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Effect of partially gelatinized corn starch on the rheological properties of wheat dough

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ABSTRACT

Ten, twenty and thirty percent (g/100 g) of wheat flour was substituted with partially gelatinized corn starch or ungelatinized corn starch and the rheological properties of the resultant dough samples were investigated. The apparent viscosity of dough increased with the increase in the concentration and degree of gelatinization of partially gelatinized starch samples except in the case of dough substituted with starch sample with high gelatinization degree (96.78%) at 30 g/100 g concentration. The presence of partially gelatinized starch increased the storage (G') and loss (G'') moduli values and decreased the frequency sensitivity of dough samples. The dough prepared from wheat flour alone (control) showed the highest creep compliance and the lowest elastic recovery. In brief, the rheological properties of dough were influenced by the degree of substitution more than by the degree of gelatinization of substitutes.

1. Introduction

Starch is the main component of wheat flour (about 80 g/100 g) and contributes to the formation of texture and quality of dough (Yang, Song, & Zheng, 2011). In many food applications, functional properties of starch can have important implication on the quality of end-use products (Hung & Morita, 2005). The different amylose/amylopectine ratio (Lee, Swanson, & Baik, 2001), granule structure (Goesaert et al., 2005) and granule size (Šebečić & Šebečić, 1996) of starch in wheat flour influences the texture, stability and elasticity of dough and bread.

In order to meet some specific requirements dough is commonly mixed with modified starches (Hung & Morita, 2004; Korus, Witczak, Ziobro, & Juszczak, 2009; Miyazaki, Maeda, & Morita, 2008). Pregelatinized starch is a physically modified starch which can reconstitute in cold water directly and provides desirable pasting and texturizing characteristics (Miyazaki, Van Hung, Maeda, & Morita, 2006). Due to these advantages, pregelatinized starch is commonly used in dough. Onyango, Mutungi, Unbehend, and Lindhauer (2011) added pregelatinized starch to the gluten-free dough and they found the presence of pregelatinized starch increased the viscosity of the liquid phase and enhanced the network created by the native starch granules. Xue, Sakai, and Fukuoka (2008) used microwave heating to partially gelatinize starch in dough for making noodles. They found that the cooking time of noodles produced by using partially gelatinized dough was reduced significantly compared to the un-gelatinized noodles.

From the results of these studies, addition of pregelatinized starch can modify the properties of dough and the quality of the products. However, these studies did not show clearly about a relationship between the addition of partially gelatinized starch and the rheological properties of dough.

Pregelatinized starch is a modified starch in which the crystalline zones in the starch granules are partially or completely destroyed. Different degrees of gelatinization in the partially gelatinized starch give rise to a diverse granule structure having different degree of crystallinity (Fu, Wang, Li, & Adhikari, 2012). This difference in degree of crystallinity in partially gelatinized

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starch is expected to influence the performance of dough. However, research on the effects of residual crystallinity and the characteristics of partially gelatinized starch granules on the rheological properties of dough is not reported.

In these contexts, the objective of this work was to study the effect of partially gelatinized corn starch on the rheological properties of wheat dough. The rheological tests included steady shear flow, frequency sweep and creep-recovery. This would provide better understanding of the rheological properties of wheat dough containing partially gelatinized starch.

2. Materials and methods

2.1. Materials

Wheat flour was obtained from Beijing Guchuan Flour Group Co., Ltd. (Beijing, China). Its protein and moisture contents were 10.8 g/100 g and 7.3 g/100 g, respectively. Commercial gluten powder was obtained from Juancheng Jianfa Flour Co., Ltd. (Shandong, China). Its moisture content was 5.9 g/100 g. Native corn starch having 10.0 g/100 g moisture content was obtained from Hebei Zhangjiakou Yujin Food Co., Ltd. (Hebei, China). Partially gelatinized starch samples were obtained by controlled gelatinization of starch at 64 °C (*S64*), 68 °C (*S68*) and 70 °C (*S70*) as previously reported (Fu et al., 2012). Corn starch suspension at a starch concentration of 10.0 g/100 g was prepared by adding 20.0 g of predried corn starch into deionized water at 24 ± 1 °C. Each batch of dispersion was thoroughly stirred at 300 rpm (in beakers) for 15 min using a thermostated water bath maintained at 64 °C, 68 °C and 70 °C. These partially gelatinized starch dispersions were spray dried using a bench-top spray drier (GPW120- II, Shandong Tianli Drying Equipment Inc., China). The inlet temperature, exhaust aspiration level, the flow rate of the air and feed rate used in the spray drying process were set at 200 °C, 95%, 0.375 m^3/h and 7.2 mL/min, respectively. Partially gelatinized starch was also prepared at 25 °C (*S25*) by stirring corn starch slurry for 15 min at 25 °C followed by spray drying. The degree of gelatinization of *S25*, *S64*, *S68* and *S70* samples was determined using a differential scanning calorimeter (DSC-Q10, TA Instruments, New Castle, USA) and was found to be 32.30%, 47.75%, 69.40% and 96.78%, respectively.

