Feeding By-Products High in Concentration of Fiber to Nonruminants

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Abstract

Fibrous feeds traditionally have not been used for nonruminants due to their documented depression of diet digestibility in pigs and poultry. However, some types of fiber and fiber sources do not exert such negative effects on nutrient digestibility in older growing pigs and sows. Dietary fiber can have positive effects on gut health, welfare, and reproductive performance of pigs. Hence, nutritionists are attempting to gain a more thorough understanding of dietary fiber in swine diets. In contrast, the potential for use of fibrous feedstuffs in poultry diets is more limited with two exceptions. First, high fiber diets have important value in welfare-friendly molting programs for laying hens. Secondly, the need for controlled growth of pullets and turkey breeder candidates makes fibrous feedstuffs useful in these phases of poultry production.

Introduction

Concerns over preserving the welfare and health of nonruminant livestock in modern, commercial production systems and tight profit margins have prompted livestock producers to seek alternative approaches to feeding their animals. In addition, steady increases in the world's human population will increase the competition between nonruminant livestock and people for grains with high nutrient density (CAST, 1999). Traditionally, fibrous feed ingredients have been reserved for use in diets of ruminant animals; however, the social and economic climate in

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the developed world has encouraged researchers and livestock producers to seek a greater understanding of the role of fibrous feedstuffs in diets for nonruminant livestock.

**Characterization of fiber**

The most widely accepted definition of fiber states that fiber is the sum of lignin and polysaccharides that are not digested by endogenous secretions of the digestive tract (Trowell et al., 1976). This definition segregates dietary polysaccharides into starch and non-starch polysaccharides (NSP) since starch is almost completely digested in the mammalian digestive tract. NSP commonly is used interchangeably with the term, fiber, when referring to fiber in diets. On the surface, the definition proposed by Trowell et al. (1976) seems simple and easily applied to practical animal nutrition. In reality, the definition and quantification of fiber in nonruminant diets is difficult due to the complexity and diversity of polysaccharides involved (Low, 1993; Grieshop et al., 2001).

Weende Crude Fiber, Van Soest Fiber, and Total Dietary Fiber (TDF) are the three predominant methods of fiber characterization that can be applied to nonruminant diets. A more thorough description of these methods is presented in reviews by Low (1993), Prosky et al. (1985), and Moore and Hatfield (1994). Each method has its strengths and weaknesses. A comparison of the three methods of fiber characterization in selected fibrous feed ingredients is shown in Table 1.

Nutritionists traditionally have used crude fiber in evaluation of feedstuffs for poultry and swine. We believe that TDF and its constituents, Soluble Dietary Fiber (SDF) and Insoluble Dietary Fiber (IDF), are a more appropriate measure of dietary NSP for monogastrics because they account for water-soluble NSP such as pectins, β-glucans, fructans and other soluble sugars. These compounds have important effects on the digestion and metabolism of nutrients in poultry
Nutritional Effects of Fiber

The quantity and character of dietary NSP greatly influences the site and degree to which dietary polysaccharides are digested. It is difficult to describe with certainty the effects of various fiber components (SDF or IDF) on digestibility because they are not a homogenous substance. Fibrous feeds may contain predominantly one type of fiber or another type but they are not pure. Consequently, conclusions are drawn from a given fiber source that is predominantly one type of fiber and those conclusions are used to generalize the effects of that fiber component.

Swine

As mentioned previously, starch is almost completely digested (90 to 100%) by the time digesta reaches the ileal-cecal junction (Bach Knudsen and Hansen, 1991; LeGoff and Noblet, 2001). In contrast, lignin is not digested by pigs nor is there any significant fermentation by resident microbes in the gut (Graham et al., 1986; Shi and Noblet, 1993). In addition to being indigestible, lignin influences the digestibility of other fibrous components of the diet. As a plant matures, cellulose becomes intertwined with lignin to increase the rigidity of the plant structure. In this process, cellulose becomes less accessible to microbes in the hindgut, which depresses the rate and extent of fermentation. Diet digestibility is inversely proportional to lignin concentration. Pectins, fructans, β-glucans, and other components of SDF increase viscosity of the digesta (Mosenthin et al., 2001; Noblet and LeGoff, 2001). Increased viscosity in the small intestine might slow gut transit time due to suppressed intestinal contractions (Cherbut et al., 1990) which in turn leads to less mixing of dietary components with endogenous
digestive enzymes. The end result is that SDF may interfere with complete digestion of dietary components (fibrous and non-fibrous) in the small intestine. However, the swelling associated with increased viscosity creates a much greater surface area for microbial attack in the hindgut. This partly explains the relatively high total tract digestibility of soluble fiber (Noblet and LeGoff, 2001).

