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Rheological characterisation of gluten from extensibility measurement

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Abstract

A simple tensile test set-up was built and attached to an Instron 5566 to determine gluten extensibility, comparing the performance of strong and weak flour mixed for various mixing time. In this work, the gluten strip was clamped at two ends and extended upward at the centre by a hook at speed of 300 mm min^{-1}. Parameters such as gluten length at fracture, measured force, actual force acting on the gluten strips, strain, strain rate and stress were obtained. Gluten obtained from strong flour has greater extensibility compared to weak flour. The extensibility of gluten from both strong and weak flour dough increased as dough mixing time increased before decreasing at a peak of 8 min. The results demonstrated the capability of the tensile test set-up to describe the development of gluten during mixing of dough. Rheological characteristic of gluten indicated that gluten exhibited strain hardening effect during extension.

Keywords: Curve-fitting; Extensibility; Gluten; Strain hardening; Tensile test

1. Introduction

Gluten is a cross-link of protein network developed during mixing of flour–water dough. By washing the dough under running water, the starch is removed and the remaining viscoelastic mass obtained is gluten. Nowadays, the uses of gluten in industry have been intensely applied in various food and non-food applications. Day et al. (2006) reported that due to the unique cohesive properties of gluten, it has become a commercial material in food industry including bakery, breakfast cereals, noodles, sausages and also meat substitute. Its application has been expanding to other sectors such as pet food, aquaculture feed, natural adhesives and also as biodegradable films.

Rheological properties of gluten are always being connected to the quality of its end product: textural attributes, shape and expansion (Amemiya and Menjivar, 1992; Anderssen et al., 2004; Tronsmo et al., 2003) and they had been studied in terms of small and large deformation measurements (Amemiya and Menjivar, 1992; Janssen et al., 1996; Uthayakumaran et al., 2002; Tronsmo et al., 2003). However, gluten quality measurement using large deformation is more suitable for testing gluten application as food product as it can be related to its eating quality. A material is subjected to a large deformation when the stress exceeds the yield value. A commonly adapted method for large deformation testing of dough and gluten is extension. Various instruments are available in performing the extension of dough and gluten such as the extensograph, texture analyser and Instron. In this test, the sample was clamped at two ends and pulled or extended by a hook at the centre of the sample at a constant strain rate. Large deformation is applied to the sample until it fractured and the material is unable to regain the original shape. In the past, many works were done on extensibility of gluten and dough using attachments on the Universal Testing Machine such as the texture analyser and Instron (Kieffer et al., 1998; Tronsmo et al., 2003; Dunnewind et al., 2004; Sliwinski et al.,

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Nomenclature

A_o	original cross-sectional area of gluten (mm^2)	V_t	final volume of gluten (mm^3)
A_t	final cross-sectional area of gluten (mm^2)	y_o	gluten original position (mm)
d	distance (gap) between the two clips (mm)	y_t	final hook displacement at gluten fracture (mm)
F_a	actual force (N)	α	angle of deformation (°)
F_m	measured force (N)	ε_H	Hencky strain (dimensionless)
l_o	gluten original length (mm)	$\dot{\varepsilon}$	strain rate (s^{-1})
l_t	gluten final length at fracture (mm)	σ	stress ($N\ mm^{-2}$)
V_o	original volume of gluten (mm^3)		

2004a,b). Tronsmo et al. (2003) performed a uniaxial extension on dough and gluten using the Kieffer dough and gluten extensibility rig for the TA.TX2i texture analyser to test the rheological properties. They used six different wheat flours to study the difference in the breadmaking performance and determined the maximum resistance to extension and total extensibility. Another extensional instrument used to determine the extensibility of wheat flour dough was Sentmanat Extensional Rheometer (SER) (Trevor et al., 2006). In this test, a rectangular dough sample was mounted onto two cylindrical drums and was stretched until it fractured.

The main problem encountered in performing gluten and dough extensibility tests is to hold the sample so that it breaks within the sample and not at the jaws that hold the sample. This paper focuses on gluten extensibility measurement using a new tensile test set-up attached to Instron (5566 series, Instron Corporation, USA) and also its rheological characterisation. Using this set-up, gluten extensibility was determined by studying the effect of various mixing times on the development of gluten during dough mixing. Four rheological characteristics were determined: fracture strain, fracture stress, the coefficient, k and index, n. Fracture strain and fracture stress are the points when gluten fractured at its maximum extensibility. k and n, which indicate the extensional stiffness and strain hardening of gluten respectively, were determined from curve-fitting of stress–strain curve following exponential equation, $\sigma = ke^{n\varepsilon}$. Previous studies on biaxial extension of dough (Chin and Campbell, 2005; Dobraszczyk et al., 2003) fit the stress–strain curves following the exponential equation to obtain k and n.

Mixing time is one of the processing factors that influence the gluten development during mixing other than work input, mixer type and temperature. The molecular model proposed by Belton (1999) and Létang et al. (1999) suggested that at early stage of mixing, gluten fibrils are formed as the water is in contact with flour particles. Water is responsible in hydrating the protein fibrils and started the interactions between the proteins cross-links with the disulphide bonds. Too much water added to the flour will result in slurry and too little water results in slightly cohesive powder (Faubion and Hoseney, 1989). Thus, optimum water level must be used in developing cohesive, viscoelastic dough with optimum gluten strength. As mixing proceeds, more protein become hydrated and the glutenins tend to align because of the shear and stretching forces imposed. At this stage, gluten networks are more developed by the cross-linking of protein with disulphide bonds. At optimum dough development, the interactions between the polymers cross-links become stronger and that leads to an increased dough strength, maximum resistance to extension and restoring force after deformation. When the dough is mixed past its optimum development, the cross-links begin to break due to the breaking of disulphide bonds. The glutenins become depolymerised and the dough is overmixed. The presence of smaller chains in the dough makes the dough stickier. Two types of flour were used in this study as different wheat flour has different optimum mixing time (Hoseney, 1985). Longer mixing time is expected for mixing dough from strong flour. It is probably due to the dense particles of strong flour through which water penetrates slowly (Hoseney, 1985). Sliwinski et al. (2004a) reported that a positive correlation was observed between mixing time and the percentage of glutenin protein on total protein in flour. The effect of mixing time on the rheological properties of gluten has been investigated by Amemiya and Menjivar (1992), Janssen et al. (1996) and Létang et al. (1999).

2. Materials and methods

2.1. Dough preparation

Two types of flour, Diamond N (12.33% protein) and SP-3 (8.81% protein), were used in this study and they are referred as strong and weak flour, respectively. Doughs were prepared by mixing 200 g flour with water (63.4% for strong flour; 59.5% for weak flour) in mixer (5K5SS, KitchenAid, Belgium) for various mixing times: 3, 5, 8, 11 and 15 min. Treated drinking water was used to avoid any effect or reaction from other minerals on the protein of flour during flour–water mixing. Dough was left to stand in water for 1 h at room temperature to rest (AACC, 1976).