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Effect of the Hofmeister series on gluten aggregation measured using a high shear-based technique

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ABSTRACT

This study investigated differences in gluten aggregation time and gluten strength using the Hofmeister series in high shear-treated slurries. Two flours (15.1% and 10.6% protein) were evaluated by using a Gluten Peak Tester (GPT). Hofmeister anions including NaF, NaCl, NaBr, NaI, and NaSCN at concentrations ranging from 0.1 to 1.0 M and cations including KCl, NaCl, NH_4Cl, $MgCl_2$, and $CaCl_2$ at concentrations ranging from 0.0625 to 1.0 M were used. The instrument applies high shear to a flour/salt solution slurry and measures torque and aggregation time to form gluten. Aggregation time using the GPT followed the order of the Hofmeister series, with minor effects at salt concentration <0.3 M and increasing differences at higher salt concentrations. Torque increased with increasing concentration. Creating models of the trends using second and third order equations demonstrated that gluten aggregation follows a distinct natural law in the slurries. The study confirmed the potential of the high shear based method to be used a research tool to investigate gluten aggregation properties and to potentially predict functionality in baked product systems.

1. Introduction

Gluten is the aggregated product of gliadin and glutenin when wheat flour is mixed with water. Rheological aspects of gluten aggregation have been studied for many years, with research focusing on the specific interactions that play a role in gluten formation (Butow, Gras, Haraszi, & Bekes, 2002; Kinsella & Hale, 1984; Preston, 1981). The salts of the Hofmeister series have also been used to study gluten aggregation and these studies have provided information on the interactions involved in gluten formation. Preston studied the effect of different anions on gluten solubility and aggregation and reported distinct trends that follow the Hofmeister series (Preston, 1981). Kinsella and Hale further observed that different anions at the same concentration greatly affected farinograph consistency and stability (Kinsella & Hale, 1984).

In dough systems where limited water is available, the effect of ions on gluten is due to their ability to alter water structure in doughs (Zhang & Cremer, 2006). The chaotropic ions are 'water structure breakers', causing alterations in water structure that facilitate protein unfolding and solubilization. The kosmotropes have the opposite effect, enhancing water structure to facilitate proteins to remain in their native form through hydrophobic interactions (Zhang & Cremer, 2006). In doughs, at low salt concentration (0.1–0.3 M), all ions have a similar effect on protein aggregation, by shielding electrostatic forces that then allow or prevent protein interaction. At higher salt concentrations (>0.3 M), protein behavior is dictated by the salt type and the different effect that the chaotropes and kosmotropes have on water structure (He, Roach, & Hoseney, 1992; Preston, 1981). It is thought that at high salt concentrations, electrostatic forces are negligible, and hydrophobic interactions are responsible for gluten aggregation behavior (Preston, 1989).

Previous studies that have investigated gluten aggregation behavior by using Hofmeister ions have used pre-formed gluten (Bruun, Sondergaard, & Jacobsen, 2007; Clements, 1973; Preston, 1981; Preston, 1984). Other researchers have investigated aggregation behavior in flour using large sample size or long mixing time (Butow et al., 2002; Galal, Varrianomarston, & Johnson, 1978; He et al., 1992; Kinsella & Hale, 1984; Preston, 1989; Ukai, Matsumura, & Urade, 2008). The present study evaluates the aggregation properties of gluten *in situ* using small sample sizes (8 g), high water content slurries (125% water), and high shear (2750 rpm) and the output is recorded as the time to maximum peak (PMT) and maximum torque (MT).

2. Materials and methods

Two commercial flours of different protein content were used; Ibis, a hard wheat blend from western Canada, with a protein content of 15.1% and Diamant, a hard/soft blend, with a protein content of 10.6%.

Abbreviations: GPT, Gluten peak tester; PMT, Peak maximum time; MT, Maximum torque; rpm, Rotations per minute; HMW, High molecular weight.

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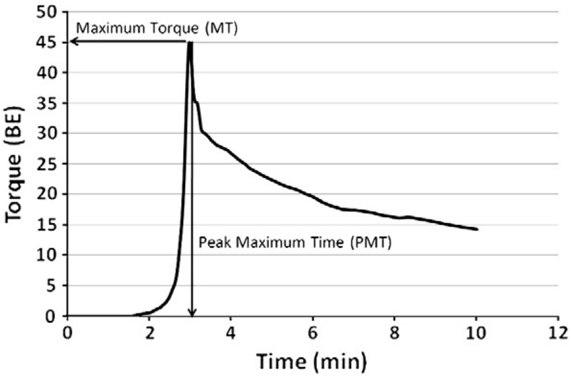

Fig. 1. Sample curve produced by Gluten Peak Tester (GPT) software during a test. During mixing, the paddle does not experience any torque until gluten aggregates. The variables of importance are highlighted: peak maximum time (PMT) and maximum torque (MT). (BE, Brabender Equivalents).

The order of the Hofmeister series from kosmotrope to chaotrope is K^+, Na^+, NH_4^+, Mg^{2+}, and Ca^{2+} and F^-, Cl^-, Br^-, I^-, and SCN^- for cations and anions, respectively. These salt solutions were chosen in order to cover the entire range of the Hofmeister series. Chloride salts (KCl, NaCl, NH_4Cl, $MgCl_2$, and $CaCl_2$) were used to test the effect of Hofmeister cations, and sodium salts (NaF, NaCl, NaBr, NaI, and NaSCN) were used to test the effect of anions. All salts were of analytical grade (Fisher Scientific, New Jersey; Merck KGaA, Germany).