Insoluble dietary fiber is digested primarily in the hindgut as a result of fermentation (Noblet and Shi, 1993; Shi and Noblet, 1993). Pigs do not secrete enzymes in the small intestine that attack components of IDF so they pass through relatively untouched to the large intestine (Shi and Noblet, 1993; Varel and Yen, 1997). Insoluble dietary fiber can negatively affect total tract digestibility of dietary nitrogen (Shi and Noblet, 1993; LeGoff and Noblet, 2001) and ether extract (LeGoff and Noblet, 2001). Pigs fed high fiber diets have proportionally heavier gastrointestinal tracts than pigs fed low fiber diets which contributes to slight increases in maintenance energy requirements (Rijnen et al., 2001; Yen et al., 2001). Fermentation of NSP in the hindgut of pigs yields short chain fatty acids (SCFA) and lactic acid (Bach Knudsen and Jorgensen, 2001). This hindgut fermentation can generate 17% of the total digestible energy derived from the diet in growing pigs and 25% in sows (Shi and Noblet, 1993). These end-products of fermentation can supply 24 to 30% of the energy needs for growing pigs (Rerat et al., 1987; Yen et al., 1991). In sows, the contribution to daily energy requirements is likely to be greater than that for growing pigs because of the sow’s greater ability to digest fibrous feed ingredients (Table 2).

Total tract digestibility of NSP increases as the pig matures (Cunningham et al., 1962). For most types of NSP, sows possess higher digestibility coefficients than growing pigs (Fernandez et al., 1986; Noblet and Shi, 1993; LeGoff and Noblet, 2001). The improvement
with age is particularly noticeable with feedstuffs that are high in IDF, which is digested mainly in the hindgut (Noblet and LeGoff, 2001; Table 2). Improved digestibility of NSP with age results from a more voluminous large intestine and cecum (Kass et al., 1980; Pekas, 1991) that contain a more extensive microbial population and fermentation (Yen, 2001). Furthermore, sows generally receive a much smaller quantity of feed relative to their body size compared with growing pigs. This practice allows slower transit time of digesta and greater contact of endogenous enzymes and microbial populations with feed in the gut which should improve digestibility.

In vivo digestibility of fibrous feed ingredients is usually determined in young growing pigs. However, it is clear that sows have a greater capacity to extract energy from fibrous feedstuffs compared with growing pigs. So, one must carefully extrapolate digestibility data determined in growing pigs to sows. Noblet and LeGoff (2001) reported a regression equation that predicts DE of diets for sows from DE determined in growing pigs. Unfortunately, this equation underestimates energy value of feeds for sows, particularly in low energy feeds or ingredients. Alternatively, this French research group (Noblet and Shi, 1993; Noblet and LeGoff, 2001) has proposed a specific set of equations to predict energy content of feeds for sows from chemical analysis of the feed. These equations may have some utility. Some require starch and sugar concentrations of the feeds as inputs. We do not routinely analyze feed ingredients for starch and sugar content in the U.S.

Inclusion of fibrous feed ingredients in the diet of gestating sows does not necessarily depress nutrient digestibility. Recently, Renteria Flores (2003) fed pregnant sows a diet based on corn and soybean meal (Control); corn-soybean meal-34% oat bran (SDF); corn-soybean meal-12% wheat straw (IDF); or corn-soybean meal-16% sugar beet pulp (SDF/IDF). Digestibility of
energy and nitrogen for the diet high in SDF was similar to that of the control diet (Table 3).
Apparent digestibility of energy and nitrogen was depressed by the addition of IDF as wheat straw. Energy digestibility of the SDF/IDF diet based on sugar beet pulp was intermediate likely due to its combination of highly digestible SDF and IDF that has a lower degree of digestibility.
Apparent digestibility of N in the SDF/IDF diet was depressed compared to SDF and control diets. An important observation is that diets containing very high levels of fibrous feed ingredients can be just as digestible as high starch diets. The degree of digestibility is dependent on the character of fiber.

