Applied Rheology | DOI: 10.3933/APPLRHEOL-26-52508 | WWW.APPLIEDRHEOLOGY.ORG

Non-linear Rheological Properties of Soft Wheat Flour Dough at Different Stages of Farinograph Mixing

Gamze Yazar[1,2], Ozlem Duvarci[1,3], Sebnem Tavman[2], Jozef L. Kokini[1*]

[1] Purdue University Food Science Department, 745 Agriculture Mall Drive, West Lafayette, IN 47907, USA
[2] Ege University Food Engineering Department, Ege University Campus, 35040 Bornova/Izmir, Turkey
[3] Izmir Institute of Technology, Department of Chemical Engineering, Urla Gülbahae, 35430 Izmir, Turkey

* Corresponding author: jkokini@purdue.edu

Received: 9.1.2016, Final version: 29.7.2016

Abstract:
During mixing of wheat flour doughs, the distribution of the gluten network changes as a result of continuously applied large deformations. Especially gliadin, changes its distribution in the whole network during mixing. It is possible to fundamentally explain the role of molecular changes in more detail using large amplitude oscillatory measurements (LAOS) in the non-linear region. Therefore, the purpose of this study is to understand the effect of mixing on the non-linear fundamental rheological behavior of soft wheat flour dough using LAOS. Dough samples were obtained at 4 different phases of the Farinograph mixing and LAOS tests were done on each of them. LAOS tets give in depth intracycle understanding of rheology. All samples showed strain stiffening *S* and shear thinning *T* behavior at large strains previously not known in the cereal rheology community. Increasing mixing time (phase 1 to phase 4) and decreasing frequency resulted in retardation in the break of strain stiffening as strain increases. The strain stiffening behavior started to decrease for the dough samples at the 3rd and the 4th phases of mixing. LAOS data enabled us to describe the non-linear rheological changes occurring both in the viscous part largely attributed to the starch matrix and elastic part largely attributed to the gluten network components of the soft wheat flour dough under large deformations.

Key words:
Soft wheat flour dough, Farinograph mixing, non-linear rheological properties, LAOS

1 INTRODUCTION

Starch and gluten are known to be the main constituents of wheat flour; however it contains other components such as non-starch polysaccharides as well as lipids [1]. The viscoelasticity of wheat flour dough is due to gluten and its ability to interact with other components of wheat flour while hydrated with adequate amount of water during mixing. The quality and the quantity of gluten in wheat flour depends on the growth conditions and thus to the type of the wheat. Wheat (Triticum aestivum L.) is classified and traded as “hard or soft” and “winter or spring” based on the endosperm hardness or texture. Hard wheat flours are known to have more protein content compared to soft wheat flours [2–5]. Therefore, the type of wheat from which the flour is milled has a major effect on the rheological and technological properties of the wheat flour dough [6]. In order to understand the differences in the technological quality of the wheat flours, which usually arise due to the variety of wheat and the method used for milling, or sometimes to obtain better quality parameters in milling (i.e. optimizing the wheat blend for better technological properties in flour), several empirical rheological instruments are used. The Farinograph is one of these instruments which has become an industry standard where technological parameters for dough mixing such as water absorption, mixing tolerance, stability, softening value are recorded [7, 8]. These values are useful in optimizing formulations for baking quality especially in terms of determining the optimum water amount for a specific type of flour, optimizing the time of mixing to obtain a well-developed dough with optimal rheology and gas holding capacity and as a result obtaining baked products with excellent sensory and textural properties.

Wheat flour dough has been shown to be linear viscoelastic below the strains of approximately 0.2 % depending on the type flour and become highly nonlinear beyond this strain level. Nonlinearity in wheat flour dough has been attributed to the breakdown of the elastic gluten protein network. The network is known

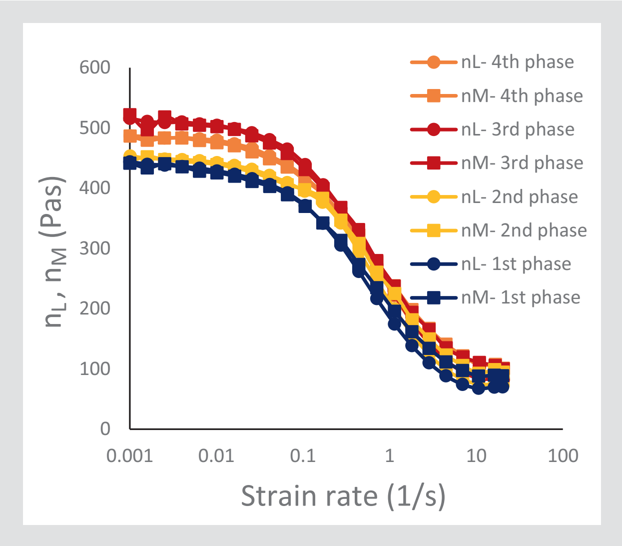

Figure 10: Large η_L and minimum strain rate viscosity η_M change versus strain rate values for soft dough sample at 10 rad/s.

samples at all phases of mixing and at all frequencies studied. And generally, these values seemed not to be affected by mixing for the soft dough samples.

