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Book of Proceedings of the 2025 Animal Nutrition Conference of Canada

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Keeping track of fibres:
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Garder les fibres à l'œil : comment les fibres influencent le transit gastro-intestinal et la digestion chez les poulets

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Abstract

By altering the gastrointestinal environment, digesta passage behaviour, and the site of nutrient digestion, physicochemical properties of fibrous ingredients, such as particle size or gelling behaviour, are likely to influence the absorption kinetics of nutrients and their metabolic use. Results of recent studies on the regulation of digesta passage behaviour and nutrient digestion by dietary fibres in chickens will be presented and discussed. Through their presumed effects on gizzard grinding activity, insoluble dietary fibres at moderate inclusion levels typically improve the digestibility of proteins and, to a lesser extent, starch and fat, whereas soluble fibres hamper nutrient digestibility already at inclusion levels beyond 20 g/kg DM. Beyond their impact on gizzard functioning and ileal digestibility, fibres – particularly soluble fibres – may impact caecal filling and retention time. When studying digesta passage behaviour in chickens, selective retention of various fractions throughout the gastrointestinal tract should be anticipated. In the proximal gastrointestinal tract, coarse fibre particles may be retained longer in the crop or proventriculus and gizzard compared with fine particles and liquids. In the distal gastrointestinal tract, reverse peristalsis and selective entrance of liquids and fine particles into the caeca elicit considerably longer total tract retention times for these fractions (~14-31h) than typically observed for solid digesta (~3-8h). However, our provisional estimates indicate that only ~30% of the liquid digesta enters the ceca. These insights enhance understanding of the digestion process and thereby aid in optimizing feeding strategies, particularly when feeding ingredients with more diverse properties, to support gastrointestinal function and health.

Keywords: non-starch polysaccharides, broilers, laying hens, particle size

Résumé

En modifiant le milieu gastro-intestinal, le transit du digesta et le site de digestion des nutriments, les propriétés physico-chimiques des ingrédients fibreux, telles que la taille des particules ou leur comportement de gélification, sont susceptibles d'influencer la cinétique d'absorption des nutriments et leur utilisation métabolique. Les résultats d'études récentes sur la régulation du transit gastro-intestinal et de la digestion des nutriments par les fibres alimentaires chez les poulets seront présentés et discutés. Les fibres alimentaires insolubles, en raison de leurs effets présumés sur l'activité de broyage du gésier, améliorent généralement la digestibilité des protéines lorsqu'elles sont présentes en concentration modérée. Dans une moindre mesure, ces fibres favorisent également la digestion de l'amidon et des graisses. En revanche, les fibres solubles réduisent la digestibilité des nutriments dès qu'elles dépassent une concentration de 20 g/kg de MS. Au-delà de leur impact sur le fonctionnement du gésier et la digestibilité iléale, les fibres - en particulier les fibres solubles - peuvent intervenir sur le remplissage du cæcum et le temps de rétention des aliments. Dans le cadre de l'analyse du transit gastro-intestinal chez les poulets, il faut s'attendre à une rétention sélective des différentes fractions le long du tube digestif. Dans la partie proximale du tube digestif, les particules de fibre grossières peuvent être retenues plus longtemps dans le jabot ou le proventricule et le gésier que les particules fines et les liquides. Dans la portion distale, le péristaltisme inverse et l'entrée sélective des liquides et des particules fines dans le cæcum entraînent des temps de rétention totale considérablement plus longs pour ces fractions (~14 à 31h) que ce qui est généralement observé pour le digesta solide (~3 à 8h). Cependant, nos estimations provisoires indiquent que seulement 30 % du digesta liquide pénètre dans le cæcum. Ces connaissances permettent de mieux comprendre le processus de digestion et donc d'optimiser les stratégies d'alimentation, en particulier lorsqu'il s'agit d'ingrédients aux propriétés plus diverses, afin de favoriser la fonction et la santé gastro-intestinales.

Introduction

By altering the gastrointestinal environment, digesta passage behaviour, and the site of nutrient digestion, physicochemical properties of fibres are likely to influence the absorption kinetics of nutrients and their subsequent metabolic use. In chickens, the role of fibres, particularly insoluble fibres, on gizzard development and function has been extensively studied (reviewed by Hetland, et al., 2004; Svihus, 2011) but the influence of specific fibre physicochemical properties - such as particle size and -stiffness, gelling- and hydration properties, and fermentability - remains insufficiently understood. Moreover, fibres may impact nutrient (re)absorption beyond the small intestine by influencing the composition- and flow behaviour of digesta in the hindgut, yet these processes are considerably less studied and remain poorly understood. Advancing our understanding of these mechanisms is crucial to effectively integrate fibre aspects into feed formulation strategies.

