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Dietary Fiber from Crude to Refined: Unraveling Its Value on Animal Performance

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Introduction

Fiber, although a simple five letter word, is like an onion. It is only once you begin to peel back the layers that you discover the complexity within. As nutritionists we are used to thinking in terms of 'crude fiber', but as we move into a world without antibiotics and the need to sometimes select alternative ingredients, we are now beginning to separate fiber into its chemical components and functional properties. To understand the functional properties, such as solubility and fermentability, we first need to ensure we can accurately measure the chemical composition of fiber for a wide variety of ingredients. This paper will review the methods used to analyze the different components of fiber, introduce a new database developed to measure Non-Starch Polysaccharides (NSP) and discuss profiles of ingredients, so that we can gain a better understanding of fiber moving forward.

Fiber: Definition and Analytical Methods

Fiber, as defined today, has both a chemical and a physiological definition. Chemically fiber refers to all non-starch polysaccharides (NSP) plus lignin. From a chemical standpoint NSPs consist of macromolecular polymers of monosaccharides joined by a specific type of linkage called a glycosidic bond. They can be large or small, branched or linear and comprised of one or more types of monomeric sugars. Physiologically, dietary fiber is the edible parts of plants or analogous carbohydrates (including polysaccharides, oligosaccharides, lignin, and associated plant substances) that are resistant to digestion and absorption in the small intestine with complete or partial fermentation in the large intestine (AACC, 2001). The oldest method to measure fiber was

developed more than 150 years ago and is referred to as 'crude fiber'. The crude fiber (CF) method (Henneberg and Stohmann, 1859) provided an estimation of lignin and cellulose content to nutritionists by solubilizing the sample in strong acid and alkali solutions and weighing the residue. As conditions set on this method are very aggressive the 'fiber' content is underestimated, and it also does not serve as a way to identify the fiber functionality. It is worth noting that CF is still used to characterize and label feeds and feed ingredients. Fast forward 104 years, acid detergent lignin (ADL), acid detergent fiber (ADF) and neutral detergent fiber (NDF) methods were developed (Van Soest *et al.*, 1963). These gravimetric methods consist of graded solubilization of the sample in a series of neutral/acid solutions, then drying and weighing the sample and, lately, discounting ash content. This method effectively measures what is insoluble in every step of the method. At its conception the researchers referred to ADL as being capable of estimating the lignin content, ADF of estimating most cellulose and lignin, while NDF accounted for hemicellulose, cellulose and lignin. The Van Soest method, also referred to as the 'detergent fiber method', is commonly used in ruminant and pig nutrition, though it is not widely employed in poultry nutrition.

Recent advances in methods for measuring fiber can now provide information on the monomeric composition of fiber. There are two main methods used for NSP determination (Englyst *et al.*, 1994; Bach Knudsen, 1997), and both methods use cellulose resistance to acid hydrolysis thereby enabling separation of cellulose from non-cellulosic polysaccharides (NCP: hemicellulose + pectin). NSPs are often referred to as soluble or insoluble, and the degree of solubility is directly proportional to the degree of branching on the NSP molecule (Annison, 1993). NSPs are composed of hemicellulose, cellulose and pectin. While cellulose is derived exclusively from glucose, hemicellulose is composed of diverse sugars such as xylose, arabinose, glucose, mannose, galactose and rhamnose. Arabinoxylans (AX) in cereals have a xylan backbone with varying degrees of substitution with arabinose (measured as xylose + arabinose) while in leguminous ingredients, such as soy or canola, these sugars will primarily be associated with glucans forming xyloglucans. The enzymatic hydrolysis of AXs yields arabino-xylo-oligosaccharides (AXOS). The ratio of arabinose to xylose is used to determine the degree of substitution of AX in cereals. An increase in substitutions on the AX composition of plant tissues are associated with a maturation and lignification. From the A:X ratios, it is also apparent there are big variations in the structural features of AX molecules caused by the type of grains and the

relative proportions of the different tissues. For example, in barley or oats, the AX from hulls are mostly non-substituted (which means a lower A:X ratio), while the endosperm would present more substituted AX (or higher A:X ratio) (Bach Knudsen, 2014). In effect, understanding better the constituents of NSPs can benefit in the long run to improve performance and/or health of animals. Many years ago, we focused on the crude protein level of the diet, today we formulate for specific individual amino acids and ratio for optimal performance. The ability to measure the different sugar components and their solubility is a big step forward in our knowledge of fiber in feed ingredients being fed to animals. Being able to evaluate the soluble and insoluble fractions may help us to understand or predict their physiological effects within the animal and optimize their use in feed formulation. While we are still discovering the benefits of fiber, the wet chemistry methods for hydrolyzing fiber into their monomeric components are laborious, time consuming and expensive. Hence most nutritionists continue to look at crude fiber, NDF or ADF. In the last few years, however, AB Vista has developed NIR (Near Infra-Red) calibrations for the rapid determination of NSPs within cereals and protein feed ingredients. Tables 1 & 2 summarizes the results obtained from analyzing samples employing the Englyst method.

