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Effect of thermal processing and storage on digestibility of starch in whole wheat grains

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ABSTRACT

Gelatinisation and retrogradation of starch in wheat flour systems and whole wheat grains were studied using DSC and the impact of these events on starch digestibility was investigated. Gelatinisation of starch was possible in wheat flours with more than 60% moisture content (dwb) and gelatinised samples had higher digestibility values. Retrogradation of starch was studied with partially and fully cooked (boiled at 100 °C for 12 min and 32 min, respectively) wheat grains that were subjected to storage at 22 °C for 48 h. Stored samples had lower digestibility values when compared to the freshly cooked counterparts. The effect of moisture on retrogradation was studied with fully cooked wheat grains that were dried to a range of moisture contents (14.6–35.9%, wwb) and stored at 20 °C for 24 h. Retrogradation enthalpy increased with increasing moisture content; however, digestibility values did not reflect the changes in retrogradation enthalpy. The possibility of estimating the degree of retrogradation in fully cooked grains (32 min cooking) was investigated using a wheat flour-water system. The retrogradation enthalpy of fully cooked grains was slightly higher than the wheat flour-water system (at a moisture content of 49%, wwb) during the course of storage at 22 °C.

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1. Introduction

Recent data indicates that the intake of whole grain products only constitute 5–10% of the overall consumption of cereal products (with up to 90% coming from non-whole grain products). The daily recommended consumption of whole grain products is three servings and yet the current consumer intake is one serving per day (Marquart et al., 2007). Nevertheless, evidence supporting the health benefits of increased whole grain intake continues to amass. The consumption of whole grain foods is encouraged by health authorities and in the dietary guidelines. Whole grains and/or their components have been shown to:

(a) Have cholesterol lowering effects (soluble fibre)
(b) Directly and indirectly affect other coronary heart disease-related factors such as hypertension and obesity
(c) Exert a significant effect on glucose and insulin metabolism
(d) Provide significant protection against gastrointestinal cancers and possibly other systemic cancers
(e) Contain many other potential health-supporting phytonutrients such as antioxidants, sterols, vitamins and mineral (Miller, 2001; Pins et al., 2001; Topping, 2007).

Whole wheat grains are usually subjected to heat treatments in the presence of water before consumption. This produces an edible product, increases the nutritive value of the grain and generates desirable flavour and texture (Caldwell et al., 2000; Miller, 1988). A number of changes occur in the structure of starch during heating with sufficient amount of water. These changes include swelling, gelatinisation and pasting of starch. On storage, retrogradation of gelatinised starch takes place. Water uptake is another important event that occurs during the cooking of the whole grains (Atwell et al., 1988). Cooking of the wheat grains involves (1) the diffusion of water from the surface to the core and (2) the transfer of heat from the surrounding medium to the surface of the grain and then the conduction of heat into the centre of the grain. The diffusion of water is limited in the cooking process as it would require only a matter of seconds for the heat transfer to take place while the cooking of the grains usually takes 30–40 min (Jankowski and Rha, 1986a). In an NMR imaging study, Stapley et al. (1997a) defined two regions in the transverse images of the wheat grains

Abbreviations: AOAC, Association of Official Agricultural Chemists; DSC, Differential scanning calorimetry; dwb, dry weight basis; NMR, Nuclear magnetic resonance; RS, resistant starch; SD, standard deviation; wwb, wet weight basis; w/w, by weight.

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during steaming at 100 °C: (1) a high moisture (~50%) outer plateau region where the concentration varies only slightly (2) an inner core with much lower moisture content. Separating these two regions was a well defined front, which moved towards the centre of the grain as cooking progressed. The presence of moisture throughout the grain may affect the gelatinisation and retrogradation of starch as both phenomena are sensitive to the amount of water in a system (Gudmundsson, 1994). Redistribution of moisture within the cooked grains may also take place during storage.

The amount of uncooked, gelatinised and retrograded starch in the processed grains may affect the nutritional and processing quality and the digestibility of starch in the final product. Native starch granules are hydrolysed much slower than gelatinised starch by the amylolytic enzymes. Gelatinised starch is easily digestible (Garcia-Alonso et al., 1998). However, the retrogradation of gelatinised starch during storage gives rise to a decrease in hydrolysis with amylolytic enzymes, due to the changes in the crystalline structure (Roos, 1995a).

The effect of processing of foods on the digestibility of starch is very important from a nutritional point of view. The incomplete or slow digestion of starch leads to slow glucose release and such products can be used in the diets of diabetes patients and for weight management of healthy individuals (Annison and Topping, 1994; Bornet et al., 1989; Brown, 2004; Johnson and Gee, 1996).

