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A novel method to prepare gluten-free dough using a meso-structured whey protein particle system

Lieke E. van Riemsdijk [a,b], Pascalle J.M. Pelgrom [a], Atze J. van der Goot [a,*], Remko M. Boom [a], Rob J. Hamer [b]

[a] Laboratory of Food Process Engineering, Wageningen University, P.O. Box 8129, 6700 EV Wageningen, The Netherlands
[b] Laboratory of Food Chemistry, Wageningen University, P.O. Box 8129, 6700 EV Wageningen, The Netherlands

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ABSTRACT

This paper presents a novel concept for making an elastic dough using a structured protein suspension. The idea behind it is based on the hypothesis that a number of gluten properties originate from a particle structure present in the gluten network. Three different mesoscopically structured whey protein suspensions were produced: whey protein aggregates, a whey protein cold set gel and whey protein particles. Dough mixtures or batters were prepared by mixing the structured protein particle suspension with starch. Farinograph curves, small and large deformation experiments showed that the presence of a mesoscopic protein structure had a large impact on the properties of gluten-free starch mixtures. The whey protein that was structured into a mesoscopic particle suspension changed the starch mixture from a liquid into a cohesive material, having strain hardening properties.

1. Introduction

People suffering from coeliac disease - gluten intolerance - cannot enjoy the structural and functional properties that gluten provides in many food products. Due to increasing number of people having an intolerance for gluten, a need is raised for the production of breads without the gluten. A huge number of recipes are available to produce gluten-free breads. Industries, scientist, and also patients themselves are designing their own gluten-free recipes. Generally, those recipes contain many different ingredients such as hydrocolloids e.g. (Anton and Artfield, 2008; Demirkesen et al., 2010), dairy powders e.g. (Gallagher et al., 2003; Nunes et al., 2009), gelatin (Boswell et al., 2009) and gluten-free cereals. The consistency of current gluten-free mixtures is not comparable to the consistency of wheat dough, though recent studies showed great progress here e.g. (Demirkesen et al., 2010). Nevertheless, gluten-free mixtures are often batters, which do not have the elasticity that is characteristic for wheat dough. In addition, mixtures with hydrocolloids or milk powders have low values for the storage modulus and comparable values for the loss modulus giving a higher loss factor, compared to wheat dough (Lazaridou et al., 2007; Nunes et al., 2009; Witczak et al., 2010). This means that those batters are not very elastic. Mechanical properties, such as strain hardening are not reported, probably due to the fact that those batters do not form a coherent mass, which makes a large deformation test not possible. However, strain hardening of dough is reported to be a good indicator for bread-making properties (Dobraszczyk and Morgenstern, 2003).

In this paper, we present an alternative concept for the design of a gluten-free mixture. The gluten will be replaced by a protein (whey) structured at a mesoscopic scale. The use of a protein (in combination with a polysaccharide) is not new (Boswell et al., 2009), but altering the protein structure on the mesoscopic level is a new concept. We mainly focus on the mesoscopic structure, because this scale is very promising in producing product analogues, such as fat replacers and meat alternatives (Manski et al., 2007; Norton et al., 2006). In those examples, the differences at a molecular scale could be largely compensated by a correct structure at mesoscale. Here, we selected a protein (whey) that can be structured into particles of mesoscopic scale. As a result of the high degree of interactions present in the whey protein particle suspension, these whey protein particles can form a particle network. Previously, it was shown that this whey protein particle network is strongly elastic at small strain values (van

Abbreviations: db, dry basis; GDL, glucono-delta-lacton; GMP, glutenin macropolymer; ε, Henky-strain at fracture stress; RH, relative humidity; σ, stress at fracture; n, strain hardening coefficient; WP, whey protein.

* Corresponding author. Tel.: +31 317 480852; fax: +31 317 482237.
E-mail address: Atzejan.vanderGoot@wur.nl (A.J. van der Goot).

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Riemsdijk et al., 2010). The use of a whey protein suspension as a gluten alternative is based on the hypothesis that gluten contains a particle structure (Hamer and van Vliet, 2000). Although the debate on the role of mesoscopic gluten structure is still ongoing, a few things are commonly accepted. The main structure builder of gluten is the glutenin, which forms an elastic network in dough. This network is very resistant for stretching, and is thought to be responsible for the self-healing properties of gluten (Don et al., 2005; Goesaert et al., 2005; Li et al., 2003; Tipples and Kilborn, 1975). Both fast formation of physical linkage between the glutenin molecules, and strong disulfide bridges are considered to be important for the network properties (Shewry et al., 2003).

The aim of this study is, therefore, to investigate the potential of a protein–starch mixture as a gluten-free dough formulation. The protein will be structured at the mesoscopic scale using three different methods to quantify the effects of different structures on the final properties. The protein–starch mixtures will be evaluated on rheological and mechanical properties and Farinograph characteristics.

