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Nutritional and Metabolic Consequences of Feeding High-Fiber Diets to Swine: A Review

Atta K. Agyekum [a], C. Martin Nyachoti [b,*]

[a] Prairie Swine Center Inc., Saskatoon, SK S7H 5N9, Canada
[b] Department of Animal Science, University of Manitoba, Winnipeg, MB R3T 2N2, Canada

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ABSTRACT

At present, substantial amounts of low-cost, fibrous co-products are incorporated into pig diets to reduce the cost of raising swine. However, diets that are rich in fiber are of low nutritive value because pigs cannot degrade dietary fiber. In addition, high-fiber diets have been associated with reduced nutrient utilization and pig performance. However, recent reports are often contradictory and the negative effects of high-fiber diets are influenced by the fiber source, type, and inclusion level. In addition, the effects of dietary fiber on pig growth and physiological responses are often confounded by the many analytical methods that are used to measure dietary fiber and its components. Several strategies have been employed to ameliorate the negative effects associated with the ingestion of high-fiber diets in pigs and to improve the nutritive value of such diets. Exogenous fiber-degrading enzymes are widely used to improve nutrient utilization and pig performance. However, the results of research reports have not been consistent and there is a need to elucidate the mode of action of exogenous enzymes on the metabolic and physiological responses in pigs that are fed high-fiber diets. On the other hand, dietary fiber is increasingly used as a means of promoting pig gut health and gestating sow welfare. In this review, dietary fiber and its effects on pig nutrition, gut physiology, and sow welfare are discussed. In addition, areas that need further research are suggested to gain more insight into dietary fiber and into the use of exogenous enzymes to improve the utilization of high-fiber diets by pigs.

1. Introduction

Conventional swine diets contain substantial amounts of cereal grains (e.g., corn and wheat) and protein supplements such as soybean meal to provide pigs with the energy and nutrients they require. However, recent trends in the demand and supply of these conventional feedstuffs require swine producers around the world to seek low-cost alternatives such as cereal co-products from the biofuel and milling industries to feed their pigs, in order to reduce feed costs [1]. The majority of these co-products have a high energy and nutrient content but are fibrous in nature. When fibrous co-products are incorporated into pig diets, the carbohydrate composition inevitably changes from a high-starch diet toward a diet containing less starch and more non-starch polysaccharides, which are the major component of dietary fiber.

In general, diets that are rich in dietary fiber have a lower nutritive value for monogastric animals, including pigs, because these animals' digestive enzymes are not suited to degrading non-starch polysaccharides [2]. The ingestion of high-fiber diets also has the potential to adversely affect energy and nutrient utilization and consequently result in lower pig performance [3–6]. Therefore, only a minimal level of fiber is typically included in diets fed to swine. However, dietary fiber has received a considerable amount of attention in recent years because some fiber components have beneficial effects on pigs when fermented in the intestine [7,8], and can also affect satiety and animal behavior [9,10].

This review discusses dietary fiber, its effects in pig nutrition, and the mechanisms involved in its utilization. Furthermore, the effects

* Corresponding author.
E-mail address: martin_nyachoti@umanitoba.ca

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of dietary fiber on pig gut health and sow welfare are discussed. Finally, areas that require further research to expand our knowledge on fiber and some of the strategies used to improve fiber utilization in pigs are outlined.

2. Dietary fiber

2.1. Definition and classification

Plant carbohydrates can be classified as sugars, disaccharides, oligosaccharides, or polysaccharides (i.e., starch and non-starch polysaccharides). Sugars, oligosaccharides, and starch are found in the interior of the plant cell, whereas non-starch polysaccharides, together with lignin, are the main constituents of the plant cell walls, and are called dietary fiber. The term "dietary fiber" has several definitions; however, all these definitions have limitations because plant cell wall components are variable and complex in their chemical and physical composition and in their metabolic effects. The initial definition of dietary fiber as "the sum of lignin and cell wall polysaccharides that are resistant to enzymatic hydrolysis in the digestive system of man" was coined by Trowell et al. [11] in relation to human medicine. However, this definition of dietary fiber is also applicable to other monogastric animals, such as pigs [12]. The Codex Alimentarius Commission [13] finalized the definition of dietary fiber as "carbohydrate polymers with 10 or more monomeric units, which are not hydrolyzed by the endogenous enzymes in the small intestine of humans." Dietary fiber also includes any polysaccharides that reach the hindgut, such as resistant starch and oligosaccharides, which constitute plant cell contents and include fructo-oligosaccharides. The main constituents of the plant cell wall polysaccharides are cellulose, hemicellulose, and pectin.

