC) are the main hydration properties measured of dietary fibers; they describe volume change and water retention respectively. These properties depend on the fiber porosity, structure of the fiber, ionic form, and solution pH (Tejada-Ortigoza et al., 2015). Water holding or water retention capacity is described as the amount of water that is retained by 1 gram of fiber under specified conditions of temperature, soaking time, and centrifugation speed; it consists in the assessment of the physically trapped water, the bound water, and the hydrodynamic water. (Tejada-Ortigoza et al., 2015; McRorie and McKeown, 2017). On the other hand, water absorption or swelling capacity is determined by measuring the change in volume after an overnight water immersion of the fiber (Tejada-Ortigoza et al. 2015).

3. Fiber digestion and its effects

a. Fiber fermentability and SCFA

Fermentability is an important characteristic of fiber, but it is highly variable, ranging from 48% to 95% (Jha and Berrocoso, 2015). Fermentability variation can be attributed to the physicochemical characteristics of the fiber. For example, some fibers like lignin have little to no fermentation. On the other hand, pectin and some hemicelluloses, can go through an almost complete fermentation (McRorie and McKeown, 2016; Mudguil, 2017). Fermentation takes place in the cecum and proximal and distal colon (Macfarlane and Gibson, 1995). Fermentation of soluble fiber occurs mainly at the proximal colon, whereas fermentation of insoluble fiber happens at the distal colon (Choct, 1997).

Fermentation is a mechanism by which colonic microbes utilize fiber as an energy source. Microbial fermentation results in the production of principally acetate, propionate, and butyrate (Jorgensen and Jensen 1994), which play an important role in regulating energy metabolism, immunological function, and intestinal cell proliferation of the host (Koh et al., 2016). Other acids produced include formate, valerate, caproate and gasses like hydrogen, methane, and carbon dioxide (Koh et al., 2016). From the three main SCFA produced, acetate is the most abundant with 60% of the total, and propionate and butyrate are produced in smaller quantities (Lunn and Butriss, 2007). Short chain fatty acids (SCFA) are absorbed by the intestinal cells and satisfy 10% to 30% of the pig's maintenance energy requirement (Varel and Pond 1985).

Recent advances have allowed us to understand how bacteria are responsible for SCFA production. Complex cell wall polymers are broken down by bacterial enzymes such as polysaccharidases (Salyers et al., 1996). These enzymes degrade polymers into their respective sugar components, into oligosaccharides and then monosaccharides (den Besten et al., 2013; Williams et al., 2017). After microbial hydrolysis of cell wall polymers (Williams et al., 2017), pyruvate is produced (Figure 2.4) through the glycolytic pathway for deoxy- hexoses and hexoses, and through the pentose-phosphate pathway for pentoses (Hugenholtz et al., 2013). Pyruvate is the main precursor for SCFA (Macfarlane and Macfarlane, 2003). Acetate production pathways are distributed among several bacterial groups, whereas pathways for propionate, butyrate and lactate production seem more highly conserved and substrate specific (Morrison and Preston, 2016).

Acetate is the major contributor to the overall production of SFCA (Macfarlane and Macfarlane, 2003). Production of acetate derives from pyruvate. First, the pyruvate dehydrogenase (PHD) complex converts pyruvate to Acetyl-CoA. Next, the enzyme Acetyl-CoA synthetase is responsible for acetate being metabolized in various tissues such as liver, heart, kidney (Macy et al., 1978).

Propionate can be produced through two pathways, the succinate pathway (the most common) and the propanediol pathway (Reichdart et al., 2014). First, in the succinate pathway, succinate acts as the substrate for propionate formation. Methylmalonyl-CoA is decarboxylated to propionyl-CoA and propionyl-CoA synthetase converts it to propionate (Macy et al., 1978). On the other hand, propionate production through the propanediol pathway which is particular of deoxy-hexose sugars is dependent on the carbohydrate available for growth in other bacteria, with fucose and rhamnose reported as being propionigenic (Reichdart et al., 2014).

Formation of butyrate starts from condensation of two molecules of acetyl-CoA and subsequent reduction to butyryl-CoA (den Besten et al., 2013). There are two pathways from where butyrate can be synthesized, the butyryl-CoA: acetate CoA transferase, and the butyrate kinase pathways. The butyryl CoA: acetate CoA transferase pathway is used by most of the microbial population (Duncan et al., 2004; Louis and Flint, 2009). Acetyl-CoA is converted to Butyryl-CoA, then in one enzyme reaction facilitated by butyryl-CoA: acetate- CoA transferase butyrate is produced.

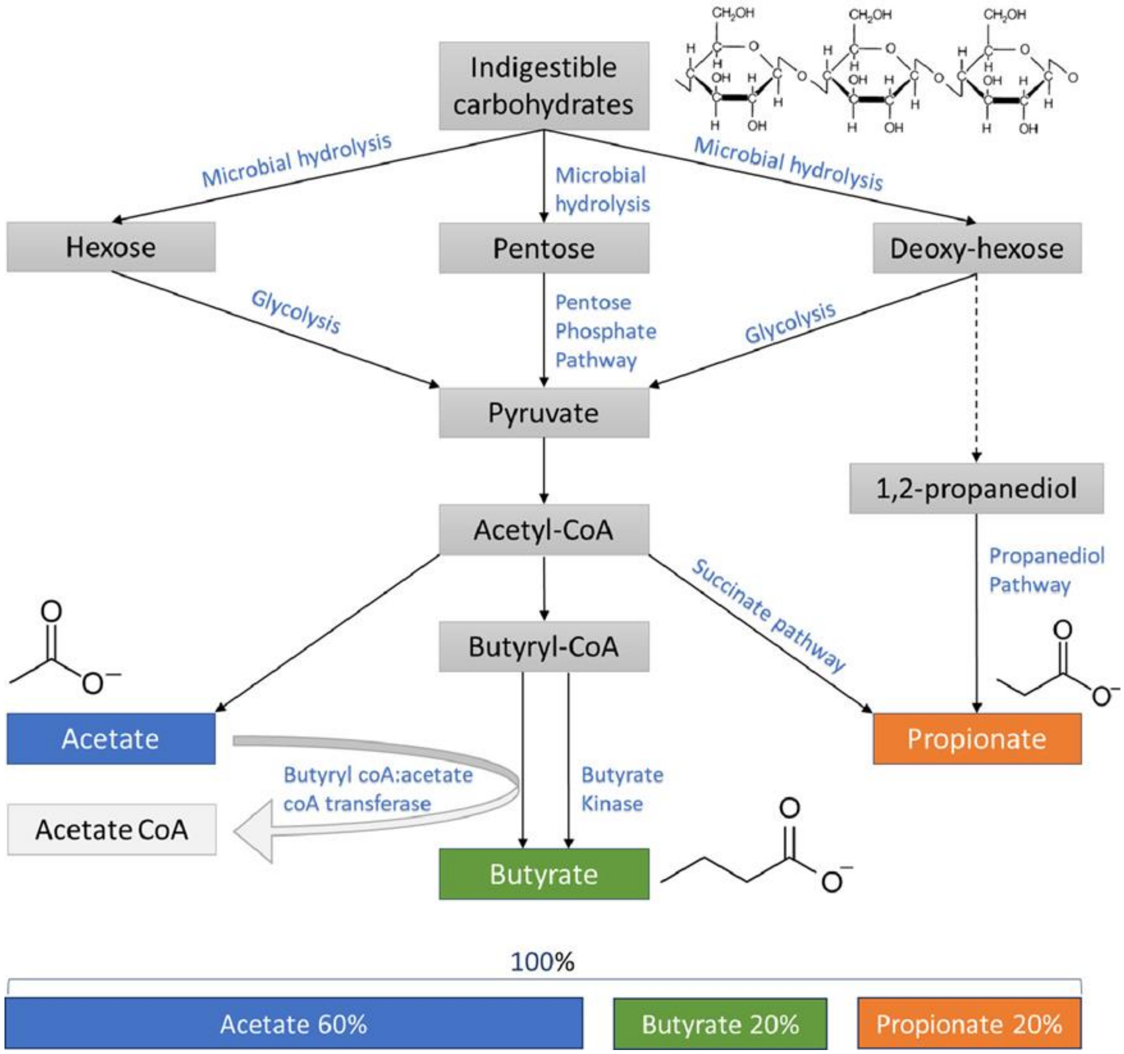

Figure 2.4 Overview of the pathways of bacterial fermentation resulting in the production of SCFA hydrolysis. Source: Deleu et al., 2021

After their formation, SCFA are rapidly absorbed from the hindgut, approximately 95% (Von Engelhardt et al., 1989). The amount of SCFA absorbed varies among species; in the dog it is 7.5 mmol per day, whereas in the pig it is 95 mmol per day (Clemens and Stevens, 1980). Once SCFA are absorbed, they are metabolized in colon, liver, and skeletal and cardiac muscles (Gibson and Roberfroid, 1995).

The colonocytes absorb butyrate and other SCFAs through different mechanisms of apical membrane SCFA uptake. The uptake involves two mechanisms: 1) passive diffusion and 2) active transport. The active transport occurs primarily in the anionic dissociated form (more than

95%) and they use an anion exchanger ($SCFA/HCO^{-}_{3}$) (Sellin, 1999). As for passive diffusion, the protonated form of short chain fatty acids is lipid soluble, thus, no transporter is required. Although only a small portion of the short chain fatty acids is present in this form. Additionally, SCFA uptake by colonocyte cells are performed through H+ -linked monocarboxylate transporters (MCTs) and sodium- linked monocarboxylate transporters (SMCTs) (Schönfeld and Wojtczak,2016).

b. Effects of dietary fiber in the gastrointestinal tract

Livestock relies greatly on a healthy gut to ensure optimal growth performance, feed efficiency, and to maintain overall health (Pluske et al., 2018). The effects of dietary fiber on gut health and intestinal development are continuously studied. Dietary fiber has proven to support intestinal health by promoting beneficial bacterial community and hindgut fermentation . It also promotes intestinal mucosal growth through butyrate serving as the main energy source for colonocytes (Kripe et al., 1989). Although dietary fiber may be beneficial, not all fibers are equal in terms of the health benefits they provide. Dietary fiber has different fractions, and chemical structures that are utilized differently by gut microorganisms. Hence, the effect of feeding a higher fiber diet, without considering the soluble and insoluble portions, and chemical profile may result in different outcomes.

The type of dietary fiber has different effects on the gastrointestinal tract and has considerable impact on gut microbiota. Insoluble fiber (ISF) has been reported to decrease the transit time of digesta, and it contributes substantially to fecal bulk. Soluble fiber (SF) on the other hand, is readily fermentable by colonic bacteria (Renteria-Flores, 2003), which affect both gut morphology and function (Jha and Berrocoso, 2015). Opposite to ISF, SF can create a viscous intestinal content, that may delay gastric emptying and interfere with intestinal absorption (Slavin, 2005).

The preferred energy substrates by epithelial cells in the colon are short-chain fatty acids, ketone bodies, amino acids, and glucose. (Williams et al., 2005). Priester et al. (2020) showed that high fiber diet had a positive effect by increasing jejunum length and stomach volume, as well as colonic crypt depth and circumference. Colonocytes preferentially utilize butyrate as an energy source. Butyrate provides energy to the intestinal epithelial cells by β-oxidation in the mitochondrial tricarboxylic acid cycle (TCA cycle) (Parada Venegas et al., 2019). Additionally, butyrate stimulates cell proliferation in the basal crypt in the colon.

By nature, the environment of the large intestine is anaerobic and acidic (Williams et al., 2005). One of the contributions of short chain fatty acids to intestinal health, is the preservation of that anaerobic environment by maintaining an acidic pH between 5.5 and 6.5 (den Besten et al., 2013). A low pH provides a suitable growth environment for the proliferation of beneficial bacteria, such as *Bifidobacterium* and *Lactobacillus*, and further reduces intestinal pH and bacteria susceptible to acidic conditions (Yang and Zhao, 2021). As a result, the growth of pathogenic bacteria and invasion of pathogens is inhibited (Macfarlane and Macfarlane, 2012; Yang and Zhao, 2021).

c. SCFA and satiety signaling

Short chain fatty acids produced by microbial fermentation affect satiety by stimulating enteroendocrine cells to produce glucagon-like peptide 1 (GLP-1) and peptide tyrosine-tyrosine (PYY; Yang and Zhao, 2021). The SCFA produced by the fermentation of dietary fibers bind to the G-protein-coupled receptors (GPCRs) GPR41 and GPR43, thereby triggering GLP-1 secretion by the L-cells. (Figure 2.5). These two satiety hormones are released in response to food intake from endocrine L-cells in the distal part of the GI tract. GPR41 activated by SCFA promotes the secretion of PYY which inhibits gastric emptying and food intake, whereas GPR41 and 43 promote the secretion of GLP-1 (Psichas et al., 2014).

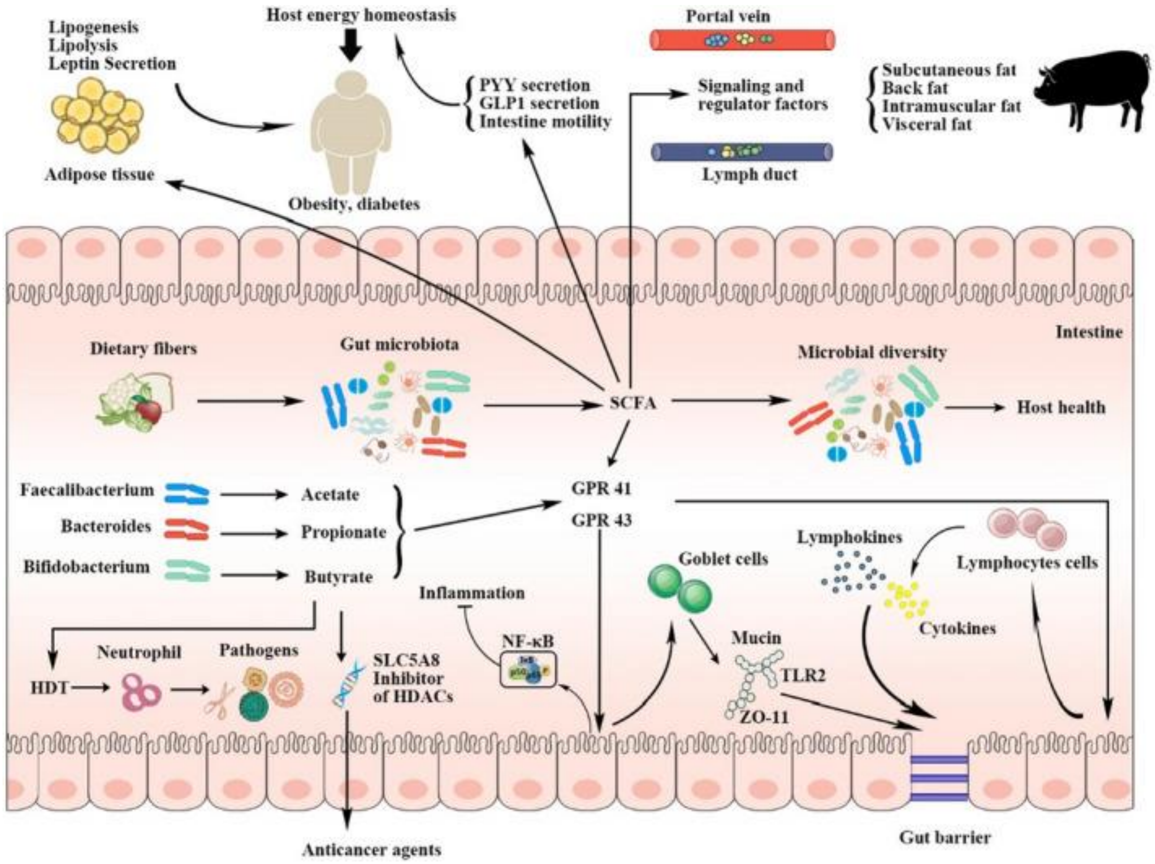

Figure 2.5. Trophic mechanisms of dietary fibers fermented by gut microbiota on energy metabolism and gut health in pigs and humans. Source: Yang and Zhao, 2021

Huang et al. (2020) reported that using two different fiber sources in gestational diets, 5% resistant starch (RS) or 5% fermented soybean fiber (FSF) with the same NDF resulted in different serum concentration of PYY and GLP-1 on d 70. The concentrations were higher for RS than for FSF 2h postprandial, which led them to the conclusion that the secretions of these two hormones are dependent on the diet composition and not just the NDF level.

