ENERGY VALUES IN PISTACHIO SHELL POWDER AND SOYBEAN HULLS FED TO GESTATING AND LACTATING SOWS

BY

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THESIS

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ABSTRACT

Two experiments were conducted to determine the nutritional composition and nutrient and energy digestibility of pistachio shell powder, soybean hulls, and soybean meal. In Exp. 1, the objective was to test the hypothesis that apparent total tract digestibility (**ATTD**) of gross energy (**GE**), dry matter (**DM**), and total dietary fiber (**TDF**) and concentration of digestible energy (**DE**) in pistachio shell powder are not different from those in soybean hulls when fed to gestating or lactating sows. Twenty-four gestating sows were housed in metabolism crates and fed a corn-based diet or a diet that contained corn and 20% pistachio shell powder, or a diet containing corn and 20% soybean hulls. Sows were fed experimental diets for 13 d with feces and urine being quantitatively collected for 4 d after 7 d of adaptation. Twenty-four lactating sows were housed in farrowing crates and fed a diet based on corn and soybean meal (**SBM**) or 2 diets that contained corn, SBM, and 20% of either pistachio shell powder or soybean hulls, and feces were collected for 6 d after 7 d of adaptation to the diets. Results indicated that for gestating sows, the diet containing soybean hulls had greater ($P < 0.05$) ATTD of DM, GE, and TDF than the diet containing pistachio shell powder. The DE and metabolizable energy (**ME**) in the pistachio shell powder diet were less ($P < 0.05$) than in the basal diet and the diet containing soybean hulls. The ME in pistachio shells (2,606 kcal/kg DM) was also less ($P < 0.05$) than in soybean hulls (3,645 kcal/kg DM). When fed to lactating sows, ATTD of DM, GE, and TDF in the diet containing pistachio shell powder was less ($P < 0.05$) than in the diet containing soybean hulls or in the basal diet. The DE in the diet containing pistachio shell powder was also less ($P < 0.05$) than in the soybean hulls diet. The DE in pistachio shell powder (1,664 kcal/kg DM) was less ($P < 0.05$) than in soybean hulls (2,795 kcal/kg DM). In Exp. 2, the objective was to test the hypothesis that ATTD of GE and concentrations of DE in soybean meal **(SBM)** and soybean hulls are greater when fed to gestating sows or lactating sows than to growing pigs and that there is no difference between gestating and lactating sows in ATTD of GE. Three experimental diets were prepared. The basal diet consisted of corn as the sole source of energy and two additional diets contained corn and 30% SBM or corn and 20% soybean hulls. All diets were fed to growing pigs and gestating and lactating sows. Twenty-four growing pigs and twenty-four gestating sows were housed in metabolism crates and fecal and urine samples were quantitatively collected. Twenty-four lactating sows were housed in farrowing crates and feces were grab-sampled. The ATTD of GE, DE, and ME were calculated in diets fed to growing pigs and gestating sows, and DE and ME in SBM and soybean hulls were calculated as well. The ATTD of GE and DE were also calculated in diets fed to lactating sows and DE was calculated in SBM and soybean hulls. Results from growing pigs indicated that DE and ME were greater ($P < 0.05$) in corn and SBM compared with soybean hulls. For gestating sows, DE in corn and SBM was also greater ($P < 0.05$) than in soybean hulls and ME in corn was greater ($P < 0.05$) than in SBM; whereas, soybean hulls had the least ($P < 0.05$) ME. Results for lactating sows indicated that DE in corn and SBM was greater ($P < 0.05$) than in soybean hulls, but lactating sows had greater ($P < 0.05$) DE in soybean hulls than gestating sows; whereas, gestating sows had greater ($P < 0.05$) DE in corn than lactating sows. The ME in corn was greater ($P < 0.05$) in gestating sows than growing pigs; whereas, growing pigs had greater ($P < 0.05$) ME in SBM than gestating sows. In conclusion, the ATTD of DM and GE and the DE in pistachio shell powder were less than in soybean hulls, therefore, inclusion in lactation diets needs to be limited. Soybean hulls contain less DE and ME than corn and SBM, but there are no consistent differences in DE and ME among growing pigs, gestating, and lactating sows.

Keywords: digestibility, energy, fiber, pistachio shell powder, soybean meals, soybean hulls.

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CHAPTER 1: INTRODUCTION

Swine, often known as pigs, have been domesticated for thousands of years. These versatile and intelligent animals have played a crucial role in human agriculture. Swine are renowned for having powerful bodies, keen senses of smell, and environmental adaptability (Smith et al., 2014). Not only do pigs provide meat, but they also provide medical resources, such as insulin (Aggarwal et al., 2022).

The capacity of pigs to consume a broad range of plant and animal materials makes them omnivores, which enhances their adaptability. Swine nutrition is an essential component of pig production and optimal growth rates, reproductive effectiveness, and overall well-being of the animals requires proper nutrition to make sure all nutritional needs are met. However, diets represent 60 to 75% of the total cost of pork production (Patience et al., 2015). Swine diets are designed to satisfy their requirements for vitamins, minerals, energy, fatty acids, and amino acids. Grains such as corn and wheat primarily provide energy to diets, whereas oilseed-coproducts, such as soybean meal, canola meal, and sunflower meal, provide both amino acids and energy to diets (Stein et al., 2016). High-fiber co-products from other agro-industries may also be used as energy sources in diets for pigs, but the energy value pigs can obtain from these ingredients depends on the fermentability of the fibers in these co-products (Zijlstra and Beltranena, 2013). The corn-soybean meal diet has been the most commonly used combination in diets for pigs in the United States; whereas, wheat-soybean meal diets are often used in western Canada, Europe, and Australia due to the lack of corn and greater availability of wheat in those areas (NRC, 2012).

Due to certain fiber components' beneficial impacts on pigs through intestinal fermentation and their influence on satiety and animal behavior, dietary fiber has drawn attention in recent years (Montagne et al., 2003; De Leeuw et al., 2008). Dietary fiber is the indigestible part of plant carbohydrates and is primarily composed of cellulose, hemicellulose, lignin, and pectin (Bach Krudsen, 2011; NRC, 2012). Dietary fiber may be divided into two types: soluble dietary fiber and insoluble dietary fiber. Soluble dietary fiber dissolves in water and is usually fermented by gut bacteria in the cecum (Jaworski and Stein, 2017), resulting in synthesis of short-chain fatty acids (SCFA), which supply energy to the animal. Insoluble dietary fiber does not dissolve in water and has a lower fermentability in the cecum and the colon (Jaworski and Stein, 2017) and contributes to fecal bulk.

Increased dietary fiber may result in greater fecal output and reduced digestibility of nutrients and energy (Pedersen et al., 2007). However, fiber is essential for gestating sows because it promotes gastrointestinal motility, prevents constipation, and improves satiety (Bosse, 2017). High-fiber diets for sows have been associated with better reproductive performance and improved welfare because hunger-related stereotypical behaviors are reduced (Noblet and Le Goff, 2001). Inclusion of high fiber ingredients in diets reduces energy density of the diet, which may reduce growth performance of growing-finishing pigs (Shi et al., 2021). Because gestating sows are fed a restricted amount of feed, a reduction in energy density is not a concern and high-fiber ingredients may, therefore, be used in diets for gestating sows. Because pigs do not express fiber-digesting enzymes, exogenous enzymes may be included in diets to promote hydrolysis of glycosidic bonds among monosaccharides in the fiber and increasing the amount of metabolizable energy the animal can obtain from fiber due to increased fiber degradation (Casas and Stein, 2016; Abelilla and Stein, 2019; Acosta et al., 2024).

Sows may have an increased ability to digest energy or nutrients compared with growing pigs due to the larger digestive tracts (Noblet and Shi, 1993). Although there is no difference in fiber fermentation between gestating sows and growing pigs for some feed ingredients, sows are generally able to utilize high-fiber ingredients, such as soybean hulls, better than growing pigs (Lowell et al., 2015). There is a lack of information about the fermentability of soluble versus insoluble dietary fiber by gestating and lactating sows and it is not established how much digestible energy fiber can contribute to diets for sows. There is, therefore, a need for more research in this area.

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CHAPTER 2: USE OF DIETARY FIBER IN DIETS FOR SOWS: A REVIEW

Introduction to Fiber

Carbohydrates typically make up 60 to 70% of the total energy intake by pigs (Bach Knudsen et al., 2013). Carbohydrates are made up of monosaccharides joined by α- or β-glycosidic bonds to form compounds with varying degrees of polymerization, including complex organized polysaccharides present in plant cells, oligosaccharides, and disaccharides (Cummings and Stephen, 2007; Navarro et al., 2019). Endogenous enzymes secreted by pigs cannot hydrolyze the glycosidic bonds in fiber, and different types of fiber differ greatly in terms of their physicochemical characteristics due to the differences in their monosaccharide composition. The physicochemical characteristics of dietary fiber, such as molecular structure, water-binding capacity, viscosity, and particle size, affect gut physiological function in different ways. Dietary fiber may contain fructose, galactose, mannose, rhamnose, xylose, and arabinose, in addition to glucose, which serves as its main constituent because it is abundant in cellulose and other non-starch glucans (McDougall et al., 1996).

Physical Characteristics of Dietary Fiber

Water binding capacity, viscosity, and bulk density are some of the physicochemical characteristics of dietary fiber (Eastwood and Morris, 1992). Digestible energy and metabolizable energy in feed ingredients may be predicted from some chemical constituents and from in vitro digestibility of DM, but not from physical characteristics. Because these traits are linked to the chemical makeup of dietary fiber, it may be possible to correlate the physicochemical characteristics with solubility of fiber (Navarro et al., 2018).

The amount of water that is retained in dietary fiber after it has been hydrated and after an external force has been applied is estimated by its water binding capacity (Robertson et al., 2000). Dietary fibers' capacity to retain water is determined by its lignification level, intermolecular structure, and composition (Serena and Bach Knudsen, 2007). According to Canibe and Bach Knudsen (2002), the swine feed business may benefit from the rapid and easily reproducible water binding capacity measurement approach. Cellulose and lignin have a low water binding capacity, and soluble dietary fiber usually has a greater water binding capacity than insoluble dietary fiber (Auffret et al., 1994; Robertson et al., 2000; Shelton and Lee, 2000). Conversely, there is a positive correlation between water binding capacity and the amounts of arabinose and xylose because a high concentration of arabinose and xylose usually is a result of a high concentration of arabinoxylan which may be soluble (Holloway and Greig, 1984). There is also a positive correlation between water binding capacity and the amount of soluble fiber in brewer's spent grain, pea hull, rye grass, potato pulp, sugar beet pulp, and pectin residue (Serena and Bach Knudsen, 2007). However, high water binding capacity of diets may have a detrimental impact on the apparent ileal digestibility (**AID**) of starch, and diets with greater water biding capacity due to greater dietary fiber concentrations have lower dietary metabolizable energy (Canibe and Bach Knudsen, 2002; Serena et al., 2008). Increases in water binding capacity can result in increases in endogenous nitrogen losses, and pigs fed semi-purified diets had lower AID of crude protein when diet water binding capacity levels were increased (Leterme et al., 1998; Cervantes-Pahm et al., 2014).

The viscosity of dietary fiber determines its capacity to thicken or gel in solution (Dikeman and Fahey, 2006). Water has low viscosity and flows freely but corn syrup has high viscosity and resists flow. Dietary fibers with high viscosity, including gums, pectins, and βglucans, account for the majority of soluble non-starch polysaccharides (**NSP**; Dikeman and Fahey, 2006). According to Takahashi et al. (2009), insoluble NSP may affect viscosity by absorbing water. The viscosity of brewer's spent grain, pea hull, rye grass, potato pulp, sugar beet pulp, and pectin residue was similar to that of water, despite varying concentrations of soluble NSP (Serena and Bach Knudsen 2007). A positive correlation between viscosity of sow diets and the concentration of soluble NSP has also been reported (Serena et al., 2008). The difference in viscosity between components and diets indicates that soluble NSP, as well as carbohydrate, protein, and fat, can impact viscosity in mixed diets.

Bulk density refers to the weight of a feed ingredient or diet in a container with a specific volume, thus a lower value for bulk density means that more feed material can be stored per volume unit. (Giger-Reverdin, 2000; Rojas et al., 2016). To determine bulk density, a feed ingredient or diet is placed in a graduated cylinder with a specified volume and weighed (Cromwell et al., 2000). Reduced particle size of corn reduced bulk density of both the corn grain and diets in which the corn is used (Rojas et al., 2016). According to Kyriazakis and Emmans (1995), the addition of wheat bran and dried grass meal decreased bulk density of diets, whereas dried citrus pulp increased bulk density. This indicates that increased insoluble dietary fiber concentrations reduces bulk density, but soluble dietary fiber concentrations may increase bulk density. When a bulky, less digestible fibrous feed ingredient is added to a diet, pigs tend to increase their feed intake to maintain a steady intake of digestible energy, which promotes growth. Gut fill is the term used to describe the situation where a pig can no longer eat enough large, fibrous feed element to sustain growth (Kyriazakis and Emmans, 1995). Additionally, the weight of the gastrointestinal tract increased as the bulk density of diets was reduced, which increased the maintenance energy requirement (Kyriazakis and Emmans, 1995).

