Food Hydrocolloids 85 (2018) 39–50

Contents lists available at ScienceDirect

Food Hydrocolloids

journal homepage: www.elsevier.com/locate/foodhyd

Rheological nature and dropping performance of sweet potato starch dough as influenced by the binder pastes

Yang Wang[a], Fayin Ye[a], Jia Liu[a], Yun Zhou[a], Lin Lei[a], Guohua Zhao[a,b,*]

[a] College of Food Science, Southwest University, Chongqing 400715, PR China
[b] Chongqing Engineering Research Centre for Sweet Potato, Chongqing 400715, PR China

ARTICLE INFO

Keywords:
Starch paste
Dough
Rheological properties
Starch noodles
Correlation analysis

ABSTRACT

Starch dough is a biphasic system in which the solid starch granules are dispersed in a continuous liquid matrix of binder paste. Experiencedly, the rheological nature of starch dough is vital to starch noodle production and heavily depends on the binder paste applied. The starch dough processing in the manufacture of starch noodle is widely spread but lacks scientific evidence. In the present study, the rheological behaviours of nine binder pastes and their corresponding sweet potato starch doughs were investigated by both steady shear and dynamic oscillatory shear measurements. The results showed that the processing characteristics of starch doughs were highly dependent on the binder paste applied, i.e., the doughs with binder pastes from sweet potato, cassava, potato and waxy maize starch displayed better dropping performance than that with binder pastes from pea, mung bean, wheat, rice or maize starch. Rheologically, both binder pastes and starch dough exhibit overall shear-thinning and thixotropic properties. A good binder paste could be defined by a lower thixotropy, consistency and loss modulus, as well as a higher loss tangent. For the first time, the present study performed a rheological characterization of starch dough and cast a new light on the dependence of its processing suitability on the binder paste involved. The findings herein successfully merge the experiences of starch dough processing into science.

1. Introduction

Starch noodles are one of the most popular staple foods, widely consumed in Southeast Asia, especially in China (Chandla, Saxena, & Singh, 2017; Han, Seo, Lim, & Dong, 2011). Unlike wheat flour-based noodles, starch noodles are produced with purified starches derived from various plant sources, such as beans, tubers and cereals (Sandhu & Kaur, 2010; Tan, Li, & Tan, 2009). In this regard, starch noodles are gluten free and thus being a potential staple food for those intolerant to gluten, such as patients suffering from celiac disease (Pruska-Kedzior et al., 2008). Industrially, the starch from mung beans is most commonly used in fabricating starch noodles, mainly due to its high amylose content (30–45%) (Dhital, Shrestha, Hasjim, & Gidley, 2013). However, commercial mung bean starch is expensive (approximately 15.0 RMB/kg). As an alternative to mung bean starch, sweet potato starch is much less expensive (approximately 8.0 RMB/kg). Additionally, sweet potatoes can be grown in poor soils with little fertilizer, pesticides and effort (Zhao et al., 2015).

Traditionally, starch noodles are mainly produced by a dropping method, which consists of five steps, i.e., preparing the binder paste and starch dough, dropping as noodles, cooking, cooling and drying (Collado & Corke, 1997). The preparation of starch dough is the first and most important stage in producing starch noodles. Due to the fact that the purified starches are gluten-free, they cannot form dough as the wheat flour does (Chansri, Puttanlek, Rungsadthogy, & Uttapap, 2005). Therefore, to form a starch dough, an exogenous binder acting as the "gluten" in wheat flour dough is necessary. Usually, a starch paste is used as the binder and mixed with dry starch and a specific amount of water to result in a viscoelastic dough (Tan, Tan, Gao, & Gu, 2007). Apparently, the starch dough is a heterogeneous system, wherein starch granules disperse in the interconnected three-dimensional network formed by the binder (Tan et al., 2009). Clearly, the starch dough is in a metastable nonequilibrium state and tends to flow and extend upon shearing and gravitational stretching, thus demonstrating both a pseudoplastic and thixotropic nature (Rao, 2007). In this sense, the production of starch noodles is intrinsically a process of rheological control, especially in the preparation of binder paste and starch dough, as well as for the dropping to form noodles (Menon, Padmaja, Jyothi, Asha, & Sajeev, 2016). Starch dough is thus an intriguing model to investigate the complex rheological behaviours of viscoelastic food