4. Fiber use and its application in swine production

a. Fiber use in nursery diets

Fiber can be used in nursery diets to ameliorate postweaning diarrhea (PWD) that typically affects weanling pigs the first two weeks after weaning (Rhouma et al., 2017). Postweaning diarrhea economically impacts producers, as it causes a slower growth, dehydration, reduced nutrient digestibility and in severe cases death (Heo et al. 2013). Insoluble fiber is preferred in nursery diets to prevent colonization of pathogenic bacteria (Helm et al., 2021). Wheat bran and oat hulls, contain high insoluble fiber and act as a bulking agent and has water-binding capacity (Jha and Berrocoso, 2015). Research showed that the inclusion of 1.5% purified cellulose reduced the incidence of diarrhea in weaned pigs, and it was proposed that the adherence sites of pathogenic bacteria were blocked by the inclusion of cellulose (Pascoal et al., 2012). Furthermore, pigs that received 4% coarse wheat bran reduced diarrhea due to the decreased ability of *E.coli* to adhere to the small intestine (Molist et al., 2011).

Despite the variability in their particle size, chemical composition, and nutrient digestibility (Cromwell et al., 1993) the use of DDGS in nursery diet formulation is a common practice. Similar growth performance has been observed when pigs are fed DDGS concentrations between 10% (Cromwell et al., 1993) or 20% (Combs and Wallace, 1969) of the diet. However, others have reported that a reduction in performance from the addition of DDGS (Wahlstrom and Libal, 1980). Diets with DDGS concentrations up to 25% from day 18 to day 39 post-weaning were fed without affecting growth performance, but including them in diets for pigs below 7 kg, showed to be detrimental for feed intake and growth (Whitney and Shurson, 2004). Additionally, the effects of adding 7.5% DDGS, soybean hulls or citrus pulp showed no difference on growth performance, or circulating markers of inflammation, but feeding DDGS increased the expression of both proinflammatory and anti-inflammatory cytokines in intestinal tissue (Weber et al., 2008).

The inclusion of other fiber sources such as rice hulls or wheat middlings in diet formulations used the first three weeks post-weaning increased feed intake and reduced the probability of mortality and morbidity (Ebarb et al., 2021). Additionally, there was no effect of fiber source on growth performance when pigs were fed coarse wheat bran, oat hulls, or cellulose after weaning, but pigs fed cellulose had increased fecal dry matter when compared to the other two sources (Batson et al., 2021).Overall, the inclusion of fibrous ingredients in nursery diets has shown to have a positive impact on gastrointestinal health, without negatively affecting growth rate and performance.

c. *Fiber use in finishing diets*

Diets for growing pigs are primarily formulated to improve the efficiency of feed utilization and increase protein accretion. The addition of fiber in diets is usually associated with reduction in digestibility and carcass yield (Mauch et al., 2018). Hence, using appropriate levels during finishing is important to prevent the feed conversion from being negatively affected and market pigs at the target weight without increasing time in the barn.

The events from the COVID-19 pandemic presented challenges in packing plants around the U.S. from processing capacity being reduced and supply chain disruptions. This unexpected event meant nutritionist had to modify their diet formulations to slow growth rate at finishing barns. Using highly fibrous ingredients in the diets was one of the mechanisms suggested to slow animal growth (Patience and Greiner, 2020; Tockach et al., 2021). Patience and Greiner (2020) recommended the use of DDGS, wheat midds, corn germ, or soy hulls, which have high TDF and are primarily insoluble; the NDF content in the diet advised was 20% or higher in order to decline growth rate. DDGS are commonly used in finishing diets, but unlike other fibrous ingredients their apparent total tract digestibility (ATTD) varies significantly from 23% to 55% due to the different methods used for ethanol production (Kerr and Shrurson, 2013).

Moore et al. (1988) found that high fiber diets (14.3% to 17.3% NDF) reduced ATTD of GE, DM, and N in growing pigs. Similar findings were reported by Helm et al. (2021) that showed that increasing NDF levels by adding soybean hulls for 28 days in pigs (approximately 70 kg BW) had a linear relationship with decreased ADG, backfat and loin muscle area, which meant that carcass composition was altered. Although not significant, pigs fed the 25% NDF diet were 7.3 kg lighter than the control.

c. Fiber use in gilt development diets

Gilt replacement and management in conventional production systems are one of the main factors to maintain an optimal reproductive performance of the sow herd. Normally, the return on investment for a gilt is reached after their third parity. Hence, their development, reproductive performance and longevity are crucial. The main factors that affect sow longevity are BW, body condition and gilt breeding age. To achieve optimal gilt development and improve mammary development in pre-pubertal stages special attention must be given to the feeding strategies (Farmer, 2018). Appropriate mammary gland development can be reached without maximizing energy intake, but low intake may reduce mammary DNA, especially after day 90, which means mammary development may be impaired (Faccin et al., 2022).

Recent research suggests that ovarian follicle development and embryo survival could be enhanced by dietary fiber (Renteria-Flores et al., 2008). The number of primordial follicles and total follicles per cubic centimeter of ovarian tissue linearly increased with dietary fiber level when gilts were fed 50, 75 and 100 percent more dietary fiber compared to the control (Cao et al., 2019). Ferguson et al. (2007) studied the effect of high fiber from the third post-pubertal oestrus until either day 19 of the same cycle or insemination on oocyte maturity, embryo survival and hormonal changes. The results from the previously mentioned study reported more oocytes recovered on day 19, and embryo survival was higher on d 27-29 after insemination (73.2 vs 91.2

%; $P = 0.021$) from gilts fed a high fiber diet (50% sugar beet pulp) compared to the control. However, no effect was found on ovulation rate or progesterone concentrations on d 10-12 after insemination. This suggests that a high fiber diets prior to mating may be beneficial on embryo survival, and consequently impact the gestation outcome.

Fiber can reduce the nutrient absorption in the digestive tract (Wenk et al., 2001). However, this may be beneficial if the purpose of the feeding program is to control BW gain. Gilts being over-conditioned, weighing more than 170 kg are at less likely to reach a third parity, due to a higher culling rate for locomotion problems, lameness, and leg problems (Kummer, 2008; Farmer, 2018). Gregory et al., (2020) found that gilts who were fed an ad-libitum high fiber diet from day 90 to 190 of age weighed less at breeding than those fed the control diet (146.5 vs 152.7 kg), and consequently had less back fat (14.9 vs 16.7 mm; $P < 0.05$). Although controlling weight in gilts to prevent future performance issues is important, they should weigh at least 135 kg at breeding to minimize protein loss during lactation and increase lifetime productivity and longevity in the herd (Williams et al.; 2005). Winkel et al. (2018) showed that gilts fed a restricted energy diet, via addition of 40% soy hulls, were lighter at d 109 of gestation (216.33 vs. 232.06 kg; $P = 0.003$) and had less backfat (1.83 vs 2.4 mm; $P = 0.041$) prior to parturition but had no different backfat thickness at weaning compared to gilts fed a control diet.

While ensuring optimal reproductive performance of gilts is a priority, it is also important to ensure an optimal gastrointestinal development. Priester et al. (2020) showed that gilts fed a high fiber diet had a stomach 100 grams heavier ($P = 0.007$) and the jejunum was approximately 2 meters longer ($P = 0.019$) compared to gilts receiving a lower fiber concentration. The high fiber diet also had an impact on the development of colon crypts, with a difference of 44μm ($P = 0.099$) in crypt depth and almost 100 μm in crypt circumference ($P=0.090$) from samples taken from the proximal colon. In the same experiment, subsequent litter performance showed an improvement when fed a high fiber diet with higher swelling capacity, by an increase in litter size, significant difference in litter birth weight (20.6 vs 15.9 kg; P= 0.045) and a higher number of pigs weaned (12.2 vs 10.3; P=0.001). Although the benefits of fiber inclusion in gilt diets have been reported, there are still contradictive results, which may be attributed to the length and phase at which the high fiber diets are fed, and no optimal level of dietary fiber has been stated.

5. Sow Nutrition

a. Gestational period

The gestational period can be separated in three major phases. The first phase is early pregnancy (d 0-30) when ovulation occurs and the fertilized embryos elongate and attach to the uterus between d 12-15, and placental expansion begins. The next phase is mid-gestation (d 30-77) when noticeable organ development begins, and bones start calcifying around d 40. Pigs that die during this phase will present as mummies at farrowing. The third phase is late gestation (d 75-115) where mammary tissue expands, colostrum and milk production begin, and fetal growth continues (Hines and Chandool, 2021). Protein and energy requirements become higher during this period to support the sow and its progeny (Theil, 2015).

Breeding sows are commonly fed to obtain and maintain an optimal body condition throughout the reproductive cycle. Generally gestational diets are formulated to be less energy dense and restrictive feeding during gestation is used to prevent the excess BW gain and back fat, with the purpose of ensuring fewer complications at farrowing, or decreased reproductive performance. There is consistent research that supports the negative impact of over-feeding sows on litter size and sow performance. Mallmann et al. (2020a) fed three different feeding levels from d 6 to 30 of gestation and reported that the number of piglets born decreased linearly when the feed levels increased (P=0.041), but there was no effect on the pigs born alive. In addition to a decreased litter size, over-conditioned sows may have a lower feed intake during lactation (MacPherson et al., 2004) which would mean a greater BW loss and possibly lighter weaned pigs.

When looking at litter birth and weaning weight, we can think of the correlation this has with the amounts and nutrient content in the milk produced. The sow will be in a negative nutrient balance during lactation, as she will mobilize nutrients from her body tissue reserves to produce milk (Strathe et al., 2015). The negative energy and nutrient balance can be managed by offering an energy dense diet during lactation, but the feeding capacity of the animal will determine how much feed can be consumed (Priester et al., 2020).

b. Sow nutrition strategies

Genetic improvement has led to very prolific maternal genetic lines. In 2020 the upper 10^{th} percentile of sows had an average total pigs born per litter of 16.22 and weaned 12.79 pigs (PigChamp, 2021). As a result of the increased productivity, the nutritional requirements have changed over time. Sow requirements vary by stage. During the gestational period diets are formulated to support the sow maintenance requirements and the products of conception. Generally, gestational diets are less nutrient dense, and the feed amount is adjusted to prevent sows from being over or under conditioned. Current practices in a sow nutritional program include feeding an extra kg of feed in late gestation (d 90) to poorly-conditioned sows, aiming to provide sufficient nutrients to the fast-growing fetuses. Shelton et al. (2009) found that gilts had increased number and total weight of the total born, live born, and number after fostering ($P < 0.02$) compared with older parity sows. In contrast, Mallman et al. (2018) reported no benefits on litter size ($P > 0.13$) or piglet weigh at birth for either sows or gilts ($P > 0.90$). These results however, may be due to the study using only well-conditioned animals.

Different from gestation, lactational diets have higher nutritional content as the sow utilizes her fat and muscle tissue for milk production, and nutrient requirements are higher. Ensuring the consumption of optimal nutrient and energy levels becomes particularly important during lactation to maximize lactation output and long-term productivity and prevent sows from being culled after weaning due to being poorly conditioned. Increasing lactation feed intake in addition to a diet formulated to meet or exceed sow requirements during lactation will aim to decrease the body condition and BW loss during lactation, and to ensure a proper transition to the subsequent cycle (Beyer et al., 2007; Gauthier et al., 2019). The use of soluble fiber in gestational diets has shown to increase average daily feed intake in lactation and lead to a lower body weight loss (Danielsen and Vestergaard, 2001; Renteria Flores et al., 2008)

c. Fiber use in gestational diets

Over the last decade litter size has increased as a result of genetic improvement (Rohrer et al., 2017). Hence, gilt and sow nutritional requirements have increased. During gestation the target is to have the majority of the sow herd in an optimal body condition. In order to control BW gain gestational diets are formulated to be less dense, and sows are restrictive-fed to avoid being over-conditioned as this has shown to be detrimental in terms of sow longevity and reproductive performance (Williams et al., 2005; Farmer, 2018). While the benefits of controlling feed and energy intake during gestation are reported (MacPherson et al., 2004; Mallmann et al., 2020a), there are concerns regarding sow welfare, especially for grouped housed sows due to feed competition and stereotyped behavior. Abnormal behaviors and abnormal physical activity may reflect animal satiety (De Leeuw et al., 2008).

High fiber diets in gestation have been used to contribute to satiety (Sapkota et al., 2016), reduce stress during gestation (Holt et al., 2006), and maintain normal reproductive performance. Conventional fiber sources in gestational diets include wheat midds, soybean hulls, oats, alfalfa meal, sugar beet pulp, rice bran, DDGS, sunflower meal and barley (NRC, 2012; Flis et al., 2017). The use of fibrous ingredients can reduce hunger and ameliorate the behavioral problems associated with restrictive feeding (De Leeuw et al.,2008). It also helps decrease the stereotyped behavior by increasing the sense of satiety when the fiber source has characteristics of being viscous and soluble, as these two will affect passage rate (De Leeuw et al.,2008; Serena et al., 2008). Fibrous ingredients depending on their physicochemical characteristics can increase eating and chewing time, increase gastric fill (increased mechanoreception), slow down nutrient absorption and increase transit time of digesta (De Leeuw, 2008).

Several studies have been conducted to assess the impact of feeding high fiber levels during gestation on the pregnancy outcome. Previous research in gestation showed that increasing fiber can improve litter size, but fiber physicochemical characteristics are just as significant as the fiber levels (Renteria Flores et al. 2008). While fiber is important for digestion and performance, its solubility, viscosity, and water holding capacity are key when choosing fiber sources. Sows fed a higher percent of SF (30% oat bran) prior to mating and early gestation showed an increased embryonic survival compared to the other diets that had fibrous ingredients with high ISF (12% wheat straw and 21% high soluble and insoluble fiber) suggesting that ISF might be detrimental to embryo survival (Renteria Flores et al., 2008). However, the decreased embryo survival may be only attributed to fiber inclusion prior to mating, as the there was no impact in litter size when fiber was supplemented from d 2 to d 109 of gestation (Renteria Flores et al., 2008).

