Journal of Cereal Science 60 (2014) 346–351

Contents lists available at ScienceDirect

Journal of Cereal Science

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

Rheological properties of pasta dough during pasta extrusion: Effect of moisture and dough formulation

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ARTICLE INFO

Article history:
Received 24 February 2014
Received in revised form
22 May 2014
Accepted 30 May 2014
Available online 21 June 2014

Keywords:
Capillary rheology
Pasta
Dough
Extrusion

ABSTRACT

A study was conducted to investigate the effect of dough formulation and hydration level on the rheological properties of pasta dough during pasta extrusion. Semolina 100%, whole wheat 100%, and the following mixtures semolina-whole wheat (49:51), semolina-flaxseed flour (90:10), whole wheat-flaxseed flour (90:10), and semolina-whole wheat-flaxseed flour (39:51:10) were the formulations used for the experiments. Dough was hydrated at 30, 32, and 34% moisture content. Pasta was extruded with a capillary and a semi-commercial pasta extruder to determine the apparent viscosity of the dough during extrusion conditions and its relationship to the behavior of the dough during pasta processing. Results showed that non-traditional pasta dough behaved like a shear thinning fluid that can be described by the Power Law model. Increased hydration levels and/or presence of flaxseed flour on the dough formulation decreased the apparent viscosity of the dough, which correlated with extrusion pressure, mechanical energy, and specific mechanical energy that were required to extrude the dough in the pasta extruder. The strong correlations found between the apparent viscosity of the dough and the pasta extrusion parameters indicates the possibility of using a capillary rheometer to determine the appropriate hydration level of ingredient formulations before extruding with a pasta press.

1. Introduction

Nowadays, consumption of fortified food products is becoming a new trend (Rodrigo and Vadillo, 2004). In that regard, pasta is a staple food product that can be fortified with non-traditional ingredients, being especially important those that contribute to improve the essential amino acids and essential fatty acids profile or that increase the fiber, vitamins, and mineral content (Bahnassey and Khan, 1986).

Both flaxseed flour and whole wheat flour can be considered as good candidates for pasta fortification due to the health benefits they both provide when consumed (Liu, 2007; Cardoso-Carraro et al., 2012). Fortification of pasta products with flaxseed flour or whole wheat flour have been previously studied by several authors (Hirawan et al., 2010; Manthey et al., 2002; Manthey and Schorno, 2002; Sinha and Manthey, 2008; Villeneuve et al., 2013; Yalla and Manthey, 2006), however the effect of the inclusion of both flaxseed and whole wheat flour together in pasta formulation has not been studied.

The addition of different raw materials during pasta dough preparation involves changes at different levels of the pasta production process (Roda, 2013). It has been observed that when pasta dough is fortified with non-traditional ingredients, it behaves differently than when only semolina is present (Rayas-Duartes et al., 1996). The presence of flaxseed flour or whole wheat flour alters the extrusion pressure, mechanical energy, extrusion rate and specific mechanical energy of pasta products (Yalla and Manthey, 2006). These changes in pasta extrusion parameters are attributed to the effect of non-traditional ingredients in the rheological properties of the pasta dough. Rheology influences the machinability, processing conditions and quality of products (Chillo et al., 2010). Subsequently, the study of dough rheology is important to the understanding of the effect of non-traditional ingredients in the flow properties of pasta dough during extrusion.

Rheology studies the flow and deformation of materials e.g. wheat doughs, under the action of stresses (Bagley et al., 1998).

Abbreviations: ER, Extrusion rate; EP, Extrusion pressure; ME, Mechanical energy; S, Semolina; SFF, Semolina-flaxseed flour; SME, Specific mechanical energy; SWW, Semolina-whole wheat flour; SWWFF, Semolina-whole wheat flour-flaxseed flour; WW, Whole wheat flour; WWFF, Whole wheat flour-flaxseed flour.

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http://dx.doi.org/10.1016/j.jcs.2014.05.013
0733-5210/

Rheological characteristics of cereal doughs using a capillary rheometer, especially for bread making applications, have been previously described in the literature (Bagley, 1998; Cuq et al., 2002; Hicks and See, 2010; Singh and Smith, 1999). Cuq et al. (2003) has reported the visco-plastic behavior of fresh pasta and the textural changes that pasta exhibits with changes in moisture content and temperature by using a modified TA-XT2 instrument. Other authors have studied the rheological behavior of plain and fortified semolina and flour dough through farinograph, and mixograph studies (Bahnassey and Khan, 1986; Baiano et al., 2011; Doxastakis et al., 2007; Kovacs et al., 1997). However, the behavior of semolina dough during extrusion has not been extensively studied from a rheological standpoint (Chillo et al., 2010; Le Roux and Vergnes, 1995).

Capillary rheology is a technique based on the application of high stresses and high shear rates during the extrusion of the material through a capillary die (Macosko, 1994). Determination of the pressures necessary to force the material through the capillary die with a given flow rate as well the expansion swelling at the exit of the capillary enable the determination of shear and extensional viscosity of the material (Macosko, 1994). The concept of capillary rheology is similar to fluid flow in pipes and extrusion dies, which makes it suitable to study the rheological properties of extruded products (Macosko, 1994). A capillary rheometer can be adapted to the characterization of shear sensitive fluids such as wheat flour dough (Cuq et al., 2002) therefore its utilization for the characterization of pasta dough is justifiable.