4 CONCLUSIONS

Soft wheat flour dough samples obtained at different phases of Farinograph mixing showed non-linear behavior at strains larger than 0.015 – 0.06 %. As the frequency increased from 1 to 20 rad/s, soft flour dough samples started to behave more elastically as shown in Lissajous curves. On the other hand, as the strain increases from 0.01 to 200 % gradually, soft dough samples started to display more viscously dominated viscoelastic character due to the structural breakdown in the gluten network at high strains and the increasingly dominant role that starch played because the gluten network started to break down. The elastic component of the soft wheat flour dough was affected by mixing more compared to the viscous component. When Lissajous curves were evaluated at the beginning and at the end of Farinograph mixing at different frequencies, more remarkable changes were observed in the elastic component. Clearly the elastic component of the soft dough samples influenced the non-linear region more. This may be attributed to the changes occurring in the protein fibrils in gluten network at large strains [10].

The dough samples obtained at the four phases of mixing showed strain stiffening ($S > 0$) and shear thinning ($T < 0$) behavior at all frequencies studied up to the strain value of 200 %. e_3/e_1 values showed an increase supporting the strain stiffening behavior as the strain increased gradually. However, a decrease in the intensity of e_3/e_1 values were observed when the strain reached 44 – 70 %. This strain range may be the critical strain for the soft wheat flour dough where the gluten network starts to weaken with increasing strain and the resulting mechanical energy introduced in the sample. This critical strain value increased as the frequency decreased from 20 to 1 rad/s. When the applied frequency of oscillation was lower the critical strain values were higher and the protein fibrils in the gluten network could recover and align themselves up to these critical strain levels. The large strain modulus G_L increased with increasing mixing time. Except for the highest frequency applied, G_L values at the 3rd and the 4th phase of Farinograph mixing were close in magnitude which showed that the gluten network development stopped when the sample reached to the 3rd phase of mixing. On the other hand, the decreasing strain stiffening behavior occurred in the gluten network after the strain values of 44 – 70 % and the shear thinning behavior observed in the starch matrix as the strain increased can be regarded as the explanation for the decreasing trend observed in the Farinograms as the mixing continued.

ACKNOWLEDGEMENTS

This research was partly funded by USDA Hatch funds, the William R. Scholle Foundation, a Fellowship to Gamze Yazar from The Scientific and Technological Research Council of Turkey (TUBITAK). The authors gratefully acknowledge all of these funding sources which made this research possible.

REFERENCES

[1] Goesaert H, Brijs K, Veraverbeke WS, Courtin CM, Gebruers K, Delcour JA: Wheat flour constituents: how they impact bread quality, and how to impact their functionality, Trends Food Sci. Tech. 16 (2005) 12 – 30.

[2] Hoseney RC, Rogers DE: The formation and properties of wheat flour doughs, Crit. Rev. Food Sci. Nutr. 29:2 (1990) 73 – 93.

[3] McGuire CF, McNeal FH: Quality response of 10 hard red spring wheat cultivars to 25 environments, Crop Sci. 14 (1974) 175 – 178.

[4] Maghirang EB, Lookhart GL, Bean SR, Pierce RO, Xie F, Caley MS, Wilson JD, Seabourn BW, Ram MS, Park SH, Chung OK, Dowell FE: Comparison of quality characteristics and breadmaking functionality of hard red winter and hard red spring wheat, Cereal Chem. 83:5 (2006) 520 – 528.

[5] Tsilo TJ, Simsek S, Ohm J-B, Hareland GA, Chao S, Anderson JA: Quantitative trait loci influencing endosperm texture, dough-mixing strength, and bread-making properties of the hard red spring wheat breeding lines, Genome 54 (2011) 460 – 470.

[6] Rao VK, Mulvaney SJ, Dexter JE: Rheological characterization of long- and short- mixing flours based on stress-relaxation, J. Cereal Sci. 31 (2000) 159 – 171.