Litter performance can also be impacted by using fiber. Results reported by Van der Peet-Schewering et al. (2003) showed that sows fed a fibrous diet with fermentable NSP (38% sugar beet pulp) over three cycles had litters with a higher number of piglets born and live-born (0.5 piglet; $P<0.05$), but piglet weight was lower at birth (0.05 kg; $P<0.10$), although overall litter weight at birth was not affected. However, sows fed a lactation diet with fermentable NSP (20% sugar beet pulp) weaned lighter pigs (7.3 vs 7.8 kg; $P<0.05$), but the percent of pig weaned after fostering was not impacted by the diet. Similarly, sows fed a high fiber diet (13.35% ground wheat straw) over three successive reproductive cycles farrowed and weaned 0.51 more pigs than sows fed a control corn-soybean meal diet (Veum et al., 2009).

During lactation sows will lose body weight due to a negative nutrient balance caused by the use of nutrients from body tissue reserves to support milk production (Hansen et al., 2012). While a lactation diet will be formulated to meet the high requirements of the lactating sow, feed consumption will also depend on the feeding capacity (Gauthier et al., 2019). Therefore, using fiber as a resource to improve the gastrointestinal tract would increase feed intake during lactation (Serena et al., 2008 and Priester et al., 2020) resulting in a higher energy and nutrient availability for the sow, and her progeny.

6. Conclusion

The inclusion of fiber in gestion is a common practice, currently used to feed a lower energy dense diet. Although studies have shown that fiber inclusion can be beneficial, the studies conducted have used different analytical methods to quantify fiber in the diet. The two most common methods, crude fiber (CF) and neutral detergent fiber (NDF), can misestimate the fiber level in the diet. Thus, total dietary fiber (TDF), and its two fractions insoluble fiber (ISF) and soluble fiber (SF) provide a better estimate of fiber content and its properties. Until now, there is not a defined value on how much fiber should be included in the diet, and fiber solubility as well the insoluble to soluble fiber ratio are still being studied.

Therefore, a series of experiments were conducted to evaluate the effects of different levels of TDF, ISF:SF ratio and the inclusion of a stimbiotic in gestational diets from mating to weaning. Sows received one of two dietary treatments from breeding until placement in the farrowing room, and sow and piglet measurements were collected in addition to litter size and performance.

CHAPTER III

EFFECT OF TOTAL DIETARY FIBER CONTENT DURING GESTATION ON SOW REPRODUCTIVE PERFORMANCE

INTRODUCTION

The nutritional requirements of the gestating sow have been widely studied. During gestation, sows are limit-fed to avoid extra weight gain that may result in fat or obese sows at the time of parturition. Hence, they are fed based on a body condition target. Over conditioned sows have problems at birth and have a lower feed intake during lactation, with excessive weight loss at weaning and difficulties with milk production (MacPherson et al., 2004), and are more likely to have rear heel lesions and leg problems (Knauer, 2007a). From a production standpoint, the target is to have well-conditioned sows during gestation, not only for their improved reproductive efficiency and welfare, but also to make appropriate use of feed, without overfeeding or underfeeding sows.

Feeding higher concentrations of fiber has beneficial effects on stereotypic behaviors (Robert et al., 1993; De Leeuw, 2004), and enhances postprandial satiety (Sapkota et al., 2016) without compromising adequate amounts of energy provided.

During gestation dietary fiber helps control weight gain and minimizes stress from housing conditions and restricted feed (De Leeuw, 2004). Studies have shown that its addition may impact litter size by reducing the number of stillborn pigs (Feyera et al., 2017), and it could potentially increase lactation feed intake (Quesnel et al., 2009) resulting in less BW loss during lactation.

While fiber inclusion has been proven to be beneficial, there are discrepancies on the levels recommended to use, and a standard recommendation on total dietary fiber inclusion level has not been made. This may be attributed to the fact that previous research used diet formulations based on crude fiber (CF) or neutral detergent fiber (NDF), which may misestimate the level of fiber in feed ingredients. Recently, the use of total dietary fiber (TDF) as a measurement of fiber content in feed and feed ingredients has become more popular as it provides a more accurate measurement of fiber concentration (Urriola et al., 2022).

Traditionally, swine producers used fibrous feedstuffs as an alternative to decrease feeding costs (Langemeier, 2021). However, in recent years, fiber has also become a matter of animal welfare and a popular topic when sustainable agriculture practices are mentioned (Alonso et al., 2020). Hence, understanding the impact of total dietary fiber on the reproductive performance of the sow herd is essential. Although outcomes from previous studies are promising, the feed ingredients used in the formulations are not cost effective for current production systems or not widely available, and its applicability in commercial practices may be limited due to increased diet costs.

The objective of this study was to investigate the effects of total dietary fiber (TDF) levels during gestation on sow and litter performance, using feed ingredients typically used in gestational diet formulations in the U.S.

MATERIALS AND METHODS

This study was conducted at a 2,600-sow commercial research farm located in Mooreland, OK, from June through December of 2020. All procedures were approved by Hanor's Research and Veterinarian teams and were in compliance with regulations for humane care and use of animals in research.

Experimental design, animals, and treatment

Three hundred and ninety-seven sows (PIC L42; 4 to 10 of parity; 247 ± 3.9 kg BW) from 4 consecutive breeding groups were used. Each week sows from a breeding group were randomly allotted to one of two treatments, receiving gestational diets with 9% (Lo Fiber) or 18% (Hi Fiber) TDF. Sows were balanced by parity and body condition score (BCS). The study began at breeding and concluded at weaning. The first group was placed in June, 2020, and the last group was weaned in December, 2020.

Experimental diets were manufactured at a commercial feed mill (Hanor Company, Enid, OK). The gestation diets were common milo-soybean meal-based diets (Table 3.1) formulated to contain 0.56% standardized ileal digestible (**SID**) Lys, were isocaloric and the insoluble to soluble fiber ratio was approximately 7.5 (Table 3.2). During lactation all sows received the same diet. Additionally, grain and protein ingredients were kept constant across diets, to control the potential impact of changes in ingredient composition on sow performance. All diets were formulated to meet or exceed nutrient requirements of gestating and lactating sows (NRC,2012). Samples of 0.5 kg from each diet were collected from every new batch that was made at the feed mill, and were stored at -20°C. Once the trial concluded, the samples were homogenized, and a subsample from each diet was sent to a commercial laboratory for analysis.

Housing and feeding methods

Both the gestation and farrowing rooms were environmentally controlled and mechanically ventilated. The temperature inside the building was regulated by a cool cell system. Inside the gestation room the temperature was set to an average of 20°C, and in the farrowing rooms at 22 °C. Sows were individually housed and fed during gestation, and had free access to water. Each stall had a nipple waterer and an adjustable feeder.

Throughout gestation all sows were fed the dietary treatments twice a day (0600 and 1100 h) according to their body condition score (Table 3.3). Individual feeders were adjusted on d 7, 45 and 90 of gestation. On d 90 under-conditioned sows received an extra kilogram of feed until they were moved to the farrowing room. Once placed in the farrowing room (approx. d 112 of gestation) all sows received 1.81 kg/d of lactation feed until parturition. After, they received ad-libitum feed (Big Dutchman, DryExactPro Automatic Feeding system). Farrowing crates had supplemental heat provided to piglets by heat lamps or heat mats and were left for 6 days after parturition.

Sow measurements and performance data

Sow data was taken at placement, throughout gestation, at placement in the farrowing room and at weaning. The body condition score (BCS) was measured with a Knauer Sow Body Condition Caliper (Third version) at the last rib, and it was taken at placement in the breeding room, d 45 and 90 of gestation and at weaning. Sow BCS changes were calculated from two stages. First, the sow BCS difference from breeding to d 90. Next, the sow BCS change from d 90 to weaning. To create categories for the BCS, sows were grouped based on Hanor's parameters for body condition (Thin ≤ 8, Poor 9-10, Ideal 11-13, Fat 14-15, Obese ≥ 16). Additionally, sow BW was captured at placement (breeding), when moved to the farrowing room (approx. d 112 of gestation) and at weaning. The post-partum BW was adjusted to account for piglet and placental weight using Rosero et al. equation from 2013.

$$Post - partum\ BW(kg) = -8.246 + 0.981 * pre - farrow\ BW - 0.679 * pigs\ born$$

Similar to the BCS, sow BW change was calculated from two stages. First, the sow BW difference from breeding to placement in the farrowing room, to determine gestation BW gain. Reproductive traits included born alive (BA), Stillborn (SB), mummies (MM), total born (TB) which was calculated as the sum of BA and SB, weaned pigs and farrowing rate (FR).

Litter measurements and Performance Data

Sixty-eight litters were used as a subsample for piglet weight measurements, thirty-six litters from the Hi Fiber diet and thirty-two from the Lo Fiber diet. Individual piglet weight from born alive and stillborn pigs was taken within 24 h of birth, at processing (d 4) and at weaning (~21 d of age). The percent of small pigs was calculated as the sum of pigs below 0.9 kg at birth, or below 3.6 kg at weaning divided by the total number of pigs weighed. These values were chosen based on commercial parameters used to evaluate the viability of the pigs. Throughout lactation piglet mortality from all litters was recorded along with the causes of death. Pigs did not have access to creep feed or supplemental milk during the experiment. Pre-wean mortality (PWM) was calculated as follows:

$$PWM = \frac{Dead + Euthanized}{Born\ alive}$$

Statistical analysis

All data were analyzed as a completely randomized design using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) for normal distributed variables and the GLIMMIX procedure of SAS for binomial variables. In the model, body condition category at breeding, dietary treatment and body condition category at breeding × dietary treatment interaction were used as fixed effects, and breeding group as a random effect. To understand the sow herd distribution changes in terms of BCS categories, the breeding BCS category was excluded from the model.

Maternal performance data were analyzed with sow as the experimental unit, and litter performance data were analyzed with litter as the experimental unit. Observations were considered outliers when the absolute value of the studentized residuals was greater than 3.5. Means are presented as Least Square means (LS). Results were considered statistically significant at $P \leq 0.05$, and values between 0.05 and 0.10 were considered a tendency toward difference.

RESULTS

Sow performance

There were no differences between treatments at the onset of the experiment for BW (247.0 ±3.9; $P = 0.426$) and caliper units (9.60 ± 0.06; $P = 0.714$). The sow BW and BCS was different among the BCS categories at breeding, as expected. There were no interactions between experimental diet and the BCS category for the sow measures and litter size variables ($P >$ 0.152).

During the gestational period, from breeding until sows were moved to the farrowing room, BW gain was higher for sows fed the LoFiber diet. Consequently, sow BW at placement in the farrowing room was 26 kg higher when sows received a lower concentration of fiber (Table 3.4; $P = 0.012$). The estimated post-partum and weaning BW were lower when sows received the Hi Fiber diet (283.1 vs. 256.1 kg and 271.3 vs 257.1 kg respectively; $P < 0.008$). However, sows fed a lower fiber level tended to lose more weight throughout lactation (P =0.080). At placement in the farrowing room there were no differences between the three body condition categories (P = 0.713). However, sows that started as thin or poor conditioned were 13 kg lighter at weaning compared to those bred in an ideal body condition.

Similarly, BCS on d 45 and 90 were higher ($P < 0.001$) when sows received the LoFiber diet, a difference of 1.31 and 1.59 units between treatments, respectively. Even though there were no significant differences for BCS at weaning ($P = 0.0404$), sows fed the LoFiber diet lost more caliper units from d 90 to weaning (3.44 vs. 1.52; *P* =0.002). Additionally, increased TDF had no effect on farrowing rate or lactation feed intake (*P* >0.05). Sows who were thin at breeding lost almost 2 extra units from d 90 to weaning compared to the other two categories (*P* = 0.011).

Approximately 40% of the sows used in this trial were culled, but there were no differences between treatments (*P* = 0.806). Most sows were culled for old age (53%, data not shown). Furthermore, there were no differences (*P* = 0.173) in the mortality of sows between treatments.

Sow herd composition throughout gestation

The herd distribution by body condition category at the onset of the trial was evenly distributed, and there were no differences between treatments for each body condition category (Figure 3.1). However, on d 45 and 90 the distributions changed. The group that received the Lo Fiber diet had a higher percentage of over-conditioned sows on d 45 and 90 compared to the ones that were fed the Hi Fiber diet (54.23 vs. 22.92 and 56.38 vs. 21.58 respectively; *P* < 0.01). In contrast, sows fed the Hi Fiber diet had a higher proportion in the Ideal category (42.92.96 vs 64.58 and 42.02 vs 62.63; *P* < 0.01). At weaning, there were no differences in distributions between treatments.

Litter size, performance, and weight

No effect of total dietary fiber levels during gestation was found on the number of born alive, stillborn, and mummified fetuses (Table 3.5; *P* > 0.05). The TDF level had no impact on the individual piglet weights at birth, processing, and weaning (Table 3.6; *P* > 0.05). Similarly, there were no differences in light pig percentages at birth and at weaning between treatments (*P* > 0.05). Pre-wean mortality was not affected by the different levels of TDF and there were no significant differences on the mortality reasons (laid on and small) (Table 3.5; *P*>0.05). Thin sows however, tended to have higher stillborn piglets, 0.4 more than poor or ideal (P=0.094).

DISCUSSION

This study was conducted with the objective to determine whether a high TDF fiber level had an impact on sow and litter performance. Our data showed that feeding a gestational diet with a high fiber content (18% TDF) was beneficial in terms of controlling sow BW gain and body condition during gestation. These results were consistent with findings reported by Holt et al. (2006) that fed a high fiber gestational diet (27.41% NDF) and sows gained less BW and less backfat when compared to the control (7.52% NDF). The same was found by Darroch et al. (2008) when sows received a diet with a 20% inclusion of soybean hulls, and Guillemet et al. (2007) reported a difference of 1.5 mm in backfat thickness prior to farrowing. In contrast, Quesnel et al. (2009) found no difference in BW gain and backfat loss in sows fed a diet with 30.7% NDF vs. 17.2%. However, Quesnel et al. (2009) used 9 gilts per treatment, and our project and the one conducted by Holt et al. (2006) had mature sows and no gilts, implying that the effects of fiber may vary depending on sow maturity. Sows fed the 9% TDF diet lost an extra 2 caliper units from day 90 to weaning, in agreeance to Che et al. (2011) study where parity one sows gained more backfat during gestation but lost more during lactation.

Feeding a high fiber diet reduced DM digestibility (Holt et al., 2006) and Lowell et al. (2015) showed that digestible energy in sows for wheat middlings and soybean hulls were different (13.42 vs 12.59 MJ/kg, as-fed basis), indicating that the fiber source physicochemical characteristics influence its digestibility. In addition, sows fed high fiber levels tend to spend more time standing and less time lying down (Holt et al., 2006) which increases the energy used by the sow. This could explain why sows fed a low fiber diet gained more weight and had a higher BCS prior to parturition, in this study. However, we did not evaluate the physical movement of the sows. There are no studies reporting the herd proportion changes by body condition from increasing fiber in gestational diets. Nevertheless, the increase in sow BW during gestation and the differences in backfat thickness reported in previous research (Holt et al., 2006; Guillemet et al., 2007; Darroch et al., 2008) supports the differences in this trial.

In this experiment, we expected sows that received the Hi Fiber diet during gestation to increase their lactation feed intake as reported by previous research. Though, our findings showed that lactation feed intake was not impacted by the concentration of TDF in the diet. Guillemet et al. (2007) had findings similar to ours for overall lactation feed intake but found a difference on the feed intake over time, where sows fed a high fiber diet during gestation ate more the first week after parturition. Quesnel et al. (2009) and Danielsen et al. (1998) reported that sows fed a high fiber diet increased their lactation feed intake between 5% to 15% compared to sows receiving low fiber diets. The feed intake increase was attributed to the low leptin concentration prior to parturition, which meant sows would be more motivated to eat during lactation (Quesnel et al., 2009). Although there were no differences in feed intake in this trial, sows tended to lose less weight during lactation.