**Poultry**

The digestive tract of galliforms including commercial poultry is composed of a crop (food storage), proventriculus (glandular stomach), gizzard (grinding), small intestine, and paired ceca located at the junction of the small and large intestine (Duke, 1976). The ceca is considered to be the main site of fiber digestion. With its fermentation capability, the ceca is a source of major VFA production in the bird (McNab, 1976). Cecotomy (removal of ceca) reduced the coefficient of corn fiber digestibility to 0 as compared to 18.5 in intact chicken hens (Sturkie, 1976). Sources of fiber are digested to different extents depending on the source of the fiber and ingredient. Digestion of corn fiber is greater than that of wheat or barley (McNab, 1976). ADF was poorly digested by laying hens in comparison to NDF (2.5% vs 35%) (Moran and Evans, 1977). Finer particles of fiber appear more likely to enter the ceca. Lignin, pectins, agar, and chitin are considered to be indigestible. There is some limited digestion of hemicellulose. Any cellulose digestion is thought to occur in the ceca as a result of fermentation and is slight. Duke (1996) indicated that digestibility of cellulose could be improved by conditioning the turkey with a high fiber diet prior to the measurement of digestibility. In fiber conditioned birds, 15% of the
ingested fiber was metabolized to CO$_2$ while only 3% of the ingested fiber was metabolized in unconditioned turkeys.

**Effects of Dietary Fiber on Animal Health**

Dietary fiber can influence health of the animal through several potential mechanisms. Structure and function of the gut is directly influenced by fiber in the diet. Several authors have reported hypertrophy of the gastrointestinal tract (GIT) of pigs (Bohman et al., 1955; Kass et al., 1980; Pond et al., 1989) when fed diets high in fiber. While a proportional increase in size and weight of the GIT may not directly influence health of the animal, it does increase the energy and amino acid requirements for maintenance of the animal because the metabolically active GIT requires a disproportionate amount of the animal's total energy consumption (Baldwin et al., 1980). This relatively high, energy demand of the gut is likely due to the high cell turnover rate observed in the epithelial lining of the gut. Jin et al. (1994) demonstrated feeding diets containing elevated insoluble fiber from wheat straw increased cell proliferation in intestinal crypts of the jejunum and colon and increased rate of epithelial cell death in the jejunum and ileum of growing pigs. Proliferation of epithelial cells is supported by butyrate which is generated in the fermentation of dietary fiber (Mosenthin et al., 2001; Montagne et al., 2003).

The short-chained fatty acids (SCFA) including butyrate generated during fermentation of dietary fiber are almost completely absorbed from the GIT (Montagne et al., 2003). The absorption of SCFA's stimulate absorption of sodium which causes re-absorption of water from the colon (Mosenthin et al., 2001). Consequently, feeding dietary fiber supports hindgut fermentation and reduces the potential for non-pathogenic diarrhea to occur.

Several studies have demonstrated that dietary fiber increases the secretion of mucins in the ileum of many species (Montagne et al., 2003). Maintenance of an intact mucus lining serves
as an important protector against invading organisms, and physical and chemical injury to the epithelium. Enhanced capacity of the epithelium to secrete mucins likely is a response to mechanical irritation caused by insoluble dietary fiber (Montagne et al., 2003). Increased secretion of mucins may reduce the incidence and(or) severity of gastric ulcers. Lee and Close (1987) reviewed several studies in which dietary fiber was investigated as a tool to control gastric ulcers. They reported variable effects of dietary fiber on the occurrence of gastric ulcers in pigs and surmised that much of the reported benefits were due to increased particle size of high fiber diets.

Potentially beneficial effects of dietary fiber on animal health may be manifested through changes in microbiota of the GIT. Composition of the diet influences the species and number of bacteria in the gut (Varel and Pond, 1985; Jensen et al., 2003; Hedemann et al., 2003). Anugwa et al. (1989) reported an increase in the total number of anaerobic and cellulolytic bacteria in the colon of pigs fed alfalfa meal for 34 days. Elevated numbers of cellulolytic bacteria resulting from greater availability of substrate in the diet enhances hindgut fermentation and production of SCFA which decreases pH of the gut contents. A decrease in pH favors the growth of lactobacillus and bifidobacteria species which are beneficial to the pig. Proliferation of these beneficial bacteria tend to limit the growth of pathogenic species and ultimately enhance the health of the pig (Gaskins, 2003).