Analysis of Fiber

Different methods are used to quantify and describe dietary fiber in foodstuffs. Crude fiber is the most widely used and oldest method of analysis. The Weende analysis system employs a chemical-gravimetric method to extract sugars and starch using 0.255N sulfuric acid hydrolysis, and 0.313N sodium hydroxide for alkaline hydrolysis of protein, hemicelluloses, and lignin (Bach Knudsen, 2001). The digestion of samples in acid and alkali solutions yields crude fiber and nitrogen-free extract, but this method may underestimate fiber content by 30-50% due to the presence of cellulose, little hemicellulose, and variable lignin concentrations (Fahey et al., 2019).

The Van Soest method analyzes fiber by measuring acid detergent lignin, acid detergent fiber, and neutral detergent fiber (Van Soest et al., 1991). To detect lignin, acid detergent fiber residues (cellulose and lignin) are obtained by boiling a test sample in a sulfuric acid detergent solution. Neutral detergent fiber (hemicellulose, cellulose, and lignin) is the remaining insoluble residue after boiling in a neutral detergent solution. The Van Soest technique does not account for soluble hemicelluloses in cereal grains, oilseeds, or their co-products, resulting in a significant portion of fiber being disregarded (Bach Knudsen, 2001).

An enzymatic-gravimetric technique was created by Prosky et al. (1992) to quantify soluble, insoluble, and total dietary fiber. Because the method is reliable and easily repeatable, it is the most common method for analyzing fiber in human nutrition. In this procedure, protein and starch are hydrolyzed enzymatically, and low-molecular-weight carbohydrates and lipids are extracted to eliminate all non-fiber components. To extract the soluble components of dietary fiber, the residue is precipitated in aqueous ethanol and then weighed and adjusted for protein and ash (McCleary, 2003). However, inulin and polydextrose are not included in this procedure, and it also determines only a portion of the resistant starch (Bach Knudsen, 2001). Nevertheless, because the dietary fiber procedure has become automated and because it provides information about both soluble and insoluble dietary fiber, the total dietary fiber procedure is the most accurate and practical method for analyzing fiber in feed ingredients and diets for pigs. Both soluble dietary fiber and insoluble dietary fiber in feed ingredients can be analyzed using Ankom total dietary fiber analyzer (Ankom Technology, Macedon, NY). While there are several AOAC methods, it is recommended to use the Method AOAC 991.43 to determine soluble, insoluble and total dietary fiber in feed ingredients and diets for pigs (Nguyen et al., 2019).

Englyst et al. (2007) used an enzymatic-chemical technique to assess dietary fiber as total soluble and insoluble NSP. This involves extracting low-molecular weight sugars, removing starch, and hydrolyzing polysaccharides. Monosaccharide residues can be determined by gas-liquid chromatography, HPLC, or colorimetry (McCleary et al., 2019). The concentration of monosaccharides (rhamnose, fucose, arabinose, xylose, mannose, galactose, and glucose) and uronic acids (measured using a colorimetric method; Scott, 1979) equals the total NSP (Bach-Knudsen, 1997). This method provides a full study of fiber components, but is time consuming and costly. Previously disclosed methods can analyze and classify dietary fiber based on its solubility and type of compound in the feed sample.

Fermentation of Dietary Fiber

Pigs may use dietary lipids, proteins, and carbohydrates to obtain metabolic energy, but not all nutrients are hydrolyzed and absorbed by the gastrointestinal tract. Dietary fiber increases microbial fermentation because pigs lack the endogenous enzymes necessary to digest fiber (Anguita et al., 2006). Due to energy loss via gas generation, the contribution from dietary fiber to the energy needs of pigs is low compared with that of other nutrients (Kerr and Shurson, 2013). About 25% of dietary energy is wasted in gas and heat, and pigs cannot absorb or metabolize gas (Jørgensen et al., 2007; Bach Knudsen et al., 2013). Microbes can ferment undigested proteins and carbohydrates (Abelilla and Stein, 2019), and the large intestine is where fermentation primarily occurs because of its high moisture content, low flow rate, and low oxygen level (Bach Knudsen et al., 2013; Jha and Berrocoso, 2015). Branch chained fatty acids and potentially hazardous byproducts such as ammonia, indoles, and phenols are produced by proteolytic fermentation; whereas, saccharolytic fermentation yields short chain fatty acids (**SCFA**) and lactate (Tiwari et al., 2019). Among all dietary components, dietary fiber has the greatest impact on the intestinal environment (Jha and Leterme, 2012). Given its capacity to alter microbiota composition, dietary fiber may improve animal health by influencing gut microbiota and increase the concentration of beneficial microbes such as *Streptococcus*, *Eubacterium, Lactobacillus, Clostridium*, and *Propionibacterium* (Hu et al., 2023).

Insoluble fiber fractions are hydrophobic, crystalline, and partly resistant to microbial fermentation, and their proportion in fibrous feed components is greater than that of soluble fiber (Bach Knudsen, 2011; 2014). Because soluble dietary fiber increases digesta viscosity, a physical barrier in the intestinal surface may be formed which may reduce and consequently decrease nutrient digestion and absorption (Molist et al., 2014).

Fermentable carbohydrates may have a prebiotic-like effect on gut microbiota regulation because SCFA encourages the growth and activity of beneficial bacteria in the gut (Jha and Berrocoso, 2015). Therefore, there are fewer harmful bacteria like E. *Coli* and other Enterobacteriaceae members that can thrive in an acidic environment if fiber fermentation is increased (Tiwari et al., 2019). In fact, bacteria that resemble *Clostridium* and *Ruminococcus*, which hydrolyze insoluble fiber and create SCFA, were more prevalent when cereal grain fiber was fermented compared with fermentation of non-cereal fibers (Bindelle et al., 2008; Ivarsson et al., 2014). As an example, *Bifidobacteria* and *Lactobacilli* species proliferate as a result of wheat fiber fermentation, potentially improving gut architecture (Chen et al., 2014).

Impacts of Dietary Fiber on Digestibility and Growth Performance

Higher fiber concentration in pig diets usually results in lower energy density, less effective nutrient absorption and digestion, and increased manure production, all of which have a detrimental impact on the efficiency of commercial pork production systems (Urriola and Stein 2010; Gutierrez et al., 2014). A balance among commensal microbiota, dietary variables, and mucosal components, including the digestive epithelium and its mucus layer, is necessary to maintain gut health (Montagne et al., 2003). Although the effect of dietary fiber on gut health may differ based on the type of fiber substrate available for fermentation, fiber in the gut affects the microbial habitat and may create favorable conditions by encouraging the growth of beneficial bacteria instead of pathogens. The intestinal epithelium heat-shock protein, which is physiologically essential for gut function, is influenced by consumption of dietary fiber (Lindberg, 2014). Dietary fiber also contributes to managing bacterial infections, specifically in lowering post-weaning diarrhea, which continues to be a major problem for the global pig industry (Williams et al., 2001; Mateos et al., 2006; Molist et al., 2014). An imbalance in the microbiota composition results in gut dysbiosis, which has been linked to a number of health problems in pigs (Greese et al., 2017), post-weaning diarrhea (Ringseis et al., 2022), disruption of the gut-liver connection (Zhang et al., 2022), and impaired function of the intestinal barrier (Desai et al., 2015).

Impact of Fiber on Reproductive Performance of Sows

Feeding gestating sows high-fiber diets may minimize constipation, promote satiety, and assist in maintaining normal reproductive performance while avoiding problems associated with severe feed restrictions (Knage-Rasmussen et al., 2014). Consuming high-fiber diet during the perinatal stage reduced farrowing duration by softening stools and providing energy from the hindgut (Feyera et al., 2017). Providing sows with a high dietary fiber diet for 19 d before mating affected follicular development and increased oocyte maturity, which was linked to altered levels of estradiol hormone caused by the inclusion of beet residue in the diets (Ferguson et al., 2007). When sows were fed diets containing 40% SBM during gestation, the birth weights of pigs increased, which was attributable to increased microbial activity (Rooney et al., 2019). Pigs born by sows fed gestation diets containing 35% soybean hulls had less skin lesions than those born by sows fed a low-fiber diet, indicating less aggressiveness among the litters (Bernardino et al., 2016). Pig development, immunological responses, intestinal morphology, barrier function, and microbiota were improved by supplementing gestation diets with a combination of wheat bran, a source of insoluble dietary fiber, and sugar beet pulp, a source of soluble dietary fiber, during late gestation and lactation (Shang et al., 2021). A balanced microbiota and reduced systemic inflammation caused by dietary fiber may increase reproductive performance in gestating sows (Zhuo et al., 2020). Individual studies, however, have produced contradictory results in terms of the impact of dietary fiber supplementation in the gestation diet on reproductive performance (Table 2.1). Results of some experiments indicated that there is no significant influence; whereas, other experiments of dietary fiber on reproductive performance others yielded positive or negative outcomes. Colostrum and milk may also have greater concentrations of immunoglobulins and cytokines if dietary fiber is included in gestation diets (Shang et al., 2021).

When compared with sows fed a diet containing 15% lignocellulose, sows fed diets enhanced with 15% sugar beet pulp had lower levels of *Clostridium difficile* and *Escherichia-Shigella* in the feces of their suckling piglets were increased in diets for gestating sows (Grześkowiak et al., 2022). Both total litter size and the number of live-born pigs can be increased by feeding a large percentage of unmolassed sugar beet pulp during late lactation and pre-insemination (Ferguson et al., 2004). Feeding more dietary fiber to gestating sows increased the number of pigs born alive by 0.4 per litter (Reeses, 1997). Dietary fiber supplementation during gestation for three successive parities resulted in improved litter size and weight and increase placental weight in the second and third parities (Li et al., 2021). Although dietary fiber can improve the reproductive performance of sows at different stages, the selection of fiber source and the optimal inclusion in sow diet needs to be considered.

Fiber Sources for Sows

Co-products from the food and biofuel sectors, such as wheat bran, maize bran, soybean hulls, sugar beet pulp, and distillers dried grains with solubles, are examples of fiber-rich ingredients that have been added to diets for growing pigs and sows to reduce feed costs. In the United States, distillers dried grains with solubles, hybrid rye, soybean hulls, and wheat middlings are fiber sources that are readily available. Replacing 25% or 50% of corn with hybrid rye resulted in improved lactation performance, and replacing 75% of corn with hybrid rye resulted in sow and litter performance that was no different from that of sows fed control diets (McGhee and Stein, 2021). Because these fiber-rich ingredients had lower levels of amino acids and digestible energy than concentrated ingredients with greater levels of protein and starch, they have been regarded as having low nutritional value (Woyengo et al., 2014). While numerous fibrous ingredients are available, the physicochemical characteristics of the fiber source and the rate of fiber inclusion in the diet determine how satiety and behavior are affected by diets high in fiber (Do et al., 2023). Sows can ferment different sources of fibers including konjac flour, sugar beet pulp, palm kernel expellers, and rice hulls. (Sun et al., 2014; Shang et al, 2019; Weng et al., 2019). Although gestating sows can maintain or improve performance if high-fiber ingredients are included in the diets (Zhuo et al., 2020), there is less information about the impact of fiber ingredients in diets for lactating sows.

Conclusion

Cereals, cereal coproducts, and oilseed coproducts contain different types and compositions of dietary fiber. A comprehensive chemical examination of fibrous feed ingredients is required because the physicochemical properties of fiber affect how well nutrients are digested and fermented and, therefore, influence nutrient absorption. As a result, determining a suitable quantity and source of fiber in diets for pigs is critical. Dietary fiber improves productivity and well-being of sows and may function as a prebiotic, encouraging the growth of beneficial bacteria, boosting satiety and relieving constipation, despite the fact that fiber also reduces energy availability, nutrient digestibility, and growth performance in pigs.

Table

Table 2.1. The effects of dietary fiber on reproductive performance of sows[1)]

Ingredient	Total dietary fiber in diet (%)	Litter size, weaned[2)]	Litter weight, weaned (kg)[2)]	Reference
Konjac flour	24.64	1.00*	13.0*	Tan et al., 2018
Sugar beet pulp	24.69	0.40	3.40	Tan et al., 2018
Soybean hulls	23.44	1.10	1.10	Loisel et al., 2013
Alfa meal	24.98	-0.02	6.40	Liu et al., 2021
Oat bran	11.07	-0.10	-0.49	Renteria-Flores et al., 2008
Wheat straw	16.75	-0.20	-1.12	Renteria-Flores et al., 2008

[1)] Asterisk sign (*) represents the significant difference at $P < 0.05$.

