Food Hydrocolloids 30 (2013) 42–52

Contents lists available at SciVerse ScienceDirect

Food Hydrocolloids

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

Controlling rheology and structure of sweet potato starch noodles with high broccoli powder content by hydrocolloids

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ARTICLE INFO

Article history:
Received 8 March 2012
Accepted 1 May 2012

Keywords:
Noodles
Vegetable particles
Particle swelling
Hydrocolloids
Rheology

ABSTRACT

Incorporating high volume fractions of broccoli powder in starch noodle dough has a major effect on its shear modulus, as a result of significant swelling of the broccoli particles. Several hydrocolloids with distinct water binding capacity (locust bean gum (LBG), guar gum, konjac glucomannan (KG), hydroxypropyl methylcellulose (HPMC) and xanthan gum), were added to systems with 4 and 20% (v/v dry based) broccoli particles, and the effect of this addition on dough rheology, mechanical properties and structure of cooked noodles was investigated. Hydrocolloids with low (LBG and guar gum) and intermediate (KG) water binding capacity had no significant effect on shear rheology of the dough. Adding hydrocolloids with high water binding capacity (HPMC and xanthan gum) decreased the shear modulus of dough with 20% broccoli particles significantly. CLSM analysis of cooked noodles showed that in samples containing xanthan gum there was also an inhibition of swelling of starch granules. Strength and stiffness of cooked noodles with 20% broccoli particles were higher for samples containing xanthan gum, than samples without xanthan gum. The cooking loss and swelling index of samples with added hydrocolloids were slightly lower than samples without hydrocolloids. Our results showed that hydrocolloids with high water binding capacity can be used to control the degree of swelling of vegetable particles and starch granules in starch noodle products, and thereby control both dough rheology and textural properties of the cooked noodles.

1. Introduction

Incorporating high volume fractions of vegetable particles in pasta-like products can increase the nutritional value of these products (Gallegos-Infante et al., 2010; Torres, Frias, Granito, & Vidal-Valverde, 2007; Wood, 2009). But this incorporation has a significant effect on the rheological properties of the dough (Silva, Scholten, van der Linden, & Sagis, in press), and on the properties of cooked noodles. For example, the addition of legume flours to durum wheat semolina has been reported to cause a deterioration in the cooking quality and textural properties of these products (Petitot, Boyer, Minier, & Micard, 2010; Rayas-Duarte, Mock, & Satterlee, 1996; Torres, Frias, Granito, Guerra, & Vidal-Valverde, 2007; Zhao, Manthey, Chang, Hou, & Yuan, 2005). In recent work, we incorporated 20% (v/v) of dried broccoli particles in a starch matrix, and observed that this incorporation caused an increase in the shear modulus of the dough by two orders of magnitude, in comparison with samples without broccoli. This rather large increase in shear modulus was found to be caused by the swelling of the broccoli particles (Silva et al., in press). The swelling behavior of these particles was studied and it was found that in dilute dispersions they can swell up to 7.6 times their original volume. As a result of this swelling, at high volume fractions of particles (>11% v/v dry basis) the system can no longer be considered a dispersion of solid particles in an elastic matrix, but is in fact a cellular material in which starch granules and vegetable particles are closely packed. In the latter type of system, the modulus of the system is determined by the volume fraction and mechanical properties of the particles, whereas in a system that consists of a gelled matrix with dispersed particles, the modulus is mostly influenced by the particle volume fraction and mechanical properties of the *gel matrix* (Walstra, 2003).

The significant swelling of the broccoli particles limits the amount of vegetables which can be incorporated in the starch noodles. In the present work, different hydrocolloids were added to the starch-broccoli system in an effort to limit the degree of swelling of the particles. Five hydrocolloids in order of increasing water

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0268-005X/$ – see front matter
doi:10.1016/j.foodhyd.2012.05.002

binding capacity (locust bean gum, guar gum, konjac glucomannan, hydroxypropyl methylcellulose and xanthan gum) were selected based on their distinct water binding capacity. We study the effect of the addition of these hydrocolloids on the swelling of the broccoli particles, by studying the rheology and microstructure of noodles with 4 and 20% v/v broccoli particles. Textural properties of the cooked noodles were also studied. Several authors have studied the effect of hydrocolloids on starch and found that some hydrocolloids are capable of limiting the gelatinization of the starch granules (Chaisawang & Suphantharika, 2006; Funami et al., 2005; Khanna & Tester, 2006; Krüger, Ferrero, & Zaritzky, 2003; Shi & BeMiller, 2002; Tester & Sommerville, 2003). Based on this, our expectation was that a hydrocolloid with a high water binding capacity could diminish the swelling of the broccoli and starch particles, by competing with the particles for the available water. Limiting the extent of swelling can be used to incorporate more broccoli particles in the noodles, or to control their textural properties.