At various stages of whole grain processing, the product may contain uncooked, gelatinised and retrograded starch with different degrees of digestibility due to the structural changes occurring during the heat-moisture treatment. This work aims to investigate the gelatinisation and retrogradation of starch using differential scanning calorimetry (DSC) and their effect on starch digestibility during the cooking and storage of the whole wheat grains. The first part of the study (Section 3.1) looks at the effect of water on gelatinisation behaviour and digestibility of starch in wheat flours. The second part (Section 3.2) studies the effect of different degree of cooking and storage on retrogradation and digestibility of starch in whole wheat grains. The third part (Section 3.3) looks at the effect of moisture on the retrogradation of starch and starch digestibility in fully cooked grains. The last part of the study (Section 3.4) investigates the possibility of estimating retrogradation enthalpies of whole wheat grains using a wheat flour system.

2. Experimental

2.1. Wheat grains and flour

2.1.1. Wheat grains

The wheat grains used in the study were UK grown (Hertfordshire, Essex and East Anglia Regions) soft grains (Consort wheat) and their size varied between 5.5 and 8.0 mm in length and 3.5–4.0 mm in width. The average moisture content (wwb) of the wheat grains was between 11 and 12%.

2.1.2. Wheat flour

The wheat flour was obtained by milling the whole wheat grains (uncooked) in a Cyclotec 1093 mill with a mesh size of 1 mm. The flour had an initial moisture content of 12.5 ± 0.1% (wwb).

2.1.3. Cooking of the wheat grains

The whole wheat grains were placed in boiled water in a beaker and cooked on a hot plate with gentle stirring. The grains were cooked at 100 °C for 12 and 32 min. Cooked grains were treated with liquid nitrogen and stored at −23 °C, when required. Before the analysis, frozen grains were thawed at ambient temperature for approximately 15 min.

2.1.4. Flour of the cooked grains

The cooked wheat grains (12 and 32 min cooking) were milled in a Cyclotec 1093 mill with a mesh size of 1 mm. The samples were treated with liquid nitrogen to ease the milling process.

2.2. Moisture content determination

Moisture content of the wheat samples was determined by oven drying (Gallenkamp Hotbox Oven) at 105 °C for 24 h.

2.3. Differential scanning calorimetry (DSC)

A PC-driven differential scanning calorimeter (Perkin–Elmer DSC-7, Beaconsfield, UK) was used for the measurements. The instrument was calibrated for temperature and enthalpy with Indium (Tonset = 156.6 °C and ΔH = 28.45 J/g) and Cyclohexane (Tonset = 6.7 °C). Dry air was used as a purging agent over the head. Cooling was achieved with an intra-cooler allowing temperatures down to −60 °C. Two types of pans were used depending on the type of the experiment, aluminium pans with a volume of 20 μl, or stainless steel pans with a volume of 40 μl. Sample pans were allowed to equilibrate overnight at room temperature unless otherwise stated. All DSC scans were carried out with a heating rate of 10 °C/min. The preparation of samples for analyses for different sections is given below.

2.3.1. Gelatinisation in wheat flour at different water contents (Section 3.1)

Water was added to the flour of the wheat grains (uncooked) to obtain samples with water/dry flour (w/w) ratio of 20, 30, 40, 50, 60 and 70%. Samples were run in duplicate in stainless steel pans from 5 to 140 °C. Approximately 20 mg sample was used.

2.3.2. Retrogradation in cooked wheat grains (Section 3.2)

Flour of 12 and 32 min cooked wheat grains were used. Freshly cooked samples (3–5 mg) were placed in the DSC pans and analysed immediately. The same pans were scanned the second time after storage at 22 °C for 48 h. DSC conditions were: Aluminium pans, 5–100 °C, sample/water ratio: 1/3, number of replicates: 3.

2.3.3. Effect of moisture content on retrogradation (Section 3.3)

The flour of the fully cooked (32 min cooking) wheat grains was dried to various moisture contents (14.6, 19.4, 22.6, 28.6 and 35.9%, wwb). A 3–5 mg sample was placed in the DSC pans. DSC conditions were: Aluminium pans, 5–100 °C, sample/water ratio: 1/3, number of replicates: 3.

2.3.4. Studying retrogradation: whole grains versus wheat-flour–water mixture (Section 3.4)

Water was added to wheat flour (untreated) in the DSC pans to generate a moisture content of 49%, wwb and this sample was heated in the DSC to ensure cooking. Both wheat flour–water mixture and the flour of the 32 min cooked wheat grains were stored in DSC pans during storage. Approximately 8 mg of sample was used. DSC conditions were: Stainless steel pans, 5–100 °C, sample/water ratio: 1/3, number of replicates: 5.

2.4. Starch digestibility assay

12 ml distilled water, 18 ml 0.1 M citrate phosphate buffer (pH 6.9, containing 6 mM NaCl) and pancreatic α-amylase (EC.3.2.1.1, A6255, Sigma Chemical Co., St. Louis, MO, USA) were added to approximately 100 mg of the flour of the cooked (cooked for 12 and 32 min) and untreated wheat grains. The amount of enzyme corresponded to 45.4 units α-amylase per ml starch suspension. The

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