No impact of high fiber on born alive or stillborn were reported in sows fed a high fiber diet (Guillemet et al., 2007). Feyera et al. (2017) found a decreased stillborn piglet rate of 2% when sows were fed a high fiber diet in the last two weeks of gestation, but later showed no effect of fiber inclusion on stillborn rate, born alive and total born when high fiber levels were fed throughout gestation (Feyera et al., 2021). In contrast, Huang et al. (2020) found that using 5% of resistant starch decreased the stillborn pigs by one pig per litter. Our findings did not show differences in born alive, stillborn and total born from increasing fiber levels, similar to Darroch et al. (2008). On the other hand, Holt et al. (2006) data showed a decrease in pigs born for the high fiber diet. Reese et al. (2008) suggested that feeding high fiber should be done at least for two subsequent reproductive cycles to understand the impact of feeding fiber in sow reproduction. However, due to the limitations of the research farm in terms of logistics this could not be done in this study.

Piglet birth weight was not impacted by the fiber level in the diet (Quesnel et al., 2009). Similar findings were reported by Huang et al. (2020) for piglet weight at birth, and at weaning when sows received diets with 5% resistant starch or fermented soybean fiber compared to the control diet. There were no effects of TDF level on pre-wean mortality in this study, similar to findings reported by Feyera et al. (2017) when sows were fed a high fiber diet the first two weeks of gestation. In contrast, results reported by Loisel et al. (2013) found that pre-wean mortality was lower when high fiber diets were fed in late gestation (6.2 vs. 14.7 %; P= 0.01).

CONCLUSION

Our results indicate that the impact of feeding a higher TDF diet is not detrimental to reproductive sow performance and does not impact liter size or individual piglet weight and pre-wean mortality. Also, a high fiber diet did not impact pre-wean mortality and there were no differences in the percentage of pigs that died from being crushed or small. Our findings also show that the response to increased TDF during gestation was not dependent on the body condition. However, the high TDF diet had a possible impact on the body condition distribution of the herd by having a higher proportion in the ideal body condition by d 90 and helped control BW gain throughout gestation and decrease weight loss in lactation. In conclusion, adding wheat midds to a gestational diet to increase the TDF level to 18% while keeping the insoluble to soluble fiber ratio at 7.5 does not decrease sow performance and can contribute to a higher proportion of the herd being well-conditioned.

Table 3.1. Composition of the experimental diets, as-fed basis

	Total Dietary Fiber (TDF), %	
Item	9	18
Ingredient%		
Milo	80.53	47.45
Wheat middlings	8.85	35.00
Soybean meal, 46.5% CP	3.90	7.60
Soy hulls	1.50	3.55
Soy oil	1.00	3.00
Limestone	1.25	1.25
Monocalcium phosphate, 21% P	0.92	0.51
Potassium, magnesium sulfate[1]	0.50	0.50
Salt	0.48	0.45
L-Lysine	0.30	0.07
L-Threonine	0.09	—
L-Methionine	0.08	—
Choline chloride, 60%	0.13	0.13
Sow vitamin and mineral premix[2]	0.20	0.20
Sow trace mineral mix[3]	0.08	0.08
Zeolite clay[4]	0.10	0.10
Direct-Fed microbial (*Bacillus subtillis* PB6)[5]	0.05	0.05
Enzyme blend[6]	0.04	0.04
Iron Oxide[7]	0.04	0.04

[1]Dynamate (Mosaic, Plymouth, MN).

[2]Provided 125 mg/kg Zn, 100 mg/kg Fe, 30 mg/kg Mn, 15 mg/kg Cu, 0.7 mg/kg I, 0.3 mg/kg Se, 8,378 IU/kg vitamin A, 1,764 IU/kg vitamin D3, 77.2 IU/kg vitamin E, 3 mg/kg vitamin K, 0.03 mg/kg Vitamin B12, 8.2 mg/kg Riboflavin, 26.5 mg/kg d-Pantothenate, 22 mg/kg Niacin, 5.5 mg/kg Thiamine, 3.1 mg/kg Pyridoxine, 2.6 mg/kg Folic Acid, 0.4 mg/kg Biotin, 130 mg/kg Ethoxyquin, and 0.2 mg/kg Chromium.

[3]Provided 134 mg/kg Zn, 53 mg/kg Mn and 27 mg/kg Cu

[4]KALLSIL (Kemin, Des Moines, IA)

[5]CLOSTAT (Kemin Des Moines, IA)

[6]Provided 3,180 FTU/kg Phytase, 21,773 BXU/kg Xylanase and 5,453 XylEqu/kg Xylanase D

[7] Used to color code diets

Table 3.2 Calculated and analyzed diet composition

	Total Dietary Fiber (TDF), %	
Item	9	18
Calculated Composition		
ME, Mcal/kg	3.25	3.24
Ne, Mcal/kg	2.52	2.52
Total Fat, %	3.70	5.80
CP, %	11.51	14.45
Total Lys, %	0.64	0.67
SID Lys, %	0.56	0.56
Total Ca, %	0.88	0.85
Total P, %	0.53	0.62
Crude Fiber, %	4.98	6.77
Neutral Detergent Fiber, %	12.39	18.26
Total Dietary Fiber, %	9.00	18.01
Soluble Fiber, %	1.07	2.12
Insoluble Fiber, %	7.93	15.89
InSol:Sol Fiber ratio	7.39	7.50
Analyzed composition		
Moisture, %	12.73	13.29
Total Fat, %	5.59	7.19
CP, %	14.58	15.50
Crude Fiber, %	4.10	5.88
Neutral Detergent Fiber, %	13.87	19.91
Ash, %	4.60	3.60
Starch, %	39.75	33.35
Sugar, %	4.63	4.63

Table 3.3 Feeding program for gestating sows

Feed allowance by BCS[2], kg/d			
Stage	BCS group[1]		
	1-10	11-13	14-19
Day 0-7	1.81	1.81	1.81
Day 7-90	2.72	2.04	1.59
Day 90-112	3.63	2.04	1.59
Placement in farrowing crate	1.81	1.81	1.81
Lactation	Ad libitum	Ad libitum	Ad libitum

[1] Units were grouped to fit Hanor's body condition standards

[2] Body Condition Score

Table 3.4 Effects of total dietary fiber on sow performance

Item	Total Dietary Fiber, %		SEM	Body Condition Category[5]			SEM	P-values		
	9	18		Thin	Poor	Ideal		TRT*BCS	TRT	BCS
Sows placed, n	198	199		87	156	154				
Sow Body Weight, kg										
Breeding, kg	249.2	244.8	3.9	232.1[a]	243.0[a]	265.9	4.8	0.996	0.426	0.001
Placement in farrow crate, kg[1]	306.6	280.6	6.9	299.5	292.2	289.1	8.5	0.530	0.012	0.713
Post-Partum, kg (estimation)[2]	283.1	256.1	6.7	275.7	268.1	265.1	8.2	0.526	0.008	0.689
Weaning, kg[3]	271.3	257.1	3.3	258.8[a]	259.8[a]	273.9	4.0	0.841	0.003	0.009
Δ Breeding-Placement in farrow crate, kg	56.0	37.4	5.7	62.9[a]	44.9[ab]	32.4[b]	7.0	0.725	0.029	0.019
Δ Post-Partum - Weaning, kg	-17.0	-4.0	5.0	-26.9	-8.1[a]	3.6[a]	6.1	0.547	0.080	0.010
Body Condition Score, caliper units										
Breeding	9.62	9.59	0.06	7.28	9.59	11.93	0.07	0.362	0.714	0.001
Day 45	13.60	12.29	0.13	11.89	12.93	14.01	0.16	0.790	0.001	0.001
Day 90	13.63	12.03	0.12	11.72	12.85	13.92	0.14	0.498	0.001	0.001
Weaning	10.49	11.00	0.42	8.70	10.96	12.57	0.51	0.421	0.404	0.001
Δ Breeding- Day 90	4.01	2.43	0.11	4.43	3.26	1.98	0.13	0.314	0.001	0.001
Δ Day 90 - Weaning	-3.44	-1.52	0.80	-3.95	-1.9[a]	-1.57[a]	0.49	0.863	0.002	0.011
Lactation ADFI, kg/d[4]	6.09	6.09	0.22	6.10	6.18	5.98	0.28	0.623	0.963	0.581

[a,b] values with the same letter are not significantly different

[1] At day 112 of gestation

[2] Rosero et al., 2013 Equation to estimate post-partum BW

[3] At approximately 21 days

[4] A subsample of 103 sows fed with the BigDutchman feeding system

[5] Categories grouped at breeding

Table 3.5 Effects of total dietary fiber on litter size and pre-wean mortality

	Total Dietary Fiber, %			Body Condition Category[1]				*P*-values		
Item	9	18	SEM	Thin	Poor	Ideal	SEM	TRT*BCS	TRT	BCS
Litter Performance, pigs/litter										
Total pigs born	14.73	14.87	0.32	15.12	14.41	14.86	0.39	0.453	0.767	0.427
Born alive	12.93	13.02	0.31	12.97	12.72	13.24	0.37	0.152	0.821	0.540
Stillborn	1.81	1.84	0.14	2.15	1.70	1.63	0.17	0.376	0.850	0.094
Mummies	0.16	0.14	0.04	0.10	0.18	0.17	0.04	0.155	0.772	0.503
Pre wean mortality										
Dead pigs, n	2.96	2.81	0.17	2.75	2.84	3.07	0.21	0.400	0.547	0.527
Dead pigs, %	22.42	21.33	1.46	20.31	23.28	22.03	1.78	0.972	0.597	0.530
Laid on, % of litter	14.49	13.40	1.26	12.92	14.34	14.57	1.53	0.985	0.542	0.756
Small, % litter	7.49	7.31	0.78	6.86	8.36	6.99	0.95	0.713	0.869	0.420
Laid on, % of dead	59.55	53.64	3.01	56.15	54.90	58.73	3.64	0.175	0.165	0.707
Small, % of dead	30.48	32.99	2.74	33.58	32.67	28.96	3.32	0.701	0.517	0.571
Weaned, pigs/litter	9.85	9.95	0.14	9.85	9.94	9.92	0.17	0.218	0.620	0.935

[1] Categories grouped at breeding

Table 3.6 Effects of total dietary fiber on individual piglet weight

	Total Dietary Fiber, %			Body Condition Category[5]				*P*-values		
Item	9	18	SEM	Thin	Poor	Ideal	SEM	TRT*BCS	TRT	BCS
Litters, n	32	36		14	22	32				
Pigs, n	427	481		204	302	402				
Individual piglet weight, kg										
Birth[1]	1.44	1.47	0.05	1.45	1.44	1.49	0.06	0.667	0.729	0.809
Stillborn[1]	1.24	1.16	0.07	1.17	1.16	1.27	0.09	0.780	0.454	0.600
Processing[2]	1.85	1.88	0.06	1.84	1.85	1.90	0.08	0.966	0.767	0.842
Weaning[3]	6.37	6.32	0.18	6.27	6.43	6.33	0.22	0.126	0.855	0.891
Light weight pigs[4], % per litter										
< 0.9 kg at farrowing	10.71	8.01	2.13	10.15	8.04	9.89	2.57	0.493	0.374	0.819
< 3.6 kg at weaning	6.23	3.26	1.80	4.82	3.76	5.65	2.19	0.195	0.250	0.820

[1]Taken within 24 h after birth

[2] At approximately day 3

[3] At 21 days of age

[4] Parameters based on commercial practices

[5] Categories grouped at breeding

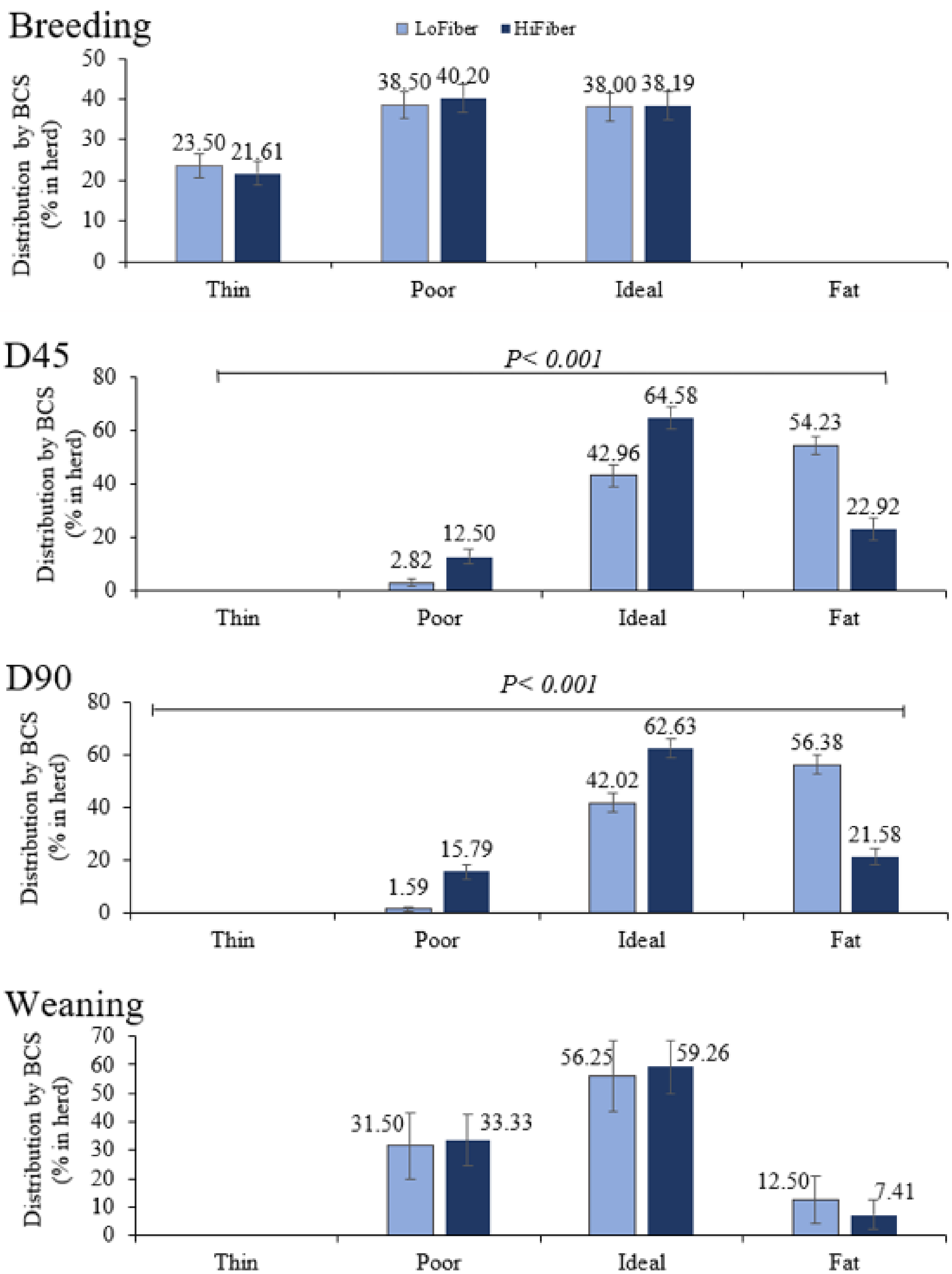

Figure 3.1 Body condition distribution in the herd throughout gestation

CHAPTER IV

EFFECTS OF INSOLUBLE TO SOLUBLE FIBER RATIO DURING GESTATION ON SOW REPRODUCTIVE PERFORMANCE

INTRODUCTION

Previous studies have shown that fiber inclusion in gestational diets may be beneficial for sow reproductive performance and that feeding high fiber levels could impact litter size and reduce stillborn rate (Renteria-Flores et al, 2008; Feyera et al., 2017; Li et al., 2019). Furthermore, research has shown that fiber physicochemical characteristics should be considered when formulating diets, as the impact on nutrient absorption varies based on the solubility, viscosity, fermentability and water holding capacity. Studies have shown that soluble fiber is prone to bacterial fermentation in the large intestine and as a result SCFA are produced which are absorbed by the intestinal cells and satisfy 10% to 30% of the pig's maintenance energy requirement (Varel and Pond, 1985). On the other hand, insoluble fiber is slowly fermented and may speed up transit rate (De Leeuw et al., 2008).