[2)]The increase or decrease in litter size and litter weight measured in dietary fiber groups relative to the control group.

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CHAPTER 3: DEFINITION OF ENERGY VALUES IN PISTACHIO SHELL POWDER AND SOYBEAN HULLS FED TO GESTATIING AND LACTATING SOWS

Abstract

Pistachio shell powder is a high-fiber co-product from the pistachio nut industry that may provide energy and nutrients in animal diets, but no data have been reported for the nutritional value of pistachio shell powder when fed to pigs. Two experiments were, therefore, conducted to test the hypothesis that apparent total tract digestibility (**ATTD**) of gross energy (**GE**), dry matter (**DM**), and total dietary fiber (**TDF**) and concentration of digestible energy (**DE**) in pistachio shell powder are not different from those in soybean hulls when fed to gestating or lactating sows. In experiment 1, 24 gestating sows were housed in metabolism crates and fed a corn-based basal diet or 2 diets that contained corn and 20% pistachio shell powder or corn and 20% soybean hulls. Sows were fed experimental diets for 13 d with feces and urine being quantitatively collected for 4 d after 6 d of adaptation. In experiment 2, 24 lactating sows were housed in farrowing crates and fed a diet based on corn and soybean meal (**SBM**) or 2 diets that contained corn, SBM, and 20% of either pistachio shell powder or soybean hulls, and feces were collected for 6 d after 7 d of adaptation to the diets. Results indicated that for gestating sows, the diet containing soybean hulls had greater ($P < 0.05$) ATTD of DM, GE, and TDF than the diet containing pistachio shell powder. The DE and metabolizable energy (**ME**) in the pistachio shell powder diet were less ($P < 0.05$) than in the basal diet and the diet containing soybean hulls. The ME in pistachio shells (2,606 kcal/kg DM) was less ($P < 0.05$) than in soybean hulls (3,645 kcal/kg DM). When fed to lactating sows, ATTD of DM, GE, and TDF in the diet containing pistachio shell powder were less ($P < 0.05$) than in the diet containing soybean hulls or in the basal diet. The DE in the diet containing pistachio shell powder was also less ($P < 0.05$) than in the soybean hulls diet. The DE in pistachio shell powder (1,664 kcal/kg DM) was less ($P < 0.05$) than in soybean hulls (2,795 kcal/kg DM). In conclusion, the ATTD of DM and GE and the DE in pistachio shell powder were less than in soybean hulls, and inclusion in lactation diets, therefore, needs to be limited.

Keywords: digestibility, energy, fiber, pistachio shell powder, sows, soybean hulls.

Abbreviations: ATTD, apparent total tract digestibility; DE, digestible energy; DM, dry matter; GE, gross energy; IDF, insoluble dietary fiber; ME, metabolizable energy; SDF, soluble dietary fiber; SBM, soybean meal; TDF, total dietary fiber.

Introduction

California is the leading producer of pistachios in the United States and globally followed by Iran and Turkey (Toghiani et al., 2023). Production of pistachios is increasing, and the American Pistachio Growers Association estimated that the production would reach 1.04 million metric tons in 2031 (Tootelian, 2023). As a result, around 15.6 thousand metric tons of pistachio shells will be produced after the nuts are processed for human consumption (Tootelian, 2023). Whereas pistachio nuts are a good source of protein, with a Digestible Indispensable Amino Acid Score greater than 75 (Bailey and Stein, 2020), pistachio shells are not used for human consumption. The inclusion of a pistachio shell powder product in diets fed to sheep had no negative impact on apparent total tract digestibility (ATTD) or nitrogen retention (Ghasemi et al., 2012), but no data for feeding pistachio shells to pigs have been reported. However, if pistachio shells can be finely ground, the shell powder can be used as a high-fiber ingredient in diets for pigs. Specifically, gestating sows may benefit from the high-fiber concentration in pistachio shell powder because this may increase satiety and reduce stress, but, at this time, there is no information about the nutritional value of pistachio shell powder when fed to sows. However, If the nutritional value of pistachio shell powder can be established, this ingredient can potentially be used in diets for sows as an alternative to other high-fiber ingredients. Therefore, 2 experiments were conducted to test the null hypothesis that ATTD of gross energy (GE), dry matter (DM), total dietary fiber (TDF), and digestible energy (DE) in pistachio shell powder are not different from those in soybean hulls when fed to gestating or lactating sows.

Materials and Methods

Protocols for 2 experiments were submitted to the Institutional Animal Care and Use Committee at the University of Illinois and approved prior to initiation of the experiments. In both experiments, Camborough sows (PIC, Hendersonville, TN, USA) were used. One batch of pistachio shell powder (The Wonderful Company, Los Angeles, CA, USA, and the University of Kansas, Lawrence, KS, USA) and one batch of soybean hulls (South Central FS, Watson, IL, USA) were procured and the same sources of the 2 ingredients were used in both experiments (Table 3.1). Likewise, the same source of corn, which was grown locally, was used in both experiments.

Experiment 1: Gestating Sows

Twenty-four gestating sows (initial body weight [BW]:209.85 ± 15.26 kg; parity 2 to 6) that were approximately 65 d into gestation were allotted to 2 blocks of 12 sows using a randomized complete block design with 3 diets and 4 sows per treatment in each block for a total of 8 replicate sows per diet. The breeding group was the blocking factor. A corn-based basal diet and 2 diets containing corn and 20% pistachio shell powder, or corn and 20% soybean hulls were formulated (Table 3.2). Vitamins and minerals were included in all diets to meet or exceed requirements (NRC, 2012). Daily feed allowance was 1.5 times the maintenance energy requirement for gestating sows (i.e., 100 kcal/kg $BW^{0.75}$; NRC, 2012). Sows had free access to water at all times throughout the experiment. Daily feed allotments were divided into 2 equal meals that were provided at 0800 and 1600 hours. Gestating sows were housed in metabolism crates (0.91 × 2.08 m) that were equipped with a self-feeder, a nipple drinker, and a fully slatted T-bar floor. A screen floor and a urine pan were installed under the T-bar floor for a separate collection of feces and urine. Sows were fed experimental diets for 13 d. The initial 6 d in the metabolism crates were considered the adaptation period to the crates and the diets, and urine and feces were collected from the diet provided during the following 4 d using the marker-to-marker procedure (Adeola, 2001). The fecal collection was initiated when the first marker (i.e., chromic oxide), which was fed in the morning meal on day 7, appeared in the feces, and collection of feces ceased when the second marker (i.e., ferric oxide), which was fed in the morning meal on day 11, appeared. Collected fecal samples were stored at −20 °C immediately after collection. Urine was collected in buckets placed under the urine pans and 50 mL of 3 N HCl was added to each bucket every day. Buckets were emptied daily, the weight of the collected urine was recorded, and 10% of the collected urine was stored at −20 °C until subsampling.

Experiment 2: Lactating Sows

Twenty-four multiparous sows in lactation (initial BW:228.52 ± 20.07 kg; parity 2 to 6) were used in a randomized complete block design with 2 blocks of 12 sows, 3 diets, and 4 sows per diet in each block for a total of 8 replicate sows per treatment. The breeding group was the blocking factor. The basal diet was formulated based on corn and soybean meal (SBM) and this diet met all nutrient requirement estimates for lactating sows (Table 3.2; NRC, 2012). Two additional diets were formulated by including 20% of either pistachio shell powder or soybean hulls in the basal diet at the expense of corn and SBM. All diets contained corn and SBM at a ratio of 2.87:1.00, and 0.40% TiO^2 was included in all diets as an indigestible marker. The lactating sows used in experiment 2 were different from the gestating sows used in experiment 1. Sows were fed a commercial diet for gestating sows before being moved to farrowing crates 7 d before farrowing where they remained until weaning on day 20 post-farrowing. The farrowing crates had fully slatted floors. A commercial lactation diet was provided from day 7 before farrowing to day 4 post-farrowing, but experimental diets were fed from day 5 post-farrowing to day 18 post-farrowing. The initial 8 d were the adaptation period to experimental diets, and fecal samples were collected once daily via grab sampling from days 13 to 18. Collected fecal samples were immediately stored at −20 °C. Experimental diets were provided on an ad libitum basis and water was available at all times.

Chemical Analysis

At the conclusion of experiment 1, urine samples were thawed and mixed, and a subsample was lyophilized before analysis (Kim et al., 2009). Fecal samples from both experiments were thawed and dried at 55 °C in a forced-air drying oven for 7 d (Heratherm OMH750; Thermo Fisher 1873 Scientifc Inc., Waltham, MA, USA). Samples were then ground through a 1-mm screen using a hammermill (model: MM4; Schutte Buffalo, NY, USA), mixed, and subsampled for analysis. Ingredient, diet, and fecal samples were analyzed for DM (method 930.15; AOAC Int., 2019). Diets and ingredient samples, fecal samples from both experiments, and lyophilized urine samples from experiment 1 were analyzed for GE on an isoperibol bomb calorimeter (Model 6400, Parr Instruments, Moline, IL, USA) using benzoic acid as the internal standard. All diets and ingredients were also analyzed for ash (method 942.05; AOAC Int., 2019), and ingredients, diets, and fecal samples were analyzed for insoluble dietary fber (IDF), and soluble dietary fber (SDF) according to method 991.43 (AOAC Int., 2019) using the AnkomTDF Dietary Fiber Analyzer (Ankom Technology, Macedon,NY, USA). The TDF was calculated as the sum of IDF and SDF. Nitrogen was analyzed in ingredients and diets by combustion using a LECO FP628 Nitrogen Analyzer (LECO Corp., Saint Joseph, MI, USA; method 990.03; AOAC Int., 2019) and crude protein was calculated as N × 6.25. Crude fat was analyzed in ingredients by acid hydrolysis using 3 N HCl (AnkomHCl, Ankom Technology) followed by crude fat extraction using petroleum ether (method 2003.06; AOAC Int., 2019) on an Ankom fat analyzer (AnkomXT15, Ankom Technology). Titanium was analyzed in lactation diets and feces from lactating sows (method 985.01 A, B, and C; AOAC Int., 2019) using inductively coupled plasma-optical emission spectrometry (ICP-OES; Avio 200, PerkinElmer, Waltham, MA, USA). Sample preparation included dry ashing at 600°C for 4 h (method 942.05; AOAC Int., 2019) and wet digestion with sulfuric acids (method 3050 B; U.S. Environmental Protection Agency, 2000). Minerals were also analyzed in ingredients by ICP OES. Ingredients were also analyzed for AA (method 982.30 E [a, b, c]; AOAC Int., 2019) on a Hitachi Amino Acid Analyzer, Model No. L8800 (Hitachi High Technologies America, Inc.; Pleasanton, CA, USA) using ninhydrin for postcolumn derivatization and nor-leucine as the internal standard. Ingredients were analyzed for nonstarch polysaccharides using gas-liquid chromatography based on the individual sugar constituents as alditol acetates after a 3-parallel extraction procedure: 1) total nonstarch polysaccharides, 2) noncellulosic polysaccharides, and 3) insoluble noncellulosic polysaccharides. All procedures followed those described by Jaworski et al. (2015). Total starch was analyzed in ingredients by the amyloglucosidase-alpha-amylase procedure corresponding to the enzymatically hydrolyzed starch converted to glucose, and glucose was quantifed by spectrophotometry (method 996.11; AOAC Int., 2019).

Calculations

Values for ATTD of DM, GE, and TDF, and the concentration of DE were calculated for each diet for both gestating and lactating sows, and the ME in the diets fed to gestating sows was also calculated (Adeola, 2001). By subtracting the GE contributed by corn (experiment 1) or corn and SBM (experiment 2) from GE in diets containing pistachio shell powder or soybean hulls, the DE and ME in pistachio shell powder and soybean hulls were calculated by difference for gestating sows (Adeola, 2001) and the DE was calculated for lactating sows.

Statistical Analysis

Data were analyzed using the MIXED Procedure of SAS (SAS Inst. Inc., Cary, NC, USA). The homogeneity of the variances among treatments was confirmed. Outliers were tested using the UNIVARIATE procedure of SAS, but no outliers were detected in either experiment. Sow was the experimental unit for all analyses. For both experiments, the statistical models included diet or ingredient as the fixed effect and block and replicate within block as the random effects. Least squares means were calculated, and means were separated with the pdiff option using Tukey's adjustment if the model P-value was significant (Tukey, 1977). Statistical significance was considered at $P < 0.05$.

