Viscoelastic properties of wheat kernel, dough, gluten, proteins and non-gluten constituents on end-product quality

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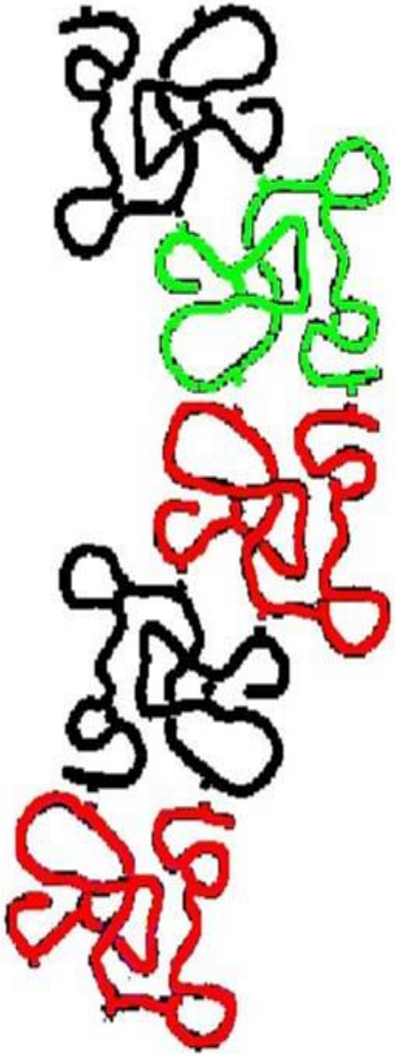
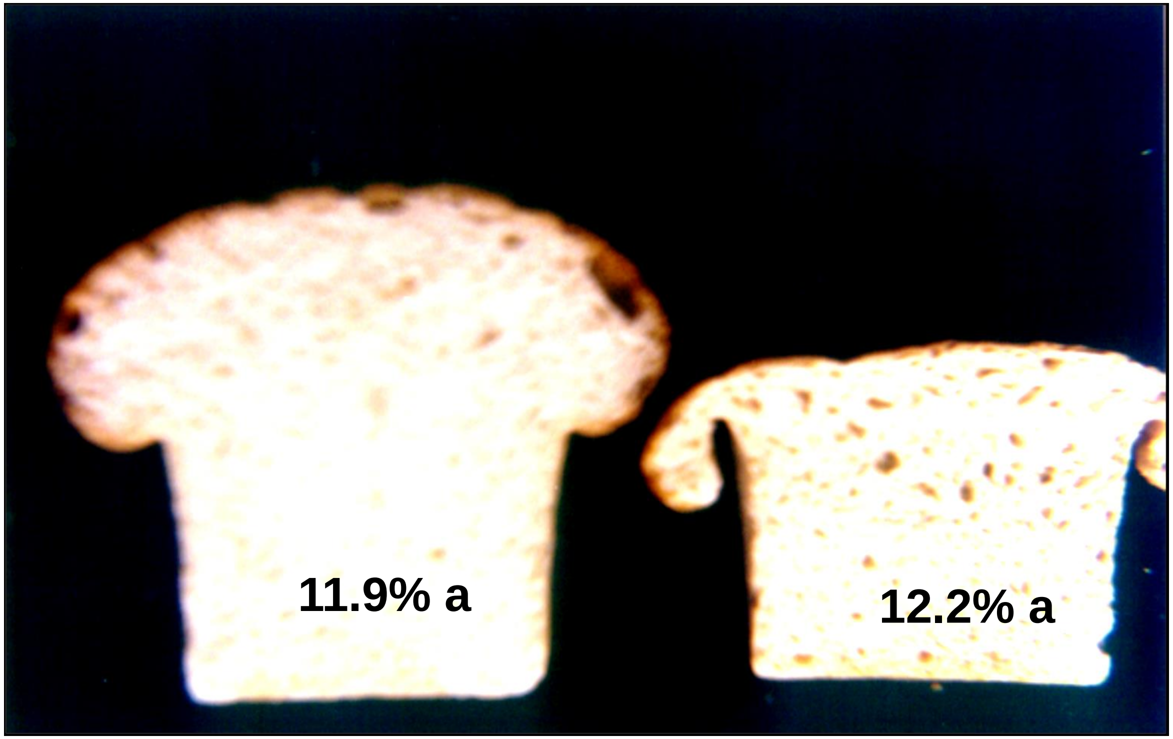
March 16, 2018

