DIETARY FIBER: THE GOOD, THE BAD AND THE UGLY

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I have always questioned why fiber was an important part of the human diet but needed to be minimized in poultry diets. That was when I realized that not all fiber is the same. The anti-nutritive properties of some sources of fiber in poultry diets have been recognized for many decades, but the potential benefits of other sources of fiber have only recently been investigated. González-Alvarado et al. (2007) showed that the inclusion of moderate amounts of fiber in low fiber diets improved chick performance at early ages by reducing gizzard pH and improving utilization of nutrients. Therefore, young broilers may require a minimal (>1.5% crude fiber) amount of fiber in the diet. The potential benefits, or hazards, of dietary fiber are dependent on its physical and chemical characteristics.

WHAT IS DIETARY FIBER?

The term 'fiber' is a misnomer since many types of dietary fiber are not exactly fibrous. Dietary fiber is the indigestible portion of plant-derived foods. Chemically, dietary fiber consists primarily of non-starch polysaccharides. It also includes other plant components such as resistant starch, inulin, lignin, chitin, pectin, ß-glucan, and oligosaccharides.

Polysaccharides are large strings of simple sugar molecules (monosaccharides). Each of the sugars are linked by what is referred to as glycosidic bonds which are formed between specific parts of the sugar molecules. The bonds are identified by the number of the carbon atoms of the sugars that are linked. To complicate things, they can be bound in one of two possible orientations referred to as beta (β) and alpha (α).

There are over 100 sugars, known as monosaccharides, found in nature although only nine of these make up the building blocks of fiber polysaccharides or chains of sugars. These are the pentose (5-carbon) sugars arabinose and xylose; the hexose (6-carbon) sugars glucose, mannose, and galactose; and the hexauronic acids (galacturonic and glucuronic acids). The potential polysaccharide structures are numerous and the number is increased by the additional binding of several non-sugar compounds such as methyl or acetyl groups, phenolic acids, proteins, and lignin, as well as the bonding within and between polysaccharides.

Starch is a polysaccharide made up of glucose molecules linked by an α-(1→4) and some α-(1→6) glycosidic bonds which are easily broken down by the digestive enzymes produced in the intestines of poultry. Polysaccharides other than starch (*non-starch polysaccharides*, NSP) contain sugars other than glucose and have links that cannot be broken down by the digestive enzymes produced in the intestines of poultry. NSP molecules can, however, be broken down by enzymes produced by microbes.

Oligosaccharides are different from NSPs and are short chains of a few simple sugar molecules and are often linked to other compounds such as amino acids or lipids. Examples include fructo-oligosaccharides which are short chains of fructose molecules; galacto-oligosaccharides made up of galactose molecules and mannan-oligosaccharides with mannose molecules.

Inulin is a natural storage carbohydrate in many plant foods and is a fructo-oligosaccharide. Inulin is found in the stems of many species of grasses. *Lignin* is a constituent of the cell walls of almost all dry land plants. Chemically, lignins are cross-linked phenol polymers. *Chitin* is a fibrous substance found in the exoskeleton of arthropods (insects and crustaceans) and the cell walls of fungi. It is a nitrogen-containing polysaccharide. *Pectin* is a soluble gelatinous polysaccharide that is present in ripe fruits. Pectin is commonly used when canning jams and jellies. *β-glucans* are soluble fibers readily available in oat and barley grains. β-Glucans are a group of β-D-glucose polysaccharides naturally occurring in the cell walls of cereals, yeast, bacteria and fungi.

Cellulose is a polysaccharide consisting of chains of glucose molecules. It differs from starch in orientation of the glycosidic bonds. While starch has alpha glycosidic bonds, those in cellulose are in a beta orientation. This difference makes cellulose resistant to the digestive enzymes of poultry. Cellulose is a major component of the cell walls of most plants. *Hemi-cellulose* is any of several heterpolymer molecules. These polysaccharides contain many different sugar molecules. While cellulose is resistant to breakdown in the poultry digestive tract, hemi-cellulose has a random, amorphous structure which has very little strength and is easily broken down.

