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Relationships between wheat flour baking properties and tensile characteristics of derived thermoplastic films

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ABSTRACT

This work was aimed at defining models to explain tensile properties of thermoplastic films derived from common wheat flours as a function of source flours characteristics. A total of 26 flours, two blends from an industrial mill and 24 single-cultivar flours collected over three different years of grain production (from 2013 to 2015) and cultivar grain hardness (from soft to hard) were used in a wide range of protein content (from 9.0 to 16.2%) and values of Chopin's alveograph parameters (as indexes of gluten characteristics), i.e., P (from 27 to 160 mm), L (from 32 to 236 mm), P/L (from 0.13 to 4.44), and W (from 63 to 398). The same plasticization recipe and filming procedure was adopted for all manufactures. The maximum tensile strength ($\sigma_{\max}$) and the elongation at break ($\varepsilon_{\max}$), as well as the elastic modulus (E), stiffness (k) and energy at break (w_b) of films from flours having moderate to high values of P (>60 mm), P/L ($\geq$0.43) and W (>170) were positively correlated to P and negatively correlated to P/L and W, with all the variables significant (p-value <0.05) and $R^2 = 0.72$ for $\sigma_{\max}$, 0.62 for $\varepsilon_{\max}$, 0.81 for E, 0.83 for k and 0.72 for w_b. The $\varepsilon_{\max}$ of films obtained from flours having moderate to low values of P ($\leq$45 mm), P/L ($\leq$0.42) and W ($\leq$160) was negatively correlated to P, L and P/L, and positively correlated with W, with all the variables significant (p-value <0.05) and $R^2 = 0.86$. On the contrary, no relationship was found for the $\sigma_{\max}$, as well as for E, k and w_b of these films. Results encourage further research aimed at improving the robustness and reliability of models so that tensile properties of a thermoplastic film can be predicted for any given source flour.

1. Introduction

The use of wheat flours to obtain bioplastics has been proposed about a decade ago (Leblanc et al., 2008) as an energetically and economically cheap alternative to purified starch, giving similar physical properties to manufacture, except for a lower strain-to-break. Low protein flours have been tested for this purpose (Saiter et al., 2012; Terrié et al., 2010), based on the assumption that high protein ones should better be devoted to food. Although this is a shareable opinion, our belief is that a research study on this subject should consider all kinds of flours in order to draw general laws between wheat flour characteristics and bioplastic performances. Moreover, several contingencies may occur (e.g. above-threshold presence of mycotoxins or chemicals, low technological quality for food industry, mill surplus) that cause flours have a destination alternative to food.

It is well documented in the literature that wheat flours may differ much for composition and characteristics, depending on the cultivated variety (i.e. the cultivar), the crop cultivation technique, the climate and soil environment, the season weather, the grain storage duration and conditions, the milling procedure (Ghodke et al., 2009; González-Torralba et al., 2013; Hadnadev et al., 2013; Morris, 2002). All this factors may affect the contents of starch and gluten (i.e. the structural protein pool), which both go through plasticization when the flour is plasticized (Montano-Levya et al., 2013; Reddy and Yang, 2011; Zárate-Ramírez et al., 2011).

Starch is the main component of the grain and its percent content is of relevance, together with the shape and size of starch granules, because this affects the interaction with the plasticizer. Similarly, the strength of adhesion between the starch granules

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and protein matrix, which is revealed by the grain hardness, may affect the percent of damaged starch during milling (which affects the starch–plasticizer interface), the thermal behaviour of starch (Eliasson et al., 1995), the water absorption of flour (Rahman et al., 2000), and thus the flour suitability to plasticization (Da Róz et al., 2006). The grain hardness is strictly dependent on the wheat cultivar (Morris, 2002).

As far as gluten is concerned, it represents an ideal raw material for bioplastics production due to the presence of many polar and non-polar amino acids providing a broad spectrum of functional and structural properties (Guilbert and Cuq, 2005). It consists of two different proteic fractions, glutenins and gliadins, having different molecular weights and properties (Wrigley et al., 2006). From a baking point of view, glutenins are known to give the dough resistance to deformation (tenacity), whereas gliadins give the dough extensibility (Prabhasankar et al., 2000). These properties may be quantified by making a dough with standard procedure from wheat flour and water and testing its deformation by a Chopin's alveograph, where dough disks are blown by an air flow until bubble explosion. In the outcoming alveogram, the maximum value in the *y*-axis represents the maximum pressure (*P*) needed to start blowing the dough disc, i.e. the tenacity of the dough; the maximum value on the *x*-axis is the time needed to blow up the bubble, i.e. the extensibility of the dough; the *P*/*L* ratio indicates the curve shape; and the integral of the curve, i.e. its width (*W*), expresses the deformation energy of the dough. Gluten composition and dough alveographic performance are primarily dependent on the genotype (Costa et al., 2013).

All the aspects above are expected to affect the suitability of a wheat flour to be plasticized, the plasticization yield, the rheologic and mechanical features of bioplastics and their biodegradability (Dahesh et al., 2014; Nafchi et al., 2013; Rahman et al., 2000; Saiah et al., 2009). Thus, finding out correlations between the characteristics of source flours and properties of plasticized films would allow to tailor flour selection and blending according to film requirements.