The Gluten Peak Tester (Brabender GmbH and Co KG, Duisburg, Germany) is an instrument designed to measure the influence of high shear when mixing a high moisture content flour/water slurry to create a gluten network. Flour (8 g) and water or salt solution (10 g) were weighed into the sample cup. Sample temperature was maintained at 35 °C by circulating water through the jacketed sample cup. The paddle was set to rotate at 2750 rpm and the torque reading was recorded over time with a peak occurring as gluten aggregates, and the torque falling off when gluten breaks down (Fig. 1). Tests ran for a maximum of 10 min whether or not a peak was observed. Salt solutions of the five anions were made at concentrations of 0.1 M, 0.2 M, 0.3 M, 0.4 M, 0.6 M, 0.8 M, and 1.0 M. Cations were tested at 0.0625 M, 0.125 M, 0.25 M, 0.5 M, and 1.0 M. The control for all tests was double distilled water and all runs were done in duplicate. Error bars are included on all graphs and represent the standard deviation.

3. Results

3.1. Effect of salt type and concentration on peak maximum time

The effect of anions and cations of the Hofmeister series on gluten aggregation is evident since Peak maximum time (PMT) and Maximum torque (MT) followed distinct trends. At low concentration (0.0625 M to 0.3 M), all salts had a similar effect on PMT, which was significantly lower than for the control (Fig. 2). As the ionic concentration increased, ion-related differences in PMT became evident, indicating that each ion had a different effect on the flour with these effects being more pronounced at higher concentration. At each concentration, changes in PMT followed the Hofmeister series; i.e., decreasing from the most kosmotropic to the most chaotropic species. At salt concentrations greater than 0.3 M, ions at the kosmotropic end of the series resulted in increasing PMT as salt concentration increased; i.e., gluten network formation was delayed. The opposite effect (faster gluten formation) was observed with

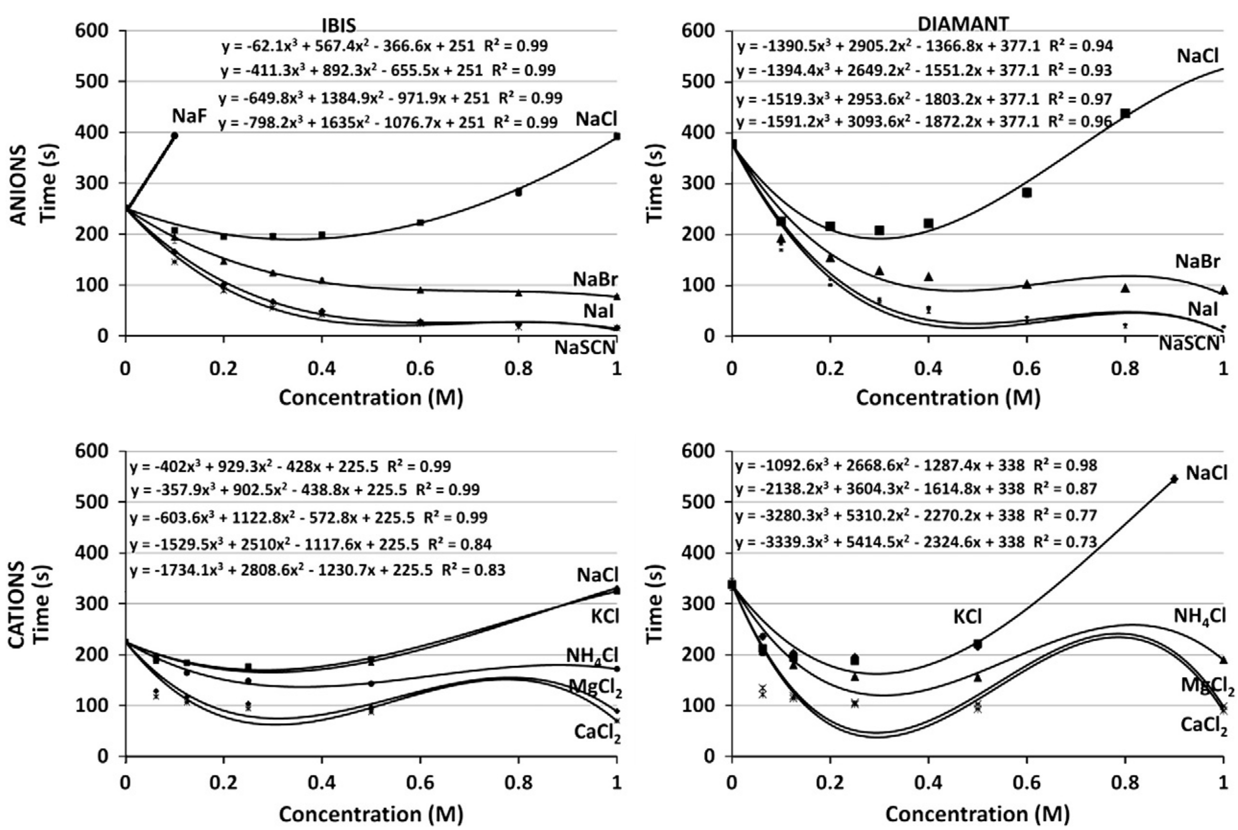

Fig. 2. Peak Maximum Time (PMT) of Ibis and Diamant in the presence of anionic salt solutions of the Hofmeister series at a range of concentrations (0.1 M, 0.2 M, 0.3 M, 0.4 M, 0.6 M, 0.8 M, and 1.0 M) and in the presence of cationic salt solutions of the Hofmeister series at a range of concentrations (0.0625 M, 0.125 M, 0.25 M, 0.5 M, and 1.0 M). The data shows that at each concentration the time followed the Hofmeister series with kosmotropes increasing aggregation time and chaotropes decreasing aggregation time as concentration increases. All data points have error bars although small and difficult to view.