2. Materials and methods

2.1. Materials

Sweet potato starch (**SPS**) (Mong Lee Shang), was kindly supplied by Deximport (Barendrecht, The Netherlands). The hydrocolloids (**HC**), xanthan gum (**XG**), locust bean gum (**LBG**) and guar gum (**GG**) were kindly provided by Cargill Texturizing Solutions (Sas van Gent, The Netherlands). Konjac glucomannan (**KG**) and hydroxypropyl methylcellulose (**HPMC**) were purchased from Konjac Foods (Sunnyvale, USA) and Sigma–Aldrich (St. Louis, USA), respectively. Broccoli powder (**BP**) was prepared according to Silva et al. (in press). A commercial pasta product, tagliatelle verdi (1.5% spinach powder, Mamma Lucia) was bought in supermarket Real (Guetersloh, Germany) and it was used for comparison since other comparable commercial noodle products are not available on the market. Deionized water was used to prepare all samples.

2.2. Sweet potato starch and hydrocolloid dough preparation

The sweet potato starch and hydrocolloid dough was prepared by dissolving the hydrocolloid powder in the water used for the pre-gelatinization of the starch. When the hydrocolloid was completely dissolved, 10% of the total starch was added to the solution for pre-gelatinization. For pre-gelatinization, the ratio starch: water used was 1:9 and it took place in a water-bath with boiling water. The solution (hydrocolloid + water) was mixed with the starch and stirred until a homogeneous solution was obtained (≈1–2 min). After this, the dough consisting of pre-gelatinized starch and hydrocolloid was moved to a water-bath at 40 °C and the rest of the starch and water were added gradually to facilitate mixing. Stirring was continued until a uniform dough was obtained. The temperature of 40 °C is far below the gelatinization temperature, so most of the starch is not swollen and present as granules. Three different sets of samples were prepared: a so-called blank dough, with broccoli powder but no hydrocolloid added, a dough with hydrocolloid and no broccoli powder added, and a dough with hydrocolloid and broccoli powder added. Broccoli powder, 4 and 20% (v/v) was incorporated after the starch dough was prepared and the solution was stirred for 5–6 min. When broccoli powder was included, part of the starch was replaced by an equal volume of broccoli powder. The noodle recipe was based on a total water content of 55%.

2.3. Noodle production

The blank dough was placed in 10 ml syringes (Plastipak, Italy) and the noodles were produced by depressing the plunger of the syringes with a texture analyzer (TA.XT Plus, Stable Micro Systems, Surrey, UK), at 2 mm/s and with a load cell of 5 kg. After the noodles were produced, they were dried in an oven at 42.5 ± 2.5 °C for 4 h. The vegetable noodles were produced by passing the dough through a commercial sheeting/cutting machine and dried for 5 h at 42.5 ± 2.5 °C. Different times were used for the drying step so that the blank and vegetable samples had the same moisture content. Until further analysis, all the samples were kept in a desiccator. Two different methods for the production of blank and vegetable noodle were used because, when the moisture content was kept constant, the blank dough was too liquid for the sheeting/cutting machine and the vegetable dough was too tough to be extruded through a syringe.

2.4. Water binding capacity

The water binding capacity (WBC) of the hydrocolloids and broccoli powder was measured by two different methods, the Baumann capillary method, done according to Wallingford and Labuza (1983), and the centrifugation method, according to Elhardallou and Walker (1993). In the Baumann capillary method, the determination of the WBC was made by placing approximately 10 mg of hydrocolloid on top of the glass filter and measuring the water uptake over time, until equilibrium was reached. Water evaporation was also taken into account. In the centrifugation method, 1 g of sample was weighed into 50 ml plastic tubes and the samples were centrifuged (Avanti J-26 XP Beckmann, Beckmann Coulter, USA) at 16,040 g for 1 h. For both methods an average of three measurements was taken.

2.5. Shear rheology of dough

Rheological experiments were performed on the dough samples with a Paar Physica MCR 301 (Anton Paar, Austria) stress-controlled rheometer with serrated parallel plates with a diameter of 25 mm (PP25) and a gap of 1 mm.

After loading the sample in the rheometer, all the samples had a resting period of 15 min. A time sweep of 30 min at 25 °C, at a strain of 0.01% and a frequency of 1 Hz was performed after the resting period. Subsequently, a strain sweep was done, with strains from 0.001% to 10%, with a frequency of 1 Hz, at 25 °C, during 30 min. All the values that were used from the rheological measurements were taken from the linear viscoelastic region. In order to study the effect of each hydrocolloid, the results were expressed in terms of a relative complex modulus, $G_r^* \equiv G^*_{SPS+BP(+HC)}/G^*_{SPS(+HC)}$, where $G^*_{SPS+BP(+HC)}$ corresponds to the G^* of the SPS matrix containing broccoli powder (and hydrocolloid added) and $G^*_{SPS(+HC)}$ is the G^* of the SPS matrix (and hydrocolloid added).

2.6. Confocal laser scanning microscopy of dough and cooked noodles

Both dough and cooked noodles were analyzed by confocal laser scanning microscopy (CLSM). The samples were prepared as described before (Section 2.2) and were analyzed in the same day. The uncooked dough (before being processed into strands) was cut with dissecting blades in a cubic shape with the dimensions of 3 × 3 × 3 mm (approximately). The cooked noodles, that had a rectangular shape and a cross section area of approximately 5 mm^2, were cut in pieces of 3 mm length. Both dough and noodles were post-stained with a solution of 0.25% (w/w) Fluorescein 5-isothiocyanate (FITC) and 0.025% Rhodamin B in water. FITC will preferentially stain starch and Rhodamin B will preferentially stain