Soluble and Insoluble Fiber

Bautil *et al.* (2019) recently divided fiber into three categories based on their physicochemical properties: oligomers, polymers and larger polymer networks (Figure 1). These three categories are essentially dividing fiber based on their degree of polymerization (dP). Oligomers or oligosaccharides are short chains of simple sugars and are considered very soluble and highly fermentable. Polymers are also soluble and provide an intermediate potential for fermentation. Larger polymer networks are longer, more complex chains, and are usually fermented more slowly, and in some instances, only to a limited extent. It's important to note, however, that solubility and fermentability are not always correlated (Figure 2). Historically, insoluble fiber in poultry was primarily considered a diluent of nutrients (Edwards *et al.*, 1995). However, the use of moderate levels of insoluble fiber has shown to improve gizzard development (Bournazel *et al.*, 2018) and gut function (Hetland and Svihus, 2001; Mateos *et al.*, 2012) resulting in beneficial effects in terms of nutrient digestibility, intestinal integrity, gut health and animal welfare. In pigs increasing the insoluble NSP content in a diet generally increases digesta passage rate in the gastrointestinal tract (GIT), reducing the time of exposure of the diet to endogenous

enzymes and hence reducing nutrient digestibility and increasing endogenous losses of amino acids (Bindelle *et al.*, 2009). However, including low amounts (2-4%) of insoluble NSP (i.e. oat bran or wheat bran)

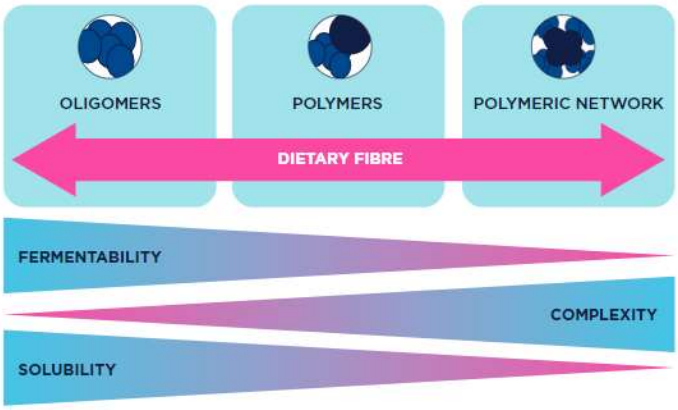

Figure 1. Schematic representation of dietary fiber constituents and digestion. (Adapted from Bautil *et al.*, 2019)

is known to prevent prolonged digesta retention in the GIT therefore reducing the risk of bacterial overgrowth (dysbacteriosis) in the small intestine. Moreover, a small amount of insoluble fiber has been reported to increase feed intake of animals as digesta passage increases. A level of insoluble NSP that causes digesta passage rate to be too fast will reduce nutrient digestibility in the small intestine, while a level of insoluble NSP that is not compromising nutrient digestibility but increasing feed intake will improve performance of animals (Molist *et al.*, 2010). So clearly there is an optimum level of a certain type of fiber.

Today, there is not yet a recommendation regarding an optimal range or even the best criteria to look at, but with the experience we are accumulating regarding the functionality of the different NSPs components we should be able to help in determining the most relevant criteria in order to properly use fiber and optimize it in feed formulations to improve bird performance. Recently, Gomes *et al.* (2021) have shown that broiler performance was improved with diets containing more soluble AX, however, the impact of the soluble AX for optimal performance was dependent on the age of the bird.

Fiber as a Tool to a Healthy Microbiome

Beyond the effect on viscosity, the soluble part of the NSP also represents a source of energy as this is the substrate that will be more easily fermented by the bacteria in the hindgut of poultry and pigs under anaerobic conditions (Figure 1). Therefore, determining fiber content and characteristics like solubility and even the degree of polymerization, may help us to reduce the anti-nutritional effects that some of these components have, as well as to provide an appropriate substrate for the beneficial bacteria to ferment. Solubility and fermentability however are not always correlated and not all soluble NSPs are viscous. In general, solubility affects fermentability and the more soluble a fiber is, the more rapid it can be fermented, which is the case with smaller oligosaccharides. Due to the desire to break down long chain soluble fibers to reduce viscosity and create more soluble fiber for bacterial fermentation, the use of NSP degrading enzymes has become common practice in monogastric production. Xylanase is one of the main NSP degrading enzymes used for AX degradation (Aftab and Bedford, 2018). Although xylanase products may differ in their ability to break down AX, this was the primary reason NSP enzymes were initially used, as this led to lower viscosity. Therefore, attention should be paid to all those fiber components that arrive in the hindgut as this is the substrate for the hindgut microbiome to ferment. Depending on the substrate, bacterial fermentation may produce different volatile fatty acids (VFA). Butyrate is one of the most studied VFA and its benefits especially on the integrity of the upper gut is well described in the literature. Propionic acid (or total VFAs in general) regulates the production of secretory IgA in the lamina propria and the production of IgG in the systemic tissues such as the spleen (Kim *et al.*, 2018). Therefore, increased VFA production from shifting the commensal microbiota to a more fiber fermenting community will strengthen the mucosal barrier and systemic immunity of monogastric animals. It's also important to note that beyond the fiber source, age of the animal is a pivotal factor (Bautil *et al.*, 2019). There is in fact, a close relationship between fiber, the microbiome and the age of the animal. Developing a highly active fiber-fermenting microbiome as early as possible to degrade fiber more efficiently is a useful tool to maximize animal performance and reduce the risk of invasion of opportunistic pathogens. The fibrolytic microbiome will ferment fiber thereby producing VFA's (which lowers hindgut pH) that not only provide energy to maintain the enterocytes but also modulate the mucosal immunity as well as preventing pathogen attachment by a competitive exclusion mechanism.