Introduction

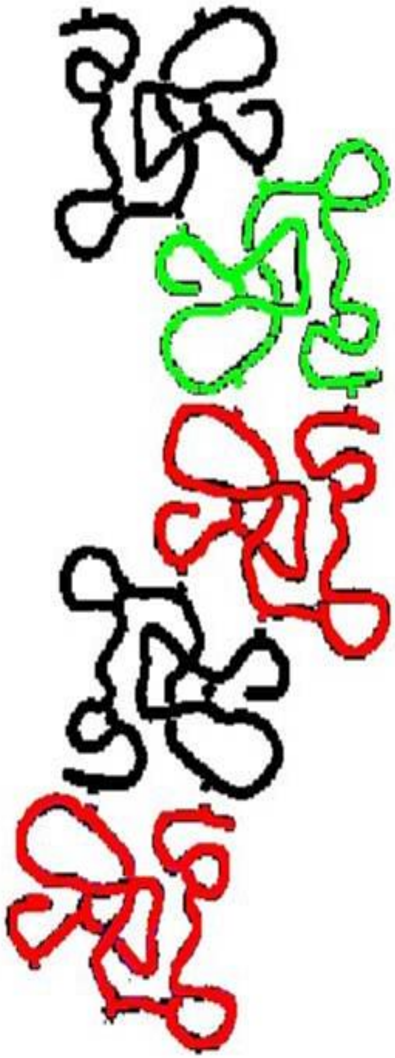
Gluten proteins, HMW and/or LMW?





Introduction

Gluten proteins, HMW and/or LMW?



Viscoelasticity theories of glutenin/dough

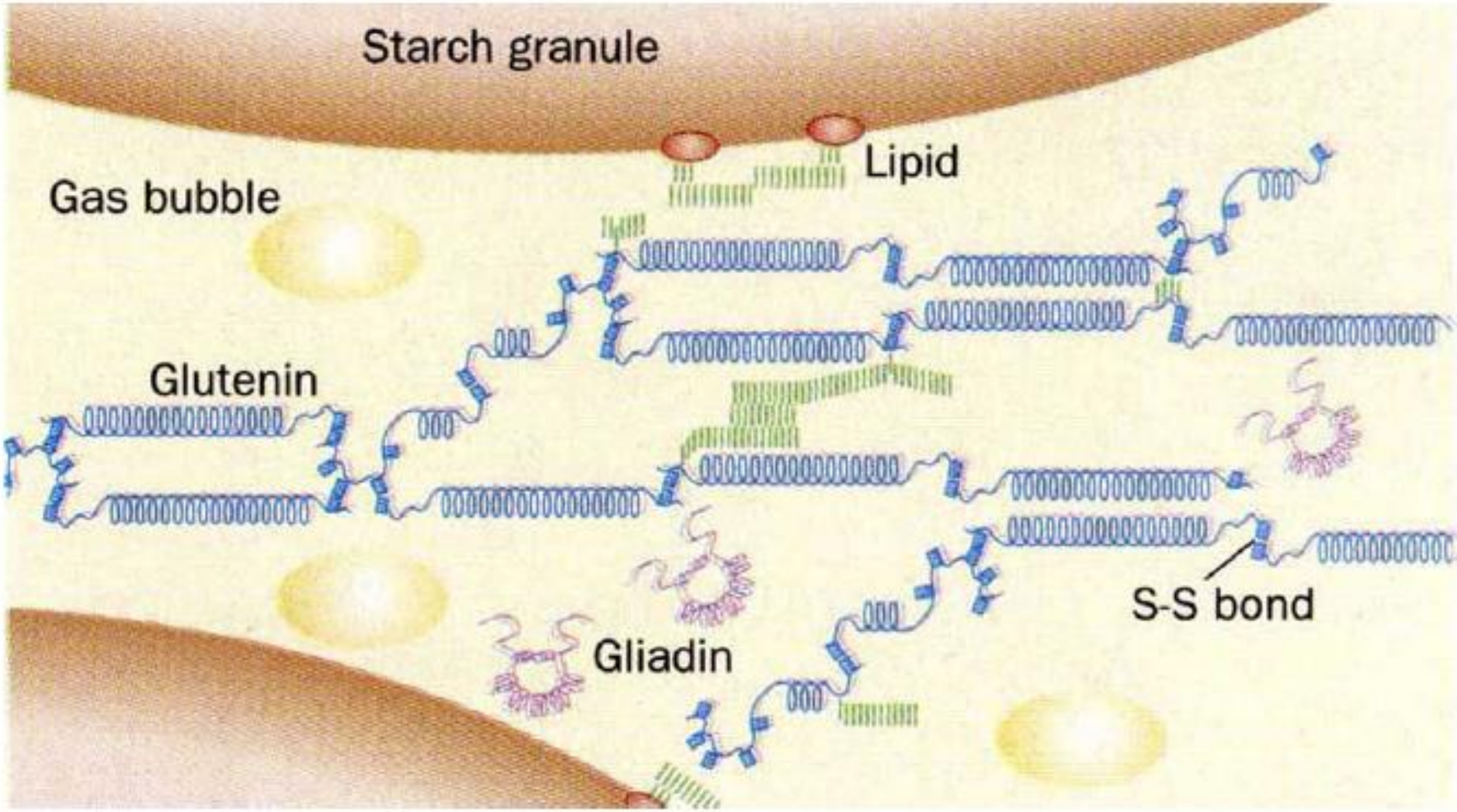
The theory of Belton 1999
Loop and train mechanism in which the H-bounds account for the Elasticity and **not the SS** disulfide bonds.