From the commonly used fibrous ingredients, wheat midds have approximately 28% TDF, 25% ISF and 3% SF, rice bran has a TDF content of 19%, 18% ISF and 1% SF. However, sugar beet pulp has 46% TDF, from which 28% is ISF and 18% SF (Appendix 1). The variability in fiber composition and physicochemical characteristics between ingredients supports the recommendation that diet formulation should consider ISF and SF content.

Soluble dietary fiber delays gastric emptying due to its water holding capacity and ability to form a viscous material. This is beneficial as delayed gastric emptying improves nutrient absorption, promotes satiety and reduces hunger (Anderson, 1985; Renteria-Flores, 2003). On the contrary, insoluble fiber tends to decrease transit time, and this results in decreased nutrient digestibility (Renteria-Flores, 2003). If we take fiber characteristics in consideration, we face the decision of choosing the right combination of soluble and insoluble fibers to ensure an optimal reproductive performance, and prevent a negative impact on nutrient absorption, gestation outcome and litter performance.

Over the last decade, studies have shown that fiber inclusion in gestational diets can impact intestinal microbiota of the piglets and prevent the migration of pathogenic bacteria (Chen et al., 2013). This results in a healthier litter and could potentially reduce the incidence of diarrhea (Flis et al.,2017; Cheng et al., 2018). These findings have been associated with fiber ingredients with high SF like sugar beet pulp, oat hulls, soyhulls, oat β-glucans, and barley (Zijlstra et al., 2012; Urriola et al., 2012). Shang et al. (2019) reported that the inclusion of sugar beet pulp (20%) at an ISF:SF of 2.6 had positive impact growth performance of piglets, compared to higher ISF:SF diet (10.45) when wheat bran was added in the diet (30%). However, prior research by Danielsen and Vestengaard (2001) reported a decrease in birth weight when diets contained 50% SBP.

The contradicting findings for soluble and insoluble fiber inclusion as well as the recent studies on ISF:SF and its impact on piglet performance are of interest, as fiber use is becoming more popular in gestation diets. Hence, the objective of this study was to evaluate the impact of same TDF content with different ISF:SF gestation diets on sow and litter performance.

MATERIALS AND METHODS

This study was conducted at a 2,600-sow commercial research farm located in Mooreland, OK, from October 2020 through March of 2021. All procedures were approved by Hanor's Research and Veterinarian teams, and were in compliance with regulations for humane care and use of animals in research.

Experimental design, animals, and treatment

Three hundred and forty-four sows (PIC L42; 2 to 10 of parity; 10.88 ± 0.09 BCS units) from 4 consecutive breeding groups were used. Each week sows from the same breeding group were randomly allotted to one of two dietary treatments, receiving gestational diets with 3.98 Insol:Sol ratio (LR) or 7.99 Insol:Sol ratio (HR). Sows were balanced by parity and body condition score (BCS) at the time of placement. The study began at breeding and concluded at weaning. The first group of sows was placed in October, 2020, and the last group was weaned in March, 2021.

Experimental diets were manufactured at a commercial feed mill (Hanor Company, Enid, OK). The gestation diets were common corn-soybean meal based. Fiber sources in the gestational diet formulation were rice bran and wheat middlings, and sugar beet pulp was added to the low ratio diet due to its higher soluble fiber content (Table 4.1). Diets were formulated to contain 0.56% standardized ileal digestible (**SID**) Lys, be isocaloric and keep their total dietary fiber level (TDF) at approximately 12% (Table 4.2). During lactation all sows received the same diet. Additionally, grain and protein ingredients were kept constant across diets, to control the potential impact of changes in ingredient composition on sow performance. All diets were formulated to meet or exceed nutrient requirements of gestating and lactating sows (NRC,2012). Samples of 0.5 kg from each diet were collected from every new batch that was made at the feed mill, and were stored at -20°C. Once the trial concluded, the samples were homogenized, and a subsample from each diet was sent to a commercial laboratory for analysis.

Housing and feeding methods

Both the gestation and farrowing rooms were environmentally controlled and mechanically ventilated. The temperature inside the building was regulated by a cool cell system. Inside the gestation room temperature was set to an average of 20°C, and in the farrowing rooms at 22 °C. Sows were individually housed and fed during gestation and had free access to water. Each stall had a nipple waterer and an adjustable feeder. Approximately on d 112, sows were moved to the farrowing room. Farrowing crates had supplemental heat provided to piglets by heat lamps or heat mats and were left for 6 days after parturition.

Throughout gestation all sows were fed the dietary treatments twice a day (0600 and 1100 h), the feed allowance was determined by their body condition score (Table 4.3). Individual feeders were adjusted on d 7, 45 and 90 of gestation. Once placed in the farrowing room (approx. d 112 of gestation) all sows received 1.82 kg/d of lactation feed until parturition. After, they received ad-libitum feed (Big Dutchman, DryExactPro Automatic Feeding system).

Sow measurements and performance data

Sow data was captured at placement, throughout gestation, at placement in the farrowing room and at weaning. The body condition score (BCS) was measured using a Knauer Sow Body Condition Caliper (Third version) at the last rib, and it was taken at placement (breeding day), d 45 and 90 of gestation, at placement in the farrowing room and at weaning. Sow BCS changes were calculated from two stages. First, the sow BCS difference from breeding to d 90 of gestation. Next, the sow BCS change from placement in the farrowing room (d 112) to weaning. Additionally, sow BW was captured from a subsample of sows when they were moved to the farrowing room (d 112 of gestation, n = 102) and at weaning. The post-partum BW was adjusted to account for piglet and placental weight using Rosero et al. equation from 2013.

$$Post - partum\ BW(kg) = -8.246 + 0.981 * pre - farrow\ BW - 0.679 * pigs\ born$$

Sow BW change from post-partum to weaning was calculated to determine the lactation weight loss. Reproductive traits included born alive (BA), Stillborn (SB), mummies (MM), total born (TB) which was calculated as the sum of BA and SB, weaned pigs and farrowing rate (FR). The subsequent performance traits included wean to estrus interval (WEI), percent of mated sows, and litter size. Sow mortality and cull rate with their respective reasons were registered throughout the entire length of the project.

Litter measurements and performance data

Sixty-six litters were used as a subsample for piglet weight measurements, thirty-three litters from each treatment. Individual piglet weight from born alive and stillborn pigs was taken within 24 h of birth, at processing (d 4) and at weaning. The percentage of small pigs was calculated as the sum of pigs below 0.9 kg at birth, or below 3.6 kg at weaning divided by the total number of pigs weighed. Throughout lactation piglet mortality from all litters was recorded along with the cause. Pigs did not have access to creep feed or supplemental milk during the experiment.

Statistical analysis

All data were analyzed as a complete randomized design using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) for normal distributed variables and the GLIMMIX procedure of SAS for binomial variables. In the model, body condition category at breeding, dietary treatment and body condition category at breeding × dietary treatment interaction were used as fixed effects, and breeding group as a random effect. Parity was used as a covariate in the model.

Maternal performance data were analyzed with sow as the experimental unit, and litter performance data were analyzed with litter as the experimental unit. For herd distribution by body condition the breeding BCS category was excluded from the model. Observations were considered outliers when the absolute value of the studentized residuals was greater than 3.5. Means are presented as Least Square means. Results were considered statistically significant at $P \leq 0.05$, and values between 0.05 and 0.10 were considered a tendency toward difference.

RESULTS

Sow performance

There were no differences between treatments at the onset of the experiment between LR and HR for caliper units (10.88 ± 0.09; $P = 0.297$). The BCS units were different among the BCS categories at breeding, as expected.

Sow BW at placement in the farrowing room was not different between dietary treatments and neither was the post-partum calculated BW (Table 4.4). The same was observed for BW across the different body condition categories. However, sows that were thin at breeding were lighter than ideal and fat at weaning (33 and 43 kg lighter respectively; $P < 0.016$) but heavier than those poor conditioned at mating. There was no effect of insoluble to soluble fiber ratio on lactation BW loss, but thin and poor sows tended to lose more BW than ideal and fat sows.

On d 45 and 90, BCS were one unit higher for sows fed the low ratio (LR) diet (12.09 vs. 11.11 and 13.00 vs. 12.15 units respectively; $P < 0.001$). At placement in the farrowing crate, there was an interaction between diet and BCS category ($P = 0.014$). Thin and poor conditioned sows fed the LR diet had a higher BCS than those fed the HR diet (1.8 and 0.57 units different respectively; $P < 0.066$). No interaction or diet main effects were seen for BCS at weaning, but poor-conditioned sows had a lower BCS than well-conditioned and fat sows. Sows fed the LR diet gained an extra 0.84 units (*P* < 0.001) from breeding to d 90. During the gestational period sows changed their body conditioned as expected by the feeding program. Thin sows gained more units, and fat sows lost units (*P* < 0.001). The body condition lost during lactation was higher for the LR fed sows (0.61 vs. 0.39 units; *P* < 0.001).

Sow herd composition throughout gestation

The herd composition at the onset of the trial was evenly distributed, and there were no differences between treatments for each body condition category (Figure 4.1), but the LR group tended to have more fat sows (15.60 vs. 9.10; *P* = 0.080). On d 45 the group that received LR had less poor-conditioned sows (24.50% vs 40.43%; *P* = 0.004) but had more over-conditioned sows (28.48 vs. 14.89; *P* = 0.006). Similar results were observed on d 90, sows fed the LR diet had 15% less poor conditioned sows than the HR (*P* = 0.004) but had 11% more fat sows (*P* = 0.038). At farrowing however, the distributions were no different, but LR sows tended to have less poor conditioned sows, and while not statistically different, had 10% more well-conditioned sows. No differences we found at weaning.

Litter size, performance, and weight

No effect of insoluble to soluble fiber ratio during gestation was found on the total, stillborn pigs and mummified fetuses (Table 4.5; *P* > 0.05). There was an interaction between diet and BCS for the number of born alive pigs, poor conditioned sows fed the LR diet had less pigs (11.22 vs. 13.35 pigs; *P* = 0.012) and a tendency to have less stillborn pigs. The dietary treatment and body condition had no impact on the individual piglet weights at birth, processing, and weaning (Table 4.6; *P* > 0.05). However, there was a tendency for sows fed the LR diet to have heavier stillborn pigs (1.55 vs. 1.27 kg; *P* = 0.090). Similarly, there were no differences in light pig percentages at birth and at weaning between treatments (*P* > 0.05).

As shown in table 4.5 pre-wean mortality was not affected by the dietary treatment, but there was a tendency for body condition (*P* = 0.098) which was mainly attributed to the high pre-wean mortality from fat sows. Fat sows had a higher percentage of dead pigs from the small mortality reason (*P* < 0.06), and sows who received the HR diet tended to have higher percent of total pre-wean mortality from small pigs (25.17 vs. 36.45; *P* = 0.085). The number of pigs weaned was not impacted by the diet but was affected by the sow body condition (*P* = 0.015).

The culling rate tented to be higher for sows fed the LR diet (*P* = 0.090), but culling reasons were different between treatments. Fifty percent of culled sows from the HR diets were due to conformation (*P* = 0.006), whereas 61% of the culled sows from the LR diet were culled for old age (*P* = 0.038). The number of rebred sows was not different, but the WEI was higher for the LR sows (4.61 vs. 4.25 d; *P* = 0.036).

DISCUSSION

Our results show that dietary treatment had no effect on sow BW at placement in farrowing, and lactation BW loss. However, sows fed the LR diet had a higher BCS on d 45 and 90. In contrasts, Renteria-Flores et al. (2008) found that feeding a diet with high concentration of soluble fiber increased BW when fed throughout gestion from d 2 to d 109, the diet's ISF:SF was lower than ours (2.47 vs. 3.98 ISF:SF). Our findings were similar to those by Loisel et al. (2013) that reported no changes in BW from supplementing sugar beet pulp, but contrary to ours saw no effect on backfat thickness, which would in turn affect the BCS.

The LR diet had a positive effect for thin and poor conditioned sows, which had a higher BCS at placement in the farrowing room than ideal or fat sows. On d 45 and 90, LR had fewer poor conditioned sows, but also had more fat sows. This outcome could be explained by observations reported by Renteria-Flores et al. (2008) after comparing the effects of soluble and insoluble fiber digestibility on sows where results showed that fecal excretion from the high insoluble fiber diet (10.52 ISF:SF) were higher than the high soluble diet (2.8 ISF:SF) (343.4 g vs 175.3 g of DM/d) and the energy excreted in feces was higher (1,239 vs 776 kcal/day). This may be attributed to the fermentability associated with soluble fiber, as microbial fermentation produces SCFA that can be used by the sow.

We did not see an impact on litter size or litter weight from feeding a lower ISF:SF, but there was a tendency for sows fed the LR diet to have heavier stillborn pigs. Similar findings were reported by Loisel et al. (2013) when comparing LF and HF diets, but the ISF:SF for the LF and HF diets were 6 and 7.5, which although different, they didn't have as much of a difference as the diets used in our trial. Comparable to our results, Renteria-Flores et al. (2008) saw no significant difference for pig BW at birth or at weaning between the HS or HIS when compared to the control, and no stillborn BW was reported. Li et al. (2019) conducted a trial similar to ours, where diets were formulated to have a same fiber level, although they were formulated to have the same CF and we formulated for an equal TDF. Their findings showed that average pig BW at weaning was increased by one kilogram when sows received the 3.89 or 5.59 ISF:SF compared to those that received 9.12 or 12.81 ISF:SF and attributed this the effect on intestinal morphology of the pigs, as the saw an increased villus height in the jejunum of neonatal pigs. We did not find differences in pig BW at weaning or pigs weaned, but sows who received the HR diet tended to have a higher percent of total pre-wean mortality from small pigs (11% difference; $P = 0.085$).

Even though LR had a tendency for a higher culling rate, its majority was from old age, in comparison to HR that had 50% for poor conformation. The findings we used for reference did not report effects of diet on mortality or culling rate. However, we can imply that diet was not the cause of culling, as old age and sow conformation are not dependent on nutrition.

CONCLUSION

The present experiment showed that increasing ISF:SF while maintaining TDF constant, had an effect on BCS by a decrease of one caliper unit on d 45 and 90, and this may be attributed to the different physicochemical characteristics used in the diet formulation. The low ISF:SF has sugar beet pulp in its formulation, and this ingredient is known for its high SF content, which in turn improves microbial fermentability. Litter size and piglet weight at birth were not improved by a lower ISF:SF. In contrast, by d 90 higher ISF:SF increased the proportion of poor-conditioned sows in the herd, while lower ISF:SF increased the proportion of over-conditioned sows, but there was no improvement from either diet on the number of well-conditioned sows. Over conditioned sows have been associated with reduced reproductive performance and leg problems. Hence, using the high ISF:SF may be the best option to control the over-conditioned sows in the herd.

