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Fibre - Chemistry and Functions in Poultry Nutrition

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The word "fibre" used in the animal nutrition context is broad, confusing and chemically ill-defined. It is broad because fibre has traditionally been referred to as the organic residue remaining after a series of acid, alkaline and/or detergent extractions. It is confusing because various terms are used to describe fibre, such as Crude Fibre, Acid Detergent Fibre, Neutral Detergent Fibre and Dietary Fibre. These terms refer to a proportion of the same chemical entities or all of some entities but none of the other entities. They also do not correspond or relate to each other in a meaningful manner. It is chemically ill-defined because of the way in which all these fibres, except Dietary Fibre, are obtained, and relies on solvent extractions that do not distinguish specific chemical entities. As animal nutrition is becoming more about producing "more from less" sustainably, every nutrient that takes up the nutrient matrix in feed has to be scrutinised. In recent years, a great deal of interest has emerged in knowing what fibre does in poultry feed. To achieve this, the chemical entities that make up fibre need to be elucidated, and their physical and functional properties properly understood. This paper discusses the terms used to describe fibre, their chemical and physical characteristics, and their functions in relation to poultry nutrition.

Keywords: fibre; NSP; nutrition; feed formulation

Introduction

A typical feed for broiler chickens, for instance, contains 65% cereal grains, *i.e.*, corn or wheat, 25% soybean meal and some other minor ingredients which make up the rest. The crude fibre content of such a diet is around 2.5-3% but when all the nutrients listed in the matrix are added up, including the minor ingredients, they usually account for less than 90%. The missing 10% represent the rest of the total fibre that is not captured in the crude fibre determination. To account for the true fibre content of feed ingredients, a system for "detergent fibres" was instigated (van Soest 1963). This system includes two fractions, the neutral detergent fibre and the acid detergent fibre. This was devised in order to separate the more fermentable "hemicellulose" from the less digestible cellulose and lignin and was a much improved measurement of fibre compared with crude fibre. However, commercial feed formulators have largely ignored it, despite much research and refinement.

From the late 1970s onwards, fibre started to attract increased attention in human nutrition research due to the benefits of high dietary fibre food on bowel health with the added advantage of calorie reduction (Trowell *et al.* 1976; Stephens and Cummings 1980). This led to new definitions of fibre, that is "dietary fiber is the edible parts of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. Dietary fiber includes polysaccharides, oligosaccharides, lignin, and associated plant substances. Dietary fibers promote beneficial physiological effects including laxation, and/or blood cholesterol attenuation, and/or blood glucose attenuation" (AACC 2000). There remains much controversy over this definition. But this review will not discuss definitions of dietary fibre; rather the current review will cover the development of methodology to measure dietary fibre, the momentum to characterise the physicochemical properties of the individual components of dietary fibre, and the assignment of dietary fibre values to food items in the context of poultry nutrition.

Fibre and its chemistry

The term "fibre" has been used broadly to describe non-starch polysaccharides (NSP) and lignin, the latter being a polyphenolic compound. However, there are a number of key issues that poultry nutritionists encounter when it comes to fibre. First, there are many fibre terms that are difficult to differentiate. The following are the commonly used terms and their key chemical components and relationship to each other:

Crude Fibre

The Proximate Analysis System devised by the Weende Station in Germany (Henneberg and Stohmann 1859, 1860) classified feed carbohydrates into a more digestible component, called "nitrogen free extract (NFE)" and a less digestible fibrous component, called Crude Fibre. The advantage of the system was that the separation of feed components (NFE, CF, moisture, ash, ether extract, *i.e.*, crude fat, and crude protein) was based on detailed analytical procedures. Such an approach created a system that has stood the test of time despite the massive advances in analytical science and nutritional understanding which have occurred since it was first introduced some 150 years ago.

So what is crude fibre? It refers to the organic remnant of feedstuffs that was insoluble in hot, dilute sulphuric acid and sodium hydroxide. It represents variable portions of the insoluble NSP, including cellulose and some "hemicellulose". This variation in the CF value depends very much on the ingredient and the physicochemical nature of the NSP present in it. Firstly, none of the soluble NSP is accounted for. For instance, much of pectic polysaccharides, mixed linked ß-glucans, and arabinoxylans is not measured at all. In addition, it is highly likely that some of the amorphous, *i.e.*, less crystalline, less lignified cellulose may also be missed by the crude fibre measurement as it relies on extraction with hot acid and alkali over an extended period of time. Nevertheless, the poultry industry still uses crude fibre in feed formulation. Since almost all pectic polysaccharides are not measured in crude fibre, vegetable protein sources that are rich in these polymers, such as soybean meal, have a large proportion of their true fibre unaccounted for. As a result, approximately 25% of soybean meal is nowhere to be seen in most nutrient databases, which are used to formulate millions of tonnes of feed.