The theory of Hamer et al (Don et al 2005)
Glutenin Macro Polymer (GMP)
Good correlation with Extensograph Rmax

Theory of Doi and Edwards 1986
Entanglement polymer system

Shing and MacRitchie 2001.
HMW-GS model entanglement/SS bonds

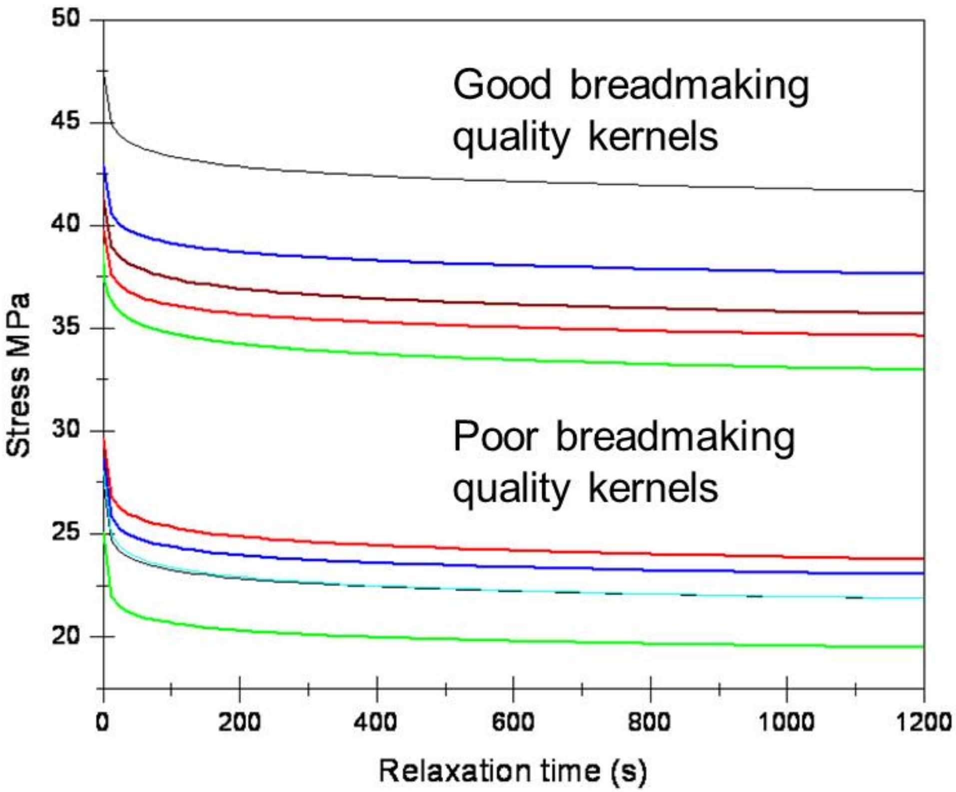
Wheat Dough Model

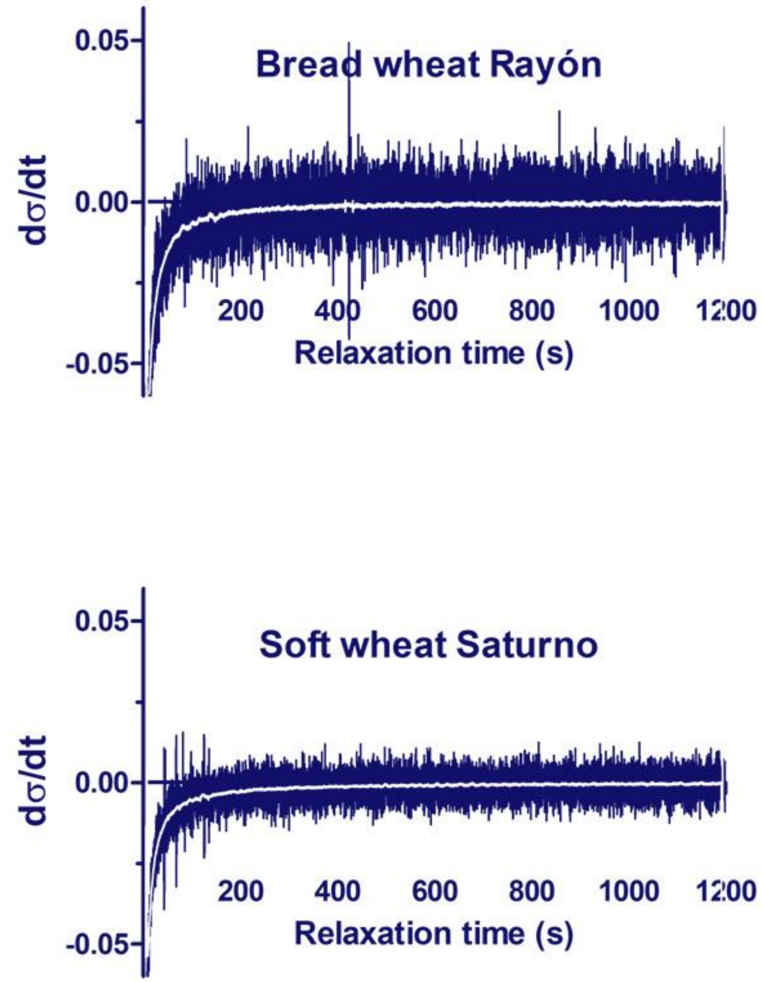


The disulphide-bonded polymeric structure of wheat glutenin, which forms the protein matrix between the starch granules and gas bubbles in dough. (Original drawing by R. Appels.)

Wrigley .1996. Nature, 381:738-739.

Stress relaxation curves from kernels of Bread wheat and Soft wheat cultivars





Farino kernel curves

Figueroa, JDC. Manuel. I., Hernández-Estrada,,Z.and Ramírez-Wong. (2012) Cereal Chem 89(4):211-216.

