



# Effects of starch from five different botanical sources on the rheological and structural properties of starch–gluten model doughs



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## ARTICLE INFO

### Chemical compounds studied in this article:

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 Sodium acetate (PubChem CID: 517045)  
 Sodium hydroxide (PubChem CID: 14798)  
 Boric acid (PubChem CID: 7628)  
 Acetic acid (PubChem CID: 176)  
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## ABSTRACT

Wheat, corn, tapioca, sweet potato and potato starches were independently mixed into starch–gluten model doughs containing 15% (w/w) vital gluten. Rheological properties, including linear viscoelasticity region, frequency dependence and recovery capacity, were studied by strain sweep, frequency sweep, and creep and recovery measurements. Structural properties were also investigated by measuring the disulfide bonds (–SS–) content, SDS-PAGE and low-resolution <sup>1</sup>H nuclear magnetic resonance. Wheat starch (WS)–gluten dough had the greatest linear viscoelasticity region (0.190%), lowest frequency dependence (0.128) and greatest recovery capacity (67.39%), while potato starch–gluten dough had the smallest linear viscoelasticity region (0.126%), greatest frequency dependence (0.195) and lowest recovery capacity (54.97%). Furthermore, WS–gluten dough showed the highest disulfide bonds (–SS–) content (3.47 μmol/g), lowest intensity of extracted glutenin bands and highest bond water content (23.20%). This suggested that WS–gluten dough formed stronger starch–gluten interactions compared with those of the other four starch–gluten model doughs.

## 1. Introduction

Dough is a viscoelastic material with a high degree of elasticity, as well as considerable plasticity and viscosity (Smewing, Albertini, Maesmans, & Schofield, 2003). The rheological properties of dough are extremely important because they can influence the mechanical and technological properties of doughs, including extensibility, molding and shaping capacities, mixing behavior, gas-holding capacity, and steaming and baking performance (Van Bockstaele, De Leyn, Eeckhout, & Dewettinck, 2011).

Gluten is the major component of wheat protein, and it plays an important role in controlling the rheological properties of wheat dough (Faubion & Hoseney, 1990). Gluten forms a network structure through the formation of intra- and inter-molecular disulfide bonds between different gluten protein fractions (Shewry, Halford, Belton, & Tatham, 2002). Many studies have focused on the rheology of the gluten network and its formation mechanism, and various conceptual models have been developed to describe the unique structure of the gluten network, as well as its viscoelastic properties (Johansson et al., 2013;

Tuhumury, Small, & Day, 2014). These studies focused on the formation of the gluten network under conditions in which starch and other interfering factors were eliminated. However, the rheological properties of dough may also be influenced by starch–starch and starch–protein interactions because starch represents a larger fraction of the dough than the protein (McCann, Small, Batey, Wrigley, & Day, 2009).

Starch, as a major component of doughs, can significantly affect the rheological properties and other characteristics (Delcour et al., 2000). In practice, to meet some specific requirements, dough is commonly mixed with different flours or starches. For instance, addition 30% of tapioca starch to wheat flour could improve the texture and cooking properties of noodles (Charles et al., 2007). Inclusion 40% of sweet potato starch to wheat flour resulted in acceptable bread with desired colors (Hussein, Emmanuel, Chinyere, & Majekodunmi, 2015). Adding 20% potato flour to wheat flour will maintain the technological quality and improve the nutritional value of the steamed bread (Liu, Mu, Sun, Zhang, & Chen, 2016). Although the effects of flours and starches from different sources on the rheological properties of doughs have been widely studied, most of the tested doughs contain a variety of

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**Table 1**  
The approximate composition of different starches and vital gluten (%).

Samples	Starch	Protein	Fat	Moisture	Ash	Amylose
WS	86.87 ± 0.23 <sup>d</sup>	0.31 ± 0.01 <sup>b</sup>	0.74 ± 0.01 <sup>b</sup>	12.15 ± 0.01 <sup>b</sup>	0.15 ± 0.00 <sup>c</sup>	26.40 ± 3.75 <sup>a</sup>
CS	87.63 ± 0.76 <sup>c</sup>	0.25 ± 0.00 <sup>c</sup>	0.62 ± 0.01 <sup>c</sup>	11.29 ± 0.07 <sup>c</sup>	0.10 ± 0.09 <sup>d</sup>	28.49 ± 2.15 <sup>a</sup>
TS	88.95 ± 0.16 <sup>b</sup>	0.02 ± 0.00 <sup>f</sup>	0.14 ± 0.04 <sup>d</sup>	10.93 ± 0.05 <sup>d</sup>	0.10 ± 0.01 <sup>d</sup>	17.71 ± 4.87 <sup>c</sup>
SS	89.97 ± 0.35 <sup>a</sup>	0.06 ± 0.00 <sup>d</sup>	0.13 ± 0.01 <sup>d</sup>	9.72 ± 0.04 <sup>e</sup>	0.11 ± 0.01 <sup>d</sup>	18.82 ± 2.05 <sup>c</sup>
PS	86.80 ± 0.41 <sup>d</sup>	0.04 ± 0.01 <sup>e</sup>	0.12 ± 0.07 <sup>d</sup>	13.01 ± 0.02 <sup>a</sup>	0.40 ± 0.01 <sup>a</sup>	24.16 ± 1.16 <sup>b</sup>
Vital gluten	4.53 ± 0.29 <sup>e</sup>	80.04 ± 0.34 <sup>a</sup>	5.40 ± 0.32 <sup>a</sup>	9.70 ± 0.01 <sup>e</sup>	0.30 ± 0.01 <sup>b</sup>	–

Values are the mean ± SD.

Values followed by the same letter in the same column are not significantly different ( $P > 0.05$ ).