However, to the best of our knowledge, the correlation between the properties of plasticized films and the characteristics of flours, even from sources other than wheat, has never been studied in the past: for example, Patil et al. (2005) demonstrated that pressure and net torque in extrusion cooking were highly correlated with die temperature and moisture content of the feed, while Dowell et al. (2008) studied how the dough quality of different wheat flours can be combined into models to predict bread quality. Recently, Arun Kumar et al. (2015) analyzed the effect of processing variables on the responses of extrudates manufactured from different blends of sorghum and soybean. Interestingly, Ganjyal et al. (2006) and Shihani et al. (2006) developed neural network (NN) models for prediction of individual product properties, such as expansion ratio, water solubility index, and water absorption index. As far as thermoplastic films are concerned, a first work on the optimal formulation for the preparation of amaranth flour films plasticized with glycerol and sorbitol was carried out by Tapia-Blácido et al. (2011), whereas no literature is available that correlates thermoplastic film properties with flour characteristics. Only a recent work by Puglia et al. (2016), concerning films derived from wheat flours, gave some preliminary results on this. In that study, eight single-cultivar flours were considered, differing for grain hardness, protein content, *W*, *P*, *L*, *P*/*L*. After defining an appropriate recipe and procedure to plasticize wheat flours and extrude plastic films, the authors found that the maximum tensile strength and elongation at break of films depended on grain hardness and Chopin's alveograph parameters. However, in the study by Puglia et al. (2016) the number of tested flours was low and the experiment was planned to allow just pairwise comparisons between flours. In other words, there was no series of three or more flours varying for just one parameter (i.e. origin, milling, hardness, protein content, *W*, *P*, *L*, *P*/*L*) and this did not allow to define general relationships between baking properties of flours and mechanical properties of plastic films. For this reason, in the present work a greater number of flours in a wide range of baking properties was tested, with the aim of finding out general relationships with the mechanical properties of films.

2. Materials and methods

2.1. Flours and their characteristics

A total of 26 flours were plasticized, 24 single-cultivar flours obtained by laboratory mills, plus two blends provided by industrial mills (Table 1). 22 single-cultivar flours were obtained in the ASSAM (Agenzia Servizi Settore Agroalimentare delle Marche) laboratory of Jesi (Ancona Province) from grains harvested in cultivar evaluation trials carried out near Jesi across three growing seasons (2012/2013, 2013/2014, 2014/2015), the other two (Albachiara and Aquilante) were provided by CoNaSe (Consorzio Nazionale Sementi) Conselice (RA). The two blends were provided by the Spigadoro Mill of Bastia Umbra (Perugia Province). Table 1 reports the grain hardness of cultivars and the protein % content (except for blends) and the values of alveographic parameters of all the flours. Each value reported in the table is derived from the average of five alveograms obtained from five dough disks. Single-cultivar flours were obtained by laboratory mills either for ASSAM (Labormill, 4.RB., R. Bona srl, Italy) or CoNaSe (Chopin CD1) with standardized calibration and procedure. The use of single-cultivar flours was aimed at having well defined baking properties and limit their variability across years and environments, based on the fact that these properties are primarily determined by the genotype.

Overall, the 26 flours represent a wide range of flours, derived from grains with different hardness, and differing for protein content (from 9.0 of Artico to 16.2 of Albachiara) and alveographic parameters: *P* (from 27 mm of Mantegna to 160 mm of Exuma), *L* (from 32 mm of Tintoretto to 236 mm of Aquilante), *P*/*L* (from 0.13 of Aquilante to 4.44 of Exuma) and *W* (from 63 of Mantegna to 398 of Spigadoro Blend 2). It is worth to notice that the *P*, *L* and *P*/*L* values of Exuma, as well as the *L* and *P*/*L* values of Tintoretto, are to be considered unlikely for common wheat and actually outlier, due to a very strange weather pattern in 2014, but they were included anyway to exploit the maximum available range of flours.

2.2. Plasticization, filming and measurements on films

The same recipe was adopted for each flour (Puglia et al., 2016): flour (68%, w/w), glycerol (23%, w/w), magnesium stearate (1.8%, w/w), sorbitol (5.2%, w/w), PVA in aqueous solution PVA/water 1:20 (2%, w/w). All chemicals used for plasticization were bought from Sigma–Aldrich. This recipe was selected on the basis of most used concentrations found in literature for glycerol plasticized starch (Saiter et al., 2012); in particular, glycerol and sorbitol act as plasticizers, in synergy with water, while magnesium stearate is usually selected as lubricant in plastic processing. The polymeric additive (PVA) is generally used in combination with starch/flour, due to its good film-forming capability and water solubility. All the values were chosen regardless of the specific characteristics of the wheat flour and applied for all the flours without any variation, in order to establish a comparative set of samples. Thermoplastic films were obtained by using a twin-screw microextruder (DSM Explorer 5&15 CC Micro Compounder) provided with a microfilm die and coupled with a line for cast film (DSM Film Device). All the ingredients were mixed at low speed in a laboratory mixer (planetary mixer, 60 rpm for 3 min), then the mix was introduced in the extruder and a further mixing was obtained at 30 rpm for 3 min.