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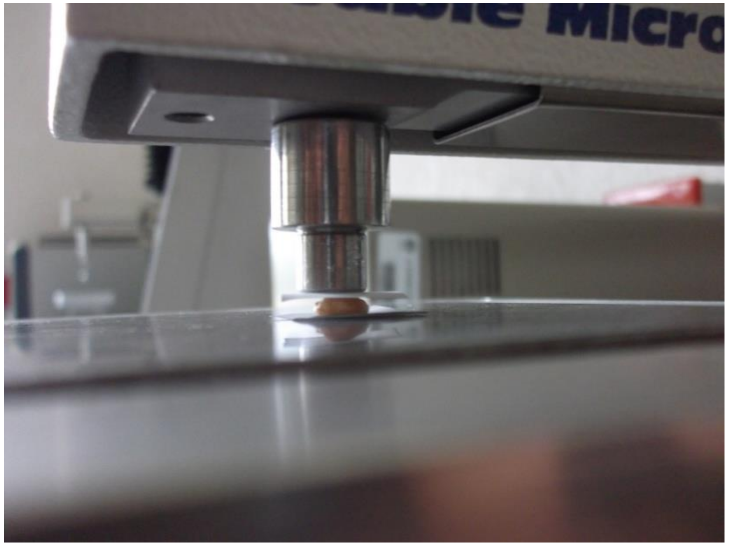
Figueroa, J.D.C., Hernández, E.Z., Rayas-Duarte, P., and Peña R.J. **2013**. Cereal Foods World.58(3):139-144.

Table I. Wheat kernel creep measured using a texture analyzer[a] **(Compressional stress)**

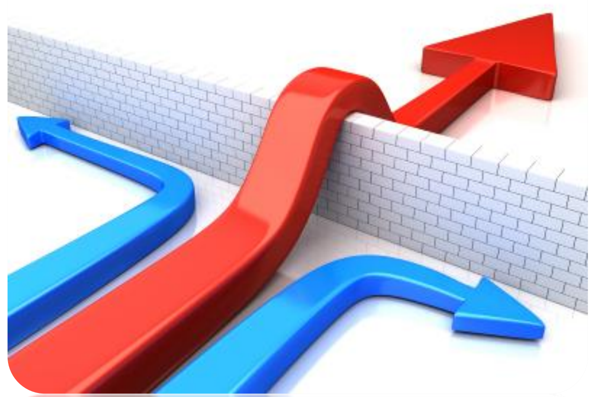
Genotypic Group / Glutenin Subunit	Modulus of Elasticity (MPa) and Retardation Time (sec)					Coefficient of Viscosity (MPa·sec)			Compliance (1/MPa)		
	E_0	E_1 ($\times 10^3$)	λ_1	E_2 ($\times 10^3$)	λ_2	μ_0 ($\times 10^7$)	μ_1 ($\times 10^5$)	μ_2 ($\times 10^6$)	D_0 ($\times 10^{-3}$)	D_1 ($\times 10^{-4}$)	D_2 ($\times 10^{-4}$)
Glu-D1											
5+10	245 a	7.52 a	13.4 a	7.58 a	177 a	1.56 a	1.02 a	1.36 a	4.36 b	1.90 b	1.72 b
2+12	205 b	4.58 b	13.0 a	5.16 b	161 a	1.19 a	0.69 a	0.90 b	6.64 a	7.94 a	3.68 a