MEASURING DIETARY FIBER CONTENT

With the diversity of the compounds that can be included in 'dietary fiber' the question becomes how to measure the fiber level in a feedstuff. Crude fiber was invented in the middle of the last century and is used extensively by non-ruminant nutritionists. Crude fiber is basically the organic remnant of a feedstuff that was insoluble in hot dilute sulfuric acid and sodium hydroxide. It includes variable portions of the insoluble NSPs including pectin, mixed linked β-glucans, and arabinoxylans. Ruminant nutritionists work more with neutral detergent fiber (NDF) and acid detergent fiber (ADF). ADF has been correlated with Crude fiber and is determined by extracting with acidic detergent. It includes cellulose, insoluble crude protein, and acid-insoluble ash. NDF uses a neutral detergent (non-acidic and non-alkaline) for extraction and includes ADF plus cellulose. It is more applicable to ruminants since it does not work with legumes and oilseeds that are rich in pectic polysaccharides. It is for these types of issues that non-ruminants have continued to use Crude Fiber. If pasture is included in the diet of non-ruminants the NDF/ADF system may be more applicable for determination of nutrient availability.

PROPERTIES OF FIBER

Dietary fiber is divided into two main components. The first is the soluble fiber which, as the name implies, are readily dissolved in water. Insoluble fiber, on the other hand, does not dissolve in water. Solubility is an important factor in the properties of dietary fiber.

When dissolved in water, many NSPs interact with the water molecules and become entangled. The result is a thick gel-like material. When this occurs in the digestive tract, the increase in the viscous nature of the digesta reduces the rate of passage through the intestines and decreases feed intake.

The insoluble fiber passes through the intestines undigested. One of the principal roles of this part of dietary fiber is to provide substrates for fermentation by bacteria in the ceca. Examination of bacterial cultures from the ceca of turkeys fed either a high or low fiber diet indicated that direct counts of microbes were significantly higher in high-fiber fed than low-fiber fed turkeys (Bedbury and Duke, 1983).

INTERACTION BETWEEN DIETARY FIBER AND INTESTINAL DEVELOPMENT IN POULTRY

The poultry digestive tract is home to a population of commensal flora which are important to good gut health. The lining of the gut is composed of the digestive epithelium, the gut-associated lymphoid tissue (GALT) and the mucus produced by the epithelium. The interactions among the GALT, commensal bacteria, mucus and the cells of the intestinal lining exist and the balance of these constituents are important for gut health. Gut health, in turn, is important for efficient functioning of the digestive system. Dietary fiber interacts with the mucosa and the microflora giving it an important role in gut health.

There is a large, diverse population of bacteria found in the intestines of non-ruminant animals. Although similar types of bacteria are found in the healthy guts of most animals, the types and numbers of bacteria are species-specific and varies with age, physiological state, and gut site. The composition can also be altered depending on the diet composition. Numerous studies have reported that dietary fiber has marked effects on gut anatomy, gut development and gut function. In general, dietary fiber leads to increased size and length of the digestive organs.

Dietary fiber is poorly digested and does not supply nutrients to non-ruminant animals. Recent research, however, has shown that addition of some fiber can play an important role in poultry diets. Dietary fiber is preferentially used by the intestinal bacteria *Lactobacillus* and *Bifidobacteria* species which results in the production of lactic acid and short chain fatty acids. As a result, the pH of the digesta decreases providing an environmental ideal for the commensal bacteria in the gut. Maintaining a healthy gut microflora is important in preventing colonization by pathogenic bacteria.

A prebiotic is a mixture of indigestible feed ingredients that beneficially affect the host by selectively stimulating the growth and/or activity of beneficial bacterial species residing in the digestive tract. This includes a variety of molecules. The majority are considered dietary fibers such as oligosaccharides. They enhance feed efficiency and the number of goblet cells in the jejunum of broiler chickens (Baurhoo et al., 2007).