WS, wheat starch; CS, corn starch; TS, tapioca starch; SS, sweet potato starch; PS, potato starch.

ingredients, making it difficult to identify the effects of starch on the rheological properties.

Thus, to exclude the interference of other factors, starch–gluten model doughs were made using each of the following starches independently: wheat (WS), corn (CS), tapioca (TS), sweet potato (SS) and potato (PS). The rheological properties of the different starch–gluten model doughs were studied by dynamic strain sweep, frequency sweep, and creep and recovery measurements. In addition, the measurement of the disulfide bonds content, SDS-PAGE and low-resolution <sup>1</sup>H nuclear magnetic resonance (NMR) were conducted to investigate the structural properties of the starch–gluten model doughs.

## 2. Material and methods

### 2.1. Material

The vital gluten and starches from five different botanical sources (wheat, corn, tapioca, sweet potato, and potato) were purchased from a local market in Beijing, China. Table 1 shows the approximate composition of different starches and vital gluten. A pre-stained protein marker (multicolor broad range, 11–245 kDa) was purchased from Tiangen Biotech Co., Ltd. (Beijing, China). Dithio-bis-nitrobenzoic acid was purchased from Sigma–Aldrich (St. Louis, MO, USA). All other chemical reagents used in this study were of analytical grade, and purchased from Sinopharm Chemical Reagent Co., Ltd. (Beijing, China).

### 2.2. Dough preparation

On a dry basis, wheat flour dough contains approximately 14% gluten proteins (Addo, Xiong, & Blanchard, 2001). Therefore, 15.0% vital gluten (based on the protein content of the vital gluten showed in Table 1) was added to the different starches (WS, CS, TS, SS and PS) to prepare starch–gluten model doughs. Water addition was based on the  $W_{\text{abs}}$  values obtained from the Mixolab apparatus (see Section 2.3). By mixing constantly for 15 min, the uniform starch–gluten model doughs were prepared.

The starch–gluten model doughs were covered by a protective film and allowed to rest for 25 min before further analyses.

### 2.3. Mixolab measurements

The thermomechanical properties of the starch–gluten model doughs were studied using a Mixolab apparatus (Chopin Technologies, Villeneuve-la-Garenne, France). Measurements were performed using the Mixolab “Chopin +” protocol described in our previous publications (Mu & Sun, 2017). The process was repeated twice for each sample.

The following parameters were calculated from the Mixolab recorded curve: the amount of water absorption required for the dough to produce a torque of  $1.10 \pm 0.05$  Nm for “Chopin +”,  $W_{\text{abs}}$  (%); dough development time, DDT (min); dough strength against mixing or the difference of the maximum dough consistency at the initial mixing

stage ( $C_1$ ) and the minimum value of torque produced by the dough passage subjected to mechanical and thermal constraints ( $C_2$ ),  $C_1$ – $C_2$  (Nm); dough setback or the difference of the torque obtained after cooling at 50 °C ( $C_5$ ) and the minimum torque during the heating period ( $C_4$ ),  $C_5$ – $C_4$  (Nm) (Mu & Sun, 2017).

### 2.4. Rheological properties of the model doughs

The rheological properties were determined using a controlled stress rheometer (Physica MCR301; Anton Paar, Graz, Austria) operated using a 25 mm parallel-plate geometry in diameter with a gap of 2 mm. After being mixed and then rest for 25 min, each dough sample was placed between the plates, and the test was started after allowing the dough to rest for another 10 min. The rim of the dough sample was trimmed carefully and coated with silicone oil to prevent water loss during the test (Zhang, Mu, & Sun, 2016). The determination was carried out in three replications.

#### 2.4.1. Dynamic strain sweep

The linear viscoelasticity region (LVR) was determined by a dynamic strain sweep, which was performed over a strain range of 0.01%–10% at an angular frequency of  $10 \text{ s}^{-1}$  and 25 °C. Curves of the storage modulus ( $G'$ ) and loss modulus ( $G''$ ) versus strain were recorded and analyzed by using RHEOPLUS/32 version 3.21 software (Anton Paar, Graz, Austria) to obtain the LVR of the model doughs.

#### 2.4.2. Dynamic frequency sweep

A frequency sweep was run from 0.1 to  $100 \text{ s}^{-1}$  at a strain of 0.1% and temperature of 25 °C to determine  $G'$  and  $G''$  as functions of frequency. The degree of dependence of  $G'$  on the frequency sweep ( $z'$ ) and the strength of the dough ( $K$ ) were obtained by fitting the frequency sweep data into the following power law model:

$$G' = K'(\omega)^{z'}, \quad (1)$$

where  $\omega$  is the angular frequency.

#### 2.4.3. Creep and recovery measurements

Creep and recovery were measured as follows: The creep phase was recorded at a shear stress of 250 MPa, which exceeds the LVR for 300 s, followed by a recovery phase of 300 s at a stress of 0 Pa. Measurements were performed at  $25 \pm 0.1$  °C. Creep and recovery curves were recorded and analyzed using RHEOPLUS/32 version 3.21 software (Anton Paar) to obtain the parameters, including the maximum creep compliance ( $J_{\text{max}}$ ), zero shear viscosity ( $\eta_0$ ), relative elastic part of the maximum creep compliance ( $J_e/J_{\text{max}}$ ), and the relative viscous part of the maximum creep compliance ( $J_v/J_{\text{max}}$ ).

### 2.5. Disulfide bond content measurements

Model doughs were freeze-dried at  $-60$  °C for 72 h, milled into powder by a hammer mill from Beijing Kaichuang Tonghe Technology Development Co., Ltd. (Beijing, China), and sieved with a 100  $\mu\text{m}$

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