Enhancing hindgut fermentation may not always enhance health of the pig. Hampson et al. (2001) reported that a highly digestible diet based on cooked rice with essentially no fermentable dietary fiber prevented swine dysentery in pigs inoculated with *B. hyodysenteriae*, the causative organism for dysentery. Inclusion of sweet lupins in the diet which contained fermentable dietary fiber caused pigs to become infected with swine dysentery. They argued that
reduction of fermentable fiber in the diet reduced hindgut fermentation and the associated drop in pH. Maintaining an elevated pH was not favorable for colonization of the gut by *B. hyodysenteriae*. In support of their hypothesis, addition of guar gum, a source of soluble fiber, to diets for weaner pigs increased the incidence of hemolytic *E. coli* in the small intestine of pigs compared to contemporary pigs fed the control diet without guar gum.

Non-digested oligosaccharides such as mannan-oligosaccharides, fructo-oligosaccharides, galacto-oligosaccharides, and others can limit the population of pathogenic bacteria in the gut and consequently, improve health of the animal (Hathaway, 2000; Pettigrew, 2000). Mannan-oligosaccharides bind to lectins on the cell walls of pathogenic bacteria like *E. coli* thus preventing them from binding to and colonizing epithelial tissue (Pettigrew, 2000). The pathogenic bacteria-oligosaccharide complex then harmlessly passes through the digestive tract and out of the animal. Other oligosaccharides escape breakdown in the upper digestive tract and arrive in the colon where they are fermented producing SCFA's. As described above, these conditions favor proliferation of beneficial bacteria which crowd out pathogenic bacteria. There is some evidence that oligosaccharides may have modulating effects on the immune system (Pettigrew, 2000).

**Response of Nonruminants to Dietary Fiber**

**Growing Pigs**

Dietary fiber has traditionally been avoided in diets for growing pigs because of its depressing effects on diet digestibility and energy concentration of the diet. Theoretically, performance of growing-finishing pigs fed dietary fiber will not decline if one formulates diets so that pigs consume adequate amounts of net energy (NE), ileal digestible amino acids and other essential nutrients (Just, 1984). Unfortunately, swine diets in the U.S. are not formulated on an
NE basis so nutritionists are left to make educated guesses about the energy content of fibrous feeds and the effects of these feedstuffs on pig performance. Consequently, there have been few studies documenting the effects of fibrous feedstuffs on growth performance and carcass traits of growing-finishing swine.

Dietary fiber has received some renewed interest from swine nutritionists recently as a tool to manipulate energy concentration of low protein diets and as a tool to alter odor generation from swine slurry. Shriver et al. (2003) found that adding 10% soybean hulls to a low-protein, amino acid-supplemented diet did not influence growth performance of pigs from 60 to 250 lb body weight (Table 4). Addition of soybean hulls actually improved carcass leanness likely due to the lower NE content of soybean hulls compared to the other dietary components. Similarly, Kornegay (1981) reported that feeding up to 15% soybean hulls to pigs weighing between 50 and 185 lb had no detrimental effects on growth performance of pigs. These studies demonstrate that moderate levels of fermentable dietary fiber can be used in diets for relatively light pigs.

The pig's ability to utilize dietary fiber is positively related to age and weight of the pig (see above). Consequently, a wider range of fibrous feedstuffs may be appropriate for use in diets of late finishing pigs. Galassi et al. (2003) studied the effects of diets containing 24% wheat bran or 16% sugar beet pulp on performance and carcass traits of pigs weighing from 187 to 350 lb destined for production of Parma hams. Digestibility of both types of fibrous diets increased as the pigs increased in age and weight regardless of whether the fiber source was highly fermentable (sugar beet pulp) or lowly fermentable (wheat bran). Retained energy, protein accretion and fat accretion were similar for pigs fed the high fiber and control diets. Similarly, Fortin et al. (2003) demonstrated little effects of high oat (70%), high β-glucan diets on growth performance and carcass traits of pigs weighing between 115 and 240 lb. These
studies demonstrate that fibrous feedstuffs can be fed successfully to growing-finishing swine if care is taken to match the maturity of the pig to the type of fiber. Some fiber sources such as barley and wheat straw do not fit in diets for commercial swine production because they have no nutritional value for growing swine (Just, 1982; Schrama and Bakker, 1999).

Type of fiber also influences pig behavior and ultimately daily energy requirements. Growing pigs fed diets containing a high proportion of fermentable fiber exhibited significantly reduced heat production associated with activity (Schrama and Bakker, 1999). This reduction in activity partially compensated for the reduced energy content of the diet that contain a high proportion of fermentable fiber.

