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Rheological properties of water insoluble date fiber incorporated wheat flour dough

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The influence of water insoluble date fiber addition, to standard flour was studied through rheological tests at small and large deformations and at different levels of fiber incorporation (1–10 g/100 g). The added DF increased the water absorption of the dough. An increase in mixing time and stability were recorded upon addition of DF (≤5 g/100 g), and the extensibility decreased at similar condition. The elastic modulus, G' of the blended doughs increased with fiber concentration in the frequency range of 0.1–10 Hz, and the dough exhibited predominating solid-like behavior. The difference in microstructure between control and fiber incorporated dough samples were characterized by a plot of G' vs. G''. During non-isothermal heating of doughs from 30 to 95 °C at a heating rate of 2.5 °C/min, the G' achieved its peak value ($T_{G'\max}$) at a temperature representing the peak gelatinization temperature (T_p). Addition of DF did not significantly affect the T_p of the dough. The dough gelatinization kinetics was described by two rate equations corresponding to upward and downward of gelatinization curve. The upward and downward curves fitted the first-order and the second-order reaction kinetics, respectively. The gelatinization process activation energies ranged between 129 and 194 kJ mol^{-1}.

1. Introduction

In recent food science and nutrition literature, dietary fiber (DF) occupies a major space. Dietary fiber has received tremendous attention from researchers and industry due to the likely beneficial effects on the reduction of coronary heart-related diseases, diabetes incidence, gut neoplasia and constipation (Lairon et al., 2005; Park, Seib, & Chung, 1997). Dietary fiber is subject to the Nutritional Labeling and Education Act and is a mandatory field on nutritional labels (Singh, Liu, & Vaughn, 2012). Food processing industries are spending a huge amount of money on development of new generation food products by incorporating dietary fibers into conventional foods. The emergence of new dietary fiber sources and also the new processing methods for improving their functionality have widened the applications of dietary fibers in food industry and opened new possibilities for designing fiber-enriched products and for generating new textures in a range of applications (Rosell, Santos, & Collar, 2009). Based on this information, consumption and market share of fiber-enriched food especially cereal based products have increased many folds.

Bread can be enriched with dietary fiber from various sources, namely wheat bran (Gómez, Jiménez, Ruiz, & Oliete, 2011), β-glucans (Thondre & Henry, 2009), inulin (Morris & Morris, 2012), carob fiber and many other biopolymers (Miś, 2011; Miś, Grundas, Dziki, & Laskowski, 2012). Incorporation of fiber into wheat flour interacts directly with structural elements of the three dimensional gluten networks and disrupts the starch–gluten matrix, and finally affects the rheological behavior of blended dough during mixing, fermentation, and baking. However, the addition of these fibers sometime causes a negative effect on the final bread quality. The most notable change is the reduction of loaf volume (Lai, Hoseney, & Davis, 1989), and poor sensory characteristics (Miś et al., 2012). It has been reported that fiber incorporation strengthens the structure of bread dough which finally shows solid-like properties, whereas, at the same time, the extensibility of blended dough is reduced significantly, and thus resulting in a lower volume of bread and a deteriorated texture of its crumb (Lai et al., 1989).

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Date fiber is a by-product of date processing industry with high proportions of insoluble dietary fiber. Date fiber has some advantages in functional, anti-oxidant properties and some health benefits (Elleuch et al., 2011). In contrast to the abundant literature on their nutritional and health-promoting values, there is a scarcity of information on the use of date fiber for bread enrichment, and in particular there is a lack of characterization of changes in the rheological properties of wheat dough under the effect of increasing doses of those additions. In our earlier publication, the isolation and characterization of date fibers have been reported (Ahmed, Almusallam, & Al-Hooti, 2013), and the present work reports the incorporation of date fibers into wheat flour dough to develop fiber rich bakery products.

Gelatinization – a thermal transition of hydrated starch occurs in a non-equilibrium state, and thus, reaction kinetics pertaining to gelatinization provides definite set of process parameters (temperature, time, concentration, viscosity, shear rate/oscillation frequency etc.) for a specific starch (Ahmed & Auras, 2011; Dolan & Steefe, 1990). These data could be useful for process and equipment design for baking and extrusion. Gelatinization kinetics is mostly studied from differential scanning calorimetric (DSC) measurement and is reported as first-order reaction kinetics. Pseudo-first order kinetics has been assumed for starch gelatinization (Lund, 1984) although gelatinization is probably more correctly modeled as a set of reactions. Small amplitude oscillatory measurement is a more precise way to detect gelatinization temperature during non-isothermal heating, and it provides more reliable information on gelatinization kinetics (Ahmed, Dolan, & Mishra, 2012a). In this work, rheometric measurement of fiber-incorporated dough is focused on obtaining gelatinization reaction kinetics, which is limited in the literature.