2.2. Dough preparation

In each formulation, 10, 20 and 30 g/100 g of native and partially gelatinized corn starch containing 10.8 g/100 g of gluten powder was substituted for wheat flour. A fixed amount of water was added to each sample to attain 42 g/100 g moisture content on wet basis. The dough samples were mixed for about 10 min and allowed to stabilize for 20 min in a sealed container before further tests. The dough formulations containing the mixture of native corn starch and gluten powder and only wheat flour (100 g/100 g) were used as control.

2.3. Rheological tests

Rheological measurements were performed using AR2000ex rheometer (TA Instruments Ltd., Crawley, UK). The temperature was maintained at 30 °C using a water bath connected to a Peltier system. An aluminum parallel plate geometry was chosen to conduct steady shear flow tests (20 mm diameter, 1 mm gap). The frequency sweep tests and creep-recovery tests were conducted using parallel plate geometry having 40 mm diameter and 1 mm gap. A thin layer of silicone oil was applied on the rim of the samples in order to prevent evaporation. The linear viscoelastic region was determined for each sample through strain sweep tests at 0.1, 1 and100 Hz, respectively (data not shown). Viscoelastic properties (storage moduli G' and loss moduli G'') of all the samples were determined within the linear viscoelastic region. A stabilization time of 15 min was applied to all the samples before measuring.

2.3.1. Steady shear flow tests

The steady shear flow tests were performed over a shear rate range of 0.01–10 s^{-1} to measure the apparent viscosity. The apparent viscosity versus shear rate data were fitted by using the Cross model (Moreira, Chenlo, & Torres, 2011) as given by Eq. (1):

$$\eta = \eta_\infty + \frac{\eta_o - \eta_\infty}{1 + (k\gamma)^{(1-n)}} \tag{1}$$

where η (Pa s) is the apparent viscosity, γ (s^{-1}) is the shear rate, η_o and η_∞ (Pa s) are the viscosity values at zero and infinite shear rates, respectively. Similar, k (s) is the time constant and n is the flow behavior index. The value of η_∞ can be obtained from the experimental results corresponding to the equilibrium viscosity obtained at the end of shearing. In the cases where $\eta_o \gg \eta_\infty$ and $\eta \gg \eta_\infty$, it can be assumed that $\eta_o - \eta_\infty \approx \eta_o$ and $\eta_\propto \to 0$ the Eq. (1) can be rewritten as Eq. (2) (Ravi & Bhattacharya, 2004).

$$\eta = \frac{\eta_o}{1 + (k\gamma)^{(1-n)}} \tag{2}$$

2.3.2. Frequency sweep tests

The frequency sweep tests were performed over the frequency range of 0.1–100 Hz (angular frequency range of 0.6283–628.3 rad/s). The strain amplitude for these frequency sweep tests was selected as 0.25% based on the strain sweep results (data not shown) in order to confine these tests within linear viscoelastic region. Experimental G' and G'' were fitted by using Eq. (3) and Eq. (4), respectively.

$$\log G' = \log a' + b' \log \omega \tag{3}$$

$$\log G'' = \log a'' + b'' \log \omega \tag{4}$$

where ω (rad/s) is the angular frequency and a', a'', b' and b'' are the fitting parameters.

2.3.3. Creep-recovery tests

Creep-recovery tests were carried out using a constant shear stress of 50 Pa. The variation in shear strain as a function of the applied stress was measured for 3 min. The applied stress was then removed and change in strain was recorded for further 5 min. Creep data was described with creep compliance rheological parameters, $J(t)_C$ (Pa^{-1}) = γ/σ where γ is the strain and σ is the constant shear stress during creep test. The creep compliance data of dough samples was fitted to the Burgers model by Eq. (5) and Eq. (6) for creep and recovery phases, respectively (Moreira et al., 2011):

$$J(t)_C = J_o + J_m(1 - \exp(-t/\lambda)) + t/\eta_o \tag{5}$$

$$J(t)_R = J_{max} - J_o - J_m(1 - \exp(-t/\lambda)) \tag{6}$$

where, J_o (Pa^{-1}), J_m (Pa^{-1}) and J_{max} (Pa^{-1}) are the instantaneous, viscoelastic and maximum creep compliance values, respectively. t (s) and λ (s) are the phase and mean retardation time values, respectively. η_o (Pa s) is the zero-shear viscosity. The percentage recovery of dough was represented by the elastic recovery (%) given by Eq. (7).