Fibres as modulator of nutrient digestion and absorption kinetics?

Despite the limited degradation of fibres in chickens (reviewed by de Vries, et al., 2012; Lannuzel, et al., 2022), the effects of fibres on the digestion of other nutrients may be considerable. Well-known are the detrimental effects of various (soluble) fibre sources on the (apparent) digestion of protein, starch, and fat in the upper gastrointestinal (a.o. Choct and Annison, 1992; Smits and Annison, 1996; Smits, et al., 1997) by amongst others influencing digesta passage behaviour, accessibility of nutrients by enzymes and solute diffusion, microbial colonization, bile salt functionality, and endogenous losses (Grala, et al., 1998; Smits, et al., 1998; Lentle and Janssen, 2010). These adverse effects are mainly ascribed to the gelling properties of specific polysaccharides, such as soluble β-glucans and arabinoxylans commonly found in cereal grains, that modulate the digestive environment for example by increasing digesta viscosity. To limit these effects, fibre-degrading enzymes (such as β-glucanases and xylanases) are commonly added to poultry diets. Nevertheless, potential beneficial effects of fibres on intestinal health but also nutrient digestion, are increasingly addressed, and fibre-rich ingredients are nowadays considered as functional nutrients with the capacity to modulate the physical characteristics of the feed and the digesta, also in a positive manner (Mateos, et al., 2012; Kheravii, et al., 2018; Jha and Mishra, 2021; Lannuzel, et al., 2022). Through their presumed effects on development of the muscular gizzard, gizzard grinding activity, and secretion of pepsin and pancreatic enzymes, insoluble dietary fibres - at moderate inclusion levels - typically improve the digestibility of proteins and, to a lesser extent, starch and fat (reviewed by Vivares, et al., 2025, Figure 1). Inclusion of insoluble fibre sources, coarse particles, or inclusion of whole cereal grains, are, therefore, commonly used strategies to improve gastrointestinal functioning and nutrient use (Hetland, et al., 2002; Svihus, 2011; Akbari Moghaddam Kakhki, et al., 2024).

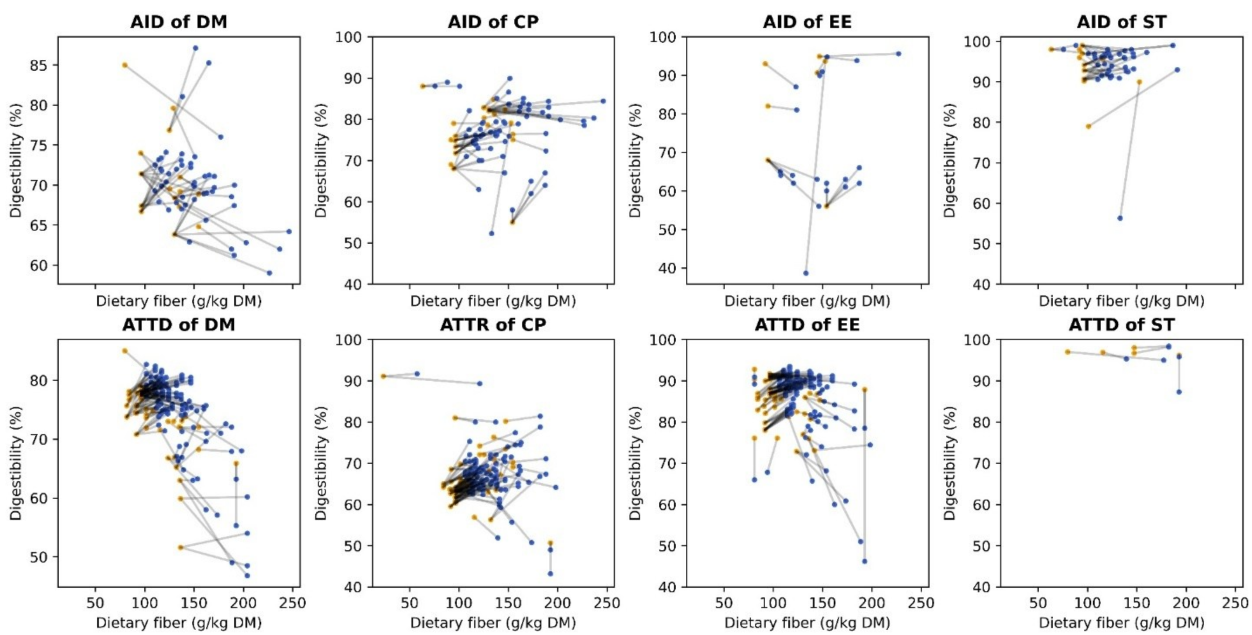

Figure 1. Relations between dietary fiber (DF) concentration (g/kg DM) and nutrient digestibility (%), as obtained from meta-analysis of a total of 45 studies and 198 experimental treatments. Orange dots indicate control diets and blue dots indicate treatment diets where DF was included, control and treatment diets within studies are connected by solid grey lines. Abbreviations: AID, apparent ileal digestibility; ATTD, apparent total tract digestibility; DM, dry matter; CP, crude protein; EE, ether extract; St, starch. Data from: Vivares et al., (2025).