Summary

Clearly our understanding of NSP enzymes and fiber has advanced. The term crude fiber has become just that. Researchers are now diving into soluble vs insoluble ratios or the degree of polymerization of fiber and the impact that has on animal performance. With the renewed focus on fiber in the absence of antibiotics and the desire to utilize alternative raw materials for feed cost savings, having the ability to measure the NSP composition of feed ingredients through NIR may bring new insights to explore the benefits that fiber fermentation can exert. Measuring fiber composition or level may correlate with animal performance and/or enteric diseases, thereby helping nutritionists to mitigate the inherent variability on performance usually seen in animal production.

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Table 1 – Non-starch polysaccharide content of cereals (% as fed) (Gomes *et al.*, 2020)

	Xylose	Arabinose	Glucose	Galactose	Mannose	Total
	Wheat (n=408)					
Insoluble	2.94	1.90	2.34	0.19	0.16	7.28
Soluble	0.64	0.42	0.29	0.15	0.12	1.59
	Corn (n=345)					
Insoluble	2.11	1.51	1.78	0.41	0.08	5.91
Soluble	0.12	0.12	0.24	0.10	0.06	0.68
	Barley (n=128)					
Insoluble	4.55	2.17	3.84	0.27	0.24	10.39
Soluble	0.34	0.29	3.26	0.13	0.07	3.92
	Sorghum (n=117)					
Insoluble	1.07	1.16	2.09	0.21	0.09	4.49
Soluble	0.06	0.07	0.20	0.07	0.07	0.51
	Rice (n=31)					
Insoluble	0.92	1.57	1.80	0.21	0.12	6.49
Soluble	0.08	0.09	0.12	0.21	0.08	0.57
	Oats (n=25)					
Insoluble	10.10	1.98	8.88	0.44	0.17	19.34
Soluble	0.14	0.16	2.96	0.13	0.05	3.14
	Millet (n=22)					
Insoluble	1.65	1.24	1.77	0.29	0.07	5.01
Soluble	0.08	0.05	0.39	0.08	0.17	0.77
	Triticale (n=18)					
Insoluble	4.56	3.67	3.24	0.38	0.34	10.87
Soluble	0.58	0.44	0.26	0.15	0.08	1.35

Table 2 – Non-starch polysaccharide content of protein and fibrous ingredients (% as fed) (Gomes *et al.*, 2020)

	Xylose	Arabinose	Glucose	Galactose	Mannose	Total
	Soybean Meal (n=181)					
Insoluble	1.26	1.81	4.41	2.94	0.54	12.32
Soluble	0.22	0.63	0.34	1.17	0.45	3.95
	Full Fat Soy (n=96)					
Insoluble	1.17	1.64	3.79	2.56	0.45	10.98
Soluble	0.17	0.52	0.22	0.88	0.33	3.07
	DDGS (n=76)					
Insoluble	7.11	5.02	7.51	1.11	1.07	21.93
Soluble	0.40	0.38	0.44	0.23	0.58	2.19
	Canola Meal (n=30)					
Insoluble	1.52	3.35	6.33	1.26	0.37	15.55
Soluble	0.28	1.09	0.43	0.55	0.28	3.95
	Sunflower Meal (n=23)					
Insoluble	5.03	2.50	10.32	0.71	1.13	20.75
Soluble	0.17	0.80	0.44	0.45	0.34	4.28
	Wheat Bran (n=20)					
Insoluble	9.54	6.00	7.22	0.58	0.18	23.62
Soluble	1.07	0.60	0.61	0.20	0.19	2.83
	Corn Gluten Meal, 60% CP (n=22)					
Insoluble	0.44	0.38	0.76	0.22	0.21	2.03
Soluble	0.33	0.23	0.53	0.14	0.14	1.41
	Corn Gluten Feed, 21% CP (n=18)					
Insoluble	3.82	2.74	4.01	0.74	0.35	11.92
Soluble	0.21	0.18	0.18	0.06	0.12	0.86
	Rice Bran (n=10)					
Insoluble	4.26	3.36	6.54	0.91	0.20	15.35
Soluble	0.13	0.26	0.46	0.22	0.18	1.51