Cellulose is a linear polymer of glucose units with β-(1→4) linkages, whereas pectin consists mainly of glucuronic acid units joined in chains by α-(1→4) glycosidic linkages. The most abundant organic substrate on earth, cellulose forms the main structural component of plant cell walls. Hemicelluloses are a complex matrix of polysaccharides that include xylose, arabinose, galactose, mannose, glucuronic acid, and β-glucans. Lignin is a phenolic polymer that anchors the cell wall polysaccharides and is not digested or fermented by porcine intestinal enzymes or bacteria, respectively [2,7,8,14].

Non-starch polysaccharides can be classified as insoluble or soluble based on their solubility in water or weak alkali [12]. Insoluble non-starch polysaccharides include cellulose and some hemicelluloses, and soluble non-starch polysaccharides include pectins, gums, and β-glucans. Soluble non-starch polysaccharides are more rapidly fermented in the gastrointestinal tract of the pig than insoluble non-starch polysaccharides [7,12]. For insoluble non-starch polysaccharides, little or no fermentation occurs in the upper gut; rather, fermentation remains low in the hindgut of pigs [15].

Dietary fiber (or non-starch polysaccharide fractions) is currently classified based on physicochemical properties in order to provide more information on its metabolic and physiological activities. The physicochemical properties of dietary fiber that are relevant to pig nutrition include viscosity, hydration, and fermentability. Viscosity describes the dissociation of non-starch polysaccharides in the gastrointestinal tract to form high molecular weight viscous aggregates. Soluble fibers such as β-glucans, gums, or pectins increase digesta viscosity when ingested by pigs. Fermentability describes the ability of non-starch polysaccharides to be fermented by the microflora harbored in the intestine. Soluble fiber is generally more fermentable than insoluble fiber. The hydration properties are swelling capacity, solubility, water-holding capacity, and water-binding capacity [16]. The water-holding capacity of a fiber affects its fermentability. Thus, when physicochemical parameters are incorporated into pig feed formulation, they may provide nutritionists with a better control of the fermentation process that takes place in the pig's gut and could assist nutritionists in predicting the energy contribution and prebiotic effect of a diet or feedstuff.

2.2. Analytical methods for characterizing dietary fiber

Several methods exist for characterizing the dietary fiber component of feeds and feedstuffs; the choice of an analytical method depends on the aims of the investigator [12,17,18]. Based on how the fibrous remnants are isolated and measured, dietary fiber analytical methods are classified into three groups: chemical-gravimetric, enzymatic-gravimetric, and enzymatic-chemical methods. The numerous fiber analytical methods and the variability among these methods and among the obtained results make it rather difficult to compare information from different studies [19]. However, methods that categorize dietary fiber into soluble and insoluble components seem to provide the most accurate interpretation of study results. In what follows, the analytical methods most commonly used for measuring dietary fiber are briefly discussed.

2.2.1. Crude fiber method

Crude fiber analysis is a chemical-gravimetric method that is part of the Weende proximate analysis used for feed ingredients [19]. It was introduced to differentiate between carbohydrate that is "available" and carbohydrate that is "unavailable" for digestion. The aim of crude fiber analysis is to mimic the digestive actions of the gastric and pancreatic secretions by boiling a feed with dilute acid followed by a dilute alkali solution [19]. The crude fiber analytical method is very robust and reproducible within and among laboratories; however, there is incomplete recovery of cellulose, hemicellulose, and lignin. Therefore, crude fiber is not considered to be an acceptable definition for dietary fiber and is not suitable for characterizing the fiber component in pig feed. However, many regulatory agencies use crude fiber for quality control purposes and for regulating the minimum fiber content allowed in a feed.

2.2.2. The detergent (Van Soest) methods

The detergent methods, which are chemical-gravimetric procedures, were developed by Van Soest in the 1960s. These methods employ detergents to progressively extract neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) [18,19]. The NDF procedure recovers the insoluble components of dietary fiber (i.e., cellulose, hemicellulose, and lignin) after digesting a feed or ingredient in a solution at a neutral pH. Thus, the nutritional advantages of the NDF procedure are that it is able to approximate the insoluble dietary fiber fraction of a feedstuff and that its results are reproducible [19]. The ADF procedure recovers mainly cellulose and lignin by digesting a diet or feedstuff in a solution at an acidic pH [18], whereas the ADL recovers lignin using sulfuric acid. A more accurate estimate of hemicellulose and cellulose is obtained when the NDF, ADF, and ADL are determined sequentially using the same sample [18].

The detergent procedures, although an improvement over the crude fiber method, do not recover soluble dietary fiber (e.g., pectins, gum, and β-glucans) [19]. Therefore, these procedures can underestimate the total dietary fiber, especially for starchy feeds or ingredient samples, although probably not for cereal co-products, which have a high insoluble fiber concentration.

2.2.3. Total dietary fiber method

The total dietary fiber method was introduced to overcome some of the pitfalls of the detergent procedure. The total dietary fiber method is important for feedstocks intended for monogastric animals, including pigs, with hindgut fermentation. This procedure employs enzymes to simulate the processes that take place within the