Results

Sows remained healthy during both experiments and feed refusals were not observed. All sows assigned to experimental diets in both experiments completed the experiments.

Experiment 1: Gestating Sows

Feed intake, GE intake, and TDF intake by sows fed the 2 diets containing pistachio shell powder or soybean hulls were greater ($P < 0.05$) than by sows fed the basal diet (Table 3.3). Weight of feces, GE fecal output, concentration of TDF in feces, and TDF fecal excretion from sows fed the pistachio shell powder diet were greater ($P < 0.05$) than from sows fed the other diets, and sows fed the soybean hulls diet had greater ($P < 0.05$) fecal output, GE output in feces, and fecal excretion of TDF than sows fed the basal diet. Weight of urine was greater ($P < 0.05$) from sows fed the basal diet than from those fed the pistachio shell powder diet with an intermediate value for sows fed the soybean hulls diet, but the magnitude of the difference was greater between basal and soybean hull diets than between the soybean hull and pistachio shell powder diets. However, GE output in urine was not different among treatments. The ATTD of DM and GE was less ($P < 0.05$) in the diet containing pistachio shell powder than in the basal diet or the diet containing soybean hulls, but ATTD of TDF was greater ($P < 0.05$) in the diet containing soybean hulls than in the basal diet, whereas the ATTD of TDF was least ($P < 0.05$) in the diet containing pistachio shell powder. Concentration of DE in the basal diet was greater ($P < 0.05$) than in the other 2 diets and the soybean hulls diet contained more ($P < 0.05$) DE than the pistachio shell power diet. Concentration of ME in the basal diet was also greater ($P < 0.05$) compared with the pistachio shell powder diet, but there was no difference in ME between the basal diet and the soybean hulls diet. Concentrations of DE and ME on an as-fed basis as well as on a DM basis were less ($P < 0.05$) in pistachio shell powder compared with corn or soybean hulls (Table 3.4). On an as-fed basis, soybean hulls contained less ($P < 0.05$) DE than corn and on a DM basis, DE and ME in soybean hulls were also less ($P < 0.05$) than in corn. The DE:GE and the ME:GE in corn were greater ($P < 0.05$) than in soybean hulls, and DE:GE and ME:GE were greater ($P < 0.05$) in soybean hulls than in pistachio shell powder.

Experiment 2: Lactating Sows

Feed intake and GE intake by sows fed the basal diet or the diet containing pistachio shell powder were greater ($P < 0.05$) than by sows fed the diet containing soybean hulls, but there were no differences in feed intake between sows fed the basal diet and sows fed the diet containing pistachio shell powder (Table 3.5). The ATTD of DM and GE and the concentration of DE in the basal diet was greater ($P < 0.05$) than in the other diets, and the diet containing soybean hulls had greater ($P < 0.05$) ATTD of GE; and DM and greater ($P < 0.05$) DE than the diet containing pistachio shell powder. The ATTD of TDF was greater ($P < 0.05$) in the diet containing soybean hulls followed by the basal diet and the diet containing pistachio shell powder. The concentration of DE in pistachio shell powder on an as-fed as well as on a DM basis and DE:GE was less ($P < 0.05$) than in soybean hulls.

Discussion

The GE in all diets used in the 2 experiments was in agreement with calculated values, which indicated that errors in diet mixing, subsampling, and GE analysis were minimal. The GE in corn and soybean hulls was less than some previous values (NRC, 2012), which may be because both ingredients contained less protein than previously reported. Although crude protein in SBM was also lower than reported (NRC, 2012), GE in SBM was within the range of previous values (NRC, 2012). The ATTD of GE and concentrations of DE and ME in corn used in experiment 1 were greater than values obtained with growing pigs (NRC, 2012), which is likely a result of the greater energy digestibility by gestating sows compared with growing pigs (Le

Goff and Noblet, 2001; Casas and Stein, 2017). The ATTD of GE and concentration of DE in the basal diet fed to lactating sows in experiment 2 were in agreement with calculated values for a corn-SBM diet fed to growing pigs (NRC, 2012), which is likely because lactating sows, like growing pigs, are allowed ad libitum intake of feed, and therefore, have increased feed intake and greater passage rate, compared with gestating sows (Kim et al., 2007).

High-fiber co-products from the human food industry are often used in diets fed to livestock (Zijlstra and Beltranena, 2013; Stein et al., 2015). This is also true for co-products from the nut industry and pecan shells have successfully been incorporated into diets for finishing pigs (Flores et al., 2023) and gestating sows (Buenabad et al., 2022). Likewise, almond hulls can be included in diets for growing pigs without negative impacts on growth performance or nutrient digestibility (Ahammad et al., 2024). However, the main co-product from the production of pistachio nuts, pistachio shells, has until now primarily been limited to industrial uses (Toghiani et al, 2023), although a lower-fiber pistachio co-product may replace lucerne hay in diets for sheep without negatively impacting ATTD of energy or nutrients (Ghasemi et al., 2012). Whereas almond hulls contain around 44% TDF (Fanelli et al., 2023), the pistachio shell powder used in this experiment contained more than 90% TDF resulting in diets with greater total TDF concentrations than if almond hulls or other co-products from the nut industry are used. Pistachio shell powder is, therefore, a unique feed ingredient and to the best of our knowledge, no information about using pistachio shell powder in diets for pigs has been reported. There are, however, possible benefits of including high-fiber ingredients in diets for reproducing swine (Jo and Kim, 2023), and pistachio shell powder was, therefore, included in diets for sows in the current experiments.

Although pistachio shell powder contained more than 90% TDF, almost all the TDF was insoluble, which is the reason the concentration of soluble monosaccharides was very low. In contrast, cellulose made up almost 26% of the ingredients, and xylose contributed 35% of the pistachio shell powder, which was much more than the other ingredients used in the experiment. The high xylose concentration indicates that the fiber in pistachio shell powder likely contains xylan polysaccharides, but these do not appear to include arabinoxylans because the concentration of arabinose was very low.

The relatively high DE that was determined in pistachio shell powder when fed to gestating sows, despite the very high concentration of IDF and TDF in the ingredient, indicates that it is possible to use this ingredient in diets for sows. The greater DE determined in gestating sows compared with lactating sows is likely a result of the restricted feed intake of gestating sows that allows more time for nutrients and energy digestion and absorption and microbial fermentation in the intestinal tract. The lower DE and ME in pistachio shell powder than in soybean hulls is likely not a problem when fed to gestating sows because of the restriction of feed intake of gestating sows. In fact, feeding pistachio shell powder to gestating sows may be an advantage because feeding diets that are high in fiber increases satiety compared with low-fiber diets (Li, 2014). Indeed, the observation that urine excretion from gestating sows fed the pistachio shell powder diet was much less than from sows fed the basal diet indicates that sows fed the pistachio shell powder diet likely were less stressed than sows fed the basal diet because sows with increased stress may spend time playing with the water nipple, which may increase estimated urine output due to water spillage (Li, 2014). The observation that total energy excretion in urine was not different among treatments further indicates that the extra urine output from sows fed the basal diet likely was caused by water spillage as a result of increased stress of the sows. The fact that no negative effects on feed intake were observed when sows were fed the diet containing pistachio shell powder compared with sows fed the control diet further indicates that pistachio shell powder may be used by gestating sows. This may be because the gestating sows were fed a restricted amount of feed, but the possibility that more than 20% pistachio shell powder can be included in diets for gestating sows needs to be investigated in the future. Because the inclusion of dietary fiber in diets for gestating sows sometimes increases the reproductive performance of sows (Jo and Kim, 2023), research to determine the impact of pistachio shell powder on the reproductive performance of sows also needs to be conducted.

The fact that lactating sows fed the diet containing pistachio shell powder had daily voluntary feed intake that was not different from that of sows fed the control diet indicates that sows were not able to compensate for the reduced DE in pistachio shell powder by increasing feed intake, which may be due to gut fill. The daily DE intake will, therefore, be reduced if pistachio shell powder is included in diets for lactating sows, and as a consequence, the inclusion of pistachio shell powder in lactation diets likely needs to be limited. Nevertheless, because the DE in pistachio shell powder was less than in soybean hulls when fed to both gestating and lactating sows, the null hypothesis for the experiment was rejected.

The observation that the ATTD of TDF in diets fed to both gestating and lactating sows was close to or greater than 60% indicates that sows are able to ferment a significant part of the TDF in pistachio shell powder, which is important because more than 90% of the ingredient is TDF. As a consequence, the majority of the energy generated from pistachio shell powder was absorbed in the form of volatile fatty acids that were synthesized as a result of the fermentation of fiber in the hindgut of sows.

Although it is recognized that fecal material analyzed as TDF may contain microbial matter, which results in reduced calculated values for ATTD of TDF (Cervantes-Pahm et al., 2014; Montoya et al., 2015, 2016), this is primarily a problem in diets with low concentrations of dietary fiber, whereas ATTD of TDF in diets with greater concentration of dietary fiber are much less influenced by microbial matter (Cervantes Pahm et al., 2014). Because of the high concentrations of TDF in diets containing pistachio shell powder, it is, therefore, unlikely that microbial matter greatly influenced the calculated values for ATTD of TDF.

The feed intake of lactating sows fed the diet containing soybean hulls was less than for the other diets, which is likely because soybean hulls contained more than 10% SDF and SDF has a high water-binding capacity, which results in more gut fill and reduced rate of passage (Tan et al., 2017). However, SDF is more fermentable than IDF (Urriola et al., 2010; Jaworski and Stein, 2017), which is likely the reason the ATTD of TDF was greater in the soybean hulls diet than in the pistachio shell powder diet, despite the greater TDF intake from the pistachio shell powder diet compared with the soybean hulls diet. The observation that even though the ATTD of TDF in diets containing soybean hulls was also greater than in the basal diets is a result of the very low concentration of SDF in corn fiber (Jaworski et al., 2015).

The ATTD of GE and the DE in soybean hulls fed to both gestating and lactating sows in this experiment were greater than values obtained with growing pigs (NRC, 2012; Jaworski and Stein, 2017; Rodriguez et al., 2020). Because sows have a greater capacity to utilize energy from fiber than growing pigs due to their larger intestinal tract and increased microbial fermentation (Casas and Stein, 2017), it appears that energy digestibility and DE are increased in soybean hulls fed to sows compared with growing pigs, but because the diets used in this experiment were not fed to growing pigs, we cannot confirm this hypothesis. It is possible that nutrient digestibility changes throughout gestation because digestibility and retention of Ca and P changes from the first to the second or third trimester of gestation (Kemme et al., 1997; Lee et al., 2019). However, we are not aware of data demonstrating differences in DM and energy digestibility during gestation, and we, therefore, consider energy digestibility obtained from sows in mid-gestation to be representative of the entire gestating period.

It was not the objective to compare data for gestating and lactating sows, but the observation that ATTD of GE and DE in diets fed to gestating sows were greater compared with lactating sows was in agreement with previous data (Acosta et al., 2024). It is possible that differences in feeding methods (i.e., restricted vs. ad libitum) resulted in these differences because the passage rate is increased by greater feed intake, which may result in reduced digestibility (Kim et al., 2007). However, both gestating and lactating sows were fed amounts close to what sows consume on commercial farms, which indicates that these data can also be applied when formulating diets for sows in commercial settings.

In addition to the increased SDF in the soybean hulls used in this experiment, the concentration of fat was also greater than previously reported, which likely also contributed to the increased DE in the soybean hulls because fat not only has a high energy value, but also reduces passage rate in the intestinal tract, and therefore, increases time for digestion and absorption of nutrients (Cervantes-Pahm and Stein, 2008; Zhou et al., 2017). The combination of more SDF and reduced passage rate, however, negatively impacts feed intake of animals allowed ad libitum access to feed as was observed for the lactating sows in this experiment. Due to this reduction in feed intake, the inclusion of soybean hulls in diets for lactating sows needs to be limited, whereas the use of soybean hulls in diets for gestating sows may be advantageous because the reduced passage rate may increase satiety in sows.

Conclusions

Digestible energy in pistachio shell powder was 2,699 and 1,664 kcal/kg DM when fed to gestating sows and lactating sows, respectively, which were less than the DE in soybean hulls (3,665 and 2,795 kcal/kg DM, respectively). The ME in pistachio shell powder (i.e., 2,606 kcal/kg DM) was also less than in soybean hulls (i.e., 3,645 kcal/kg DM) when fed to gestating sows. Pistachio shell powder had a high concentration of IDF, which resulted in low energy digestibility and DE and therefore limited the inclusion in diets for lactating sows. Further research is needed to determine whether greater inclusion rates can be used, and the impact of pistachio shell powder on the reproductive performance of sows also needs to be investigated.

