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Influence of water content and negative temperatures on the mechanical properties of wheat bran and its constitutive layers

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ABSTRACT

Wheat bran is currently an undervalued by-product, and could be processed into food ingredients with high nutritional potential. The aim of this study was to determine the influence of bran moisture content, and the influence of sub-zero temperatures on the mechanical properties of whole bran layers and hand isolated bran tissues (outer pericarp, intermediate layer, aleurone layer), to get information on their potential breakage behavior during fractionation processes and determine the most suitable working conditions to develop efficient processes. The mechanical properties of bran strips were assessed by stress–strain tests using a dynamic mechanical thermal analyzer, with temperature control and relative humidity control. This work showed that it is possible to modulate the mechanical properties of bran samples by modifying their moisture content and the temperature. The extensibility (ultimate strain) of bran tissues was positively correlated to their moisture content (from 9% to 21%, w.b.) and to the temperature (from −100 to 25 °C), whereas their stiffness (Young modulus) was negatively correlated to these parameters. In certain conditions, the constitutive layers of whole bran strips broke at different locations, showing that these layers could be dissociated. At temperatures of −50 °C and below, whole bran and intermediate layers seemed to lose their plasticity. This phenomenon could be linked to a small glass transition detected between −40 and −50 °C in the intermediate layer. These results may allow adapting fractionation processes for a better use of bran.

1. Introduction

An increasing number of studies has lately underlined the high nutritional potential of wheat bran (Liu, 2007; Liyana-Pathirana and Shahidi, 2007; Mateo Anson et al., 2008; Topping, 2007), which is currently an undervalued by-product of the white flour, obtained after the conventional milling of wheat grains. Bran, which represents about 15% of the wheat grain weight after milling, is a composite multi-layer material made up of several adhesive tissues: outer pericarp, inner pericarp, testa, nucellar epidermis, and aleurone layer (schematized in Fig. 1), with attached starchy endosperm residues. The various bran layers exhibit different functions during the grain development, and are therefore characterized by distinct structures and compositions. The outer pericarp and inner pericarp are composed of empty cells and contain mostly branched heteroxylans, cellulose and lignin, with numerous cross-links between the polymer chains (Fincher and Stone, 1986; Pomeranz, 1988). The testa is a hydrophobic layer whose cell walls are rich in lignin, whereas the nucellar epidermis mainly contains cell wall polysaccharides with more than 90% poorly cross-linked arabinoxylans (Barron et al., 2007; Evers and Reed, 1988). The aleurone is made up of living cells enclosing bioactive compounds, surrounded by thick cell walls composed of relatively linear arabinoxylans and β-glucans, and of few proteins (Bacic and Stone, 1981; Pomeranz, 1988).

Several studies (Antoine et al., 2004b; Buri et al., 2004; Dexter and Wood, 1996; Hemery et al., 2007) have shown that various processes could be used for the fractionation of wheat bran, to make better use of its constitutive components by recovering separately the different bran layers, to produce fractions such as pericarp-rich fractions (rich in fiber) or aleurone-rich fractions (rich in vitamins, minerals and antioxidants). Therefore, to produce different fractions from wheat bran, it is necessary to dissociate the different bran tissues from each other in an initial process, in order to sort them out and separately recover the different layers in a subsequent process.

Different methods can be used to dissociate the distinct components of a composite material. For example, the material can be finely ground to increase the chance of damaging the interfaces between the different layers, and reducing the proportion of composite particles. Grinding at very low temperatures (i.e. cryogenic grinding) is used to increase the brittleness of the materials, to produce fine particles. It has been reported to improve the fraction-

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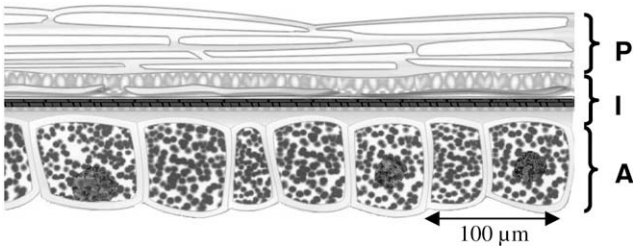

Fig. 1. Schematic representation of the structure of whole bran and its constitutive tissues. P: Outer pericarp; I: intermediate tissues; A: aleurone layer.

ation of various materials (Bastin and Simon, 2008; Goswami and Singh, 2003; Manohar and Sridhar, 2001) and of wheat bran in particular (Hemery et al., 2007). Cryogenic grinding is also said to limit the reagglomeration of particles and the destruction of thermosensitive compounds.

Another way to modify the extensibility or brittleness of bran tissues, to improve their ability to dissociate, might be to modify the plasticity of the different outer layers by adjusting the hydric conditions. Indeed, water tempering of grains before milling is well known to give bran with larger particle size (Fang and Campbell, 2003; Shellenberger, 1980). The extensibility of bran is said to control the grinding behavior of bran tissues: Greffeuille et al. (2006), reported a strong positive correlation (R^2 = 0.90) between the maximum strain (extensibility) measured for strips of whole bran layers and the size of coarse bran obtained after milling.

