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Study on the effects of wheat bran incorporation on water mobility and biopolymer behavior during bread making and storage using time-domain ^{1}H NMR relaxometry

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ABSTRACT

Water binding is suggested to be key in the deleterious effect of wheat bran on bread quality. This study investigates water mobility and biopolymer behavior during bran-rich bread making and storage, using ^{1}H NMR. Coarse, ground, and pericarp-enriched bran were incorporated in bread dough, and their impact on freshly baked and stored bread properties was assessed. Compared to wheat flour control dough, bran incorporation resulted in a progressive immobilization of water during dough resting, which could be linked to changes in evolution of dough height during fermentation and oven rise. This, together with modified starch gelatinization behavior upon baking, can be related with the inferior quality of bran-rich breads. The impact was most pronounced with pericarp-enriched bran. Textural quality during storage was less affected for coarse or ground bran-rich bread compared to wheat flour bread, which could be principally attributed to retardation of amylopectin retrogradation in the presence of bran.

1. Introduction

Wheat (*Triticum aestivum* L.) is a key ingredient in the Western diet. During roller milling, the starchy endosperm is separated from the outer layers, the bran, and is further ground to refined flour, which forms a basic ingredient for a range of products such as bread (Delcour & Hoseney, 2010). The bran co-product is mostly used in animal feed, but can also be incorporated in cereal-based products. The reason for doing this is mainly health-related: wheat bran is rich in water insoluble dietary fiber and binds considerable amounts of water in the gastro-intestinal tract. This leads to an increased fecal bulk, a reduced intestinal transit time, and a softer stool when consuming bran-rich products (EFSA Panel on Dietetic Products Nutrition and Allergies (NDA), 2010; Stevenson, Phillips, O'Sullivan, & Walton, 2012). Moreover, epidemiological studies suggest an association between the consumption of bran-rich products and a reduced risk of welfare diseases such as cardiovascular diseases (Wu et al., 2015) and colorectal cancer (Jacobs, Marquart, Slavin, & Kushi, 1998). However, addition of bran in bread has several technological and organoleptic implications, such as a decrease in bread volume, an increase in crumb firmness and a more bitter taste (Hemdane, Jacobs, et al., 2016). Although the gluten dilution effect due to partial flour replacement by bran is an important factor to explain the modifications in bread volume and crumb textural quality loss, one or more intrinsic bran properties seem to play a major role in bread loaf volume as well. Indeed, when bran fractions with different (bio)chemical reactivity and hydration properties are considered, fractions with the strongest water binding properties have the most adverse effect on bread volume (Hemdane, Langenaeken, et al., 2016), suggesting that bran hydration properties play a crucial role in the negative effect of bran on bread loaf volume. The exact mechanism behind this is, nevertheless, not fully understood. It is possible that the competition for water between bran and flour constituents during dough mixing negatively affects proper gluten network formation (Lai, Hoseney, & Davis, 1989). It is also possible that bran exerts its negative effect during fermentation, by redistribution of water from the gluten proteins to the bran, causing partial dehydration and/or conformational changes in the gluten network (Bock, Connelly, & Damodaran, 2013; Li et al., 2012). Another possible explanation for the observed effect is that during baking, starch gelatinization occurs faster in bran-rich bread compared to regular bread, resulting in an earlier setting of the bread crumb structure, and hence a smaller oven rise (Dreese & Hoseney, 1982). Finally, it is possible that less water evaporates during baking of bran-rich bread, leading to a lower gas cell expansion (Brennan & Cleary, 2007).

The replacement of flour by fiber-rich products such as bran is also reported to affect bread quality evolution during storage

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(Curti, Bubici, Carini, Baroni, & Vittadini, 2011; Katina, Salmenkallio-Marttila, Partanen, Forssell, & Autio, 2006; Santos, Rosell, & Collar, 2008). During storage of bran-free products, several changes in flour constituents occur, such as amylopectin retrogradation and gluten dehydration (Bosmans, Lagrain, Ooms, Fierens, & Delcour, 2013; Gray & Bemiller, 2003; Hug-Iten, Escher, & Conde-Petit, 2003), negatively affecting crumb firmness and crispiness. Here, the importance of water dynamics may not be underestimated, as water migrates during storage from crumb to crust, diffuses from gluten to starch, and is incorporated in the formed amylopectin crystals (Baik & Chinachoti, 2000; He & Hoseney, 1990; Willhoft, 1973). Bran incorporation in bread has been reported to modify these water dynamics, due to a higher overall water content in the bread and a lower rate of amylopectin retrogradation (Katina et al., 2006). However, confirmation is needed for this, as a more recent study showed that bran incorporation increased amylopectin retrogradation rate (Curti, Carini, Tribuzio, & Vittadini, 2015).

An interesting approach to gain insight in biopolymer interactions and water dynamics during bread making and storage is the use of time-domain (TD) proton nuclear magnetic resonance (^{1}H NMR) relaxometry. With this technique, changes in molecular mobility of water and biopolymers during bread making and subsequent storage can be studied. Furthermore, a relationship has been observed between molecular proton mobility and macroscopic processes such as a changes in bread crumb firmness (Bosmans, Lagrain, & Ooms et al., 2013). Several studies have been performed in the past few years to study transverse or spin-spin (T_2) relaxation times in wheat flour model systems (Bosmans, Lagrain, Deleu, Fierens, Hills, & Delcour, 2012; Choi & Kerr, 2003; Wynne-Jones & Blanshard, 1986), dough (Bosmans et al., 2012; Leung, Magnuson, & Bruinsma, 1979), and bread systems (Bosmans, Lagrain, & Ooms et al., 2013; Chen, Long, Ruan, & Labuza, 1997; Curti et al., 2011; Wynne-Jones & Blanshard, 1986).

