11 Fiber in Swine Nutrition

Pedro E. Urriola, Sarah K. Cervantes-Pahm, and Hans H. Stein

Introduction

Fiber can be defined as carbohydrates or lignin in plant materials that are indigestible by endogenous animal enzymes and have physiological effects on animals and humans. Cellulose is the most abundant carbohydrate in the nature, and it is important to find ways to utilize cellulose and other fibrous components or non-starch polysaccharides (NSP) in the diet for successful and sustainable future pig production.

Because of the increased usage of starch and oil in the biofuel industry in recent years, many co-products or by-products are available as a feed ingredient for swine production. Unfortunately, such alternative feed ingredients are rather high in fiber content. Pigs can obtain energy from fiber but only after microbial fermentation of the fiber in the gastrointestinal tract and subsequent absorption of volatile fatty acids (VFA), which may contribute to the energy status of pigs.

Although soluble fiber is easily fermented, fiber is, in general, not well utilized by pigs, especially insoluble fiber. The greater the concentration of fiber, the lower the overall digestibility of energy in the diet. Furthermore, fiber may reduce the digestibility of amino acids, lipids, and some minerals. Therefore, the fundamental and applied information on fiber or its utilization or both would have considerable impacts on the issue of not just utilizing fibrous components per se but also on the efficient utilization of alternative feedstuffs for swine production. The objective of this chapter is to briefly review fiber and its utilization by pigs, which may contribute to successful and sustainable swine production.

Definition of Dietary Fiber

There are numerous definitions of dietary fiber, but most of them either define dietary fiber as a group of compounds that are identified in analytical methods or as a group of compounds that have specific physiological functions (IOM, 2001). In the nineteenth century, the Weende procedure defined crude fiber as the organic residue that is insoluble in acid and alkaline treatments (Mertens, 2003). This portion of the diet was considered the de facto definition of dietary fiber and without real value to the animal (AACC, 2001).

Later, two researchers in separate ways proposed that this indigestible residue might improve human health (Kritchevsky, 1988). Denis Burkitt reported that bowel cancer is rare in humans

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who consume a "high residue diet," and Hugh Trowell suggested that high intakes of undigested residue help protect people in developing countries from ischemic heart disease (Burkitt et al., 1972; Kritchevsky, 1988; Carpenter, 2003). These conclusions triggered interest in dietary fiber, but it became clear that dietary fiber is a heterogeneous group of chemical components with multiple physiological functions and is therefore difficult to define (Carpenter, 2003).

It is now accepted that an accurate definition of dietary fiber must include the physiological effects of fiber (IOM, 2006). Therefore, an important aspect of the definition is that dietary fiber consists of carbohydrates that are indigestible by endogenous animal enzymes (AACC, 2001; IOM, 2006). The inclusion of this term in the definition is important, but difficult to measure (Englyst et al., 2007). The current definition of dietary fiber (AACC, 2001) includes the following aspects: (1) it is an indigestible portion of the diet, (2) it originates from carbohydrates or lignin, (3) it is a part of a plant, and (4) it has physiological effects in humans that improve laxation or attenuate blood cholesterol or glucose or both.

The definition of dietary fiber by the IOM separates the definition into three parts (i.e., dietary fiber, functional fiber, and total fiber). Dietary fiber consists of non-digestible carbohydrates and lignin that are intrinsic and intact in plants. Functional fiber consists of isolated, non-digestible carbohydrates that have beneficial physiological effects in humans, and total fiber is the sum of dietary fiber and functional fiber (IOM, 2006).

The term NSP is related to dietary fiber but does not cover all components that can be classified as dietary fiber (Elia and Cummings, 2007). For example, NSP does not include oligosaccharides and lignin, which were included in the definitions of dietary fiber by AACC (2001) and by IOM (2006). Therefore, use of the term NSP may not be an accurate description of fiber in feed ingredients because dietary fiber is not limited to NSP or plant cell walls (Cho et al., 1997).

The correct definition of dietary fiber is important for labeling the concentration of dietary fiber in human food products. In swine diets, it is important to clearly describe the components of dietary fiber that have nutritional and physiological effects in the animals and to define the components that contribute to the energy value of the feed ingredient. It is also important that analytical procedures are available to accurately determine the concentration of dietary fiber in animal feed and feed ingredients.