2. Experimental section

2.1. Preparation of protein structures

Three different protein structures were prepared from a whey protein (WP) solution (Davisco Foods International Inc., USA), being WP aggregates, a WP cold set gel and WP particles. The WP aggregates were prepared by heating a WP solution at 68 °C for 2.5 h. The WP particles were prepared by mixing the WP aggregate suspension with a locust bean gum (Danisco Holland BV, The Netherlands) solution and gradually decreasing the pH of the mixture through addition of GDL (Sigma Chemicals, The Netherlands). The WP cold set gel was prepared similarly to the WP particles, except for the locust bean gum addition. Upon mixing with starch in the Farinograph (see next section), it is to be expected that the WP cold set gel will be ruptured into smaller gel patches. The production procedures are schematically represented in Fig. 1. The procedures are described in more detail by van Riemsdijk et al. (2010).

2.2. Preparation of starch mixtures

Gluten-free mixtures were prepared through mixing starch (Sigma Chemicals, the Netherlands), salt (Merck, Germany) and the WP - locust bean gum suspensions in a Farinograph dough kneader. For reasons of comparison, the mixtures were diluted with locust bean gum and water to equalise the amount of WP and locust bean gum in all gluten-free mixtures. The final concentration of protein is 2.5% (w/w db), the final concentration of locust bean gum is 0.4% (w/w db) and the water percentage is 47% (w/w). The production method used for the protein particle solution restricted the protein concentration of the starch–protein mixtures to lower amounts than the protein content of normal wheat flour. The amount of water used was such that a coherent mass was obtained. Three gluten-containing reference mixtures were made. The first reference mixture consisted of Soissons wheat flour (Meneba, Rotterdam, The Netherlands), salt and water. The specific properties of this flour are described by Zalm et al. (2010). The final concentration of protein was 11% (w/w db) and the water percentage was 41%. The second and third gluten-containing reference mixtures were obtained by mixing starch, vital wheat gluten (Roquette, France), salt and water. The final concentration of gluten in the mixture was equal to that of normal wheat dough (second reference) or equal to that of the WP starch mixtures (third reference). The water percentage of the latter mixture was equal to that of gluten-free mixtures. Finally, a mixture was prepared without any protein to investigate the effect of locust bean gum. This means that the mixture only consisted of starch, salt and a locust bean gum solution. The water percentage of this mixture was equal to the other gluten-free mixtures.

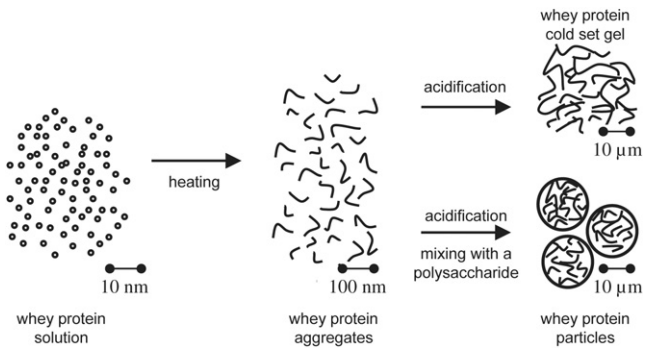

Fig. 1. Conversion of native whey protein into whey protein aggregates followed by conversion into a whey protein cold set gel or whey protein particles.

All mixtures were prepared by combining the ingredients in a 300 g Farinograph bowl (Brabender OHG, Duisburg, Germany) for 3 min using a mixing rate of 63 rpm and a temperature of 30 °C. Soissons flour, starch, gluten and salt were added before mixing, while water and protein suspensions were added during mixing within 30 s. Unless stated differently, each mixture type was prepared in duplicate and all analyses were done once for each mixture. This means that all analyses were measured in duplicate for each mixture type.

2.3. Analysis of starch mixtures

2.3.1. Protein content

The protein contents of protein suspensions and starch mixtures were determined with the Dumas method (using $N = 5.70$ for gluten and $N = 6.38$ for whey protein).

2.3.2. Small deformation measurements

Immediately after starch mixture preparation, the mixture was transferred to a Paar Physica MCR 301 (Anton Paar, Austria) stress-controlled rheometer, equipped with a serrated plate/plate geometry (diameter 25 mm – gap 1 mm) and a solvent trap. After sample loading, samples were rested for 15 min to allow relaxation of the stresses induced. This relaxation time is used more often for dough rheology (Zalm et al., 2010). Strain sweeps were performed by using a logarithmic increase of the strain from 0.001% to 400% at a constant frequency of 1 Hz and a temperature of 25 °C.

2.3.3. Large deformation measurements

The protein–starch mixtures were moulded into trapezium strips using a Kieffer mould coated with silicon oil immediately after the mixture preparation. The samples were allowed to rest inside the mould at 25 °C and 90% RH for 45 min. After resting, the sample strips were elongated using a constant deformation rate of 3.3 mm/s with a texture analyser (Instron-5564Series-Table-Model-Systems-Twin-column-design, Canton, USA) equipped with a Kieffer dough-and-gluten extensibility rig and a 50 N load cell. The sample length was 18 mm and the isosceles trapezoid cross section was 16 mm^2 ($3/5 \times 4$). At least three samples for each mixture type were tested. The force–displacement curves were transformed into stress–strain data as described by Dunnewind et al. (2004), taking into account that most of the samples had a negligible banding distance, and assuming a constant volume. The stress (σ) at fracture, the Henky-strain (ε) at fracture stress, and the