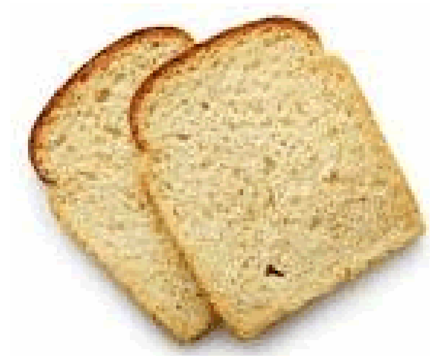
[a] Kernels were under constant compression at 70 N for 1,200 sec. Means followed by different letters within a column are significantly different ($P < 0.05$). E_0 = instantaneous modulus of elasticity; E_1 and E_2 = retarded elastic moduli at λ_i = *i*th retardation time; μ_0 = viscosity coefficient; μ_1 and μ_2 = viscosity coefficients; D_0 = instantaneous compliance; and D_1 and D_2 = retarded compliances.

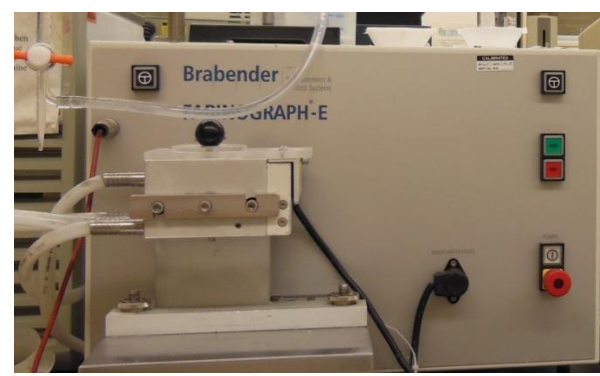


Objetive

Study the viscoelasticity of dough, gluten and protein fractions and relate that to traditional properties of flour, dough and bread and to show some applications









Material & Methods

Plant material

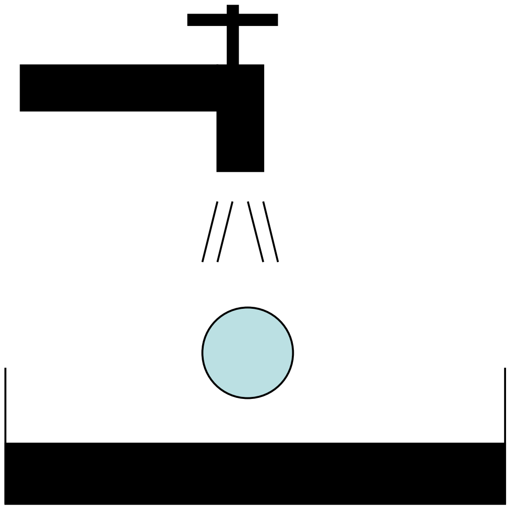
Dough and gluten evaluated using Creep-Recovery performed on 19 genotypes of HRS and HRW wheat grown in United States during crop cycle 2010-2011.

Locus	HMW Gutenin Subunits[§]	Allelic variation
Glu-A1	1 (*a*)	4
Glu-A1	2* (*b*)	15
Glu-B1	7+8 (*b*)	8
Glu-B1	17+18 (*i*)	2
Glu-B1	7+9 (*c*)	9
Glu-D1	2+12 (*a*)	4
Glu-D1	5+10 (*d*)	15

[§]·In parenthesis are the genes that express those HMW-GS (Payne et al., 1984).