**Sows**

Gestation is the most logical phase of pork production to feed fibrous diets because nutrient requirements of pregnant sows are less than growing pigs and lactating sows. Many studies have reported improvements in reproductive performance of sows fed diets high in NSP (Grieshop et al., 2001). The magnitude of improvement is quite variable and in some cases researchers reported no improvement or a depression in performance due to dietary NSP addition. Grieshop et al. (2001) summarized 20 studies reported in the literature that investigated effects of high fiber diets on reproductive performance of sows. Thirteen of 19 studies that reported data on litter size found an increase in litter size when sows received a diet high in NSP during the previous gestation. Six studies reported no difference or a depression in litter size. The magnitude of positive responses ranged from .1 to 2.3 pigs born live per litter. The overall weighted mean response for all 19 studies was .4 pigs. Fibrous diets during gestation improved sow longevity in four out of eight studies that reported such data.
The recurring improvement in litter size due to elevated dietary NSP seems real but the inconsistent nature of the response makes reliable recommendations difficult. Some attribute of high fiber diets seems to favor improved reproduction. We surmised two possible explanations for the positive reports in the literature. Firstly, sows fed the high fiber diets during early pregnancy may have consumed less energy than control sows which improved embryo survival in early pregnancy. Jindal et al. (1996) reported improved embryo survival when pre-mating high level feeding (flushing) was discontinued within one day after mating. Positive responses in litter size to dietary NSP may be attributable to the energy dilution that occurs when diets contain elevated levels of NSP. Sows fed the fibrous diets may have consumed less energy during the critical early stages of pregnancy which enhanced embryo survival and ultimately, increased litter size at birth. Secondly, dietary NSP may have elicited improved sensitivity of peripheral tissues to insulin and sustained postprandial secretion of insulin which improved ovulation rate and ultimately litter size at birth. Several authors have reported increased sensitivity of peripheral tissues to insulin in humans that suffer from non-insulin dependent diabetes when their diet contains elevated levels of dietary NSP (Hjollund et al., 1983; Karlstrom et al., 1984; Landin et al., 1992). It appears that SDF compared with other fiber fractions is most effective in influencing insulin sensitivity and secretion. Elevated concentrations of insulin in blood enhance ovulation rate (Cox et al., 1987) and subsequent litter size (Ramirez et al., 1993) in sows.

An obvious question of practicing swine nutritionists is "What level of dietary NSP intake is required to elicit improvements in litter size?" To address this question, we selected six experiments from the literature that reported positive effects of high fiber diets on litter size. We
calculated the magnitude of improvement in litter size attributable to diets high in NSP and ranked these responses according to NDF intake (Table 5).

There appears to be no particular level of NDF intake that results in a maximal litter size response. NDF intakes of 520, 880, or 1010 g/d elicited the same numerical response. One conclusion is that all the NDF intakes in this sample exceeded that required to elicit a litter size response. Consequently, one might recommend an NDF intake of something less than 520 g/d but how much less? Reese (1997) recommended that sows consume 450 g NDF/d if fed alfalfa haylage, alfalfa meal or alfalfa hay; 515 g NDF/d if fed oat hulls; 380 g NDF/d if fed corn gluten feed; or 368 g NDF/d if fed wheat straw. An extensive commitment of time and resources would be required to establish ingredient specific intakes of NSP to elicit a litter size response. Currently, no research group has embarked on such a journey.

Gestating sows in commercial pork production systems are fed restricted amounts of feed to control body weight gain. Feed restriction increases the occurrence of undesirable stereotypic behaviors in gilts (Appleby and Lawrence, 1987) and probably sows. The occurrence of undesirable stereotypic behaviors is often used to measure welfare of sows. Diets high in NSP significantly reduce occurrence of stereotypic behaviors in pregnant sows (Robert et al., 1993; Ramonet et al., 1999; Bergeron et al., 2000). In contrast, McGlone and Fullwood (2001) found no effect of a pelleted diet containing 25% sugar beet pulp on stereotypic behaviors. However, pelleting may have altered the character of dietary NSP such that beneficial effects were not realized. Bergeron et al. (2000) reported that high daily intake of a nutrient dense diet was most effective at minimizing stereotypic behaviors. This suggests that sows expressing stereotypic behaviors are frustrated and have an elevated feeding motivation. Diets high in NSP can reduce feeding motivation as indicated in operant conditioning tests with sows and this response differs
according to the source of fiber (Robert et al, 1997). However, others have reported no effect of dietary fiber on feeding motivation (Bergeron et al., 2000; Ramonet et al., 2000).