Tables

Table 3.1. Analyzed nutrient composition of feed ingredients, as-fed basis

Item, %	Corn	Soybean meal	Pistachio shell powder	Soybean hulls
Dry matter	86.78	89.44	96.30	90.87
Gross energy, kcal/kg	3,796	4,257	4,379	3,806
Ash	0.95	6.15	0.29	5.05
Crude protein	6.03	45.16	1.69	11.16
Acid hydrolysis ether extract	3.36	2.13	1.72	4.26
Starch	61.88	3.60	ND[1]	0.23
Total dietary fiber	13.3	20.7	93.1	71.2
Soluble dietary fiber	2.8	3.2	1.2	11.3
Insoluble dietary fiber	10.5	17.5	91.9	59.9
Soluble-non-starch polysaccharide				
Rhamnose	ND[1]	0.03	0.02	0.30
Fucose	ND	0.03	ND	0.01
Arabinose	0.11	0.15	0.05	0.51
Xylose	0.06	ND	ND	ND
Mannose	0.16	0.31	0.27	2.06
Galactose	ND	0.29	0.09	1.15
Insoluble-non-starch polysaccharide				
Rhamnose	ND	0.19	0.32	0.37
Fucose	ND	0.29	ND	0.21
Arabinose	1.37	2.12	0.48	3.86

Table 3.1.(cont.)

Xylose	2.10	1.12	35.07	7.38
Mannose	0.14	0.71	0.10	3.32
Galactose	0.40	4.38	0.44	1.82
Glucose	0.95	0.31	1.65	1.74
Cellulose	1.90	3.42	25.78	30.99
Indispensable amino acids				
Arginine	0.32	3.45	0.13	0.68
Histidine	0.19	1.28	0.03	0.34
Isoleucine	0.24	2.38	0.06	0.56
Leucine	0.72	3.73	0.09	0.90
Lysine	0.25	3.03	0.08	0.87
Methionine	0.14	0.66	0.02	0.14
Phenylalanine	0.30	2.49	0.06	0.53
Threonine	0.23	1.83	0.06	0.47
Tryptophan	0.05	0.70	< 0.02	0.06
Valine	0.32	2.46	0.08	0.62
Total	2.76	22.01	0.63	5.17
Dispensable amino acids				
Alanine	0.46	2.04	0.07	0.55
Aspartic acid	0.44	5.48	0.14	1.28
Cysteine	0.14	0.67	0.03	0.23
Glutamic acid	1.13	8.65	0.21	1.62

Table 3.1.(cont.)

Glycine	0.27	1.99	0.07	0.91
Proline	0.55	2.44	0.10	0.67
Serine	0.28	1.94	0.07	0.58
Tyrosine	0.20	1.74	0.02	0.44
Total	3.47	24.95	0.71	6.28
Total amino acids	6.23	46.96	1.34	11.45
Minerals, %				
Ca	< 0.01	0.34	< 0.01	0.86
P	0.04	0.73	< 0.01	0.11
K	0.04	1.93	0.05	0.85
Mg	0.11	0.27	0.02	0.17
Na	< 0.01	0.02	0.01	0.03

[1]ND = not detectable.

Table 3.2. Ingredient and nutrient composition of experimental diets, as-fed basis

Item	Exp. 1 (gestating sows)			Exp. 2 (lactating sows)		
	Basal diet	Pistachio shell powder	Soybean hulls	Basal diet	Pistachio shell powder	Soybean hulls
Ingredient, %						
Corn	96.47	76.75	76.75	71.73	56.81	57.02
Soybean meal	-	-	-	25.00	19.80	19.87
Pistachio shell powder	-	20.00	-	-	20.00	-
Soybean hulls	-	-	20.00	-	-	20.00
Limestone	0.98	0.65	0.65	0.71	0.54	0.36
Dicalcium phosphate	1.65	1.70	1.70	1.26	1.55	1.45
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin-mineral premix[1]	0.50	0.50	0.50	0.50	0.50	0.50
Titanium dioxide	-	-	-	0.40	0.40	0.40
Analyzed composition						
Dry matter, %	87.78	89.41	88.09	87.68	89.62	88.28
Gross energy, kcal/kg	3,716	3,828	3,704	3,798	3,882	3,755
Crude protein, %	6.55	5.60	7.58	16.64	12.84	15.51
Ash, %	4.37	3.88	4.96	5.01	5.04	6.17
Total dietary fiber, %	12.90	29.20	24.00	15.50	32.70	27.40

[1]The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kg of complete diet: vitamin A as retinyl acetate, 10,622 IU; vitamin D_3 as cholecalciferol, 1,660 IU; vitamin E as DL-alpha-tocophero acetate, 66 IU; vitamin K as menadione nicotinamide bisulfate, 1.40 mg; thiamin as thiamine mononitrate, 1.08 mg;

Table 3.2. (cont.)

riboflavin, 6.49 mg; pyridoxine as pyridoxine hydrochloride, 0.98 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.2 mg; niacin, 43.4 mg; folic acid, 1.56 mg; biotin, 0.44 mg; Cu, 20 mg as copper chloride; Fe, 123 mg as iron sulfate; I, 1.24 mg as ethylenediamine dihydriodide; Mn, 59.4 mg as manganese hydroxychloride; Se, 0.27 mg as sodium selenite and selenium yeast; and Zn, 124.7 mg as zinc hydroxychloride.

Table 3.3. Apparent total tract digestibility (ATTD) of dry matter (DM), gross energy (GE), total dietary fiber (TDF) and digestible energy and metabolizable energy in experimental diets fed to gestating sows[1] (Exp. 1), as-fed basis

Item, %	Basal diet	Pistachio shell powder	Soybean hulls	SEM	*P*-value
Intake					
Diet, kg/d	2.51^{b}	2.78^{a}	2.75^{a}	0.05	0.004
GE, Mcal/d	9.33^{b}	10.65^{a}	10.18^{a}	0.20	0.001
TDF, kg/d	0.32^{c}	0.81^{a}	0.66^{b}	0.01	< 0.001
Fecal excretion					
Dry feces output, kg/d	0.16^{c}	0.35^{a}	0.20^{b}	0.01	< 0.001
GE, kcal/d	662^{c}	$1,526^{a}$	829^{b}	41	< 0.001
TDF, %	33.17^{c}	74.26^{a}	36.76^{b}	0.87	< 0.001
TDF, kg/d	0.06^{c}	0.26^{a}	0.07^{b}	0.01	< 0.001
Urine excretion					
Urine output, kg/d	8.87^{a}	3.20^{b}	5.03^{ab}	1.44	0.032
GE, kcal/d	214	241	198	23	0.433
ATTD of DM, %	92.93^{a}	86.23^{b}	91.98^{a}	0.33	< 0.001
ATTD of GE, %	92.90^{a}	85.69^{b}	91.84^{a}	0.34	< 0.001
ATTD of TDF, %	82.94^{b}	67.92^{c}	88.68^{a}	0.85	< 0.001
Energy in diets, kcal/kg					
Digestible energy	$3,452^{a}$	$3,280^{c}$	$3,402^{b}$	13	< 0.001
Metabolizable energy	$3,366^{a}$	$3,194^{b}$	$3,330^{a}$	15	< 0.001

[a-c]Within a row, means without a common superscript differ ($P < 0.05$).

Table 3.3 (cont.)

[1]Each least square mean represents 8 observations per diet.

Table 3.4. Digestible energy (DE) and metabolizable energy (ME) in corn, pistachio shell powder, and soybean hulls fed to gestating sows[1] (Exp. 1)

Item, %	Corn	Pistachio shell powder	Soybean hulls	SEM	*P*-value
As-fed basis, kcal/kg					
DE	3,578[a]	2,669[c]	3,277[b]	56	< 0.001
ME	3,490[a]	2,580[b]	3,258[a]	66	< 0.001
Dry matter basis, kcal/kg					
DE	4,076[a]	2,699[c]	3,665[b]	62	< 0.001
ME	3,976[a]	2,606[c]	3,645[b]	73	< 0.001
Digestibility and metabolizability					
DE:GE	94.26[a]	60.96[c]	86.10[b]	1.30	< 0.001
ME:DE	97.53	96.63	99.45	1.25	0.287
ME:GE	91.93[a]	58.92[c]	85.61[b]	1.53	< 0.001

[a-c]Within a row, means without a common superscript differ ($P < 0.05$).

[1]Each least square mean represents 8 observations per diet.

Table 3.5. Apparent total tract digestibility (ATTD) of dry matter (DM), gross energy (GE), and total dietary fiber (TDF) and digestible energy (DE) in experimental diets and ingredients fed to lactating sows[1] (Exp. 2)

Item, %	Basal diet	Pistachio shell powder	Soybean hulls	SEM	*P*-value
Intake					
Diet, kg/d	5.70[a]	5.94[a]	4.23[b]	0.33	0.003
GE, Mcal/d	21.65[a]	23.05[a]	15.87[b]	1.27	0.002
TDF, kg/d	0.88	1.94	1.16	0.08	< 0.001
ATTD of DM, %	88.77[a]	77.19[c]	85.49[b]	0.59	< 0.001
ATTD of GE, %	88.02[a]	75.97[c]	84.16[b]	0.65	< 0.001
ATTD of TDF, %	76.77[b]	59.61[c]	81.86[a]	1.54	< 0.001
DE in diet, kcal/kg, as fed basis	3,343[a]	2,951[c]	3,181[b]	25	< 0.001
DE in ingredient, kcal/kg					
As-fed basis	-	1,603	2,540	132	< 0.001
DM basis	-	1,664	2,795	144	< 0.001
DE:GE	-	34.59	68.84	3.48	< 0.001

[a-c]Within a row, means without a common superscript differ ($P < 0.05$).

[1]Each least square mean represents 8 observations per diet.

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CHAPTER 4: DIGESTIBLE ENERGY AND METABOLIZABLE ENERGY IN SOYBEAN MEAL AND SOYBEAN HULLS WHEN FED TO GROWING PIGS OR SOWS

Abstract

An experiment was conducted to test the hypothesis that the apparent total tract digestibility (**ATTD**) of gross energy (**GE**) and concentrations of digestible energy **(DE)** in soybean meal **(SBM)** and soybean hulls are greater when fed to gestating sows or lactating sows than to growing pigs, and that there is no difference in ATTD of GE between gestating and lactating sows. Three experimental diets were prepared. The basal diet consisted of corn as the sole source of energy, and two additional diets contained corn and 30% SBM or corn and 20% soybean hulls. All diets were fed to growing pigs and gestating and lactating sows. Twenty-four growing pigs and twenty-four gestating sows were housed in metabolism crates, and fecal and urine samples were quantitatively collected. Twenty-four lactating sows were housed in farrowing crates and feces were grab-sampled. The ATTD of GE, DE, and metabolizable energy **(ME)** were calculated in diets fed to growing pigs and gestating sows, and DE and ME in SBM and soybean hulls were calculated as well. The ATTD of GE and DE were also determined in diets fed to lactating sows, and DE was determined for SBM and soybean hulls. Results from growing pigs indicated that DE and ME were greater ($P < 0.05$) in corn and SBM compared with soybean hulls. For gestating sows, DE in corn and SBM was also greater ($P < 0.05$) than in soybean hulls, and ME in corn was greater ($P < 0.05$) than in SBM, whereas soybean hulls had the least ($P < 0.05$) ME. Results for lactating sows indicated that DE in corn and SBM was greater ($P < 0.05$) than in soybean hulls, but lactating sows had greater ($P < 0.05$) DE values for soybean hulls than

gestating sows; whereas, gestating sows had greater ($P < 0.05$) DE values for corn than lactating sows. Gestating sows also had greater ($P < 0.05$) ME values for corn than growing pigs; whereas, growing pigs had greater ($P < 0.05$) ME values for SBM than gestating sows. In conclusion, soybean hulls contain less DE and ME than corn and SBM, but there are no consistent differences in DE and ME among growing pigs, gestating, and lactating sows.

Key words: digestibility, energy, sows, soybean hulls, soybean meal

Abbreviations: ATTD, apparent total tract digestibility; DE, digestible energy; DM, dry matter; GE, gross energy; I-NCP, insoluble non-cellulosic polysaccharide; ME, metabolizable energy; NCP, non-cellulosic polysaccharide; NSP, non-starch polysaccharides; SBM, soybean meal.

Introduction

Values for digestible energy **(DE)** and metabolizable energy **(ME)** in feed ingredients are usually determined in growing pigs and subsequently applied to all groups of pigs. Recent research suggests that the energy content of soybean meal (**SBM**) is greater than previously measured when fed to growing pigs (Sotak-Peper et al., 2015; Lopez et al., 2020; Lee et al., 2021). This increase in energy may be a result of changes in genetic status of pigs or differences in methodologies used to measure DE and ME, but there are no recent experiments assessing DE and ME in SBM when fed to sows. Therefore, it remains unclear if sows also have greater DE and ME in SBM compared to current book values (NRC, 2012).