Although TD ^{1}H NMR has been used to analyze wheat flour bread systems, its use for studying bran-rich bread making and storage is very limited, especially during dough leavening. In a previous study, ^{1}H NMR results with regard to the different proton populations in wheat bran were assigned. At the same time, the changes in water mobility in bran-water mixtures with increasing moisture content were performed (Hemdane et al., 2017).

The present study aimed to understand water distribution and biopolymer behavior during wheat bran-rich bread making and subsequent storage as observed with ^{1}H NMR, and to use the obtained results to further hypothesize on the impact of bran incorporation on bread volume, crumb texture and crumb texture evolution. To this end, coarse, ground and pericarp-enriched (PE) bran were used in bread making. By comparing ground to coarse bran on the one hand, the effect of bran particle size on dough and bread properties and on bread storage can be assessed (Hemdane et al., 2016). PE bran, on the other hand, is very rich in insoluble dietary fiber as compared to coarse and ground bran, is biologically inert and binds water relatively strongly (Jacobs, Hemdane, Dornez, Delcour, & Courtin, 2015).

2. Materials and methods

2.1. Materials

Sound wheat (*cv*. Akteur) was provided by Dossche Mills (Deinze, Belgium), and was milled with a Bühler MLU-202 laboratory mill (Uzwil, Switzerland) to produce refined flour, coarse bran, and shorts (milling yields of 76.4%, 15.1%, and 8.5%, respectively). Additionally, coarse bran (average particle size 1100 μm, as determined using the method described by Hemdane, Leys, Jacobs, Dornez, Delcour, and Courtin (2015)) was further ground to fine bran with an average particle size of approximately 250 μm using a Cyclotec 1093 Sample mill (FOSS, Höganäs, Sweden) with sieve aperture size of 1 mm. PE bran was produced by Fugeia N.V. (Dilbeek, Belgium) using a heat-stable amylase and *Bacillus subtilis* xylanase treatment of wheat bran according to the method of Swennen, Courtin, Lindemans, and Delcour (2006). The enzyme treatment was followed by a boiling step for 50 min to inactivate most of the residual enzymes, and a washing step with deionized water (80 °C). The residue was finally dried. The particle size of PE bran was approximately 400 μm on average. The chemical composition and hydration properties of flour, coarse bran, ground bran, and PE bran are discussed in a previous study (Hemdane et al., 2017). Bran-enriched meals were fortified with vital wheat gluten (Tereos Syral, Aalst, Belgium), and for the bread making trials, commercial fresh baker's yeast, sugar and salt were used. All chemicals were of analytical grade and purchased from Sigma-Aldrich (Bornem, Belgium).

2.2. Preparation of bran-rich meals

Bran-rich meals were composed on a same overall starch level basis (67%), to take into account the differences in endosperm contamination between coarse/ground bran and PE bran (Hemdane et al., 2015). The reason for composing meals on a same overall starch level basis was that coarse/ground bran and PE bran used in this study contained different levels of endosperm attached to the botanical bran part, and thus consequently differed in gluten and botanical bran content. Indeed, coarse bran had a starch (defined as non-cellulosic glucose) content of 20.4%, whereas that of PE bran was 1.5% (Hemdane et al., 2017). Therefore, depending on the starch content of the bran samples, different levels of flour were replaced by bran sample. Furthermore, additional vital wheat gluten was mixed with the meals, in order to obtain a total gluten level similar to that of refined flour (86% of the flour protein content was gluten, as determined by Osborne fractionation). For the meal containing coarse bran, for instance, the composition of the meal was 77.4% flour, 20.0% bran sample and 2.6% additional gluten (Table 1).

2.3. Bread making and storage

Breads were prepared in triplicate according to the straight dough procedure of Finney (1984). The composite flour and meal (100.0 g, 14.0% moisture), 5.3 g compressed fresh yeast, 6.0 g sucrose, 1.5 g NaCl, 0.25 g calcium propionate and an optimal amount of deionized water (Table 1) were mixed with a 100 g pin mixer (National Manufacturing, Lincoln, NE, USA) for appropriate mixing times (Table 1). Recent work and preliminary bread making trials showed that a dough water absorption equal to that of the Farinograph water absorption of white wheat flour and to that of the Farinograph water absorption of bran-enriched meal plus 5% can be considered as optimal for refined wheat flour and bran-enriched doughs, respectively (Jacobs et al., 2016). Besides, mixing times were determined by evaluating dough consistency of each bran-rich dough and by preliminary baking trials, as neither Mixograph or Farinograph dough development times were appropriate to indicate the actual time needed for optimal dough development in bran-rich bread making (Jacobs et al., 2016). Fermentation and final proofing were performed in a fermentation cabinet (National Manufacturing) at 30 °C and 90% relative humidity for 90 and 36 min, respectively. Dough samples were punched after 52 and 77 min fermentation (puncher aperture size 4.8 mm) and punched and molded after 90 min (puncher aperture size 7.9 mm). Baking was performed for 24 min at 215 °C in a rotary oven (National Manufacturing). Bread volume was measured after