CINVESTAV

Remove the non-gluten components from dough



Hand-washing of the dough

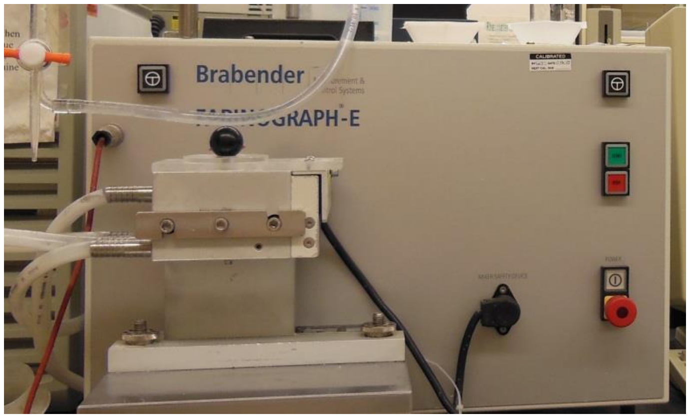
Starch,
Albumins,
Globulins
Pentosans
β-glucans

Or by

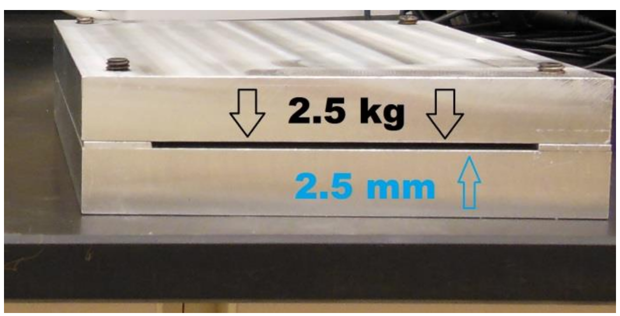
WET GLUTEN

Foto Hoseney 1998

Dough preparation for Creep test



Dough at optimal water abs at 500 BU

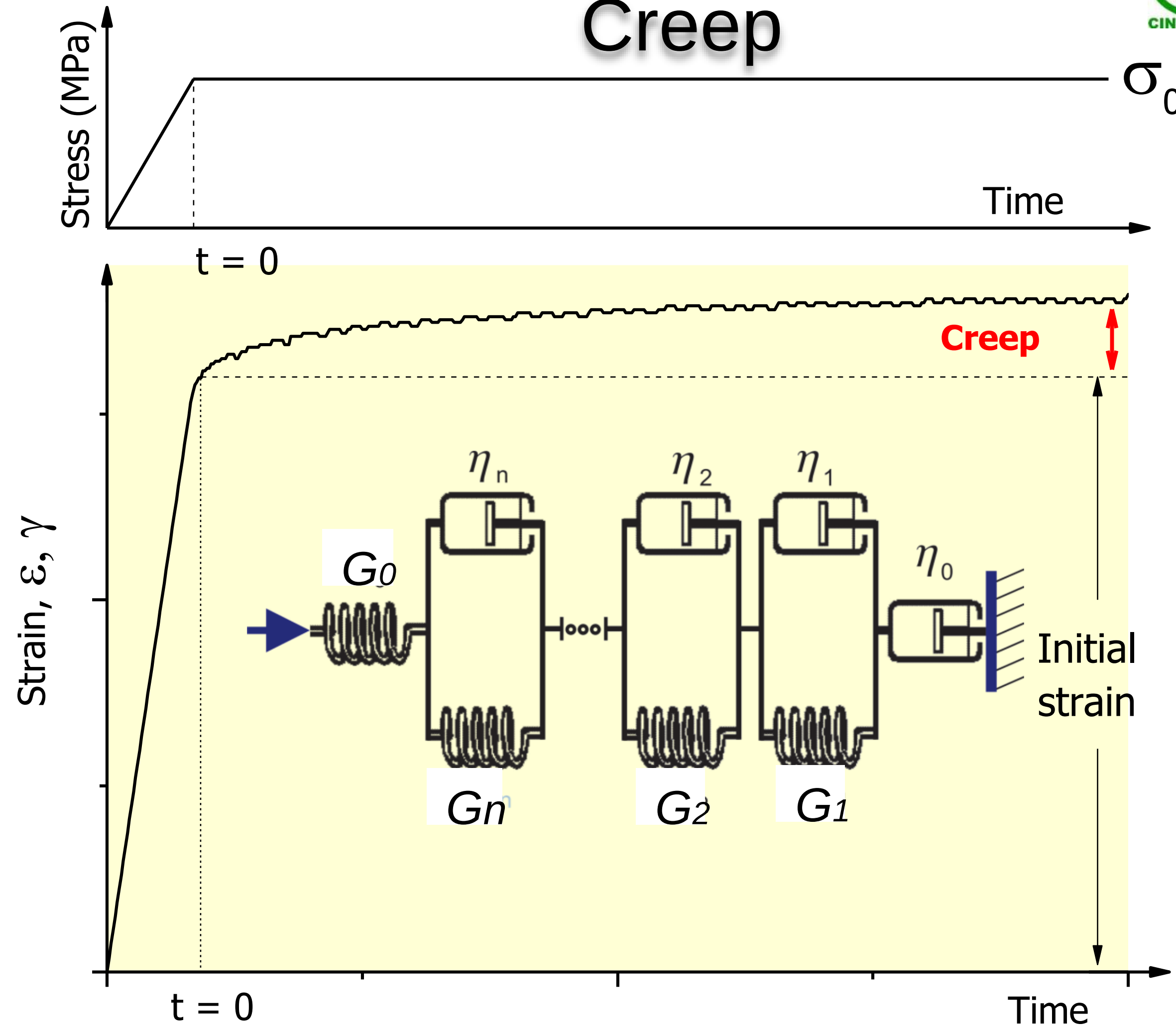


Stressed dough 40 min