[7] Faubion JM, Hoseney RC: The viscoelastic properties of

wheat flour doughs, in Faridi H, Faubion JM (Eds.), Dough rheology and baked product texture, Van Nostrand Reinhold, New York (1990).
[8] Edwards WP: The science of bakery products, The Royal Society of Chemistry, Cambridge (2007).
[9] Dus SJ, Kokini JL: Prediction of the nonlinear viscoelastic properties of a hard wheat flour dough using the Bird-Carreau constitutive model, J. Rheol. 34:7 (1990) 1069 – 1084.
[10] Amemiya JI, Menjivar JA: Comparison of small and large deformation measurements to characterize the rheology of wheat flour doughs, J. Food Eng. 16 (1992) 91 – 108.
[11] Hibberd GE, Parker NS: Dynamic viscoelastic behavior of wheat flour doughs, Part 4: Non-linear behavior, Rheol. Acta 14 (1979) 151 – 157.
[12] Khatkar BS, Schofield JD: Dynamic rheology of wheat flour dough. 1. Non-linear viscoelastic behavior, J. Sci. Food Agric. 82 (2002) 827 – 829.
[13] Lefebvre J: An outline of the non-linear viscoelastic behavior of wheat flour dough in shear, Rheol. Acta 45 (2006) 525 – 538.
[14] Lefebvre J: Nonlinear, time-dependent shear flow behavior, and shear-induced effects in wheat flour dough rheology, J. Cereal Sci. 49 (2009) 262 – 271.
[15] Ng TSK, McKinley GH, Padmanabhan M: Linear to nonlinear rheology of wheat flour dough, Appl. Rheol. 16 (2006) 265 – 274.
[16] Wilhelm M: Fourier-transform rheology, Macromol. Mater. Eng. 287 (2002) 83 – 105.
[17] Ewoldt RH, Hosoi AE, McKinley GH: New measures for characterizing nonlinear viscoelasticity in large amplitude oscillatory shear, J. Rheol. 52 (2008) 1427 – 1458.
[18] Klein C, Venema P, Sagis L, van der Linden E: Rheological discrimination and characterization of carrageenans and starches by Fourier transform-rheology in the nonlinear viscous regime, J. Non-Newtionian Fluid Mech. 151 (2008) 145 – 150.
[19] Nam JG, Ahn KH, Lee SJ, Hyun K: First normal stress difference of entangled polymer solutions in large amplitude oscillatory shear flow, J. Rheol. 54 (2010) 1243 – 1266.
[20] Kokuti Z, Volker-Pop L, Brandstatter M, Kokavecz J, Ailer P, Palkovics L, Szabo G, Czirjak A: Exploring the nonlinear viscoelasticity of a high viscosity silicone oil with LAOS, Appl. Rheol. 26:1 (2016) 1 – 9.
[21] Melito HS, Daubert CR, Foegeding EA: Creep and large amplitude oscillatory shear behavior of whey protein isolate/.-carrageenan gels, Appl. Rheol. 22:6 (2012) 521 – 534.
[22] Calin A, Wilhelm M, Balan C: Determination of the nonlinear parameter (mobility factor) of the Giesekus constitutive model using LAOS procedure, J. Non-Newtonian Fluid Mech. 165 (2010) 1564 – 1577.
[23] Cho KS, Ahn KH, Lee SJ: A geometrical interpretation of large amplitude oscillatory shear response, J. Rheol. 49 (2005) 747 – 758.
[24] Reimers MJ, Dealy JM: Sliding plate rheometer studies of concentrated polystyrene solutions: Large amplitude oscillatory shear of a very high molecular weight polymer in diethyl phthalate, J. Rheol. 40 (1996) 167 – 186.
[25] Läuger J, Stettin H: Differences between stress and strain control in the non-linear behavior of complex fluids, Rheol. Acta 49 (2010) 909 – 930.
[26] Bozkurt F, Ansari S, Yau P, Yazar G, Ryan V, Kokini J: Distribution and location of ethanol soluble proteins (Osborne gliadin) as a function of mixing time in strong wheat flour dough using quantum dots as a labeling tool with confocal laser scanning microscopy, Food Res. Int. 66 (2014) 279 – 288.
[27] Ansari S, Bozkurt F, Yazar G, Ryan V, Bhunia A, Kokini J: Probing the distribution of gliadin proteins in dough and baked bread using conjugated quantum dots as a labeling tool, J. Cereal Sci. 63 (2015) 41 – 48.
[28] Yazar G, Duvarci O, Tavman S, Kokini JL: Effect of mixing on LAOS properties of hard wheat flour dough, J. Food Eng. 190 (2016) 1 – 10.
[29] AACC: Farinograph method for flour, AACC Method 54 – 21. Approved methods of the AACC, American Association of Cereal Chemists Inc, Volume II, USA (2000).
[30] Roman-Gutierrez AD, Guilbert S, Cuq B: Description of microstructural changes in wheat flour and flour components during hydration by using environmental scanning electron microscopy, Lebensm.-Wiss. u.-Technol. 35 (2002) 730 – 740.
[31] MacRitchie F: Mechanical degradation of gluten proteins during high-speed mixing of doughs, J. Polymer Sci. 49 (1975) 85 – 90.