---

[*] Corresponding author. College of Food Science, Southwest University, 2 Tiansheng Road, Chongqing, 400715, PR China.
E-mail address: zhaogh@swu.edu.cn (G. Zhao).

https://doi.org/10.1016/j.foodhyd.2018.07.001
Received 25 March 2018; Received in revised form 18 June 2018; Accepted 1 July 2018

systems (Chen, 2003). Information about the rheological behaviour of starch dough is still very limited, leaving many questions unsolved. How to evaluate the processing adaptability or dropping performance of a starch dough? What is the relationship between the dropping performance and rheological properties of a dough? Do these behaviours display connections to the composition and rheological properties of the binder paste used?

Regarding the effects of the binder on the dough and starch noodles, the previous works mainly addressed the amount of binder added (Tan, Wen-Ying, Gao, & Jian-An, 2006). It was found that lower amount of binder were always accompanied with a lower viscosity and hysteresis of the starch dough. When the dough contains a small amount of binder even is free of binder, it displays a weak glutinosity but a high fluidity and thus could not form consecutive starch strands without break during dropping. On the other hand, dough with excessive binder is found to be too thick to be dropped as starch strands. In these two cases, the formation of starch noodles from dough is impossible (Tan, 2006). Despite of the amount of binder added, it is hypothesized that the rheological behaviour of the binder is another intrinsic governor of the dough's rheological nature and the production of starch noodles. However, this hypothesis has not been thoroughly tested and remains unconfirmed. To this end, the binder dependencies of the dropping performance and rheological behaviours of starch dough are explored, using the pastes from nine starches as the binders in preparing sweet potato starch dough. This investigation helps the starch dough processing steps from the experience to the science and from practice to theory and backward.

2. Materials and methods

2.1. Materials

Sweet potato starch was supplied by Chongqing Jintian Agricultural Group Co., Ltd., while potato starch and wheat starch were purchased from Wuxi Tianzhiyuan Food Co., Ltd. Cassava, pea, mung bean, rice, maize and waxy maize starches were purchased from Qinxin Food Co., Ltd. (Chongqing), Chengdu Yangtian Food Co., Ltd., Fuqiao Food Co., Ltd. (Hengshui), Lianhe Rice Co., Ltd. (Anhui), Jiaxian Food Co., Ltd. (Chongqing) and Fuyang Biological Technology Co., Ltd. (Shandong), respectively. The proximate compositions of starches were analyzed according to AACC methods (AACC, 2002), namely moisture (44-15A), starch (76-11), amylose (61-03), crude lipid (30-25), crude protein (46-13) and ash (08–17).

2.2. Preparation of starch dough and dropping of noodles

Considering the gelatinization temperature of sweet potato (72.31 °C), potato (69.80 °C), wheat (92.52 °C), cassava (68.73 °C), pea (72.07 °C), mung bean (76.48 °C), rice (83.97 °C), maize (78.05 °C) and waxy maize (75.78 °C) starches, binder starch (10 g db) was dispersed in 90 mL of water and heated in a boiling water bath for 2 min with continuous stirring to yield a totally gelatinized paste. After cooling to approximately 40 °C, the resultant paste, as the binder, was mixed with 190 g of sweet potato starch in a HM740 blender (Qingdaohanshang, Shangdong, China). With continuous stirring, water was gradually added into the mixture in 5 min to result in a final water content of 48 g/100 g wb in the mixture, with the original water content in the sweet potato starch taken into account. The mixture was further blended at 150 r/min for 10 min at 40 °C to form the starch dough (Tan et al., 2009). Then, the obtained dough was transferred into a steel gourd with holes (i.d. 2.5 cm) at its bottom, which was installed above a boiling water bath at a height of 35 cm. With the palm flap at a frequency of approximately 2 Hz, the dough evenly and continuously flowed through the gourd holes to form starch strands and vertically dropped into the boiling water to form starch noodles (Chansri et al., 2005). The diagram of starch noodle production is illustrated in Supplementary Material 1. Enlightened by the industrial practice, the dropping performances of starch doughs were evaluated in terms of the break frequency as well as the diameter (mm) of the strands and coefficient of variation (%). In determining these parameters, the dough was dropped from a steel gourd with a single hole. The break frequency was defined as the number of discontinuities that occurred of the strand in processing 390 g dough (Zhang, Kim, & Lim, 2016). The diameter of the strand was recorded 30 cm away from the bottom of the gourd by a camera (Canon EOS 80D).