Shang et al. (2015) showed that supplementing broiler diets with fructo-oligosaccharides (FOS) increased ileal mucosa thickness and increased the expression of certain cytokine genes. FOS supplementation also lead to alteration of leukocyte composition. When challenged by *Salmonella* Enteritidis lipopolysaccharides, there was an increase in IgY levels suggesting FOS supplementation may be effective to induce protective outcomes in gut health and immunity of broiler chickens. In addition, there was an increase in ileal villi height, jejunal and ileal microvillus height and villi height to crypt depth.

INCLUDING 'GOOD' FIBER IN POULTRY DIETS

Fiber in layer diets has been shown to reduce the incidence of cannibalism (Hartini et al., 2002). It may be that the dilution of the diet with fiber increases eating time and provide less time for feather pecking. Fiber in layer diets has also been shown to reduce ammonia emissions (Roberts et al., 2007). Fiber provides the energy to the bacteria in the lower gastro-intestinal tract where the bacteria use nitrogen for synthesis of bacterial protein. This reduces the amount of nitrogen excreted as uric acid. The bacteria also produce short-chain fatty acids which reduce the manure pH shifting ammonia to ammonium which is less volatile.

Fiber from oats, alfalfa meal, sunflower seed meal or rice hulls have been shown to greatly reduce egg yolk and plasma cholesterol levels. This could be related to the high levels of bioactive anti-nutritive factors in fiber feeds such as saponins, which possess hypocholesteromic properties (McNaughton, 1978).

Rezaei et al. (2015) showed that oligosaccharides extracted from palm kernel meal appear to improve immune responses in broiler chickens, especially at a young age when the immune system is not fully developed. Mannobiose seemed to have the greatest effect. There was an increase in the plasma IgA levels and a decrease in heterophil and basophil counts. Such ingredients are used as prebiotics. There was, however, no effect on body weight gain or feed consumption, but there was improved feed efficiency.

Broiler performance at 42 days is closely related to performance at 7 days of age. In turn, body weight at 7 days depends primarily on feed intake. Strategies have looked at ingredients with high energy and protein content. As a result, most diets for newly hatched chicks are low in crude fiber. But low crude fiber diets have been shown to be detrimental to development of the digestive tract. Low fiber diets also increase the incidence of enteric disorders (Jiménez-Moreno et al., 2009).

The inclusion of insoluble fiber in the broiler diet increases the reflux of digesta between the gizzard and the duodenum. This prolongs the exposure of food to both the mechanical and chemical components of digestion. Broilers raised on diets diluted with oat hulls exhibited improved performance due to improved gizzard function and holding capacity (Sacranie et al., 2012). This research illustrated the prevalence of reverse peristalsis, or reflux, along the entire length of the gastro-intestinal tract of broiler chickens. Many feed ingredients such as barley, oats and soybean meal contain considerable amount of insoluble fiber. Including 10% oat hulls in broiler diets increased wheat starch digestion and stimulated gizzard activity.

Mannon-oligosaccharides are one of the most popular commercially available prebiotics. However, they do not selectively enrich for beneficial bacteria. Instead, they are thought to act by binding and removing pathogens from the intestinal tract and by stimulating the intestinal immune system (Shashidhara and Devegowda, 2003). Broiler performance was found to be similar in chickens fed antibiotics or antibiotic-free diets containing mannan-oligosaccharide (MOS) or lignin. However, chickens fed MOS or lignin had a comparative advantage over chickens fed antibiotic supplemented diets with increased population of beneficial bacteria in the ceca, increased villi height, and an increase in the number of goblet cells in the jejunum and lower population of *E. coli* in the litter (Baurboo et al., 2007).

Poultry require a certain amount of dietary fiber for proper development and physiology of the digestive tract. For chickens fed a diet low in fiber had a dilation of the proventriculus which resulted in the widening of the gastric isthmus and rupture of the proventriculus at the time of processing, leading to increased carcass condemnations. Diets with high fiber content have a high distension of the walls of the digestive tract increasing gut capacity. There was also increased gizzard development and functionality.