Conditions:
100 Pa of shear stress
100 s of creep
Parallel plats with 25 mm (diam.), 2.5 mm gap and 25 ºC

General Kelvin-Voigt Model

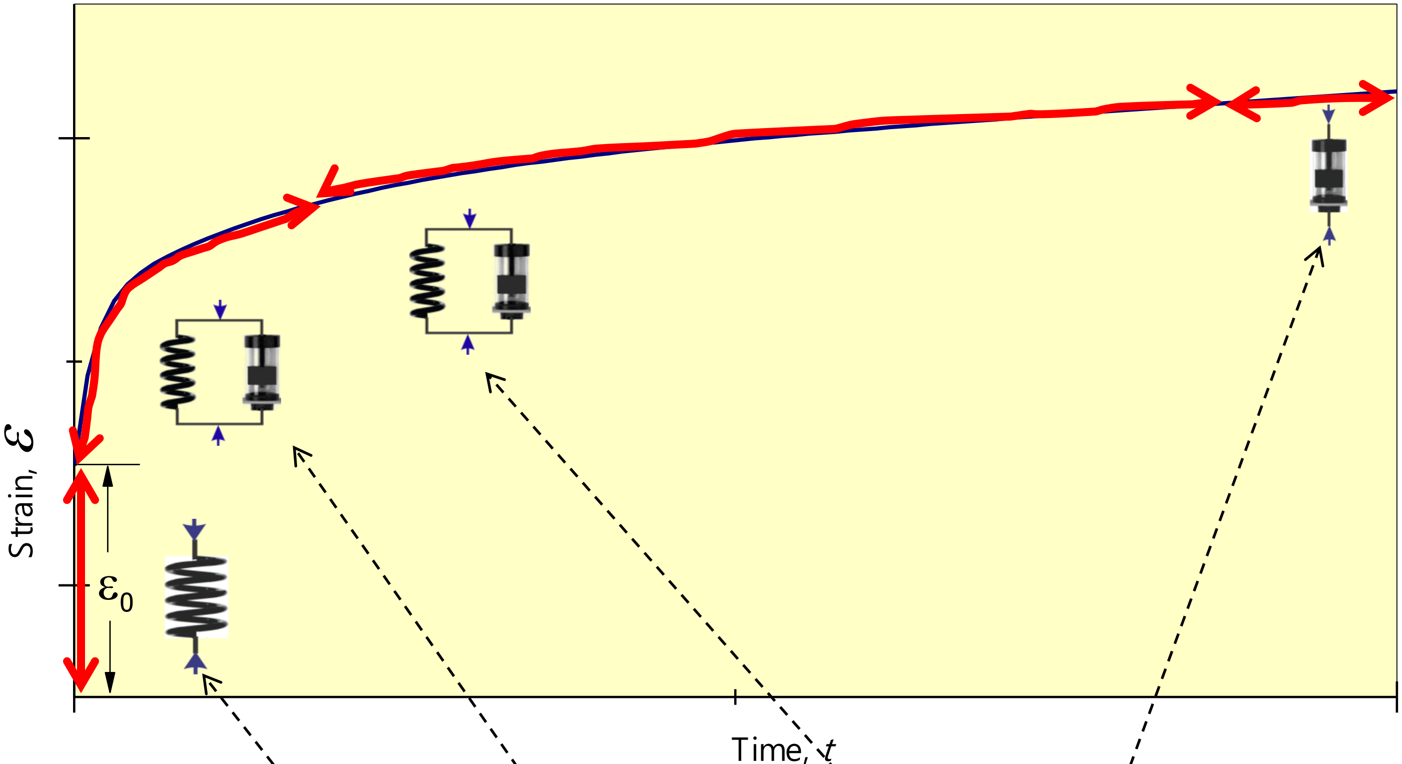
Creep



$$\gamma(t)=\frac{\sigma_0}{G_0}+\frac{\sigma_0}{G_1}\left(1-e^{t/\lambda_1}\right)+\frac{\sigma_0}{G_2}\left(1-e^{t/\lambda_2}\right)+\ldots+\frac{\sigma_0}{G_n}\left(1-e^{t/\lambda_n}\right)+\frac{\sigma_0}{\eta_0}t$$