Due to hindgut fermentation, sows can usually utilize energy in fiber-rich ingredients better than growing pigs (Casas and Stein, 2017), but it is not known if that is also the case for SBM, which is not a high fiber ingredient although SBM contains more fiber than corn (NRC, 2012).

Although soybean hulls contain less DE and ME than corn and SBM, the DE and ME in soybean hulls may be greater in sows than in growing pigs because soybean hulls is a high fiber ingredient that is presumed to be better fermented by sows than growing pigs. However, there are no recent assessments of DE and ME in soybean hulls fed to sows. Likewise, it is not known if feed ingredients have the same DE and ME for lactating sows as gestating sows because most research into energy values of feed ingredients fed to sows has focused on gestating and not lactating sows (Shi and Noblet, 1993; Lowel et al., 2015; Casas and Stein, 2017). However, because lactating sows are usually allowed *ad libitum* access to their diets, it is uncertain whether they have different DE and ME values for feed ingredients than gestating sows, and to our knowledge, this hypothesis has not been experimentally tested. Therefore, an experiment was conducted to test the hypothesis that gestating and lactating sows have greater DE and ME values for SBM and soybean hulls than growing pigs, but that there is no difference in apparent total tract digestibility (**ATTD**) of gross energy (**GE**) and DE between gestating and lactating sows. A second hypothesis was that DE and ME in SBM fed to both growing pigs and sows are greater than current book values and greater than in corn regardless of the physiological state of the animal.

Materials and Methods

All animal procedures were approved by the Institutional Animal Care and Use Committee at the University of Illinois, Urbana, IL, USA, before the experiment was initiated. One batch of SBM was procured from Archer Daniels Midland Corporation (Decatur, IL, USA) and one batch of soybean hulls was procured from South Central FS (Watson, IL, USA). Locally grown corn was obtained from the University of Illinois Feed Mill (Table 4.1), and this batch was used in all diets. There were three dietary treatments, and all diets were formulated to contain Ca, P, and all micronutrients at or above the requirements for growing pigs, which is also above the requirement for gestating and lactating sows (NRC, 2012). A basal diet contained corn as the sole source of energy, and two additional diets contained corn and 30% SBM or corn and 20% soybean hulls as the energy sources (Table 4.2). Titanium dioxide was included in all diets to allow for the calculation of digestibility in lactating sows and all pigs were fed the same diets.

Growing pigs

Twenty-four growing pigs (initial body weight: 40.51 ± 2.83 kg) that were the offspring of line 800 males mated to Camborough females (PIC, Hendersonville, TN, USA) were allotted to a completely randomized design with three diets and eight replicate pigs per diet. Pigs were fed three times the maintenance requirement for energy (i.e., 197 × kcal ME per kg body weight$^{0.60}$; NRC, 2012) and had free access to water throughout the experiment. Pigs were fed 1.52 to 1.89 kg of feed per day depending on their weight. Pigs were housed individually in metabolism crates (0.81 m × 1.52 m). A screen and a urine pan were placed under the slatted floor to allow for the total, but separate, collection of urine and fecal materials.

Daily feed allotments were divided into two equal meals that were provided at 0800 and 1600 h. Feed consumption was recorded daily. The initial seven days were considered the adaptation period to the diet, then urine and fecal materials were collected for the following four days according to the marker-to-marker approach (Adeola, 2001). The fecal collection was initiated when the first marker (i.e., chromic oxide) appeared in the feces and ceased when the second marker (i.e., ferric oxide) appeared. Markers were uniformly mixed in the first meal of d 8 and d 12 at 1% inclusion. Urine was collected in urine buckets over a preservative of 50 mL of 3 *N* HCl, which was added to each empty bucket every day after collection. The weights of orts, feces, and urine samples were recorded, and all fecal samples and 10% of the collected urine were stored at -20 °C immediately after collection.

Gestating sows

Twenty-four gestating Camborough females (Pig Improvement Company, Hendersonville, TN, USA) that were approximately 65 days into gestation (parity two to six) were allotted to two blocks of 12 sows using a randomized complete block design with three diets and four sows per diet in each block for a total of eight replicate sows for each diet. Breeding group was the blocking factor. Experimental diets were identical to those used for growing pigs. Gestating sows were fed at 1.5 times the maintenance energy requirement for gestating sows (i.e., 100 × kcal ME per kg body weight$^{0.75}$; NRC, 2012). Concentrations of ME in diets were calculated based on NRC (2012). Daily feed allotments were provided twice daily at 0700 and 1600 h. Sows were housed individually in metabolism crates (2.10 m × 0.99 m) that were equipped with a self-feeder, a nipple drinker, and a fully slatted T-bar floor. A screen floor and a urine pan were installed under the T-bar floor to allow for the collection of feces and urine. Experimental diets were fed for 13 days. Feces and urine were collected for four days, as detailed above for growing pigs.

Lactating sows

Twenty-four multiparous lactating Camborough females (Pig Improvement Company, Hendersonville, TN, USA) were used in a randomized complete block design with two blocks of 12 sows, three diets, and four sows per diet in each block for a total of eight replicate sows per treatment. Breeding group was the blocking factor. The lactating sows used in the experiment were different from the gestating sows used. Sows were moved to farrowing crates seven days before farrowing and remained there until weaning on d 20 post-farrowing. Feeding of experimental diets started on day five post-farrowing. Sows had seven days of adaptation to the diets and fecal samples were collected via rectal palpation for five days starting on day 12 of lactation. Collected fecal samples were immediately stored at -20 °C. Lactating sows had *ad libitum* access to diets and water throughout the experiment.

Chemical analysis

At the conclusion of the feeding trial, urine samples from growing pigs and gestating sows were thawed and mixed, and a sub-sample was lyophilized before analysis (Kim et al., 2009). Fecal samples from all groups of animals were thawed and dried in a 55 °C forced-air drying oven for seven days (Heratherm OMH750; Thermo Fisher 1873 Scientific Inc., Waltham, MA, USA). Samples were then ground through a 1-mm screen using a hammermill (model MM4; Schutte Buffalo, NY, USA), mixed, and sub-sampled for analysis.

Ingredient, diet, and fecal samples were analyzed for dry matter (**DM**; method 930.15; AOAC Int., 2019). Diets and ingredient samples, fecal samples, and lyophilized urine samples from growing pigs and gestating sows were analyzed for GE on an isoperibol bomb calorimeter (Model 6400, Parr Instruments, Moline, IL, USA) using benzoic acid as the internal standard. All diets and ingredients were also analyzed for ash (method 942.05; AOAC Int., 2019), and ingredients were analyzed for insoluble dietary fiber (**IDF**) and soluble dietary fiber (**SDF**) according to method 991.43 (AOAC Int., 2019) using the Ankom^{TDF} Dietary Fiber Analyzer (Ankom Technology, Macedon, NY, USA). Total dietary fiber (**TDF**) was calculated as the sum of IDF and SDF. Nitrogen was analyzed in ingredients and diets by combustion using a LECO FP628 Nitrogen Analyzer (LECO Corp., Saint Joseph, MI, USA; method 990.03; AOAC Int., 2019), and crude protein was calculated as nitrogen × 6.25. Acid hydrolyzed ether extract was analyzed in ingredients by acid hydrolysis using 3 *N* HCl (AnkomHCl, Ankom Technology, Macedon, NY) followed by crude fat extraction using petroleum ether (method 2003.06; AOAC Int., 2019) on an Ankom fat analyzer (AnkomXT15, Ankom Technology, Macedon, NY, USA). Titanium was analyzed in diets and fecal samples from lactating sows (method 985.01 A, B and C; AOAC Int., 2019) using inductively coupled plasma-optical emission spectrometry (ICP-OES; Avio 200, PerkinElmer, Waltham, MA, USA). Sample preparation included dry ashing at 600 °C for 4 h (method 942.05; AOAC Int., 2019) and wet digestion with sulfuric acids (method 3050 B; U.S. Environmental Protection Agency, 2000). Ingredients were also analyzed for AA [method 982.30 E (a, b, c); AOAC Int., 2019] on a Hitachi Amino Acid Analyzer, Model No. L8800 (Hitachi High Technologies America, Inc.; Pleasanton, CA, USA) using ninhydrin for post-column derivatization and nor-leucine as the internal standard.

Monosaccharides in ingredients were analyzed using gas-liquid chromatography based on the individual sugar constituents as alditol acetates after a three-parallel extraction procedure: 1) total non-starch polysaccharides (**NSP**), 2) non-cellulosic polysaccharides (**NCP**), and 3) insoluble non-cellulosic polysaccharides (**I-NCP**). All procedures followed those described by Jaworski et al. (2015). Ingredient samples were also analyzed for stachyose and raffinose, using high-performance liquid chromatography (Dionex App Notes 21 and 92). Total starch was analyzed in ingredients by the amyloglucosidase-alpha-amylase procedure corresponding to the enzymatically hydrolyzed starch converted to glucose, and glucose was quantified by spectrophotometry (method 996.11; AOAC Int., 2019).

Calculations

Total non-starch polysaccharides in ingredients were calculated using equation 1 (Bach Knudsen, 1997): Total NSP, % = rhamnose + fucose + arabinose + xylose + mannose + galactose + glucose + uronic acids. Cellulose was calculated using equation 2 (Bach Knudsen, 1997):

Cellulose, % = (glucose from total NSP extraction) – (glucose from NCP extraction). Insoluble NCP were calculated using equation 3 (Bach Knudsen, 1997): NCP, % = [rhamnose + fucose + arabinose + xylose + mannose + galactose + glucose + (uronic acids from insoluble-NCP)] – cellulose. Soluble NSP were calculated using equation 4 (Bach Knudsen, 1997): soluble-NSP, % = total NSP – cellulose – insoluble-NCP. Values for ATTD of DM, GE, and DE were calculated for each diet for growing pigs, gestating sows, and lactating sows, and the ME of diets fed to growing pigs and gestating sows was also calculated (Adeola, 2001). Using the energy contributions from corn to diets containing corn and SBM or soybean hulls, the ATTD of GE and concentrations of DE in SBM and soybean hulls were calculated by difference (Adeola, 2001). Likewise, the ME in diets fed to growing pigs and gestating sows was also calculated by difference.

Statistical analysis

Data were analyzed using the MIXED Procedure (SAS Inst. Inc., Cary, NC, USA). Homogeneity of the variances among treatments was confirmed. Outliers were tested using the UNIVARIATE procedure of SAS, but no outliers were detected. The growing pig, or the gestating or lactating sow was the experimental unit for all analyses. The statistical model included diet or ingredient as the fixed effect and block and replicate within block were random effects. Least square means were calculated, and means were separated using the pdiff option with the Tukey's adjustment if the model P-value was significant. Significance was considered at $P < 0.05$ and a tendency was considered at $P < 0.10$. To compare growing pigs, gestating sows, and lactating sows, data were analyzed using ANOVA. Within each ingredient, the statistical model included physiological status as the fixed variable. Least squares means were calculated, and means were separated using pdiff with the Tukey's adjustment if the model P-value was significant.

Results

Sows and growing pigs remained healthy during the experiment and feed refusals were not observed. All animals assigned to the experiment completed their feeding periods.

Growing pigs

Feed intake by growing pigs fed the corn diet or the SBM diet was less ($P < 0.05$) than by growing pigs fed the soybean hulls diet, but there was no difference in feed intake between pigs fed the corn diet and the SBM diet (Table 4.3). The GE intake by growing pigs fed the soybean hulls diet was greater ($P < 0.05$) than by growing pigs fed the corn diet, but intake of the SBM diet was not different from the other diets. The weight of feces and GE fecal excretion from pigs fed the soybean hulls diet were greater ($P < 0.05$) compared with pigs fed the corn or SBM diets, but there were no differences between the corn and SBM diets. There were no differences in urine weight or GE urine output among the three diets. The ATTD of DM and GE in the soybean hulls diet were less ($P < 0.05$) than in the corn and SBM diets, and the ATTD of GE in the SBM diet was greater ($P < 0.05$) than in the corn diet. The SBM diet had greater DE ($P < 0.05$) than the corn diet, and the soybean hulls diet had less DE ($P < 0.05$) than the corn diet. The SBM diet had greater ME ($P < 0.05$) than the other diets, but there was no difference between the corn diet and soybean hulls diet. Digestible energy, ME, and DE:GE were lower ($P < 0.05$) in soybean hulls than in corn, and corn had less ($P < 0.05$) DE, ME, and DE:GE than SBM. ME:GE was also lower ($P < 0.05$) in soybean hulls than in corn and SBM, but ME:DE was not different among the three ingredients.