If fibrous diets do decrease stereotypic behaviors and feeding motivation, one would expect sows fed high fiber diets to demonstrate less evidence of stress. McGlone and Fullwood (2001) used several physiological measures to assess stress in pregnant gilts fed a sorghum-soybean meal diet compared with others fed the control diet that contained 25% sugar beet pulp. These authors concluded that diet had no influence on the stress level of gilts housed in gestation stalls.

Increased satiation of sows fed diets high in NSP may relate to metabolic factors. Brouns et al. (1994) fed diets high in sugar beet pulp or wheat bran to determine their effects on post-prandial concentrations of insulin, glucose, and acetate in blood. They concluded that elevated acetate levels and more uniform levels of insulin and glucose may have maintained satiety for a longer period after the meal when compared to sows fed a high starch diet.

The balance of evidence suggests that diets high in NSP will reduce stereotypic behaviors in sows and increase their level of satiety. Currently, we assume that a decline in stereotypic behaviors equates to an improvement in welfare of the sow. The minimum level of NSP required in the diet to achieve these positive effects has not been elucidated. Ramonet et al. (1999) observed marked effects on behavior are realized with diets containing greater than 12% crude fiber. Meunier-Salaun (2001) suggested that crude fiber concentrations of 20% are most effective in reducing stereotypic behaviors. Character of the fiber and method of fiber analysis will influence recommendations on the appropriate level of dietary fiber to include for optimal improvements in sow welfare.
Feeding of fiber to poultry has generally been discouraged primarily because of the negative effects that fiber exerts on performance and nutrient utilization. As indicated earlier, cellulose and hemicellulose are not well digested. Inclusions of high fiber ingredients are usually limited because of the poor metabolizable energy contents. For example, true metabolizable energy contents of sunflower seed meal varying in contents of NDF and ADF was negatively correlated with CF, NDF, ADF, lignin, hemicellulose, and cellulose (Villamide and San Juan, 1998). TME values ranged from 707 to 918 kcal/lb DM with lower values associated with higher levels of hemicellulose.

Feeding of high fiber diets, however, is used as a strategy to control growth in some types of poultry such as turkey breeder candidates or chicken pullets to prevent excessive growth. In turkeys, the amount of weight control is often less compared to controlled feeding programs as the bird's GIT tract appears to adapt and larger volumes of feed are consumed. However, many early restriction programs were successful when very high fiber diets were fed (Hester and Stevens, 1990).

High fiber diets are also being examined as a replacement for fasting programs to recycle or molt chicken laying hens. Molting programs using feed withdrawal are under scrutiny from a welfare standpoint and many care guidelines prohibit the use of a fast to molt hens. Diets containing large portions of ingredients (greater than 90%) with high fiber content such as wheat midds and corn distiller dried grains are being tested for their ability to result in ovarian regression (Koelkebeck, 2002). Combinations of these ingredients were also tested with inclusion of corn. A wheat midd based diet resulted in similar second cycle performance as compared to the traditional feed withdrawal program.
Non-starch polysaccharides (NSP) are considered to cause adverse reactions in the digestive tract of birds. As reviewed by Bedford (1996), viscous grains have numerous effects on the digestive tract of the bird and nutrient utilization. Grains, which increase the viscosity of contents in the intestine, are rye, barley, oats, triticale and wheat. In wheat and rye, arabinoxylans are the predominant NSP and β-glucans in barley. Increasing the viscosity decreases nutrient utilization. Feeding of such grains also increases size of the digestive tract and pancreatic mass. Often time inclusion of these ingredients such as rye will degrade the litter through increased moisture. Research by Langhout and co-workers (2000) indicates that the antinutritive effects may be related to gut microflora as conventional chicks fed a diet high in pectin had reduced digestibilities of fat, starch and amino acids as well as reduced N retention and metabolizable energy compared to feeding of the NSP to germ-free broiler chicks. The effect of the microflora may be the result of where fermentation takes place. Work by Choct et al. (1996) indicated that a large amount of fermentation as the result of feeding soluble NSP occurred in the small intestine whereas with enzyme supplementation fermentation was shifted from the small intestine to the ceacum. Enzyme supplementation is used to improve the digestibility when such grains are used in poultry diets. In wheat-based diets, utilization of a xylanase supplement decreased intestinal viscosity and improved apparent metabolizable energy content and starch digestibility (Choct et al., 1999).