Both soluble and insoluble dietary fibres have the ability to modulate the digestive environment, by affecting morphology and functionality of the stomach-complex and intestines, physicochemical properties of the digesta, and the gastrointestinal microbiome. Understanding the effects of fibres on digesta properties and digesta flow behaviour allows for better understanding of the final consequences for nutrient absorption as well as animal performance and gut health. For example, the selective retention of coarse particles and more rapid emptying of liquid digesta in the upper gastrointestinal tract unequivocally affects the timing of nutrients entering the small intestine, where nutrients that flow predominantly with the liquid phase, e.g. a large part of the dietary proteins (de Vries, et al., 2023), arrive earlier in the small intestine than those flowing with the solid phase. Such phenomena are often neglected when total extent of nutrient absorption is considered but are relevant to predict nutrient absorption kinetics and subsequent metabolic fate of nutrients after absorption (Schop, et al., 2023). By shaping the digestive environment and modifying digesta flow, nutrient hydrolysis and -absorption, fibres are important regulators of nutrient absorption kinetics, and accounting for this variation is crucial to accurately predict the nutritional value of feed ingredients, particularly when increasingly relying on fibre-rich feed ingredients in diets fed to chickens.

Modulation of digesta flow behaviour depending on fibre physicochemical properties

Predicting modulation of digesta properties and -flow by the diverse mix of fibres present in feed ingredients is, however, not straightforward. After all, digesta is a composite of particulate matter - with particles varying in e.g. size, shape, and buoyancy - suspended in liquids, where fibres contribute to the heterogeneity of the solid phase and the viscosity of the liquid phase. It follows that a one-dimensional parameter as water-solubility will not fully capture the diverse nature of effects observed. For commonly used feed ingredients, however separating between insoluble dietary fibres (iDF) and soluble dietary fibres (sDF), allows to distinguish between (1) those ingredients that predominantly provide structure/bulk and are not, or only limitedly, fermented and (2) those that exert strong gelling properties and thus increase digesta viscosity, and serve as substrate for the microbiome. Coarse insoluble fibre sources clearly increase gizzard weight (González-Alvarado, et al., 2010; Jiménez-Moreno, et al., 2010; Jiménez-Moreno, et al., 2019) – considered a proxy for its muscularity – and may prolong retention of solid and liquid digesta in the foregut (Mens, et al., 2022), whereas viscous soluble fibres reduced gizzard weight and prolonged retention time of solid and liquid digesta throughout the gastrointestinal tract (van der Klis and van Voorst, 1993; Dorado-Montenegro, et al., 2024). That a sole distinguishment between iDF and sDF is not sufficient for all situations is illustrated by the lack of effect of purified cellulose - a fine DF source - on gizzard weight (Jiménez-Moreno, et al., 2010) and the source-dependent effects of iDF on proventriculus + gizzard weight, total tract digesta retention time, and nutrient digestibility (Akbari Moghaddam Kakhki, et al., 2024). These observations highlight that it is the combination between chemical and physical properties of fibres, such as hydration properties (including solubility and swelling), particle size and -shape distributions, gelling properties and stiffness of particles – originating from the polymers constituting the fibre fraction and their crosslinks within the plant cell wall - that finally determine the multifaceted effects of fibres in the animal.

An often understated aspect is the selective entrance of liquids and fine particles into the ceca, whereas the ceca are largely bypassed by coarse particles (Vergara, et al., 1989; de Vries, et al., 2014; Vanderghinste, et al., 2025). After passing the ileocecal junction, digesta passes through the colon to the cloaca, where coarse particles are assumed to be directly voided, resulting in typical total tract mean retention times of ~3-8 h when estimated based on tracers for solid digesta (reviewed by Svihus and Itani, 2019). Reflux from the cloaca through the colon selectively delivers fluids, including urine, and small particles to the ceca. In this way, solubilized materials and fine particles can enter the ceca and be subjected to fermentation by the microbiota residing in the ceca. Estimated mean retention times in the ceca for liquid digesta range from 500-1500 min, implying that total tract mean retention times of digesta that enter the ceca may reach ~14-31 h (Garçon, et al., 2023). However, our provisional estimates indicate that only ~30% of the liquid digesta fraction entered the ceca (Garçon, et al., 2023). Following the rapid excretion of coarse solid digesta, iDF sources may be expected to have typically little impact on digesta retention in the hindgut. Soluble DF sources may in contrast be to affect digesta flow behaviour beyond the small intestine. For example, sugar beet pulp – having a relatively high sDF content (~ 40% of total non-starch polysaccharides) but also high water binding capacity – increased gizzard weight and tended to accelerate prececal, and - more importantly - cecal retention time of digesta (Garçon, et al., 2023; Akbari Moghaddam Kakhki, et al., 2024; Dorado-Montenegro, et al., 2024). Again highlighting the complexity of predicting the multifarious effect of the heterogenous fibre fractions found in feed ingredients.