Gestating sows

No differences in feed intake or GE intake among diets were observed (Table 4.4), but the weight of dried feces and GE fecal excretion from sows fed the soybean hulls diet were greater

($P < 0.05$) than from sows fed the corn or SBM diets. Weight of urine was not different among the three diets, but GE urine output was greater ($P < 0.05$) in sows fed the SBM diet compared with the other diets, and sows fed the corn diet had less ($P < 0.05$) GE urine output than sows fed the soybean hulls diet. The ATTD of DM and GE in the soybean hulls diet was less ($P < 0.05$) than in the corn and SBM diets, but there was no difference in the ATTD of DM or GE between the corn and SBM diets. Digestible energy was also lower ($P < 0.05$) in the soybean hulls diet than in the corn diet, and DE was greatest ($P < 0.05$) in the SBM diet. Metabolizable energy was lower ($P < 0.05$) in the soybean hulls diet, but there was no difference between the corn and SBM diets. Digestible energy in SBM was greater ($P < 0.05$) than in corn and soybean hulls, but DE was greater ($P < 0.05$) in corn than in soybean hulls. The ME was lower ($P < 0.05$) in soybean hulls than in the two other ingredients, but there was no difference in the ME between corn and SBM. The DE:GE in soybean hulls was lower ($P < 0.05$) than in corn and SBM. The ME:DE and the ME:GE in corn were greater ($P < 0.05$) than in SBM and soybean hulls and the ME:GE was lower ($P < 0.05$) in soybean hulls than in SBM.

Lactating sows

Feed intake and GE intake by lactating sows were not different among diets (Table 4.5). The ATTD of DM and GE in the corn diet was greater ($P < 0.05$) than in the soybean hulls diet, but the ATTD of DM and GE in the SBM diet was not different from the other diets. The DE in the soybean hulls diet was lower ($P < 0.05$) than in the corn diet and the SBM diet, but there was no difference in DE between the corn and SBM diets. The DE and DE:GE of soybean hulls were lower ($P < 0.05$) than the other ingredients, but there was no difference between corn and SBM.

Growing pigs vs. gestating sows and lactating sows

The ATTD of DM and GE in the corn diet fed to gestating sows were greater ($P < 0.05$) than if this diet was fed to lactating sows; whereas, growing pigs were not different from gestating or lactating sows (Table 4.6). The DE of the corn diet in gestating sows was greater ($P < 0.05$) than in lactating sows, but growing pigs were not different from gestating sows or lactating sows. The ATTD of GE in corn was greater ($P < 0.05$) in gestating sows than in growing pigs and lactating sows, but the ATTD of GE in corn was not different between growing pigs and lactating sows. The gestating sows had a greater ($P < 0.05$) DE value for corn than lactating sows, but the growing pigs were not different from gestating sows or lactating sows. The ME of the corn diet and of corn in gestating sows were also greater ($P < 0.05$) than in growing pigs.

The DE and the ATTD of DM and GE in lactating sows of the SBM diet were lower ($P < 0.05$) than in growing pigs or gestating sows, but there was no difference between growing pigs and gestating sows. The ME in the SBM diet was also not different between growing pigs and gestating sows. There were no differences in ATTD of GE of SBM between growing pigs, gestating sows, or lactating sows. There was no difference in DE of SBM between growing pigs and gestating sows, but DE of SBM in lactating sows was lower ($P < 0.05$) than in growing pigs or gestating sows. The ME of SBM in growing pigs was greater ($P < 0.05$) than in gestating sows.

The DE and the ATTD of DM and GE in the soybean hulls diet were not different among growing pigs, gestating sows, and lactating sows, but the DE and ATTD of GE in soybean hulls fed to lactating sows were greater ($P < 0.05$) than when fed to growing pigs or gestating sows.

Discussion

Although the concentration of GE in corn was close to the expected values, the concentration of crude protein in corn was less than reported (NRC, 2012). Although GE values for SBM and soybean hulls were less than reported (NRC, 2012; Rodriguez et al., 2020), concentrations of crude protein and acid hydrolyzed ether extract in SBM agreed with current NRC value. The analyzed fat, crude protein, and TDF in SBM and soybean hulls were also in agreement with NRC (2012), and analyzed concentrations of amino acids in the three ingredients were in agreement with expected values.

The observation that the main monosaccharides in the non-cellulosic part of the corn fiber was xylose and arabinose is in agreement with data from Jaworski et al. (2015) and reflects that the main part of corn fiber consists of arabinoxylans. Likewise, the concentration of cellulose in corn fiber also agreed with Jaworski et al. (2015), and there appears to be about twice as much arabinoxylan as cellulose in corn fiber. The high concentrations of galactose and arabinose in the insoluble fiber from SBM indicates a high concentration of the pectic polysaccharides arabinogalactans and rhamnogalacturonans in SBM fiber (Navarro et al., 2019), although the low concentration of rhamnose indicates that there likely are more arabinogalactans than rhamnogalacturonans in fiber from SBM. The observation that the sugar concentration in the fiber from soybean hulls appears to be quite different from the composition in SBM indicates that the fiber composition of the hulls are different from the composition of fiber in other parts of the soybean. Based on the sugar composition in the fiber in soybean hulls, it is speculated that the non-cellulosic fibers in soybean hulls primarily consist of xylogalacturonan and arabinans and possibly some arabino galactans and rhamnogalacturonans. However, whereas the insoluble fiber in corn and soybean meals contain only around 25% cellulose, the insoluble fiber in soybean hulls contain more than 60% cellulose. These differences in composition of the insoluble fiber may result in different fermentation characteristics in pigs, but because fermentation characteristics were not determined in this experiment, this hypothesis cannot be confirmed from the current data.

Growing pigs were provided feed at three times the maintenance requirements for ME, which is close to ad libitum intake for growing pigs, whereas gestating sows were fed 1.5 times the maintenance requirement for ME, which is close to recommended levels for commercially fed sows (NRC, 2012). Likewise, lactating sows were offered ad libitum access to feed as is common under commercial conditions.

All diets had analyzed GE that agreed with calculated values, which indicates that errors in diet mixing, subsampling, and GE analysis were minimized. The ATTD of GE, DE, and ME in corn fed to growing pigs agreed with established values (NRC, 2012). The ATTD of GE and DE and ME in SBM were greater than reported by NRC (2012), but in agreement with other recent values (Wang et al., 2022; Kim et al., 2024). The greater DE in SBM fed to growing pigs compared with NRC (2012) is also in agreement with recent data (Sotak-Peper et al., 2015) and demonstrates that current genetics of pigs appear to be able to better digest energy in the sources of SBM that are now being used than older genotypes. The greater ME in SBM fed to growing pigs compared with NRC (2012) is a result of the greater ME to DE ratio in SBM, because the difference between DE and ME is energy excreted in the urine, which primarily consists of nitrogen from deaminated amino acids. These observations, therefore, indicate that the nitrogen was utilized more efficiently in the pigs than in previous experiments, which is consistent with recent data that demonstrated growing pigs of current genotypes are more efficient at retaining nitrogen compared with pigs of older genotypes (Millet et al., 2018).

The greater DE and ME in soybean hulls fed to growing pigs compared with some previous values is a result of the greater ATTD of GE compared with the values from NRC (2012) and Rodgriguez et al. (2020), although concentrations of fiber were not different among the sources. The ATTD of GE, DE, and ME in soybean hulls by gestating sows were in agreement with recent data (Wang et al., 2022).

Gestating sows can ferment more nutrients than growing pigs. Therefore, diets have greater energy values when fed to gestating sows compared with growing pigs (Le Goff and Noblet, 2001; Casas and Stein, 2017). Although ME in corn was greater in gestating sows than in growing pigs in this experiment, this was not the case for ME in SBM and soybean hulls, which confirms that sows do not always have greater energy digestibility than growing pigs as has been previously reported (Lowel et al., 2015). Likewise, the digestibility of energy in mixed diets is not always greater in gestating sows than in growing pigs (Shipman et al., 2023). The greater ME in SBM fed to growing pigs versus gestating sows indicates that growing pigs retain nitrogen with greater efficiency than gestating sows, which was also reflected in the greater ME:DE ratio. It is likely that gestating sows had a lower protein requirement than growing pigs because the diets containing SBM contained amino acids above the requirements for gestating sows, which may have resulted in lower protein utilization. Protein efficiency, therefore, may have been reduced in gestating sows compared to growing pigs, which could be the reason for the reduced ME to DE ratio (Lowel et al., 2015).

The observation that ATTD of GE and DE in diets containing corn and SBM were greater in gestating sows than in lactating sows is likely because gestating sows were fed at approximately 1.5 times the maintenance requirements for energy, whereas lactating sows were allowed *ad libitum* intake of diets. Greater feed intake results in a greater passage rate, which reduces the digestibility of DM and energy (Cunningham et al., 1962; Shi and Noblet 1993; Le Goff and Noblet 2001; Kim et al., 2007). Therefore, the ATTD of GE in corn and SBM fed to lactating sows was lower than in gestating sows. However, these values likely reflect ATTD of diets used in commercial settings, because the level of feed intake used in this experiment is close to commercially used levels. The greater DE of soybean hulls in lactating sows compared to growing pigs is likely a result of the larger hindgut in sows, which results in more microbes that can ferment the fiber in soybean hulls. The observation that DE of soybean hulls was also greater in lactating sows than in gestating sows seems counterintuitive because feed intake in lactating sows is greater than in gestating sows, which might have been assumed to result in reduced digestibility of nutrients. In the study by Casas et al. (2022), DE in a corn-SBM diet was not different between gestating and lactating sows; DE in defatted-rice bran, which is also a high-fiber ingredient, was greater when fed to lactating sows versus gestating sows (Casas et al., 2022). It is, therefore, possible that lactating sows have a greater ability to ferment dietary fiber than gestating sows, which may be related to increased microbial activity in lactating sows, but we are not aware of data determining microbial activity in lactating sows so we can only speculate on this mechanism, which is an area that deserves future attention. Nevertheless, the observation that DE in soybean hulls fed to lactating sows was almost 3,000 kcal/kg indicates that it may be possible to use soybean hulls in diets for lactating sows without reducing DE in the diets. Because of the greater digestibility of soybean hulls that were observed in this experiment, future research is needed to determine inclusion rates of soybean hulls in diets for gestating and lactating sows.

One potential limitation of the current work is that the total collection procedure was used to calculate digestibility in both growing pigs and gestating sows, whereas the grab sampling technique was used for the lactating sows with a subsequent calculation of digestibility based on titanium concentrations in diets and fecal samples. If the titanium procedure and the total tract procedure do not result in the same values for digestibility, this could potentially affect results. Comparisons in growing pigs of results obtained with the titanium procedure, or another indigestible marker, and the total collection procedures have not resulted in any clear differences between the two procedures (Li et al., 2016; Huang et al., 2018). We are not aware of any such comparisons in sows but assume that there would also not be significant differences between the two procedures in sows.

Conclusion

The hypothesis that energy digestibility of diets fed to gestating or lactating sows is always greater than in growing pigs was not confirmed because differences in digestibility of energy and concentrations of energy among gestating sows, lactating sows, and growing pigs depended on the feed ingredients used in the diets. However, it was concluded that in accordance with the hypothesis, sows had greater utilization of energy from soybean hulls than current NRC values, but research is needed to determine optimum inclusion levels in diets for sows. It was also confirmed that when fed to growing pigs, SBM contains more DE and ME than previously accepted values.

Tables

Table 4.1. Analyzed nutrient composition of feed ingredients, as-is basis

Item, %	Corn	Soybean meal	Soybean hulls
Dry matter	86.50	87.89	89.32
Gross energy, kcal/kg	3,935	4,110	3,832
Ash	1.42	6.26	4.81
Crude protein	7.18	47.32	11.83
Acid hydrolyzed ether extract	3.08	2.08	1.95
Starch	61.58	-	-
Total dietary fiber	13.4	20.2	71.9
Soluble dietary fiber	2.2	2.9	8.6
Insoluble dietary fiber	11.2	17.3	63.3
Soluble-non-starch polysaccharide			
Rhamnose	ND[1]	0.03	0.30
Fucose	ND	0.04	0.01
Arabinose	0.12	0.15	0.51
Xylose	0.05	ND	ND
Mannose	0.12	0.31	2.06
Galactose	ND	0.31	1.15
Total soluble-non-starch polysaccharide	0.29	0.84	4.03
Insoluble-non-starch polysaccharide			
Rhamnose	ND	0.21	0.37
Fucose	ND	0.29	0.21
Arabinose	1.35	2.12	3.85
Xylose	2.12	1.12	7.38
Mannose	0.15	0.71	3.32
Galactose	0.39	4.40	1.82
Glucose	0.92	0.31	1.74
Cellulose	1.93	3.46	30.99

Table 4.1. (cont.)