Analysis of Fiber in Animal Feed Ingredients

There are many methods to determine the concentration of dietary fiber in human food, animal feed, and feed ingredients. All methods include two basic steps: digestion of carbohydrates and other nonfiber components of the diet (i.e., protein and fat) and quantification of the undigested residue. The digestion procedure can use chemicals (e.g., acid, alkali, and detergent) or enzymes (e.g., amylase, amyloglucosidase, and protease). Measurement of the indigestible residue can be accomplished by weighing the residue (gravimetric) or by measuring chemical compounds in the residue using gas-liquid chromatography, or high-performance liquid chromatography. There are newer methods to study the composition and structure of non-starch polysaccharides in cell walls of plants and their relationship with degradation in the gut (Guillon et al., 2006). These methods include Raman Microspectroscopy, Fourier Transform Infrared Spectroscopy (FT-IR), immunolabeling, fluorescence, and mass spectroscopy, among others (Guillon et al., 2006).

Crude Fiber

This is a chemical–gravimetric method that is part of the proximate analysis of feed ingredients developed in the Agricultural Experimental Station in Weende, Germany (Grieshop et al., 2001).

The method separates carbohydrates into two portions, nitrogen free extract and crude fiber. Crude fiber is the residue that is left after digestion of a sample with 1.25% sulfuric acid and 1.25% sodium hydroxide (Cho et al., 1997; Furda, 2001). At the time of the procedure's development, it was known only that digestion included acid and alkaline processes, but the crucial enzymes were unknown (Mertens, 2003). The crude-fiber procedure is very robust and repeatable, but there is no relationship between crude fiber and the definitions of dietary fiber by AACC and IOM (Mertens, 2003) because the recovery of cellulose (40–100%), hemicelluloses (15–20%), and lignin (5–90%) is not complete (Grieshop et al., 2001; Mertens, 2003). However, the procedure is still used to regulate maximum crude-fiber guarantee level in swine feed (AAFCO, 2008).

Detergent Fiber Procedures

The detergent procedure is a chemical–gravimetric procedure that empirically relates the value from the analysis to the physiological properties of dietary fiber (Van Soest et al., 1991). The procedure was developed by Van Soest (1963) and it divides dietary fiber into neutron detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (Robertson and Horvath, 2001). This procedure was an improvement over the crude-fiber procedure; however, it does not recover soluble dietary fiber such as pectins, mucilages, gums, and β-glucans (Grieshop et al., 2001). The lack of recovery of soluble dietary fiber components is less concerning in cereal grains such as corn and dried distillers grains with solubles (DDGS) that have high concentrations of insoluble fiber (Johnston et al., 2003) than feed ingredients such as soybean hulls and sugar beet pulp that also contain soluble dietary fiber. Other problems with the detergent procedure include the possible contamination of the residue with starch and protein, which reduces robustness and repeatability (Mertens, 2003).

Total Dietary Fiber

The procedure of Prosky is known as the total dietary fiber procedure (TDF; Method 985.29; AOAC, 2006) and has been modified to determine soluble and insoluble dietary fiber (Method 991.43; AOAC, 2006). The TDF procedure uses enzymes (e.g., amylase, glucoamylase, and protease) to mimic digestion in the small intestine, and then the residue is weighed (Prosky et al., 1984). The residue also is analyzed for undigested proteins and ash. The TDF procedure is more time-consuming and less reproducible than the crude-fiber and detergent methods, but values obtained by the TDF procedure are more representative of the concept of dietary fiber (Mertens, 2003). More work is needed to improve the TDF procedure to include low-molecular-weight indigestible carbohydrates and correct for contaminants of the indigestible residue (Gordon et al., 2007).

Enzymatic Chemical Methods

There are two commonly used methods that combine the initial steps of enzymatic digestion with chemical determination of sugars in the undigested residue (Theander and Åman, 1979; Englyst et al., 1982). The Uppsala method calculates dietary fiber as the sum of amylase-resistant polysaccharides, uronic acids, and Klason lignin (AOAC, 2006). The digestion step in the AOAC Method (994.13) uses a heat-stable α-amylase and amyloglucosidase (AOAC, 2006). The residue is divided into soluble and insoluble fractions by 80% ethanol. The neutral sugars released are quantified as alditol acetate derivatives by gas liquid chromatography and uronic acids chromatographically (Theander