Formulating with fibres: quantifying fibre parameters for feed evaluation purposes

It is evident that in order to account for the diverse effects that fibres can have in the animal, one should look beyond crude fibre or neutral detergent fibre characterizations, when formulating diets. Although these commonly used analytical procedures are robust with respect to analytical variation and might correlate well with the fate of specific fibre fractions in the animal (Mertens, 2003), they recover only a part of the fibre fraction, largely neglecting soluble fibres. A recent meta-analysis showed that considering both insoluble and soluble dietary fibres (DF), instead of total DF, allowed to significantly better explain variation in nutrient digestibility found (Vivares, et al., 2025). When added to maize-soybean meal diets with ~100 g/kg DF, moderate levels of insoluble DF (up to 50 g/kg DM) increased nutrient digestibility, particularly protein digestibility, up to 10%-units, whereas soluble DF negatively affected nutrient digestibility already at levels beyond 20 g/kg DM. These insights can be used to further refine feed evaluation models and account for interactions between fibre-rich and other feed ingredients. Potentially, concentrations of digestible nutrients in ingredients that are currently reported in feed databases, can be corrected for the presence of fibres at a diet level, like proposed for ileal digestible protein and amino acid values for pigs (Zhang, et al., 2024), possibly extended by including key-physicochemical properties. Contrary to our findings in pigs, where physicochemical properties of the feed explained variation in gastric emptying but were found to be limitedly related to digesta retention in more distal segments of the gastrointestinal tract (Dorado-Montenegro, et al., 2025), preliminary meta-analyses in chickens indicate that physicochemical properties of the feed modulate digesta passage behaviour throughout the gastrointestinal tract. Using data from 224 laying hens (32 replicate pens) and 456 broiler chickens (52 replicate pens) fed one of 10 diets, we found that among all properties evaluated, water binding capacity (WBC) and extract viscosity of the feed and stiffness of coarse particles were most consistently associated with digesta flow behaviour. Most prominent relations between feed physicochemical properties and digesta mean time (MRT) were found in the small intestine where ~80% of the variation in MRT could be explained by WBC, extract viscosity, particle size and -morphometry, and stiffness of coarse particles (Figure 1). In the hindgut extract viscosity largely explained variation in MRT of liquid digesta, whereas WBC and other particle properties (size, morphometry, and stiffness of coarse particles) explained segregation of solid and liquids digesta phases. Speculatively, these point towards fibre properties that modulate cecal access, not only of liquids, but also of (coarse) particles (van der Klis and van Voorst, 1993)

A point of consideration is the appropriate digestibility proxy to be used to predict the nutritional value of feed ingredients of fibre-rich diets. Apparent digestibility estimates include the aggregate effects of fibres on (1) true digestibility of dietary nutrients and (2) fibre-induced endogenous losses, but do not reveal any insights in the mode of action. In line with above described modes of action, preliminary results from a study with diets varying in soluble fibre sources, revealed that addition of soluble arabinoxylans reduced apparent ileal digestibility of proteins by reducing true digestibility, whereas sugar beet pulp reduced apparent digestibility but increased true digestibility (Habibi, et al., Unpublished-a). Simultaneous, converse effects of fibres on true digestibility versus endogenous losses, may therefore mask potential positive effects of fibres on true digestibility. To accurately account for these multifarious effects of fibres in feed formulation, insights in the specific effects of various fibre sources on different aspects of digestive processes, are crucial. Although convenient from a methodological viewpoint, the use of standardized (SID) values does not turn useful here, as SID only accounts for basal endogenous losses related to the quantity of feed ingested but neglects diet-specific endogenous losses. New methodologies to quantify diet-specific endogenous losses under semi-practical conditions (Noorman, et al., 2024; Habibi, et al., Unpublished-b) may prove useful to map nutrient losses from the digestion process for diets varying in fibre level and composition, and separate between undigested dietary-, endogenous-, and microbial components.

These insights can facilitate progress in refining predictions of nutritional values of feed ingredients and diet formulation particularly when relying increasingly on fibre-rich feed ingredients diets with exerting diverse properties physicochemical properties.

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