Total insoluble-non-starch polysaccharide	6.86	12.62	49.68
Raffinose	0.15	0.81	0.10
Stachyose	0.01	3.57	0.81
Indispensable amino acids			
Arginine	0.37	3.20	0.64
Histidine	0.20	1.25	0.31
Isoleucine	0.25	2.37	0.53
Leucine	0.75	3.52	0.84
Lysine	0.29	3.02	0.85
Methionine	0.15	0.62	0.14
Phenylalanine	0.33	2.41	0.51
Threonine	0.25	1.72	0.45
Tryptophan	0.05	0.63	0.06
Valine	0.36	2.35	0.59
Total	3.00	21.09	4.92
Dispensable amino acids			
Alanine	0.50	1.98	0.52
Aspartic acid	0.49	5.32	1.21
Cysteine	0.16	0.69	0.23
Glutamic acid	1.23	8.3	1.56
Glycine	0.31	1.95	0.89
Proline	0.58	2.28	0.65
Serine	0.29	1.97	0.59
Tyrosine	0.20	1.55	0.46
Total	3.76	24.04	6.11
Total amino acids	6.76	45.13	11.03

[1]ND, not detected.

Table 4.2. Ingredient composition of experimental diets[1], as-fed basis

Item	Basal	Soybean meal	Soybean hulls
Ground corn, %	96.52	66.92	76.74
Soybean meal, %	-	30.00	-
Soybean hulls, %	-	-	20.00
Dicalcium phosphate, %	1.46	1.00	1.60
Ground limestone, %	0.72	0.78	0.36
Titanium dioxide, %	0.40	0.40	0.40
Sodium chloride, %	0.40	0.40	0.40
Vitamin-mineral premix[1], %	0.50	0.50	0.50
Analyzed composition			
Dry matter, %	86.71	86.66	87.18
Crude protein, %	6.93	18.89	8.65
Ash, %	3.55	4.52	4.25
Gross energy, kcal/kg	3,793	3,849	3,781

[1]The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kg of complete diet: vitamin A as retinyl acetate, 10,622 IU; vitamin D_3 as cholecalciferol, 1,660 IU; vitamin E as DL-alpha-tocopherol acetate, 66 IU; vitamin K as menadione nicotinamide bisulfate, 1.40 mg; thiamin as thiamine mononitrate, 1.08 mg; riboflavin, 6.49 mg; pyridoxine as pyridoxine hydrochloride, 0.98 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.2 mg; niacin, 43.4 mg; folic acid, 1.56 mg; biotin, 0.44 mg; Cu, 20 mg as copper chloride; Fe, 123 mg as iron sulfate; I, 1.24 mg as ethylenediamine dihydroiodide; Mn, 59.4 mg as manganese hydroxychloride; Se, 0.27 mg as sodium selenite and selenium yeast; and Zn, 124.7 mg as zinc hydroxychloride.

Table 4.3. Apparent total tract digestibility (ATTD) of dry matter (DM) and gross energy (GE) and concentrations of digestible (DE) and metabolizable energy (ME) in experimental diets fed to growing pigs[1], as-fed basis

Item	Corn	Soybean meal	Soybean hulls	SEM	*P*-value
Intake					
Feed, kg/day	1.53^{b}	1.61^{b}	1.72^{a}	0.03	0.001
GE, Mcal/day	5.82^{b}	6.20^{ab}	6.49^{a}	0.11	0.002
Fecal excretion					
Dry feces output, kg/day	0.15^{b}	0.14^{b}	0.22^{a}	0.01	< 0.001
GE, kcal/day	673^{b}	602^{b}	984^{a}	26.9	< 0.001
Urine excretion					
Urine output, kg/day	4.28	4.05	3.61	0.76	0.817
GE, kcal/day	117	168	132	19.2	0.131
ATTD of DM, %	89.4^{a}	90.5^{a}	85.9^{b}	0.34	< 0.001
ATTD of GE, %	88.5^{b}	90.3^{a}	84.8^{c}	0.39	< 0.001
Energy in diets					
DE, kcal/kg	3,356^{b}	3,475^{a}	3,207^{c}	14.9	< 0.001
ME, kcal/kg	3,280^{b}	3,371^{a}	3,130^{b}	22.8	< 0.001
Energy in ingredients[2]					
DE, kcal/kg	3,477^{b}	3,827^{a}	2,695^{c}	43.5	< 0.001
ME, kcal/kg	3,398^{b}	3,656^{a}	2,608^{c}	74.4	< 0.001
DE:GE, %	88^{b}	93^{a}	70^{c}	1.1	< 0.001
ME:DE, %	98	96	97	1.9	0.559
ME:GE, %	86^{a}	89^{a}	68^{b}	1.9	< 0.001

[a-c]Within a row, means without a common superscript differ ($P < 0.05$).

[1]Each least square mean represents 8 observations per diet.

[2]Concentrations of DE and ME in corn were calculated by dividing DE and ME in the corn diet by 96.52%.

Table 4.4. Apparent total tract digestibility (ATTD) of dry matter (DM) and gross energy (GE) and concentrations of digestible (DE) and metabolizable energy (ME) in experimental diets fed to gestating sows[1], as-fed basis

Item	Corn	Soybean meal	Soybean hulls	SEM	*P*-value
Intake					
Feed, kg/day	2.53	2.74	2.70	0.07	0.103
GE, Mcal/day	9.61	10.35	10.23	0.28	0.124
Fecal excretion					
Dry feces output, kg/day	0.23[b]	0.25[b]	0.35[a]	0.01	< 0.001
GE, kcal/day	974[b]	965[b]	1,508[a]	48.7	< 0.001
Urine excretion					
Urine output, kg/day	4.33	6.20	4.33	0.83	0.208
GE, kcal/day	176[c]	396[a]	246[b]	29.4	< 0.001
ATTD of DM, %	89.9[a]	89.9[a]	85.7[b]	0.34	< 0.001
ATTD of GE, %	89.8[a]	90.8[a]	85.2[b]	0.31	< 0.001
Energy in diets					
DE, kcal/kg	3,408[b]	3,497[a]	3,221[c]	11.8	< 0.001
ME, kcal/kg	3,339[a]	3,352[a]	3,129[b]	11.5	< 0.001
Energy in ingredients[2]					
DE, kcal/kg	3,530[b]	3,780[a]	2,559[c]	41.2	< 0.001
ME, kcal/kg	3,459[a]	3,455[a]	2,374[b]	50.7	< 0.001
DE:GE, %	90[a]	92[a]	67[b]	1.05	< 0.001
ME:DE, %	98[a]	91[b]	93[b]	1.08	< 0.001
ME:GE, %	88[a]	84[b]	62[c]	1.32	< 0.001

[a-c]Within a row, means without a common superscript differ ($P < 0.05$).

[1]Each least square mean represents 8 observations per diet.

[2]Concentrations of DE and ME in corn were calculated by dividing DE and ME in the corn diet by 96.52%.

Table 4.5. Apparent total tract digestibility (ATTD) of dry matter (DM) and gross energy (GE) and digestible energy (DE) in experimental diets and ingredients fed to lactating sows[1], as-fed basis

Item	Corn	Soybean meal	Soybean hulls	SEM	*P*-value
Intake					
Feed, kg/day	5.38	5.45	5.03	0.54	0.159
GE, Mcal/day	20.40	20.98	19.00	2.07	0.085
ATTD of DM, %	88.2[a]	87.3[ab]	86.3[b]	0.50	0.048
ATTD of GE, %	87.1[a]	86.8[ab]	85.2[b]	0.62	0.036
DE in diet, kcal/kg	3,303[a]	3,342[a]	3,219[b]	23.9	0.001
DE in ingredients[2], kcal/kg	3,426[a]	3,545[a]	2,975[b]	71.0	< 0.001
DE:GE in ingredients, %	87[a]	86[a]	78[b]	1.79	0.002

[a-c]Within a row, means without a common superscript differ ($P < 0.05$).

[1]Each least square mean represents 8 observations per diet.

[2]Concentrations of DE and ME in corn were calculated by dividing DE and ME in the corn diet by 96.52%.

Table 4.6. Apparent total tract digestibility (ATTD) of dry matter (DM) and gross energy (GE) and concentrations of digestible energy (DE) and metabolizable energy (ME) in diets and ingredients fed to growing pigs, gestating sows, and lactating sows[1], as-fed basis

Item	Growing pigs	Gestating sows	Lactating sows	SEM	*P*-value
Corn					
Energy in diet					
Feed intake, kg/day	1.53[c]	2.53[b]	5.38[a]	0.14	< 0.001
ATTD of DM, %	89.4[ab]	89.9[a]	88.2[b]	0.37	0.009
ATTD of GE, %	88.5[ab]	89.8[a]	87.1[b]	0.41	< 0.001
DE, kcal/kg	3,356[ab]	3,408[a]	3,303[b]	15.5	< 0.001
ME, kcal/kg	3,280[b]	3,339[a]	-	16.5	0.024
Energy in ingredient					
ATTD of GE, %	88.4[b]	89.8[a]	87.1[b]	0.41	< 0.001
DE, kcal/kg	3,477[ab]	3,530[a]	3,426[b]	16.1	< 0.001
ME, kcal/kg	3,398[b]	3,459[a]	-	17.1	0.024
Soybean meal					
Energy in diet					
Feed intake, kg/day	1.61[c]	2.74[b]	5.45[a]	0.16	< 0.001
ATTD of DM, %	90.5[a]	89.9[a]	87.3[b]	0.46	< 0.001
ATTD of GE, %	90.3[a]	90.8[a]	86.8[b]	0.47	< 0.001
DE, kcal/kg	3,475[a]	3,497[a]	3,342[b]	18.0	< 0.001
ME, kcal/kg	3,371	3,352	-	15.2	0.381
Energy in ingredient					
ATTD of GE, %	83.6	86.4	86.3	1.47	0.326
DE, kcal/kg	3,827[a]	3,780[a]	3,545[b]	60.3	0.007
ME, kcal/kg	3,656[a]	3,455[b]	-	50.7	0.014
Soybean hulls					
Energy in diet					
Feed intake, kg/day	1.72[c]	2.70[b]	5.03[a]	0.15	< 0.001

Table 4.6. (cont.)

ATTD of DM, %	85.9	85.7	86.3	0.35	0.483
ATTD of GE, %	84.8	85.2	85.2	0.36	0.745
DE, kcal/kg	3,207	3,221	3,219	13.8	0.745
ME, kcal/kg	3,130	3,129	-	15.7	0.997
Energy in ingredient					
ATTD of GE, %	70.3[b]	67.0[b]	77.7[a]	1.80	0.001
DE, kcal/kg	2,695[b]	2,559[b]	2,975[a]	68.9	0.001
ME, kcal/kg	2,608	2,374	-	78.6	0.054

[a-c]Within a row, means without a common superscript differ ($P < 0.05$).

[1]Each least square mean represents 8 observations per diet or ingredient.

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CHAPTER 5. CONCLUSION

Results of Exp. 1 demonstrated that pistachio shell powder, when included in diets for gestating sows, results in greater total dietary fiber (**TDF**) intake and increased fecal excretion of TDF compared with diets containing soybean hulls or corn. However, the digestible energy (**DE**) and metabolizable energy (**ME**) in pistachio shell powder were less than in soybean hulls, which may limit its use in diets for lactating sows due to reduced energy digestibility. Despite the high insoluble dietary fiber content, the digestibility of energy in pistachio shell powder was relatively high in gestating sows, likely due to the restricted feed intake allowing sufficient time for digestion and fermentation. Further research is needed to determine the impact of pistachio shell powder on the reproductive performance of sows and to evaluate if greater inclusion rates can be used in diets for sows without negatively affecting energy intake.

Results of Exp. 2 demonstrated that the digestibility of energy and nutrients in diets fed to sows and growing pigs is influenced by the specific feed ingredient used. The hypothesis that sows always have greater energy digestibility than growing pigs was not confirmed, as differences in digestibility were observed depending on the diet. Sows had greater energy utilization from soybean hulls than previously reported, indicating that the value of feeding soybean hulls to sows may be greater than current NRC values indicate. Soybean meal also provided more DE and ME for growing pigs compared with previous values, possibly due to improved nitrogen retention in current pig genotypes. These observations highlight the potential for optimizing the use of soybean hulls and soybean meal in diets for growing pigs and sows, with further research needed to determine the ideal inclusion rates of soybean hulls in sow diets.

In conclusion, dietary fiber is an important component in pig diets, not only for its direct effects on gut health and digestion, but also for its broader implications on growth performance, health, and reproductive efficiency. However, more experiments are necessary to determine the optimal fiber inclusion rate of soybean hulls and pistachio shell powder in diets fed to sows.