Detergent Fibres

Van Soest (1963) recognised that the crude fibre values were not representative of the true fibre levels of feedstuffs. There are two types of fibre: one is known as Neutral Detergent Fibre (NDF) and other as Acid Detergent Fibre (ADF). There is a degree of agreement between NDF values and total NSP levels for non-leguminous raw materials. However when it comes to legumes and oilseeds that are rich in pectic polysaccharides, the NDF value becomes unreliable because it fails to account for most, if not all, soluble NSP present in feed. This means that many of the pectic polymers, such as galacturonans, rhamnogalacturonansm, arabinans and arabinogalactions, will be unaccounted for. In soybean meal, for instance, up to 35% carbohydrates are present, of which, approximately 14% are low-molecular weight soluble sugars, and 21% are NSP. Of the NSP, between 5-7% are soluble (Choct *et al.* 2010). NDF values of soybean meal range from 7.4-12.2% on dry matter basis or 6.5-10.7% on as is basis (van Eys *et al.* 2004). This suggests that some 24-29% of the carbohydrates present in soybean meal are not captured by the NDF process. It is therefore difficult to see a great deal of relevance of the NDF value to monogastric animal nutrition.

From a chemistry point of view, the NDF and ADF values do not represent any specific entities. In a proximate term, the two fibre values overlap because NDF refers to the insoluble portion of the NSP plus lignin, and ADF refers to a portion of insoluble NSP comprised largely, but not exclusively, of cellulose and lignin. Therefore, the following approximation is commonly used to derive the value for hemicellulose:

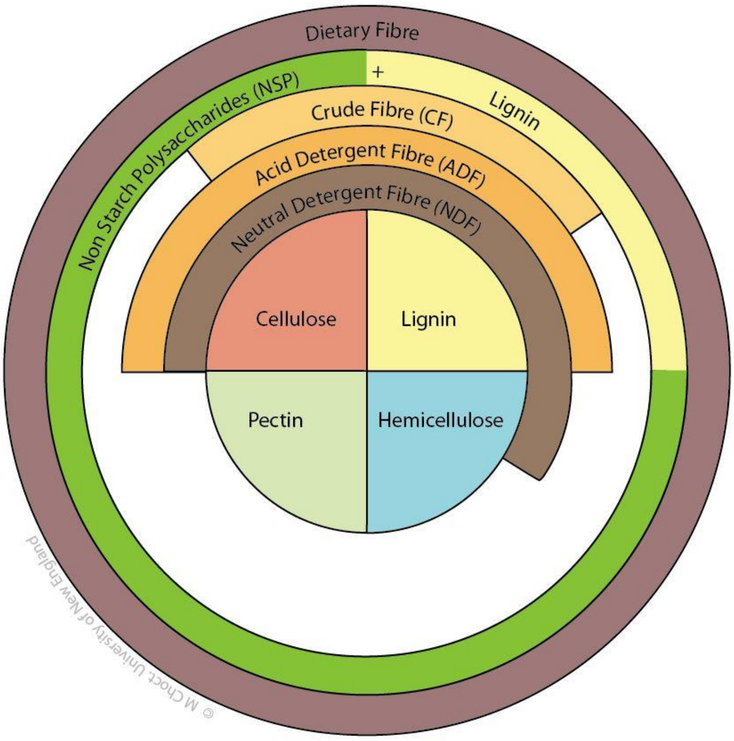
NDF – ADF = Hemicellulose

The term hemicellulose is an inaccurate definition that arose from a misunderstanding that the components in plant cell walls solubilised by alkali were precursors to cellulose (Schulze 1891), which is now known to be incorrect. In fact, the so-called hemicellulose covers arabinoxylans, mixed linked ß-glucans, xyloglucans, mannans, galactomannans, galactans, arabinans and any other neutral polysaccharides other than cellulose. But the term is still used by industry and academia as if it was a single chemical entity.

Dietary fibre

As mentioned earlier, dietary fibre (DF) is a term used in human nutrition. The definition of DF provokes a great deal of controversy because there have been numerous, at times confusing, definitions over the years, including definitions based on the physiological effects of DF and those based on methods of determination. Of direct relevance to poultry nutrition is the simple understanding that DF is the sum of NSP and lignin. There are two well established methods for measuring DF. One is the series of enzymatic-gravimetric methods provided by the Association of Official Analytical Chemists (AOAC) Total Dietary Analysis (Methods 985.20; 993.19; 991.42; 991.43; 992.16), which uses enzymatic removal of non-cell wall organic materials and then gravimetrically measures the residue corrected for ash. The other technique is known as the Uppsala Method. This method quantifies each individual sugar residues by converting them into alditol acetates and measuring them using a gas chromatograph (Theander *et al.* 1995). Lignin and uronic acids are determined separately in the Uppsala Method. There are a number of advantages in using the Uppsala Method, including the separation of the individual sugar composition of dietary fibre that gives an idea of the type of polysaccharides present in an ingredient, and the ability of fractionating NSP based on their solubility in water (the other method also offers this option).