The objective of this experiment was to characterize the rheological behavior of pasta dough under extrusion conditions in a semi-commercial extruder with the help of a capillary rheometer when the dough formulation and hydration level was varied. For that purpose, pasta dough was fortified with whole wheat flour and/or with flaxseed flour and the hydration level of the dough was varied from 32%, commonly used for traditional semolina pasta products, to 30% and 34% which yield under-hydrated and over-hydrated traditional pasta products, respectively.

2. Materials and methods

2.1. Raw material

Tests were performed using a commercial standard semolina (Durakota No.1) from North Dakota Mill (Grand Forks, ND) and whole wheat flour (Ultragrain) from ConAgra Foods (Omaha, NE), with a protein content of 12.1 and 10.9%, 12% mb respectively. Flaxseed flour was obtained by milling golden flaxseed on a pilot scale hammer mill (Fitzmill, Elmhurst, IL). The ground flaxseed was separated into fine (<600 μm) and coarse particles (>600 μm) by using a sieve with a 34XXG mesh screen. Only the fine fraction was used in the pasta dough formulation.

Nine different pasta formulations were prepared: Semolina 100% (S), whole wheat flour 100% (WW), and a blend of semolina:whole wheat flour (SWW) were the three base formulations. In order to be labeled as a whole wheat product, pasta needs to contain a minimum of 51% whole wheat flour; hence, the blend semolina:whole wheat contained a ratio 49:51. Each of the basic formulations was fortified with 10% of flaxseed flour (FF) to give semolina-flaxseed flour (SFF) (90:10), whole wheat flour-flaxseed flour (WWFF) (90:10) and semolina-whole wheat flour-flaxseed flour (SWWFF) (35:51:10).

2.2. Rheological studies

A twin-bore RH 2000 Rosand capillary rheometer (Malvern Instruments, Southborough, MA) was used to measure the shear viscosity of the pasta dough. The ingredients were mixed for 1 min in a Kitchen Aid™ mixer (Troy, Ohio, USA) and then loaded on to the rheometer. The rheometer was preheated to 45 °C, the temperature at which pasta extrusion normally occurs. Temperature was controlled by 3 heaters along the length of the barrel. For the current experiment, only the left barrel was used. The diameter of the barrel was 24 mm and approximately 88 g of material was required to fill it. The capillary die used had an *L/D* ratio of 8 (32 × 4 mm). The rheometer piston was brought into contact with the dough for the preconditioning step. The dough was allowed to rest in the barrel for 3 min to allow the dough to relax and equilibrate at 45 °C without significant moisture loss (Hicks and See, 2010). The experiment was performed by measuring the extrusion pressure required to extrude the dough at piston speeds of 21.4, 52.6, 129.8, and 320 mm/min. The software, Flowmaster (Mentor Graphics, Wilsonville, Oregon), was programmed to measure the viscosity readings only when pressure equilibrium was reached. Some samples took longer to reach pressure equilibrium, so more than one load was tested to the get a steady pressure measurement for the four selected piston speeds. Triplicate readings of pressure were recorded for each piston speed using freshly prepared dough.

Shear stress at the capillary wall (τ_w) was determined using Eq. (1).

$$\tau_w = \Delta P/(4 \cdot L/D) \tag{1}$$

where τ_w is shear stress in kPa, ΔP is the pressure exerted in the dough in a kPa, and *L/D* is the ratio of length and diameter of the capillary, a dimensionless number.

The apparent shear rate was calculated by using the flow rate at which the dough was extruded, *Q*, and the radius *R* of the capillary die.

$$\dot{\gamma}_{app} = 4 \cdot Q \Big/ \pi \cdot R^3 \tag{2}$$

Q (m^3/s), was calculated by multiplying the extrusion speed of the dough at the capillary die (m/s) by the area of the capillary die ($\pi \cdot R^2$) (m^2). The true wall shear rate ($\dot{\gamma}_w$) was obtained by applying the Rabinowitch correction:

$$\dot{\gamma}_w = 1/4 \cdot \left(3 + d\left(\log \dot{\gamma}_{app}\right) \Big/ d(\log \tau_w)\right) \dot{\gamma}_{app} \tag{3}$$

Using the shear stress and shear rate calculated from Eqs. (1) and (3), respectively, the power law model was fitted to obtain the consistency index, *k*, and the flow index, *n*, for each dough formulation-hydration level combination. The power law model is described by Eq. (4).

$$\tau_w = k \dot{\gamma}_w^n, \tag{4}$$

Units of the consistency index *k* are in kPa s^n and the flow behavior index *n* is dimensionless. The power law model was utilized to build flow curves for each dough formulation-hydration levels combination according to the following equation:

$$\eta = f(\dot{\gamma}) = \frac{\tau_w}{\dot{\gamma}_w} = \frac{k \dot{\gamma}_w^n}{\dot{\gamma}_w} = k \dot{\gamma} w^{n-1} \tag{5}$$

The variable η is the apparent viscosity of the dough and is expressed in kPa s.

2.3. Pasta processing

A total weight of 1000 g of the different dough formulations were hydrated to 30, 32, and 34% moisture and extruded using