Table 4.1 Composition of the experimental diets, as-fed basis

	InSol:Sol Fiber ratio	
Item	4	8
Ingredient, %		
Corn	62.66	58.98
Rice bran	21.15	25.00
Wheat middlings	2.00	10.10
Sugar beet pulp	7.50	—
Soybean meal, 46.5% CP	1.60	1.50
Soy oil	1.15	0.50
Limestone	1.15	1.42
Monocalcium phosphate, 21% P	0.77	0.56
Salt	0.45	0.48
L-Lysine	0.30	0.26
L-Threonine	0.11	0.08
L-Methionine	0.04	—
L-Tryptophan	0.02	0.02
Choline chloride, 60%	0.13	0.13
Potassium, magnesium sulfate[1]	0.50	0.50
Sow vitamin and mineral premix[2]	0.20	0.20
Sow trace mineral mix[3]	0.08	0.08
Zeolite clay[4]	0.10	0.10
Direct-Fed microbial (*Bacillus subtillis* PB6)[5]	0.05	0.05
Enzyme blend[6]	0.04	0.04
Iron Oxide[7]	0.04	0.04

[1]Dynamate (Mosaic, Plymouth, MN).

[2]Provided 125 mg/kg Zn, 100 mg/kg Fe, 30 mg/kg Mn, 15 mg/kg Cu, 0.7 mg/kg I, 0.3 mg/kg Se, 8,378 IU/kg vitamin A, 1,764 IU/kg vitamin D3, 77.2 IU/kg vitamin E, 3 mg/kg vitamin K, 0.03 mg/kg Vitamin B12, 8.2 mg/kg Riboflavin, 26.5 mg/kg d-Pantothenate, 22 mg/kg Niacin, 5.5 mg/kg Thiamine, 3.1 mg/kg Pyridoxine, 2.6 mg/kg Folic Acid, 0.4 mg/kg Biotin, 130 mg/kg Ethoxyquin, and 0.2 mg/kg Chromium.

[3]Provided 134 mg/kg Zn, 53 mg/kg Mn and 27 mg/kg Cu

[4]KALLSIL (Kemin, Des Moines, IA)

[5]CLOSTAT (Kemin Des Moines, IA)

[6]Provided 3,180 FTU/kg Phytase, 21,773 BXU/kg Xylanase and 5,453 XylEqu/kg Xylanase D

[7]Used to color code diets

Table 4.2 Calculated and analyzed diet composition

Item	InSol:Sol Fiber ratio 4	8
Calculated Composition		
ME, Mcal/kg	3.21	3.19
NE, Mcal/kg	2.56	2.59
Total Fat, %	6.60	6.60
CP, %	10.53	11.26
Total Lys, %	0.66	0.64
SID Lys, %	0.56	0.56
Total Ca, %	0.85	0.88
Total P, %	0.70	0.77
Crude Fiber, %	5.70	5.30
Neutral Detergent Fiber, %	13.74	12.78
Total Dietary Fiber, %	12.00	11.83
Soluble Fiber, %	2.43	1.31
Insoluble Fiber, %	9.65	10.52
InSol:Sol Fiber ratio	3.98	8.00
Analyzed composition		
Moisture, %	14.08	14.09
Total Fat, %	5.92	5.50
CP, %	9.77	11.14
Crude Fiber, %	3.05	2.27
Neutral Detergent Fiber, %	14.84	15.74
Acid Detergent Fiber, %	6.27	5.82
Starch, %	53.22	52.94
Sugar, %	3.94	3.67

Table 4.3 Feeding Program for Gestating Sows

Stage	Feed allowance by BCS[2], kg/d — BCS units[1] 1-10	11-13	14-19
Day 0-7	1.81	1.81	1.81
Day 7-90	2.72	2.04	1.59
Day 90-112	3.63	2.04	1.59
Placement in farrowing crate	1.81	1.81	1.81
Lactation	Ad libitum	Ad libitum	Ad libitum

[1] Units were grouped to fit Hanor's body condition standards
[2] Body Condition Score

Table 4.4 Effects of Insol:Sol fiber ratio on sow performance

	InSol:Sol ratio			Body Condition Category[5]					*P*-values		
Item	4	8	SEM	Thin	Poor	Ideal	Fat	SEM	TRT*BCS	TRT	BCS
Sows placed, n	175	169		39	101	161	43				
Sow Body Weight, kg											
Placement in farrow crate, kg[1]	289.9	287.6	4.9	287.3	288.1	286.1	293.5	6.8	0.785	0.747	0.921
Post-Partum, kg (estimation)[2]	276.1	274.2	4.8	273.7	274.5	272.7	279.8	6.7	0.786	0.779	0.921
Weaning, kg[3]	250.3	249.1	6.2	225.0[a]	246.9[ab]	258.1[bc]	268.7[c]	8.8	0.160	0.898	0.042
Δ Post Partum - Weaning, kg	-26.7	-16.8	-4.7	-26.6	-30.9	-18.6	-11.1	-6.6	0.805	0.166	0.107
Body Condition Score, caliper units											
Breeding	10.93	10.83	0.09	7.42	9.51	11.86	14.72	0.11	0.083	0.297	0.001
Day 45	12.09	11.11	0.37	9.81	10.58	11.98	14.03	0.40	0.384	0.001	0.001
Day 90	13.00	12.15	0.32	11.81[a]	11.26[a]	12.57	14.75	0.36	0.266	0.001	0.001
Placement in farrow crate[1]	11.99	11.58	0.47	10.98[a]	10.82[a]	11.69	13.65	0.54	0.014	0.284	0.001
Weaning	11.35	11.45	0.30	10.29[a]	10.48[a]	11.38	13.46	0.42	0.226	0.813	0.001
Δ Breeding- Day 90	2.08	1.24	0.33	4.36	1.73	0.68	-0.14	0.37	0.074	0.001	0.001
Δ Farrow- Weaning	-0.61	-0.39	-0.32	-0.09	-0.14	-0.33	-0.11	-0.44	0.251	0.028	0.909
Lactation ADFI, kg/d[4]	6.40	6.70	0.12	6.23	6.83	6.69	6.47	0.22	0.519	0.126	0.193

[a,b] values with the same letter are not significantly different
[1] At day 112 of gestation
[2] Rosero et al., 2013 Equation to estimate post-partum BW
[3] At approximately 21 days
[4] A subsample of 138 sows fed with the BigDutchman feeding system
[5] Categories grouped at breeding

Table 4.5 Effects of Insol:Sol fiber ratio on litter size and pre-wean mortality

Item	InSol:Sol ratio 4	8	SEM	Body Condition Category[1] Thin	Poor	Ideal	Fat	SEM	*P*-values TRT*BCS	TRT	BCS
Litter Performance, pigs/litter											
Total pigs born	14.15	13.96	0.46	14.12	14.05	14.13	13.91	0.59	0.105	0.746	0.992
Born alive	12.21	12.71	0.40	12.15	12.28	12.55	12.86	0.53	0.046	0.361	0.837
Stillborn	1.61	1.27	0.19	1.44	1.73	1.55	1.05	0.24	0.083	0.163	0.236
Mummies	0.20	0.20	0.05	0.23	0.12	0.23	0.22	0.07	0.325	0.955	0.398
Pre wean mortality											
Dead pigs, %	14.41	14.04	1.41	10.46	14.29	13.36	18.78	1.91	0.283	0.856	0.098
Laid on, % of litter	9.74	8.75	1.09	7.03	8.62	9.11	12.22	1.48	0.541	0.528	0.244
Small, % litter	3.29	4.22	0.60	2.53	3.73	2.77	5.99	0.81	0.957	0.269	0.028
Others, % litter	0.40	0.47	0.18	0.50	0.58	0.23	0.44	0.24	0.913	0.788	0.513
Laid on, % of dead	70.34	59.29	4.78	67.55	59.13	72.99	59.58	6.46	0.890	0.106	0.140
Small, % of dead	25.17	36.45	4.57	27.55	34.27	23.51	37.92	6.18	0.902	0.085	0.201
Others, % of dead	3.44	2.51	1.17	4.92	2.89	1.63	2.45	1.58	0.716	0.578	0.524
Weaned, pigs/litter	10.17	10.03	0.17	10.67[a]	10.29[a]	9.85[b]	9.59[b]	0.23	0.311	0.538	0.015

[a,b] values with the same letter are not significantly different

[1] Categories grouped at breeding

Table 4.6 Effects of Insol:Sol fiber ratio on individual piglet weight

	InSol:Sol ratio			Body Condition Category[5]					*P*-values		
Item	4	8	SEM	Thin	Poor	Ideal	Fat	SEM	TRT*BCS	TRT	BCS
Litters, n	33	33		11	21	21	13				
Pigs, n	423	431		115	285	281	173				
Individual piglet weight, kg											
Birth1	1.67	1.58	0.05	1.72	1.68	1.59	1.52	0.07	0.668	0.194	0.255
Stillborn[1]	1.55	1.27	0.12	1.58	1.40	1.25	1.42	0.15	0.337	0.090	0.520
Processing[2]	2.15	1.95	0.09	2.23	2.14	1.94	1.90	0.13	0.264	0.130	0.274
Weaning[3]	6.05	6.00	0.19	5.73	6.17	6.45	5.76	0.27	0.612	0.844	0.175
Light weight pigs[4], % per litter											
< 0.9 kg at farrowing	4.89	3.73	1.47	2.09	2.67	4.98	7.48	2.06	0.576	0.582	0.304
< 3.6 kg at weaning	4.34	3.37	2.32	1.99	2.73	1.95	8.75	2.89	0.383	0.696	0.199

[1]Taken within 24 h after birth
[2] At approximately day 3
[3] At age 21 days
[4] Parameters based on commercial practices
[5] Categories grouped at breeding

Table 4.7 Effects of Insol:Sol fiber ratio on herd performance

	InSol:Sol ratio			*P*-values
	4	8	SEM	TRT
Cull sows, %	31.93	23.38	0.035	0.090
Conformation (% of total cull)	14.29	50.00	0.075	0.006
Old age (% of total cull)	61.11	31.82	0.085	0.038
Rebred sows[1], %	60.84	64.94	0.038	0.450
WEI[2], d	4.61	4.25	0.117	0.036
Farrowing rate second cycle, %	89.11	87.00	0.032	0.646

[1]Sows rebred after weaning the first cycle

[2]Wean to estrus interval

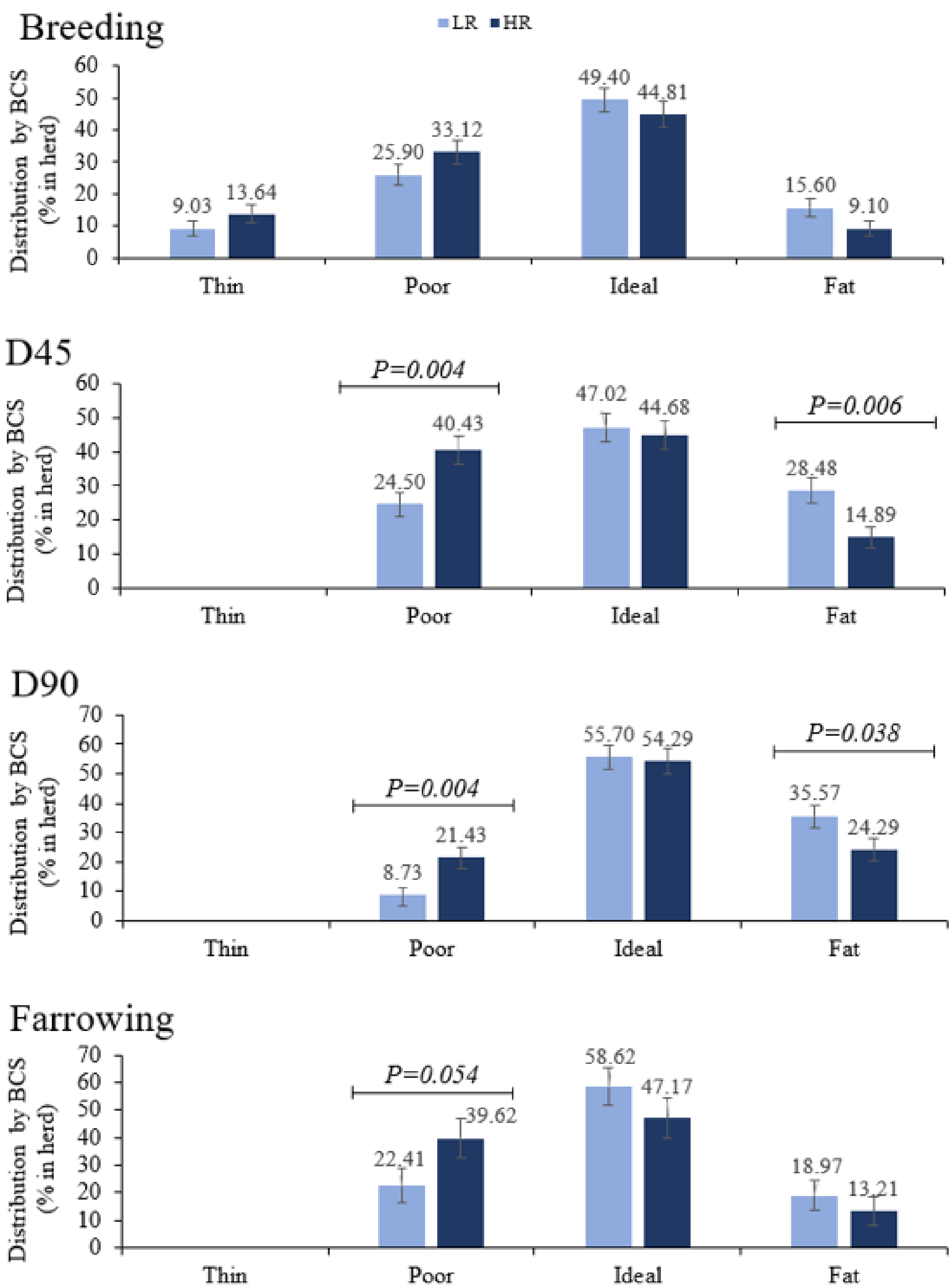

Figure 4.1 Body condition distribution in the herd throughout gestation

CHAPTER V

IMPACT OF ADDING A STIMBIOTIC TO GESTATIONAL DIETS ON SOW REPRODUCTIVE PERFORMANCE

INTRODUCTION

Gestational diets in the U.S. are usually formulated with corn; and include fibrous ingredients in order to control energy density. More often than not, the fiber sources used are high in ISF, and therefore, less fermentable by bacteria. Fermentation of fiber sources can be beneficial in terms of providing energy by short chain fatty acids (SCFA) production. Soluble fibers are usually completely fermented by intestinal microbiota (Wong and Jenkins, 2007), predominantly in the large intestine. Corn, wheat midds, and rice bran are ingredients commonly used in sow feed formulation, and these ingredients have a high percent (above 50%) of their non-starch polysaccharides in form of arabinoxylans (AXs) which are not soluble.