The relationship between various fibres is summarised below:



Physical properties and their nutritional significance

There are thousands of polysaccharides in nature. The reason is that slight modifications of the repeating unit in a polysaccharide can produce quite different polymers with contrasting characteristics. In regard to poultry nutrition, solubility and viscosity are two important properties for individual moieties, but structural architectures and the interrelationships of NSP with other cell wall components cannot be ignored (Svihus 2011).

Solubility

Solubility in water, albeit not always true, is the proxy to solubility in the gastrointestinal tract and therefore it is an extremely important property of fibre. Solubility of NSP, in turn, depends on their chemical structures and association with the rest of the cell wall components. Soluble and insoluble NSP have different nutritional impacts in poultry diets (Mateos *et al.* 2012). However, it must be borne in mind that solubility *per se* is not the key determinant of the nutritional characteristics of NSP for poultry. For example, low-molecular weight carbohydrates, such as oligosaccharides and fructans, are highly soluble in water and are well-fermented by poultry (Carré *et al.* 1995). Many such carbohydrates are also used as prebiotics. Whereas, soluble arabinoxylans and mixed linked beta-glucans form highly viscous solutions which have negative consequences on nutrient digestion and utilisation (Choct and Annison 1992). This demonstrates the importance of separating viscosity-forming NSP from non-viscous, low-molecular weight carbohydrates.

Viscosity

Viscosity is not specific to the sugar composition or linkage types present in the NSP. The physical effect of viscosity on nutrient digestion and absorption is similar regardless of the NSP sources. Generally, high gut viscosity decreases the rate of diffusion of substrates and digestive enzymes and hinders their effective interaction at the mucosal surface (Edwards *et al.* 1988; Ikegami *et al.* 1990). Soluble NSP interact with the glycocalyx of the intestinal brush border and thicken the rate-limiting unstirred water layer of the mucosa, which reduces the efficiency of nutrient absorption through the intestinal wall (Johnson and Gee 1981). As physiological and microbial changes occur, the efficiency of nutrition digestion, transport and absorption are altered. For example, since viscosity slows down digesta transit rate and reduces nutrient digestibility, more undigested nutrients remain in the gut for a longer period of time, more mucous is secreted due to stimulation of the mucosa by microbes (Chee *et al.* 2010), and more fermentation occurs in the gut due to a change in oxygen tension in the small intestine (Choct *et al.* 1996).

Structural architecture

Insoluble NSP make up the bulk of the total fibre in diets, but they have little or no effect on nutrient utilisation in monogastric animals (Begin 1961). The insoluble NSP, however, are not inert and their roles in monogastric nutrition cannot be neglected. One of the most important attributes of insoluble NSP is their ability to absorb large amounts of water and maintain normal motility of the gut (Stephen and Cummings 1979). This is essential for the consistency of the excreta in monogastric animals. Elevated levels of insoluble fibre in the diet shorten the residence time of digesta (Kirwan *et al.* 1974) and some argue that this may result in low nutrient digestibility. The rationale is that the longer the feed is exposed to the digestive processes in the gut, the more complete its digestion. This has proven incorrect as addition of insoluble fibre sources to low energy wheat increased its metabolisable energy value for poultry (Rogel 1985). In recent years, there has been increasing evidence to suggest that the addition of coarse, structural materials consisting largely of insoluble fibre to poultry diets enhances gut development, and in some cases, nutrient digestibility.
However, research in this area often emphasises the importance of "structural components" of diet, not just any individual chemical entities that make up insoluble NSP (Choct 2006; Hetland *et al.* 2007; Mateos *et al.* 2012). Indeed fibre does not exist in isolation as it is cross-linked with various components of the cell wall. For instance, lignification of cellulose (Barcelo 1997) and methylation of other NSP (McFeeters and Armstrong 1984) are important for the structural integrity of the cell, and hence the vascular body of the plant. In relation to animal nutrition, it is often the case that the whole ingredient is included in feed, rather than specific nutrients contained in it. Thus, when it comes to assessing the effects of fibre on gut health in poultry, it is essential to consider it in the context of the physical architecture of the cell wall. Indeed, beside cross-linkages, the physical structure of fibre is influenced by many factors including the degree of crystallinity of individual polymers such as cellulose, the chain length and 3-D arrangement of NSP, plant origin and processing. Processing such as heat treatment, grinding (particle size) and chemical extraction can drastically change the physical structure of fibre. For example, finely grinding oat hulls renders them ineffective in enhancing nutrient digestion and gut health (Rogel 1985; Svihus 2011).

Fibre in feed formulation

In the poultry industry, feed accounts for more than 60% of live production in most countries and regions around the world. To increase productivity and reduce production cost, it is essential that every nutrient in the matrix space in feed formulation be carefully considered and understood. In the current practice, fibre is not understood nor is it properly accounted for because crude fibre is still used. In the future, new nutrient matrices must be developed to account for all carbohydrates in the ingredients, including amounts and types of oligosaccharides and NSP (soluble, insoluble and total NSP). Such an approach will lead to a more targeted use of nutriceuticals such as NSP-degrading enzymes, fibre additives and other gut enhancers.

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