**Practical Considerations for High Fiber Diets**

*Handling high fiber diets*

Modern production systems for pigs and poultry depend almost exclusively on mechanical means for feed mixing and conveyance. Bulk bins, chutes, conventional augers, centerless augers, and cable delivery systems are designed to accommodate diets composed of
cereal grains and protein concentrate. Addition of bulky, fibrous ingredients to the diet will dramatically change the handling characteristics of the final feed. Reproductive and welfare benefits will have to be realized before commercial producers will retrofit existing feed delivery systems to allow use of fibrous diets.

Manure management

Increasing fiber concentration of diets can increase the volume of manure generated by pigs (Table 3) and the physical characteristics of poultry litter. This may require more frequent removal and spreading of manure or larger capacity manure storage structures. In addition, alterations in composition of the manure may influence the microbial environment in the manure storage structure or litter which might change odor generation and accumulation of solid residues in the structure.

Summary and Implications

Fiber characterization schemes for nonruminant diets such as Total Dietary Fiber allow a more accurate picture of the biological effects of fiber in the animal. Feed evaluation systems need to move toward including these more descriptive values for fiber in nonruminant diets. There are many reasons not to include fibrous ingredients in nonruminant diets such as: decreased digestibility of nutrients with some ingredients; increased volume of manure generated; increased potential for sludge buildup in liquid manure handling systems; and difficulty of handling bulky diets in mechanical feed manufacturing and delivery systems. However, selection of the appropriate type of fiber for the proper class of animal and the intended effect makes fibrous diets important to swine and poultry production systems. An important motivator for use of fibrous diets is the improvement in well-being of animals housed in modern, confinement systems. Use of fibrous diets seems to have broader applications in pork
compared to poultry production. As researchers and applied nutritionists better understand the effects of dietary fiber, the positive effects of fiber can be captured while minimizing the negative effects.

References


| Table 1. Corn, soybean meal and other fibrous feedstuffs fed to livestock<sup>a</sup> |
|---------------------------------|-----------|-------------|-------------|-------------|-------------|-------------|
| Feed                             | CF, %     | NDF, %      | ADF, %      | TDF, %      | SDF, %      | IDF, %      |
| Corn                             | 2.6       | 9.0         | 3.0         | 6.4         | 1.7         | 4.7         |
| SBM 44% CP                       | 7.0       | 13.3        | 9.4         | 33.1        | 1.6         | 31.5        |
| SBM 47% CP                       | 3.0       | 8.9         | 5.4         | 27.6        | 1.4         | 26.2        |
| Alfalfa                          | 26.2      | 45.0        | 35.0        | 56.7        | 4.2         | 52.4        |
| Oat Bran                          | -         | 19.2        | -           | 15.8        | 7.5         | 8.3         |
| DDGS                             | 9.9       | 44.0        | 18.0        | 42.9        | 0.7         | 42.2        |
| Oat Straw                         | 40.5      | 70.0        | 47.0        | 76.6        | 2.2         | 74.4        |
| Soybean hulls                    | 40.1      | 67.0        | 50.0        | 83.9        | 8.4         | 75.5        |
| Wheat Straw                      | 41.6      | 85.0        | 54.0        | 71.5        | 0.5         | 71.0        |
| Corn Stalk                       | 34.4      | 67.0        | 39.0        | 77.3        | 2.9         | 74.4        |
| S. Beet Pulp                     | 19.8      | 54.0        | 33.0        | 65.6        | 11.7        | 53.9        |
| Potato Pulp                      | -         | -           | -           | 33.3        | 11.0        | 22.3        |

<sup>a</sup>Sources: NRC (1998); NRC (1988); Dale (1998); and U of M laboratory analysis.

| Table 2. Digestibility coefficients for energy in growing pigs and sows<sup>a</sup> |
|-----------------------------------------------|-----------|-------------|-------------|
| Ingredient                                      | Crude fiber, % | Growing pigs | Sows         |
| Wheat                                          | 2.5       | .875        | .892        |
| Corn                                           | 2.8       | .889        | .916        |
| Barley                                         | 4.6       | .826        | .835        |
| Soybeans                                       | 5.6       | .732        | .817        |
| Lupins                                         | 17.5      | .768        | .849        |
| Soybean meal                                   | 7.2       | .845        | .894        |
| Sunflower meal (dehulled)                      | 10.3      | .737        | .789        |
| Corn gluten feed                               | 7.3       | .686        | .755        |
| Wheat bran                                     | 10.0      | .585        | .646        |
| Sugar beet pulp                                | 21.0      | .698        | .764        |
| Soybean hulls                                  | 39.1      | .473        | .712        |
| Sunflower hulls                                | 57.0      | .284        | .341        |