An opportunity to improve the use of the insoluble dietary fractions, specifically AXs would be the inclusion of xylanase, which hydrolyzes the β-1,4-glycosidic bonds of AXs (Petry and Patience, 2020). When broken down, smaller molecules, xylo-oligosaccharides (XOS) are formed. However, the efficacy of using xylanase in pig diets is highly variable. In finishing pigs it can improve growth performance and reduce mortality (Zier-Rush et al., 2016).

Xylo-oligosaccharides (XOS) supplementation is extensively used a prebiotic. XOS signal intestinal microbiome to develop the fermentability, which in turn leads to production of microbial xylanase (Riviere et al., 2016). The inclusion of XOS has shown to increase the abundance of *Lactobacillus* genus and increase SCFA production (Chen et al., 2021). Short chain fatty acids produced by microbial fermentation affect nutrient absorption by stimulating the production of satiety hormones glucagon-like peptide 1 (GLP-1) and peptide tyrosine-tyrosine (PYY) (Psichas et al., 2014) which influence the rate of gastric emptying.

Different from a prebiotic, the recently introduced term stimbiotic is defined as non-digestible, but fermentable additive, that can stimulate fiber fermentability, but at a dose too low to contribute in a meaningful way to SCFA production (Cho et al., 2020). The objective of this study was to assess the effects of feeding a corn-based gestational diet supplemented with a stimbiotic (combination of xylanase and fermentable XOS) on sow and litter performance.

MATERIALS AND METHODS

This study was conducted at a 2,600-sow commercial research farm located in Mooreland, OK, from May through November of 2021. All procedures were approved by Hanor's Research and Veterinarian teams and were in compliance with regulations for humane care and use of animals in research.

Experimental Design, Animals and Treatment

Four hundred and eighty-eight sows (PIC L42; 0 to 8 of parity; 176.48 ± 12.4 kg) from 4 consecutive breeding groups were used. Each week sows from the same breeding group were randomly allotted to one of two treatments, receiving a control diet (CON) or a diet with a stimbiotic product added (SIG). Sows were balanced by parity and body condition score (BCS).

The study began at breeding and concluded at weaning. The first group of sows was placed in May, 2021, and the last group was weaned in November,2021.

Experimental diets were manufactured at a commercial feed mill (Hanor Company, Enid, OK). The gestation diets were common corn-soybean meal based. Fiber sources in the gestational diet formulation were wheat midds and rice bran. The stimbiotic was added at an inclusion of 0.02% of the diet (Table 5.1) . Diets were formulated to contain 0.56% standardized ileal digestible (**SID**) Lys, be isocaloric and keep their total dietary fiber level (TDF) at 12% (Table 5.2). During lactation all sows received the same diet. All diets were formulated to meet or exceed nutrient requirements of gestating and lactating sows (NRC,2012). Samples of 0.5 kg from each diet were collected from every new batch that was made at the feed mill, and were stored at -20°C. Once the trial concluded, the samples were homogenized, and a subsample from each diet was sent to a commercial laboratory for analysis.

Housing and Feeding Methods

Both the gestation and farrowing rooms were environmentally controlled and mechanically ventilated. The temperature inside the building was regulated by a cool cell system. Inside the gestation room temperature was set to 20°C, and in the farrowing rooms at 22 °C. Sows were individually housed and fed during gestation and had free access to water. Each stall had a nipple waterer and an adjustable feeder.

Throughout gestation all sows were fed the dietary treatments twice a day (0600 and 1100 h) according to their body condition score (Table 4.3). Individual feeders were adjusted on d 7, 45 and 90 of gestation. Once placed in the farrowing room (approx. d 112 of gestation) all sows received 1.82 kg/d of lactation feed until parturition. After, they received ad-libitum feed (Big Dutchman, DryExactPro Automatic Feeding system). Farrowing crates had supplemental heat provided to piglets by heat lamps or heat mats and were left for 6 days after parturition.

Sow Measures and Performance Data

Sow data was taken at placement, throughout gestation, at placement in the farrowing room and at weaning. The body condition score (BCS) was measured with a Knauer Sow Body Condition Caliper (Third version) at the last rib, and it was taken at placement (breeding day), d 45 and 90 of gestation, at placement in the farrowing room and at weaning. Sow BCS changes were calculated from two stages. First, the sow BCS difference from breeding to day 90 of gestation. To create categories for the BCS, sows were grouped based on Hanor's parameters for body condition (Thin ≤ 8, Poor 9-10, Ideal 11-13, Fat 14-15, Obese ≥ 16). Additionally, sow BW was captured at placement (breeding), when moved to the farrowing room (approx. d 112 of gestation) and at weaning. Post-partum BW was adjusted to account for piglet and placental weight using Rosero et al. equation from 2013.

$$Post-partum\ BW(kg) = -8.246 + 0.981 * pre-farrow\ BW - 0.679 * pigs\ born$$

Similar to the BCS, sow BW change was calculated from two stages. First, the sow BW difference from breeding to placement in the farrowing room, to determine gestation BW gain. Next, the sow BW difference from post-partum to weaning to calculate the lactation weight loss.

Reproductive traits included born alive (BA), Stillborn (SB), mummies (MM), total born (TB) which was calculated as the sum of BA and SB, weaned pigs and farrowing rate (FR). The subsequent performance traits included wean to estrus interval (WEI), percent of mated sows, and litter size.

Litter Measurements and Performance Data

One hundred and nine litters were used as a subsample for piglet weight measurements, fifty-five from the CON diet and fifty-four from the SIG diet. Individual piglet weight from born alive and stillborn pigs was taken within 24 h of birth, and at weaning. The percent of small pigs was calculated as the sum of pigs below 0.9 kg at birth, or below 3.6 kg at weaning divided by the total number of pigs weighed. Throughout lactation piglet mortality from all litters was recorded along with the cause. Pigs did not have access to creep feed or supplemental milk during the experiment.

Statistical Analysis

All data were analyzed as a complete randomized design using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) for normal distributed variables and the GLIMMIX procedure of SAS for binomial variables. In the model, body condition category at breeding, dietary treatment and body condition category at breeding × dietary treatment interaction were used as fixed effects, and breeding group as a random effect. Maternal performance data were analyzed with sow as the experimental unit, and litter performance data were analyzed with litter as the experimental unit. For herd distribution changes in body condition, the breeding BCS category was excluded from the model. Observations were considered outliers when the absolute value of the studentized residuals was greater than 3.5. Means are presented as Least Square means (LS). Results were considered statistically significant at $P \leq 0.05$, and values between 0.05 and 0.10 were considered a tendency toward difference.

RESULTS

Sow performance

There were no differences between dietary treatments at the onset of the experiment for BW (176.5 ± 12.5 kg; $P = 0.925$) and caliper units (10.7 ± 0.07; $P = 0.345$). The BCS was different among the BCS categories at breeding, as expected. No interactions between diet and the BCS category for the sow measures and litter size variables were found.

There was a tendency for an interaction between diet and body condition (*P* = 0.097) for farrowing rate. Thin sows that received the SIG diet a higher farrowing rate compared to the control diet (10% difference, *P* = 0.043), although not significant, ideal sows fed SIG had a higher farrowing rate (92.86% vs. 97.80%; *P* = 0.139). Sow BW at placement in the farrowing room, the estimated pot-partum BW and at weaning were not different between dietary treatments and body condition categories (Table 5.4). Body weight changes during gestation and lactation were not different. Overall, sows gained an average of 60 kg during gestation.

On d 45 and 90, BCS were not different between diets. Nevertheless, there were differences between the different body condition groups. Thin and poor conditioned sows had a difference of 1 and 2 units compared to ideal and fat conditioned sows, respectively (*P* < 0.001). However, the difference between thin and poor condition sows was not significant. On d 90 and at placement in the farrowing room results for BCS were comparable as those in d45. At weaning the BCS was not different between poor, ideal and fat sows, but thin sows were approximately 1.7 units lower (*P* < 0.001). Body condition changes from breeding to d 90 were different across all categories, thin sows gained 5.13 units and fat sows only 0.31 (*P* < 0.001). During lactation the body condition lost was not different between treatments or body condition categories.

Sow herd composition throughout gestation

The herd composition at the onset of the trial was evenly distributed, and there were no differences between treatments for each body condition category (Figure 5.1). On d 45 sows that that received CTR tended to have less poor-conditioned sows (7.49 % vs. 12.27 %; *P* = 0.093). On d 90 the distributions were no different, but at placement in the farrowing room CTR sows tended to have a higher proportion of ideal condition sows (64.38% vs 50.53%; *P* = 0.090). No differences were found at weaning.

Litter size, performance, and weight

The experimental diets had no effect on born alive, stillborn pigs and mummies (Table 5.5; $P > 0.112$), but there was a tendency for an interaction for total pigs born ($P = 0.077$). Ideal and fat sows fed SIG had less pigs than those fed CTR ($P < 0.032$). Additionally, thin sows had a tendency to have 0.12 more mummies compared to the rest of the sows ($P = 0.059$). There were no differences in pre-wean mortality and mortality reasons from adding a stimbiotic to the diet or by the category at breeding. The dietary treatment had no impact on the individual piglet weight (Table 5.6) at birth, but thin sows had heavier pigs than the other sows (1.67 kg vs. ~1.38 kg; $P < 0.001$). Sows fed the SIG diet tended to have heavier stillborn pigs (1.13 kg vs. 1.34 kg; $P = 0.083$). Pigs from sow fed the CTR diet were heavier at weaning (7.61 kg vs. 6.54 kg; $P < 0.039$). However, there were no differences in light pig percentages at birth and at weaning between treatments ($P > 0.05$).

The culling rate was not impacted by the diet (Table 5.7). Although not significant, sows from the CTR treatment had a higher percent of sows culled for being returns (51.72 % vs 30.43% out of total culled sows; $P = 0.133$). The wean to estrus interval, rebred sows and subsequent farrowing rate was not affected by the diet fed.

DISCUSSION

Our results showed that the use of a stimbiotic had no effect on sow BW at farrow and weaning, gestational BW gain or lactation BW loss. We expected to see an increase in BW and BCS for sows fed the SIG diet, as the mode of action is to increase SCFA production that is later used by the animal. The results expected from this trial were that the BW and body condition changes would be similar to our second trial where sugar beet pulp was used, since this fibrous ingredient is known to be highly fermentable. Nevertheless, our findings are similar to those evaluated by Bampidis et al. (2019) from two commercial products that used endo-1,4-β-xylanase from late gestation until weaning, where no differences were observed in sow BW and body condition, and the energy digestibility of the diets was not affected by the supplementation of the additive. On the other hand, lactating sows fed diets supplemented with xylanase reduces their BW loss by approximately 3 kg, based on a meta-analysis conducted across 8 trials (Cozannet et al., 2018), interestingly the effect was more pronounced in primiparous sows than multiparous. These results agree with previous findings by de Souza et al. (2007) who found no effect of enzymes in digestibility during gestation but found an improvement when supplementing lactational diets.

There was a tendency towards an interaction between dietary treatment and body condition for the farrowing rate trait. Thin sows that received the SIG diet a higher rate than the CTR fed sows (10% difference, $P = 0.043$), although not significant, ideal sows fed SIG also had a higher farrowing rate (5% difference; $P = 0.139$). Overall litter size was not increased by the adding the stimbiotic to the diet. However, there was a tendency for an interaction for total pigs born ($P = 0.077$). Ideal and fat sows fed SIG had less pigs than those fed CTR ($P < 0.032$).

Litter performance was not improved when sows were fed the SIG diet, we expected an increase in birth or weaning weight, these results however are no different than what we found when we added a SF source in the second trial. Similarly, pre-wean mortality and mortality by reasons were no different. Comparably, the evaluation by Bampidis et al. (2019) reported that endo-1,4-β-xylanase supplementation did not have significant effects on litter size and weight. However, Cozannet et al. (2018) reported an increase litter weight gain from xylanase supplementation during lactation.

Interestingly, sows fed the SIG diet had fewer culled sows from being returns. Although this difference was not statistically significant ($P = 0.133$). This could be an area to be further explored, as there seems to be a positive effect on farrowing rate and returns when sows received the SIG diet.

CONCLUSION

The present experiment showed that adding a stimbiotic to the gestational diet had no effect on BW and body condition changes, and litter performance was no different between the CTR and SIG diets. There is an opportunity to expand research and understand the effects of using a stimbiotic in farrowing rate and returns, as well as the subsequent reproductive cycle performance. It is possible that the dose used was not great enough for gestating sows, and a dose titration would show different results.

Table 5.1 Composition of the experimental diets, as-fed basis

	Experimental Diet	
Item	CTR	SIG
Ingredient, %		
Corn	66.18	66.17
Wheat middlings	17.40	17.40
Rice bran	10.00	10.00
Soybean meal, 46.5% CP	1.70	1.70
Soy oil	0.50	0.50
Limestone	1.34	1.34
Monocalcium phosphate, 21% P	0.88	0.88
Salt	0.48	0.48
L-Lysine	0.30	0.30
L-Threonine	0.12	0.12
L-Methionine	0.02	0.02
L-Tryptophan	0.02	0.02
Choline chloride, 60%	0.13	0.13
Potassium, magnesium sulfate[1]	0.50	0.50
Sow vitamin and mineral premix[2]	0.20	0.20
Sow trace mineral mix[3]	0.08	0.08
Zeolite clay[4]	0.10	0.10
Direct-Fed microbial (*Bacillus subtillis* PB6)[5]	0.05	0.05
Stimbiotic[6]	—	0.02
Iron Oxide[7]	0.04	0.04

[1]Dynamate (Mosaic, Plymouth, MN).

[2]Provided 125 mg/kg Zn, 100 mg/kg Fe, 30 mg/kg Mn, 15 mg/kg Cu, 0.7 mg/kg I, 0.3 mg/kg Se, 8,378 IU/kg vitamin A, 1,764 IU/kg vitamin D3, 77.2 IU/kg vitamin E, 3 mg/kg vitamin K, 0.03 mg/kg Vitamin B12, 8.2 mg/kg Riboflavin, 26.5 mg/kg d-Pantothenate, 22 mg/kg Niacin, 5.5 mg/kg Thiamine, 3.1 mg/kg Pyridoxine, 2.6 mg/kg Folic Acid, 0.4 mg/kg Biotin, 130 mg/kg Ethoxyquin, and 0.2 mg/kg Chromium.