2.3. Determination of rheological behaviours of the binder and starch dough

The rheological behaviours of the pasty binders and starch dough were determined using a DHR-1 rheometer (TA Instruments, USA) fitted with parallel plate geometry (40 mm diameter, 1.0 mm gap). The pasty binders from nine starches and corresponding doughs were prepared as above. Both steady shear and dynamic oscillatory shear measurements were performed at 40 °C, and the loaded samples were equilibrated for 2 min prior to test (Fu, Che, Li, Wang, & Adhikari, 2016). In steady shear determinations of the binders, the shear rate was increased step-wise from 0.01 s^{-1} to 300 s^{-1} (upward) and immediately decreased from 300 s^{-1} to 0.01 s^{-1} (downward); as for the starch dough, the shear rate was increased step-wise from 0.01 s^{-1} to 50 s^{-1} (upward) and immediately decreased from 50 s^{-1} to 0.01 s^{-1} (downward) (Temsiripong, Pongsawatmanit, Ikeda, & Nishinari, 2005). The data of shear stress (τ) and shear rate ($\dot{\gamma}$) from the upward were respectively fitted to the Herschel-Bulkley model (Equation (1)) to characterize the rheological behaviour of the binders in terms of yield stress (τ_0, Pa), flow behaviour index (n, dimensionless) and consistency coefficient (K, Pa s^n) (Chen et al., 2018).

$$\tau = \tau_0 + K\dot{\gamma}^n \tag{1}$$

Herein, τ is the shear stress (Pa), while $\dot{\gamma}$ is the shear rate (s^{-1}). Taking into consideration the severe and abnormal fluctuations observed with τ data at very high shear rates, only the data corresponding to the first smooth interval of each curve, from the beginning to the visible fluctuation point, were subjected to the fitting of the model (Fig. 1) In addition, the degree of thixotropy (Dt) of the pasty binders was expressed by the area of the hysteresis loop (s^{-1}·Pa·s) between the upward and downward curves of the steady shear within their thixotropic regions. The calculation of Dt was performed by using TRIOS software (TA Instruments, USA). To ensure valid comparisons between the obtained Dt results, they were acquired across the shear thixotropic region (0.10–5.45 s^{-1}) of all the binder pastes (Tan et al., 2007).

In dynamic oscillatory shear measurements, small amplitude oscillatory shear (SAOS) and large amplitude oscillatory shear (LAOS) were conducted, and data related to the viscoelastic properties including storage modulus (G') and loss modulus (G'') were obtained. For LAOS, deformation sweeps were conducted at a fixed frequency of 1.0 Hz (ω = 6.28 rad/s) and the amplitude of strain varied from 0.01% to 500%. The rheological parameters under LAOS were characterized by the shear modulus (G'_0) and shear exponent (β), which were obtained by fitting strain (γ_0) and storage modulus (G') data in the linear region to *Equation* 2 and non-linear region to *Equation* 3, respectively. Moreover, the complex shear modulus (G^*) was obtained from the shear storage modulus (G') and shear loss modulus (G'') via *Equation* 4 (Laguna, Vallons, Jurgens, & Sanz, 2013; Marze, Guillermic, & Saintjalmes, 2009; Ptaszek, 2017).

$$G_0{}' = \lim_{\gamma_0 \to 0} G'(\gamma_0) \tag{2}$$

$$G_0{}' \sim \gamma_0^{-\beta} \tag{3}$$

$$G^* = \sqrt{G''^{\,2} + G'^{\,2}} \tag{4}$$

From the curves resulting from LAOS, the linear viscoelastic regions (LVR) of binder pastes and doughs were determined. SAOS was conducted as a frequency sweep with an amplitude of strain 1.0% and