<sup>a</sup>After Noblet and LeGoff, 2001.

| Table 3. Effect of diets high in SDF and IDF on energy and N digestibility<sup>a</sup> |
|-----------------------------------------------|-----------|-------------|-------------|-------------|
| Item                                          | Control   | SDF         | IDF         | SDF/IDF     |
| Feed intake, g/d                              | 1826<sup>y</sup> | 1870<sup>y</sup> | 1961<sup>y</sup> | 1915<sup>yx</sup> |
| Sow wt. gain, g/d                             | 315       | 302         | 313         | 334         |
| Fecal DM output, g/d                          | 180<sup>y</sup> | 175.3<sup>y</sup> | 346.2<sup>y</sup> | 207.9<sup>x</sup> |
| Urine output, g/d                             | 5707      | 7700        | 4754        | 7006        |
| App. digestibility of GE, %                   | 87.9<sup>x</sup> | 89.3<sup>y</sup> | 82.7<sup>z</sup> | 86.8<sup>y</sup> |
| App. digestibility of N, %                    | 86.1<sup>y</sup> | 86.2<sup>y</sup> | 82.8<sup>x</sup> | 82.8<sup>x</sup> |

<sup>a</sup>Renteria Flores, 2003.

<sup>y</sup><sup>x</sup>Means within a row with different superscripts differ, P < .01.
Table 4. Effect of low protein diets and fiber addition on growth performance and carcass traits of finishing pigs\textsuperscript{a}

<table>
<thead>
<tr>
<th>Trait</th>
<th>Control</th>
<th>LPAA</th>
<th>SBH</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADG, lb</td>
<td>1.81</td>
<td>1.72</td>
<td>1.70</td>
</tr>
<tr>
<td>ADFI, lb</td>
<td>4.94</td>
<td>4.83</td>
<td>4.96</td>
</tr>
<tr>
<td>G:F</td>
<td>.37</td>
<td>.36</td>
<td>.34</td>
</tr>
<tr>
<td>Avg. backfat, in.</td>
<td>1.17</td>
<td>1.30\textsuperscript{x}</td>
<td>1.13\textsuperscript{y}</td>
</tr>
<tr>
<td>10\textsuperscript{th} rib fat depth, in</td>
<td>.88</td>
<td>.89</td>
<td>.80</td>
</tr>
<tr>
<td>Fat-free lean, %</td>
<td>50.30</td>
<td>49.55</td>
<td>50.13</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Adapted from Shriver et al., 2003

\textsuperscript{b}Control = corn-soybean meal diet; LPAA = low protein, amino acid-supplemented diet; SBH = LPAA + 10\% soybean hulls.

\textsuperscript{x,y}Means differ, P < .02

Table 5. Relationship of estimated NDF intake of gestating sows to litter size at birth

<table>
<thead>
<tr>
<th>NDF intake, g/d</th>
<th>Difference from control</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total pigs/litter</td>
<td>Live pigs/litter</td>
</tr>
<tr>
<td>520</td>
<td>.80</td>
<td>.80</td>
</tr>
<tr>
<td>526</td>
<td>.70</td>
<td>.70</td>
</tr>
<tr>
<td>640</td>
<td>--</td>
<td>1.00</td>
</tr>
<tr>
<td>660</td>
<td>.55</td>
<td>-.02</td>
</tr>
<tr>
<td>880</td>
<td>.80</td>
<td>.80</td>
</tr>
<tr>
<td>922</td>
<td>.56</td>
<td>.49</td>
</tr>
<tr>
<td>970</td>
<td>1.10</td>
<td>1.10</td>
</tr>
<tr>
<td>1010</td>
<td>.80</td>
<td>.50</td>
</tr>
<tr>
<td>1030</td>
<td>.60</td>
<td>.60</td>
</tr>
<tr>
<td>1110</td>
<td>.60</td>
<td>.50</td>
</tr>
<tr>
<td>1240</td>
<td>-.99</td>
<td>-.10</td>
</tr>
<tr>
<td>1860</td>
<td>--</td>
<td>1.20</td>
</tr>
<tr>
<td>2020</td>
<td>--</td>
<td>.70</td>
</tr>
</tbody>
</table>