Modifying the working temperature or the moisture content of bran appears to be a good way to improve its processibility, by increasing its brittleness or by modifying its extensibility. However, in order to use parameters such as temperature and sample moisture content for the development of bran fractionation processes, it seems important first to acquire knowledge on the influence of these parameters on the mechanical properties of bran and its constitutive tissues. The study of the mechanical properties of these materials can give valuable information on the potential behavior (breakage, fractionation) of these materials during processing.

Uniaxial tensile tests have been developed to study the mechanical behavior of "bran strips" obtained by hand-dissection of wheat grains. These "bran strips" are composed of the tissues surrounding the endosperm, which on milling become fractionated as bran (with bran particles being less uniform than the samples used for tensile tests). Mabille et al. (2001) showed that tensile testing of wheat bran layers was a simple method, sensitive and accurate enough to characterize the mechanical properties (like stiffness or extensibility) of these samples. Several authors (Antoine et al., 2003; Greffeuille et al., 2007) studied the mechanical properties of whole bran layers and isolated tissues, and stated that the differences in structure and composition of the different layers may be responsible for their different mechanical properties. Other studies focused on the influence of various parameters on the mechanical properties of wheat bran, like the enzymatic oxidation and UV irradiation of bran (Peyron et al., 2001, 2002), or the influence of bran moisture content (Glenn and Johnston, 1992; Mabille et al., 2001), but no study on the influence of temperature on these properties has been carried out yet.

The aim of the present work was to evaluate the possibility of influencing the mechanical properties of wheat bran and bran constitutive tissues, by modifying either the characteristics of the tested material (water content) or the ambient conditions (negative temperatures), in order to get information on their potential breakage behavior during fractionation processes, and to determine the most suitable working conditions to develop efficient processes.

2. Materials and methods

2.1. Preparation of isolated wheat bran layers

Two common wheat (*Triticum aestivum* L.) cultivars differing in kernel hardness (hard wheat: Tiger, and soft wheat: Crousty), harvested in 2005 in Germany (Tiger) and France (Crousty) were studied. To obtain isolated grain tissues, the grains ends (germ and brush) were cut with a razor blade and the remaining parts were immersed in distilled water for 12–16 h at 20 °C. A crease incision was made and the endosperm was removed using a scalpel. The crease area was removed and three different strips were separated from the "whole bran layers" using a scalpel. Antoine et al. (2003), using a similar procedure, showed that the outer strip corresponds to the outer pericarp (epidermis and hypodermis), the inner strip corresponds to the aleurone layer, and the intermediate layer is a composite of several tissues (inner pericarp, testa, and nucellar tissue). The whole bran layers and isolated tissues were placed between glass plates for 1 h to give them a plane shape, and their moisture content was adjusted (to 9%, 13%, 16%, or 21%) by conditioning them at 25 °C in chambers containing saturated saline solutions ($Mg(NO_3)_2$, NaCl, KCl, or KNO_3) that kept the relative humidity constant (53%, 75%, 84%, and 92% RH, respectively). All the samples were kept in the conditioning chambers for 24–48 h, until the mechanical tests.

2.2. Biochemical analyses

Dissected tissues were dried at 25 °C over P_2O_5, and then ground under cryogenic conditions for 4 min (Spex CertiPrep 6750 grinder), and dried again before chemical analyses.

Ester-linked phenolic acids were saponified under argon at 35 °C in 2 N NaOH. An internal standard (2,3,5 trimethoxy-(E)-cinnamic acid, T-4002, Sigma Chemical Co., St. Louis, USA) was added before adjusting pH to 2. Phenolic acids were then extracted twice with diethylether. The ether phase was evaporated at 30 °C under argon. The dried extract was dissolved in methanol/water (1:1, v/v), filtered and injected into a RP-HPLC system as described by Antoine et al. (2003). The various forms of ferulic acid (monomer and dimers) were identified according to their UV absorption spectra, and quantified using the response factors determined for pure compounds at 320 nm. All analyses were performed in duplicate.

Neutral sugars were quantified as anhydro-sugars, after sulphuric acid hydrolysis and conversion into alditol acetates (1 M, 2 h, 100 °C) of the samples (Blakeney et al., 1983). Anhydro-sugars determination was done by gas chromatography (DB 225 capillary column) at 225 °C, using hydrogen as carrier gas and allose (5 mg) as internal standard. Analyses were performed at least in duplicate. Arabinoxylan was calculated as the sum of anhydro-arabinose and anhydro-xylose.

2.3. Water–adsorption isotherms

Water–adsorption isotherms were determined at 25 °C for Tiger and Crousty hand isolated bran layers, using a controlled ambiance microbalance (Dynamic Vapour Sorption apparatus, Surface Measurement System Ltd., London, UK), based on a Cahn microbalance housed in a controlled temperature incubator (±0.1 °C). The required water activities were generated by mixing dry and saturated vapour gas flows in the correct proportions using flow controllers (model 1179A Mass-flow and meter controller, MKS). Humidity and temperature probes were situated just below the sample and reference holders to give an independent check of system performance. The microbalance was equipped with an electrobalance (model D-200, Cahn Instruments Co., Cerritos, California)