The objective of the present study was to evaluate the potential use of date fiber as fiber enriching ingredient in bread making, and to study rheological properties of fiber enriched dough, using large and small deformation mechanical testing. Those information will be helpful for baking process design and product development.

2. Materials and methods

2.1. Materials

Commercial bread making wheat flour produced by Kuwait Flour Mills (F-Mills) was used in this study. The flour samples were analyzed for proximate composition (AACC, 2000). The flour characteristics were: moisture content (d.b.) 14.1 (g/100 g), protein content (d.b.) 10.9 (g/100 g), ash content (d.b.) 0.54 (g/100 g) and Falling Number value of 570 s. Water insoluble date fiber was obtained by sequential microwave water extraction of date cultivar *Barhee* which is described elsewhere (Ahmed et al., 2013). The date fiber characteristics (as dry basis) were: moisture content 3.98 (g/100 g), protein content 13.32 (g/100 g), fat content 1.80 (g/100 g), ash content 2.84 (g/100 g) and crude fiber content 29.5 (g/100 g). The absence of sugar in the date fiber was confirmed by the reverse-phase high-pressure liquid chromatography (HPLC). The average particle size of the date fiber was 748 nm as measured through dynamic light scattering (Zetasizer Nano-ZS instrument, Malvern Instruments Ltd, UK).

2.2. Ingredients of blends

Wheat flour was substituted by date fiber in different weight (g/100 g) to make a dough blend. Both wheat flour and date fiber was premixed in dry condition. Date fiber levels used were 0, 2.5, 5, 7.5 and 10 (g/100 g). The wheat flour sample without fiber is considered as control.

2.3. Dough characteristics by farinograph and extensograph

The composite dough behavior during development and mixing was measured by a farinograph (Model: 827504, Brabender, Duisburg, Germany) according to the standard method (AACC, 2000). The dried date fiber powder and the wheat flour were blended well in a 300 g mixing bowl of the farinograph (Brabender, Duisburg, Germany) which was connected with a circulating water pump and a preset thermostat (30 ± 0.3 °C). The measured farinographic parameters were: (i) water absorption (WA) of the wheat flour and blend which is the amount of water required to yield dough consistency of 500 BU (Brabender Units), (ii) arrival time, which is the time required for the top of the curve to reach the 500-BU line. (iii) dough development time (DDT, time to reach maximum consistency in minutes), (iv) dough stability (S) (time dough consistency remains at 500 BU), (v) mixing tolerance index (MTI) or the degree of softening of dough (DS), which is the consistency difference between height at peak and that 5 min later in BU and (vi) Twenty minute drop (TMD), which represents the difference in BU from the 500 BU line to the center of the curve measured at 20 min from the addition of water. For extension tests, dough was made in the 300 g mixing bowl of the farinograph (Brabender, Duisburg, Germany). The extension tests were conducted according to the standard procedure (AACC, 2000), using the extensograph (Model 860001, Brabender, Duisburg, Germany). The following parameters were measured: (i) extensibility, (ii) resistance to maximum extension (R_{max}) and up to 50 mm (R5), at constant deformation, (iii) ratio number (resistance to extensibility), and (iv) energy (area under the curve). Measurements of the above farinograph and extensograph indices were made in triplicate.

2.4. Rheological measurements

Oscillatory rheological measurements of the blended dough were performed on the ARES-G2 rheometer (TA Instruments, New Castle, DE). The geometry was plate–plate, with a diameter of 25 mm. Samples were placed in a 2-mm gap between two stainless steel parallel plates. The sample perimeter was covered with a thin layer of high-temperature-resistant silicone oil to prevent sample dehydration. The sample temperature was controlled by a Forced Convection Oven (air/N_2 gas convection oven) and monitored by platinum resistance thermometer sensors (accuracy of ±0.1 °C) which are positioned at the upper and lower plates.

Based on farinograph study, fiber to water ratio was maintained at 1:5 to produce the optimum dough, and this ratio was used for all rheological measurements. Dough samples were rested for 30 min for relaxation before the rheological measurement. For each test, a measured volume of well mixed sample was placed at the center of the rheometer plate for 5 min for further relaxation and temperature equilibration before the actual measurements were carried out. Frequency sweep tests were carried out at 25 °C between 0.1 and 10 Hz at the linear viscoelastic regime. In order to ensure that all the measurements are carried out within the linear viscoelastic regime, initially oscillation strain sweep tests of dough samples were performed initially. Temperature scans were performed to investigate the main transformations in the soft wheat flour dough undergoing heating. For temperature ramp, following an initial equilibration of samples for 5 min at 30 °C, linear temperature increment from 30 to 95 °C (non-isothermal heating) was carried out at 2.5 °C/min at a constant frequency of 1 Hz as per the method described by Ahmed, Ramaswamy, Ayad, and Alli (2008) for rice starch. One set of experiments was designed on heated dough samples. After heating of the dough at 95 °C, it was immediately cooled to 25 °C, followed by the frequency sweep