ELIMINATING 'BAD' FIBER FROM POULTRY DIETS

The arabinoxylans and pentosans in rye, as well as the β-glucans in barley, are responsible for the poor nutritive value of these ingredients. The nutrient content of rye is similar to other cereals, but because of the pentosans present its actual nutritive value is low. Supplementing such diets with feed enzymes targeting these compounds improves the nutritive value of rye and barley. Breeding programs have also successfully reduced the level of the anti-nutritional substances in cereals such as barley and wheat.

Some fiber sources contain phytate which has been shown to reduce phosphorus, calcium, and zinc availability to chicks. It may also reduce availability of trace minerals by binding the minerals to the fiber matrix. Again, adding feed enzymes targeting phytate can be added to the diet to minimize or eliminate this problem.

ELIMINATING 'UGLY' FIBER FROM POULTRY DIETS

Raffinose is a series of oligosaccharides that vary in distribution among leguminous species and among varieties of the same species. Because they cannot be digested in the upper digestive tract, they remain undigested until they reach the lower gut where they can be digested by microbial enzymes. A by-product of the fermentation of these compounds is the production of gases which have been associated with flatulence in non-ruminant animals, as well as causing diarrhea.

SUMMARY

Dietary fiber includes a whole group of compounds that differ in chemical composition and physical properties. The major problem nutritionists have had with the study of dietary fiber has been how to define and analyze this portion of the diet. Two definitions are generally accepted. From a physiological viewpoint dietary fiber is defined as the parts of the diet that are resistant to breakdown by digestive enzymes produced by animals. From a chemical viewpoint, dietary fiber is the total of the non-starch polysaccharides plus lignin.

Fiber in monogastric diets are generally divided into two groups – the more soluble fibers and the insoluble lignified fibers. The soluble fibers tend to result in viscous conditions in the digestive tract which can adversely affect digestion and nutrient absorption. The insoluble fibers general increased fecal output.

Grass-eating animals such as cows and goats are not, in themselves, capable of breaking down dietary fiber. The digestion of grass consumed results from a symbiotic relationship with a complex microflora population in the rumen of the animal. There are foregut or hindgut fermenters. Foregut fermenters include ruminants which have evolved to utilize low quality, high fiber forages. They generally have a long retention time relative to body weight. This allows for maximal energy extraction from fiber while limiting intake. Since fiber digestion occurs before the small intestine, the microbial mass produced can be effectively used by the animal. In hindgut fermenters, however, fiber passes through the small intestines essentially intact. This influences the rate and extent of absorption of other nutrients. Hindgut fermenters, therefore, sacrifice fiber digestion for the sake of intake. Poultry, which are hindgut fermenters, often maximize feed intake and passage of the material through the digestive tract but actually extract very little of the available energy from the dietary fiber. Hindgut fermenters generally attempt to increase intake when challenged with a higher fiber diet.

Fibers have different effects in both the production and activity of digestive enzymes. Increase fiber intake, especially with cereal fibers, can increase production of saliva, gastric juices, hydrochloric acid and pepsin. Increases in pancreatic juices and electrolyte production have also been noted. Adding wheat bran to the diet can stimulate bile secretion. But some fibers adversely affect activity of digestive enzymes.

Fibers have been shown to modify the intestinal morphology in terms of villi length and number, cell proliferation, mucus cell division and absorptive functions. Increased intestinal weight and volume have been seen with high fiber diets.

Some oligosaccharides have clear benefits with reduced disease risk and improve digestibility of various dietary fractions. Others, however, have caused problems such as raffinose which causes diarrhea in young animals.

The digestive tract of newly hatched chicks is not well adapted to the digestion and absorption of many feed components so the inclusion of highly digestible ingredients might benefit feed intake, nutrient digestibility and growth performance early in life. However, highly digestible diets are usually low in fiber, which reduces gizzard development and impairs the mixing of the digesta with endogenous enzymes, reducing nutrient utilization (Jiménez-Moreno et al., 2010).

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