Relation of dietary fibre structure and its physical behaviour

KB Development of techniques for analysis of (modified) carbohydrates
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Contents

Preface

To obtain a successful shift towards sustainability one of the KB-themes at Wageningen University and Research is the primary production and processing of biobased raw materials and products. Carbohydrates are a component of biomass and are essential in our daily lives, found in food as well as in materials and chemicals. However, their complexity and variability make it challenging to fully understand and predict their functionality. This project aims to develop improved and advanced characterization technologies to obtain more knowledge of carbohydrate structures and their potential applications. By doing so, we can make better use of (underutilized) biomass, as we gain insights into carbohydrate quantities from diverse biomass sources and their functional potential of these carbohydrates in various applications such as food and biobased products.

1 The role of sugar in food

Sugar is a critical component in shaping the sensory characteristics of food products, primarily due to its ability to impart sweetness, which is a key determinant of palatability. Beyond its sweet taste, sugar modulates other taste qualities through well-documented taste–taste interactions. For instance, sucrose has been shown to suppress bitterness in vegetables, independent of individual sensitivity to bitter compounds, indicating central neural mechanisms of taste suppression [1, 2]. Similarly, sugar reduces perceived sourness by elevating the sourness threshold of organic acids such as citric and lactic acid, a phenomenon attributed to central mixture suppression rather than peripheral interactions [1, 3]. In addition to attenuating undesirable tastes, sugar enhances overall flavour intensity via cross-modal interactions between taste and aroma. Aromas associated with sweetness, such as vanilla and fruit, have been shown to amplify perceived sweetness and flavour richness, even at reduced sugar concentrations [1]. Furthermore, sugar's physicochemical properties facilitate controlled flavour release in emulsified systems, thereby intensifying taste perception [1]. Collectively, these mechanisms underscore sugar's multifaceted role in improving the sensory profile of foods and beverages.

Sugar contributes also significantly to the structural and textural properties of sweet bakery products, serving multiple functional roles throughout processing. Its influence spans the mixing, baking, and cooling stages of biscuit and cake production. During mixing, sugar modulates dough viscosity, thereby affecting air incorporation, which is critical for achieving the desired crumb structure in cakes and biscuits [4, 5]. Owing to its hygroscopic nature, sugar also governs the hydration of biopolymers, influencing the rheological behaviour of the food matrix. During baking, sugar impacts protein denaturation and network formation, which are essential for structural integrity [6]. Furthermore, sugar alters starch gelatinization and pasting behaviour, with its concentration and composition playing a decisive role in these transitions [7, 8]. These effects collectively determine the cellular architecture of baked products, including porosity, cell size distribution, and cell wall thickness, ultimately shaping texture. Post-baking, sugar influences glass transition phenomena, affecting crispness, and modulates starch retrogradation, which governs softness during storage. Additionally, sugar's hygroscopicity enables control of water activity, a critical factor for shelf-life and microbial stability.

Several principles underlying the functional role of sugar in influencing the structure and texture of bakery products are applicable to other food systems, including dairy desserts, cream fillings, ice creams, confectionery products such as candies and jellies, and beverages. In aqueous systems, such as fruit drinks and smoothies, sugar plays a key role in modulating viscosity. Additionally, due to its hygroscopic nature, sugar affects the hydration behaviour of proteins and hydrocolloids within these matrices. Through these mechanisms, sugar contributes to desirable sensory attributes such as mouthfeel and perceived thickness in beverages [9].

2 Arabinoxylan

Arabinoxylan (AX) is a major non-starch polysaccharide present in the cell walls of cereal grains, such as wheat, and in grasses. It belongs to the class of pentosans and constitutes a significant fraction of hemicellulose [10]. Structurally, AX consists of a backbone of β-(1→4)-linked D-xylopyranosyl residues, to which L-arabinofuranosyl units are attached as side chains. These arabinose residues are typically linked to the xylose backbone at the O-2 and/or O-3 positions, forming mono- or di-substituted branches. The structural heterogeneity of AX is largely determined by the arabinose-to-xylose (A/X) ratio, which generally ranges from 0.45 to 0.94, depending on botanical source and extraction conditions [11]. In addition, ferulic acid may be esterified to L-arabinose residues, while glucuronic acid can be linked to D-xylopyranosyl units [12]. In grasses, another additional substitution has been observed, here, L-arabinofuranosyl units can carry an additional 1,2-linked L-arabinofuranose [13].

AX is among the most extensively characterized non-starch polysaccharides, recognized for its significant nutritional and technological roles in cereal-based food systems. Beyond its well-documented health-promoting properties, AX is widely utilized for its functional contributions to food processing [14], primarily governed by its solubility and molecular weight characteristics. AX is typically categorized into water-extractable arabinoxylan (WEAX) and water-unextractable arabinoxylan (WUAX) fractions [15]. WEAX has been shown to enhance gluten viscoelasticity, loaf volume, and crumb structure, whereas WUAX and low-molecular-weight AX fractions tend to disrupt gluten networks, reduce elasticity, and negatively impact bread quality [16]. Overall, the functional behaviour of AX in products such as bread, pasta, cookies, and cakes is strongly influenced by structural attributes, including molecular weight, degree of branching, and solubility [17]. For instance, low-molecular-weight, soluble AX fractions generally improve hydration, texture, and shelf-life, while high-molecular-weight AX can weaken gluten structure, resulting in denser crumb formation [14].

3 Enzymatic degradation of arabinoxylan into arabinoxylan oligosaccharides

AX can be enzymatically hydrolysed by xylanases to produce arabinoxylan-oligosaccharides (AXOS). These enzymes catalyse the cleavage of β-(1,4)-xylosidic linkages between two D-xylopyranosyl residues within the AX backbone. The yield and structural characteristics of AXOS are influenced by both the type of xylanase employed and the structural features of the AX substrate [18-23].
These class of enzymes are categorized in the glycoside hydrolyse (GH) enzyme family. GH enzyme families exhibiting high amino acid sequence homology are classified within the same GH family [24]. Members of a GH family share a common catalytic mechanism, either retaining or inverting the anomeric configuration, yet may differ in substrate specificity and mode of action [25]. For instance, β-1,4-endoxylanases derived from fungi are primarily grouped into GH10 and GH11 families, which exhibit distinct substrate specificities. GH10 in contrast to GH11 endoxylanases possess a broader substrate range compared to GH11 enzymes, making them particularly effective for the complete hydrolysis of highly substituted xylans such as AX [26]. While xylanases can be used to obtain AXOS, for the complete breakdown of these oligosaccharides to their monomeric monosaccharides also other enzymes are needed. For example, *Bifidobacterium adolescentis* has a whole set of enzymes to degrade AXOS to their monomeric units [27-29].

For the application of AXOS, such as their use as sugar replacers in food formulations, a standardized enzymatic hydrolysis process is essential/ required to ensure consistent oligosaccharide composition across production batches. In addition to chemical characterization of AXOS, it is necessary to evaluate key physical properties, including viscosity and hygroscopicity, as these parameters significantly influence their functional performance in food systems. A comprehensive understanding of both the molecular composition and physical characteristics is critical for tailoring arabinoxylan modifications to achieve the desired technological and nutritional functionalities of AXOS in specific food applications.

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The mission of Wageningen University & Research is "To explore the potential of nature to improve the quality of life". Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 7,900 employees (7,100 fte), 2,500 PhD and EngD candidates, 12,700 students and 80,000 participants to WUR's Life Long Learning, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines..