Chapter

Effect of Polyethylene Glycol 3350 on the Handling Properties of Low Salt Wheat Dough Formulations

Andrea K. Stone, Aleksandar Yovchev, Pierre J. Hucl, Martin G. Scanlon and Michael T. Nickerson

Abstract

The effect of polyethylene glycol (PEG) 3350 addition (3%, flour wt. basis) on the properties of dough made from two Canadian Western Red Spring wheat cultivars (*Triticum aestivum* L. 'Harvest' and 'Pembina') differing in dough mixing requirements and dough-handling properties was investigated in a low salt dough formulation (1% NaCl, flour wt. basis). PEG was added for experimental purposes to alter water mobility to better understand underlining mechanisms, however would not be used in real bread formulations. For cultivar Harvest, but not Pembina, dough stickiness was reduced by the addition of PEG. Dough freezable water content decreased with the addition of PEG for both cultivars. Rheological measurements showed that PEG increased dough stiffness as measured by the complex modulus $|G^*|$. Creep measurements indicated that the relative elastic component (J_{el}) increased whereas maximum deformation (J_{max}) decreased with the addition of PEG for cultivar Harvest only. Dough made with a weaker cultivar (Harvest) with the addition of PEG performed similarly to dough made with a stronger cultivar (Pembina) without PEG. Results indicate that in a low sodium environment, availability of water is critically important for controlling a number of properties that relate closely to dough machinability, especially in a weaker wheat cultivar.

Keywords: dough stickiness, polyethylene glycol 3350, dough rheology, wheat cultivar, sodium chloride

1. Introduction

Wheat flour dough in its most basic form (flour and water) is a complex diverse system comprised of starch and non-starch polysaccharides, gluten proteins, enzymes, etc. Dough components can be solubilized or adsorbed using different amounts of water as the water moves between the different phases during mixing. Water becomes either bound or remains free within the dough and this, along with the initial quantity of water added, affects the rheological properties of the dough which in turn governs its machinability [1, 2]. Reducing salt in bread is a major goal in global salt reduction strategies due to the ubiquitous nature of bread in the diet. Salt is a necessary ingredient in large scale bread production contributing to its flavor, and more importantly, to the physicochemical properties of the dough.

Sodium and chloride ions increase the ordering of water structure which promotes protein–protein hydrophobic interactions. These hydrophobic interactions are the major factor involved in the formation of the gluten network which imparts the viscoelastic dough properties required for baking [3, 4]. Without the addition of salt, dough becomes sticky when mixed due to the over hydration of the gluten proteins [5]; stickiness is a major limiting factor of salt reduction. A sticky dough will cause problems in a bakery throughout the production process, from dough sticking to mixing equipment to a decrease in bread yield [6, 7].

Osmotic regulators such as polyethylene glycol (PEG) represent an experimentally applicable means of altering water availability to gluten to better understand the underlining mechanisms involved within a low sodium environment. However, it would not be used in real dough/baking applications since its known to cause nausea, abdominal pain cramping and gas, and/or cause allergic reactions upon consumption. PEG is a water soluble non-ionic surfactant, which contains the repeat unit (–O–CH_2–CH_2–), where the hydrophilic oxygen are separated by the hydrophobic ethylene units, with a terminal end of H or OH [8]. In previous work Yovchev et al. [9] reported PEG 400 to be a dough softener however no significant differences were found between PEG of different molar masses (PEG 400, ~1600, 3350) on dough rheology or freezable water content when added at a concentration of 1% (flour weight basis). Preliminary work (data not shown) indicated that when the PEG addition level was increased from 1 to 3%, doughs with PEG 3350 behaved much differently than those with the lower molecular weight PEG (PEG 400). Based on this and the previous study [9] the amount of PEG 3350 was increased to 3% and the objective of this study was to investigate how this desiccant would affect dough rheology (stickiness and mechanical properties) and dough water distribution (freezable water content) in low salt (1% NaCl, flour weight basis) formulations as a tool to better understand the impact of water mobility in dough handling.

2. Materials and methods

2.1 Dough formulation and preparation

Two Canadian Western Red Spring (CWRS) wheat cultivars (*Triticum aestivum* L. 'Harvest' and 'Pembina') were used in this study. Historical breeder data was used in order to select a strong (Pembina) and weak (Harvest) cultivar based on gluten strength. The dough formulation consisted of 10 g flour (14% moisture basis), 0.1 g salt (NaCl), optimal water content and either with or without PEG 3350 (0.3 g). Optimal water absorption was determined from the Farinograph absorption of each cultivar (64.9% for Harvest and 62.0% for Pembina). Dough samples were mixed to peak development using a 10 g mixograph (TMCO National Mfg., Lincoln, NE).

2.2 Stickiness measurements

Dough stickiness measurements were performed using a TA.XTPlus texture analyzer with a Chen-Hoseney dough stickiness cell [10], a 25 mm perspex cylinder probe and 5 kg load cell (Texture Technologies, Stable Micro Systems, Ltd., Surrey, UK). The compression force was 40 gf, pre-test and test speed 0.5 mm/s, post-test speed 10 mm/s, return distance 15 mm, contact time 0.1 s, trigger force 5 gf, and a force vs. time curve was generated. Dough stickiness was taken as the maximum positive force (gf) of the curve. Measurements were performed in duplicate.

2.3 Differential scanning calorimetry (DSC)

Freezable water content (FWC) was measured with DSC Q2000 (TA Instruments, New Castle, DE, USA) containing a refrigerated cooling system. A small piece of dough (~15 mg) was weighed into an aluminum DSC pan then hermetically sealed. An empty pan was used as reference. The pans were equilibrated at 30°C for 5 min then cooled and held at −40°C for 5 min followed by heating to 40°C. The cooling/heating rate was 10°C/min. The freezable water content was calculated directly from the enthalpy (ΔH) of melting peak divided by the enthalpy of pure water, and expressed per gram dry matter. Measurements were performed in triplicate.

2.4 Dough rheology

Dough rheological properties were determined using an AR-1000 rheometer (TA Instruments, New Castle, DE, USA), with a 40 mm parallel plate. A 10 min rest period was employed after the dough was positioned between the plates and the gap was set to 2 mm. An oscillatory frequency sweep from 0.1 to 100.0 Hz was performed at a constant strain of 0.1% (within the linear viscoelastic region). Immediately after the frequency sweep, a creep recovery protocol was carried out on the same dough sample according to the method of Jekle and Becker [11]. For 180 s a shear stress of 250 Pa (τ0) was applied then removed and relaxation was recorded for 360 s to reach a steady state of recovery. Strain was recorded as a function of time and data was collected based on compliance using Eq. (1):

$$J(t) = \gamma(t)\,\tau_0^{-1} \tag{1}$$

where J is the compliance, γ is the strain, and τ_0 is the constant stress which was applied during the creep phase. The creep compliance J_{max} is the shear deformation at t = 180 s of the creep phase. The creep recovery compliance J_r (at t = 360 s of the recovery phase) is a measure of the mechanical energy stored in the sample during the creep phase. The relative elastic part J_{el} [−] was reported using Eq. (2):

$$J_{el} = J_r(J_{max})^{-1} \tag{2}$$

All measurements were performed at a constant temperature of 30°C. Measurements were performed in triplicate.

2.5 Statistical analysis

A one way analysis of variance was performed with a Tukey test to measure differences among means using SigmaStat 4.0 (Systat Software Inc., San Jose, CA, USA).

3. Results and discussion

3.1 Dough stickiness

The stickiness (gf) values for cultivars Harvest and Pembina with and without the addition of PEG 3350 are reported in **Table 1**. Cultivar Harvest produced a much stickier dough than Pembina (86.5 vs. 47.5 gf). Under low salt conditions the addition of PEG significantly decreased dough stickiness (86.5 to 56.3 gf) for cultivar Harvest, whereas for Pembina the stickiness remained unchanged. The addition of PEG induced a greater decrease in stickiness for cultivar Harvest than for Pembina which was most likely due to the higher starting stickiness value of Harvest. With the addition of PEG, a wheat cultivar prone to stickiness (Harvest) could behave more like a stronger wheat cultivar (Pembina) not containing PEG which is hypothesized to be due to the uptake of excess water by PEG in the dough made with Harvest resulting in better dough machinability. It is known that an increase in water content of a dough increases dough stickiness [11, 12].

3.2 Freezable water content

The freezable water content of the doughs with and without PEG was studied to find that the addition of PEG decreased the freezable water content in the dough for both cultivars (**Table 1**). The decrease was approximately the same magnitude for both cultivars; 0.50 to 0.42 g ice/g db for cultivar Harvest and 0.45 to 0.37 g ice/g db for Pembina. This decrease in the freezable water relates to more water molecules being bound in the dough and less free water in the system. It is hypothesized that the water molecules are bound to PEG and constrained in their mobility and as a result, gluten is less hydrated. Doughs made with cultivar Harvest contained more unbound water than dough made with Pembina as seen from the higher freezable water values for Harvest; this causes Harvest to produce stickier doughs than Pembina. The DSC results of PEG decreasing freezable water correspond to the texture analyzer results of PEG decreasing dough stickiness values in cultivar Harvest since free water in the dough contributes to dough stickiness [12, 13].

3.3 Rheological properties

The oscillatory shear measurements and creep recovery results are reported in **Table 1**. Overall the rheological measurements demonstrate that cultivar Pembina produces a stronger gluten network than Harvest. The complex shear modulus |G*| recorded at 1 Hz increased with the addition of PEG for both cultivars, but

	Harvest		Pembina	
	No PEG	**With PEG**	**No PEG**	**With PEG**
Stickiness (gf)	86.5 ± 9.2^{a}	56.3 ± 0.7^{b}	47.5 ± 1.4^{b}	44.7 ± 1.5^{b}
Freezable water (g ice/g db)	0.50 ± 0.01^{a}	0.42 ± 0.01^{b}	0.45 ± 0.02^{c}	0.37 ± 0.00^{d}
G' (10^3Pa)	5.5 ± 0.2^{a}	9.2 ± 0.2^{b}	8.3 ± 0.3^{b}	10.5 ± 0.6^{c}
G" (10^3Pa)	2.2 ± 0.1^{a}	4.0 ± 0.1^{b}	3.1 ± 0.1^{c}	4.4 ± 0.2^{d}
|G*| (10^3 Pa)	5.9 ± 0.2^{a}	10.0 ± 0.3^{b}	8.9 ± 0.3^{c}	11.3 ± 0.6^{d}
Tan δ	0.41 ± 0.01^{a}	0.44 ± 0.00^{b}	0.38 ± 0.00^{c}	0.42 ± 0.00^{d}
J_{el}	0.46 ± 0.03^{a}	0.66 ± 0.01^{b}	0.68 ± 0.01^{bc}	0.71 ± 0.01^{c}
J_{max} (10^{-3} Pa^{-1})	4.36 ± 0.28^{a}	2.00 ± 0.01^{b}	1.64 ± 0.00^{bc}	1.49 ± 0.13^{c}

Values are reported as the mean ± standard deviation.
Means in each row followed by different letters are significantly different ($p < 0.05$).
Oscillatory frequency sweep measurements (G', G", |G|, and tan δ) at 1 Hz.*

Table 1.
Stickiness values, freezable water content, and rheological properties of wheat doughs with and without 3% (flour weight basis) PEG 3350.

the magnitude of increase was much greater for Harvest (5.9–10.0 10^3 Pa) than for Pembina (8.9–11.4 10^3 Pa), which was due to the stronger gluten network formed by Pembina without PEG. Cultivar Pembina with PEG produced the stiffest dough with the highest |G*| value out of the four doughs whereas Harvest without PEG had the lowest |G*| value. Despite this stiffening of dough by PEG, it does not improve the gluten network since the tan δ (taken at 1 Hz) of both cultivars increased. PEG addition increased both the loss (viscous) and storage (elastic) modulus of the dough, however the magnitude of increase was larger in the loss modulus therefore the tan δ (G"/G') increased (**Table 1**). It is hypothesized that the PEG is concentrating the gluten network and dough polymers making it stronger, and therefore increasing the G' values, while also having an independent plasticizing effect on the dough which increases the G" values. At a lower molecular weight PEG is predominantly a dough plasticizer [9]. Forces between PEG and proteins are primarily repulsive [14]. From the creep recovery test the relative elastic part, J_{el}, and maximum deformation, J_{max}, were reported. The relative elastic part increased with the addition of PEG for cultivar Harvest to a comparable level with Pembina without PEG, whereas PEG had no significant effect on the dough elasticity as measured by J_{el} for Pembina. The maximum deformation of the dough was greatly reduced for doughs made with cultivar Harvest containing PEG; the J_{max} decreased from 4.36 to 2.00 10^{-3} Pa^{-1}. There was a significant difference between the two cultivars used with Pembina deforming less than Harvest, however Harvest with PEG (J_{max} 2.00 10^{-3} Pa^{-1}) deformed to a similar level as Pembina without PEG (J_{max} 1.64 10^{-3} Pa^{-1}). Therefore, PEG is substantially increasing the short-term relaxation of gluten in the weak cultivar, but because PEG effectively ties up water molecules, water is unavailable to facilitate large deformation of either dough over a longer timescale.

4. Conclusions

The interactions between water and wheat flour components are responsible for dough machinability. The addition of PEG 3350 to a low salt dough formulation improved dough machinability of a weaker flour cultivar (Harvest) by tying up the water. For cultivar Harvest the addition of PEG 3350 decreased dough stickiness, increased dough stiffness (|G*|) and dough elasticity (J_{el}), and decreased dough deformation (J_{max}). All of the aforementioned measurements for Harvest with PEG gave values similar to the stronger wheat cultivar, Pembina, without the addition of PEG. The addition of PEG 3350 also decreased the freezable water content of the doughs made from either cultivar indicating that PEG was removing free or loosely bound water from the dough polymer network. The use of a strong osmotic regulator, such as PEG 3350, in the present experiments, highlights the role of water mobility in governing dough stickiness. It is important to note, PEG 3350 was added for experimental purposes only, and should not be included in real dough/baking applications because of health concerns.

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Conflict of interest

The authors declare no conflict of interest.

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