[3]Provided 134 mg/kg Zn, 53 mg/kg Mn and 27 mg/kg Cu

[4]KALLSIL (Kemin, Des Moines, IA)

[5]CLOSTAT (Kemin Des Moines, IA)

[6]Provided 3,180 FTU/kg Phytase, 21,773 BXU/kg Xylanase and 5,453 XylEqu/kg Xylanase D

[7]Used to color code diets

Table 5.2 Calculated and analyzed diet composition

	Experimental Diet	
Item	CTR	SIG
Calculated Composition		
ME, Mcal/kg	3.19	3.19
NE, Mcal/kg	2.50	2.50
Total Fat, %	5.00	5.00
CP, %	11.05	11.05
Total Lys, %	0.65	0.65
SID Lys, %	0.56	0.56
Total Ca, %	0.88	0.88
Total P, %	0.69	0.69
Crude Fiber, %	4.34	4.34
Neutral Detergent Fiber, %	13.30	13.30
Total Dietary Fiber, %	12.00	12.00
Soluble Fiber, %	1.48	1.48
Insoluble Fiber, %	10.52	10.52
InSol:Sol Fiber ratio	7.12	7.12
Analyzed composition		
Moisture, %	14.14	14.39
Total Fat, %	5.61	5.41
CP, %	11.06	11.60
Crude Fiber, %	3.16	2.98
Neutral Detergent Fiber, %	20.62	16.66
Acid Detergent Fiber, %	7.50	6.44
Starch, %	48.02	48.62
Sugar, %	3.84	3.84

Table 5.3 Feeding Program for Gestating Sows

Feed allowance by BCS[2], kg/d			
Stage	BCS units[1]		
	1-10	11-13	14-19
Day 0-7	1.81	1.81	1.81
Day 7-90	2.72	2.04	1.59
Day 90-112	3.63	2.04	1.59
Placement in farrowing crate	1.81	1.81	1.81
Lactation	Ad libitum	Ad libitum	Ad libitum

[1]Units were grouped to fit Hanor's body condition standards
[2]Body Condition Score

Table 5.4 Effects of a stimbiotic inclusion on sow performance

	Dietary treatment			Body Condition Category[5]					*P*-values		
Item	CTR	SIG	SEM	Thin	Poor	Ideal	Fat	SEM	TRT*BCS	TRT	BCS
Sows placed, n	250	238		140	142	178	28				
Sow Body Weight, kg											
Breeding	176.22	176.74	12.47	174.3[b]	192.28	173.2[ab]	166.0[a]	13.01	0.852	0.925	0.001
Placement in farrow crate, kg[1]	246.0	243.0	9.0	247.5	253.5	237.2	239.8	10.4	0.601	0.691	0.117
Post-Partum, kg (estimation)[2]	223.7	220.2	8.9	224.9	231.0	214.8	217.1	10.1	0.534	0.645	0.098
Weaning, kg[3]	224.4	216.4	10.3	220.9	228.3	218.2	214.2	12.1	0.187	0.519	0.636
Δ Breeding-Placement in farrow crate,kg	60.7	61.8	8.6	68.9	53.5	61.2	61.3	9.6	0.282	0.866	0.180
Δ Post Partum - Weaning,kg	-2.9	-0.4	-7.1	-2.9	-0.5	-0.7	-1.9	-8.2	0.246	0.670	0.967
Body Condition Score, caliper units											
Breeding	10.69	10.60	0.07	6.96	9.44	11.88	14.31	0.09	0.873	0.345	0.001
Day 45	13.28	12.96	0.23	11.94[a]	12.24[a]	13.46	14.83	0.26	0.835	0.111	0.001
Day 90	13.09	13.02	0.35	12.04[a]	12.33[a]	13.24	14.59	0.38	0.897	0.783	0.001
Placement in farrow crate1	12.43	12.56	0.25	11.54[a]	11.85[a]	12.59	13.98	0.33	0.906	0.707	0.001
Weaning	10.64	10.02	0.42	9.04	10.25[a]	10.77[a]	11.25[a]	0.50	0.156	0.296	0.007
Δ Breeding- Day 90	2.43	2.41	0.38	5.13	2.88	1.37	0.31	0.41	0.891	0.916	0.001
Δ Farrow- Weaning	1.85	2.34	0.55	2.37	1.82	1.69	2.50	0.67	0.864	0.538	0.746
Farrowing rate, %	90.48	94.16	0.02	93.27	93.81	96.01	82.32	0.03	0.097	0.211	0.090
Lactation ADFI, kg/d[4]	5.30	5.18	0.25	5.27	5.30	5.25	5.14	0.26	0.526	0.316	0.889

[a,b] values with the same letter are not significantly different

[1] At day 112 of gestation

[2] Rosero et al., 2013 Equation to estimate post partum BW

[3] At approximately 21 days

[4] A subsample of 139 sows fed with the BigDutchman feeding system

[5] Categories grouped at breeding

Table 5.5 Effects of a stimbiotic inclusion on litter size and pre-wean mortality

Item	Dietary treatment CTR	SIG	SEM	Body Condition Category[1] Thin	Poor	Ideal	Fat	SEM	*P*-values TRT*BCS	TRT	BCS
Litter Performance, pigs/litter											
Total pigs born	15.32	14.15	0.40	15.16	14.83	14.23	14.71	0.48	0.077	0.011	0.161
Born alive	13.67	12.96	0.34	13.81	13.56	12.96	12.94	0.43	0.439	0.112	0.174
Stillborn	1.16	1.12	0.19	1.32	1.14	1.23	0.88	0.22	0.330	0.852	0.489
Mummies	0.15	0.13	0.04	0.23	0.14[a]	0.097[a]	0.07[a]	0.05	0.504	0.684	0.059
Pre wean mortality											
Dead pigs, n	2.48	2.24	0.20	2.31	2.22	2.11	2.79	0.24	0.763	0.318	0.406
Dead pigs, %	18.05	17.18	1.42	16.27	16.58	16.44	21.18	1.77	0.498	0.641	0.514
Laid on, % of dead	72.18	73.81	4.41	75.13	69.95	76.12	70.79	5.32	0.929	0.738	0.533
Small, % of dead	15.64	13.83	2.86	12.14	15.76	13.13	17.91	3.63	0.716	0.635	0.696
Others, % of dead	12.25	12.51	3.37	13.03	14.48	10.67	11.34	4.12	0.711	0.947	0.752
Weaned, pigs/litter	10.85	10.93	0.24	11.01	10.99	10.91	10.64	0.29	0.400	0.747	0.833

[a,b] values with the same letter are not significantly different

[1] Categories grouped at breeding

Table 5.6 Effects of a stimbiotic inclusion on individual piglet weight

Item	Dietary treatment CTR	SIG	SEM	Body Condition Category[4] Thin	Poor	Ideal	Fat	SEM	*P*-values TRT*BCS	TRT	BCS
Litters, n	55	54		20	35	49	5				
Pigs, n	751	699		249	470	652	79				
Individual piglet weight, kg											
Birth[1]	1.45	1.45	0.05	1.67	1.41[a]	1.46[a]	1.27[a]	0.06	0.965	0.957	0.001
Stillborn[1]	1.13	1.34	0.08	1.43[a]	1.08[b]	1.21[ab]	1.22[ab]	0.11	0.853	0.083	0.080
Weaning[2]	7.61	6.54	0.36	7.79	6.59	6.73	7.20	0.45	0.251	0.039	0.114
Light weight pigs[3], % per litter											
< 0.9 kg at farrowing	4.66	7.53	1.91	2.66	9.39	5.66	6.68	2.43	0.424	0.291	0.109
< 3.6 kg at weaning	1.81	6.38	2.90	3.47	6.74	3.06	3.13	3.70	0.613	0.275	0.692

[a,b] values with the same letter are not significantly different

[1]Taken within 24 h after birth

[2] At age 21 days

[3] Parameters based on commercial practices

[4] Categories grouped at breeding

Table 5.7 Effects of a stimbiotic inclusion on herd performance and subsequent cycle

	Dietary treatment			*P*-values
	CTR	SIG	SEM	TRT
Cull sows, %	11.84	9.91	2.000	0.501
Returns (% of total cull)	51.72	30.43	9.400	0.133
Rebred sows[1], %	86.53	84.85	2.200	0.601
WEI[2], d	5.32	5.26	0.240	0.868
Farrow rate second cycle, %	89.62	88.78	2.130	0.783
Born alive	13.18	13.87	0.370	0.067
Stillborn	1.73	1.47	0.163	0.164
Mummies	0.19	0.19	0.044	0.941
Total pigs born	14.90	15.33	0.407	0.276

[1]Sows rebred after weaning the first cycle

[2]Wean to estrus interval

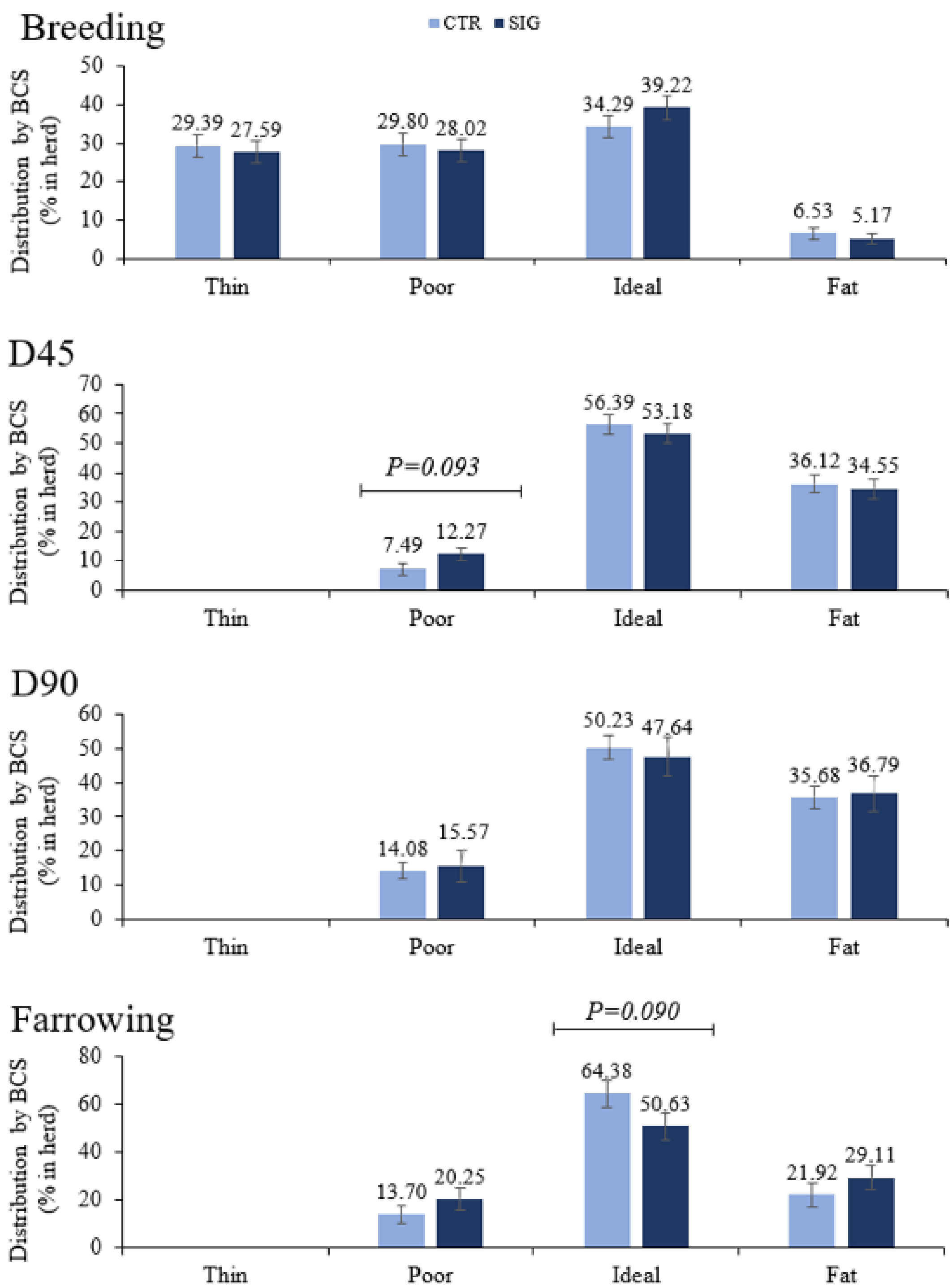

Figure 5.1 Body Condition distribution in the herd throughout gestation

CHAPTER VI

SUMMARY

Our findings showed that feeding a higher level of total dietary fiber (18 % TDF) in gestational diets to multiparous sows was beneficial in terms of controlling sow BW and body condition throughout gestation. Sows that received higher TDF had a higher proportion of well-conditioned sows at d 45 and 90, and fewer over-conditioned. In addition, there was no diet effect on litter size and performance, and a higher TDF did not negatively impact individual piglet weights at birth, processing, and weaning, as well as the small pig percentages at birth and weaning. These results show that fibrous ingredients can be added to a gestational diet at a level of 18% TDF without negatively impacting sow and litter performance. Instead, the sow herd benefits by having a higher proportion of well-conditioned sows in late gestation.

Feeding different ISF:SF (4 or 8) while keeping the same TDF (12%) during gestation had no impact on sow BW at placement in the farrowing rooms or in lactation BW loss. On the other hand, BCS was increased on d 45 and 90 when sows were fed a low ratio diet.

However, sows fed the LR diet lost more caliper units during lactation. In addition, herd composition was affected by the fiber ratio, where the LR group had fewer poor-conditioned sows but had more over-conditioned sows in late gestation. The diets had no effect on total born, stillborn pigs and mummified fetuses, and pre-wean mortality and individual piglet weights were not different. These findings show that feeding a low insoluble to soluble fiber ratio diet does not improve litter size but reduces the number of under-conditioned sows in late gestation.

Lastly, we found that supplementing a stimbiotic to sow gestational diets had no impact on sow BW, and BCS. Thus, it did not affect the sow herd body condition distributions throughout gestation and at weaning. The supplemented diet had no effect on litter size, individual piglet weight and pre-wean mortality. However, there was a tendency for an interaction between diet and body condition for farrowing rate. Thin sows that received the supplemented diet had a higher farrowing rate, and although not significant, sows from the control treatment had a higher percent of sows culled for being returns.

Overall, high levels of TDF can be fed to gestating sows without negatively impacting production, but close attention should be paid when adding a soluble fiber source, as the herd may have a bigger percentage of over-conditioned sows which could be detrimental to the herd longevity and productivity. Additionally, supplementing a stimbiotic is not detrimental to sow performance, but further research is needed to understand the positive effects in farrowing rate.

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APPENDICES

Table A.1. Analyzed fiber content from ingredients used in swine diets[1]

Ingredient	Fiber, %		
	SF	ISF	TDF
Corn	1.00	4.80	5.80
Corn DDGS	2.74	24.04	26.77
Milo	0.61	4.90	5.51
Rice bran	1.21	17.46	18.67
Soybean meal	4.10	12.80	16.90
Soy hulls	7.42	50.07	57.49
Sugar beet pulp	18.03	28.33	46.36
Wheat midds	3.63	24.75	28.38

[1]Analyzed by a commercial laboratory

Table A.2. Analyzed fiber fractions from ingredients used in swine diets[1]

Ingredient	Constituent sugars[2] (g/100 g)									
	Rha	Fuc	Ara	Xyl	Man	Gal	Glu	GlcA	GalA	Lignin
Corn	0.10	0.00	1.40	1.80	0.10	0.40	1.70	0.00	0.00	0.30
Corn DDGS	0.00	0.00	5.33	7.91	1.45	1.43	7.68	0.35	0.42	2.20
Milo	0.00	0.00	1.23	1.29	0.14	0.21	2.12	0.10	0.11	0.32
Rice bran	0.00	0.00	2.41	3.01	0.38	0.70	4.59	0.08	0.33	7.17
Soybean meal	0.30	0.30	2.20	1.00	0.80	4.40	3.30	0.00	2.10	2.50
Soy hulls	0.55	0.15	4.11	7.37	4.98	1.98	28.08	0.18	7.69	2.40
Sugar beet pulp	0.72	0.00	10.55	0.98	0.97	3.16	13.68	0.39	10.41	5.50
Wheat midds	0.01	0.00	6.45	11.19	0.47	0.67	8.01	0.18	0.33	1.10

[1]Analyzed by a commercial laboratory

[2]Rha, Rhamnose; Fuc Fucose; Ara, Arabinose; Xyl, Xylose; Man, Mannose; Gal, Galactose; Glu, β-glucan; GlcA, Glucuronic acid; GalA, Galacturonic acid

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