Hernández-Estrada, Z.J., Figueroa, J.D.C., Rayas-Duarte, P., and Peña R.J**. 2012.** J. Food Eng. 113:19-26.
Figueroa, J.D.C., Hernández, E.Z., Rayas-Duarte, P., and Peña R.J. **2013**. Cereal Foods World.58(3):139-144.
Hernández-Estrada Z.J., Rayas-Duarte, P., Figueroa, J.D.C and Morales-Sánchez E. **2014**. Food Eng.

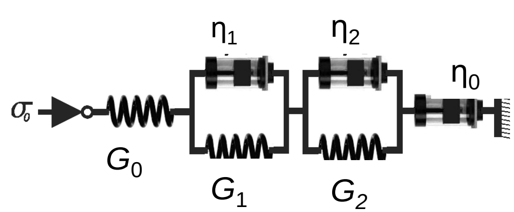
General Kelvin-Voigt Model



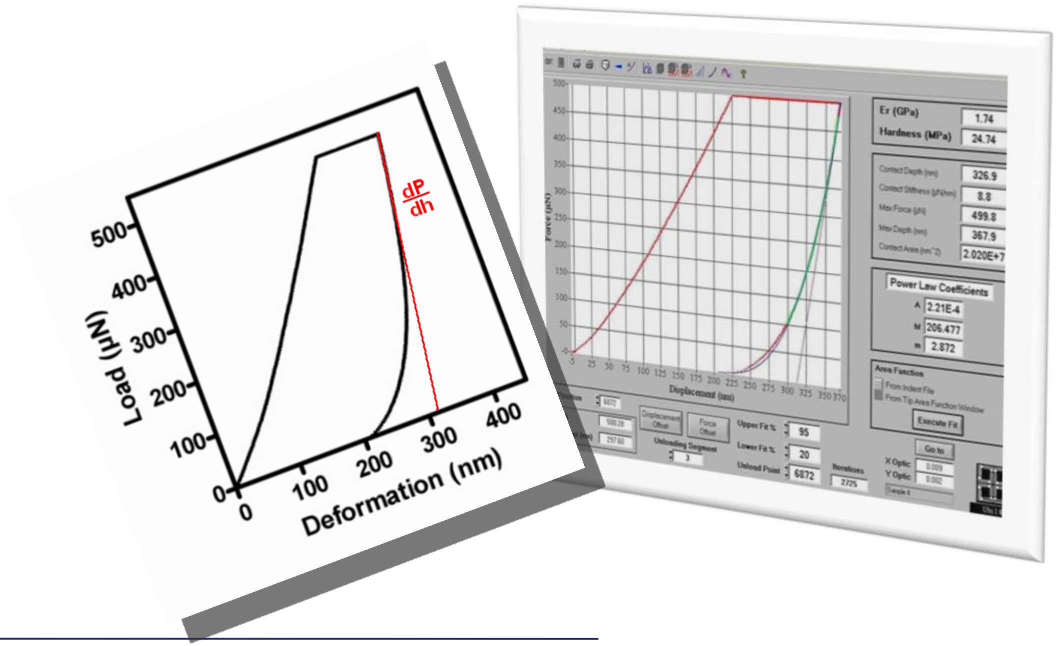
$$\gamma(t) = \frac{\sigma_0}{G_0} + \frac{\sigma_0}{G_1}\left(1 - e^{-t/\lambda_1}\right) + \frac{\sigma_0}{G_2}\left(1 - e^{-t/\lambda_2}\right) + \frac{\sigma_0}{\eta_0} t$$

Retardation time

$$\lambda_i = \frac{\eta_i}{E_i}$$



E_0 = instantaneous modulus of elasticity due to Maxwell spring; G_1 and G_2 are retarded viscoelastic deformation (λ_1 and λ_2) due to retarded stretching of the spring caused by a dashpot connected in parallel in Kelvin-Voigt elements; η_0 = the viscous deformation due to Maxwell dashpot; η_1 and η_2 are the viscous coefficients of the dashpot in the Kelvin-Voigt units.



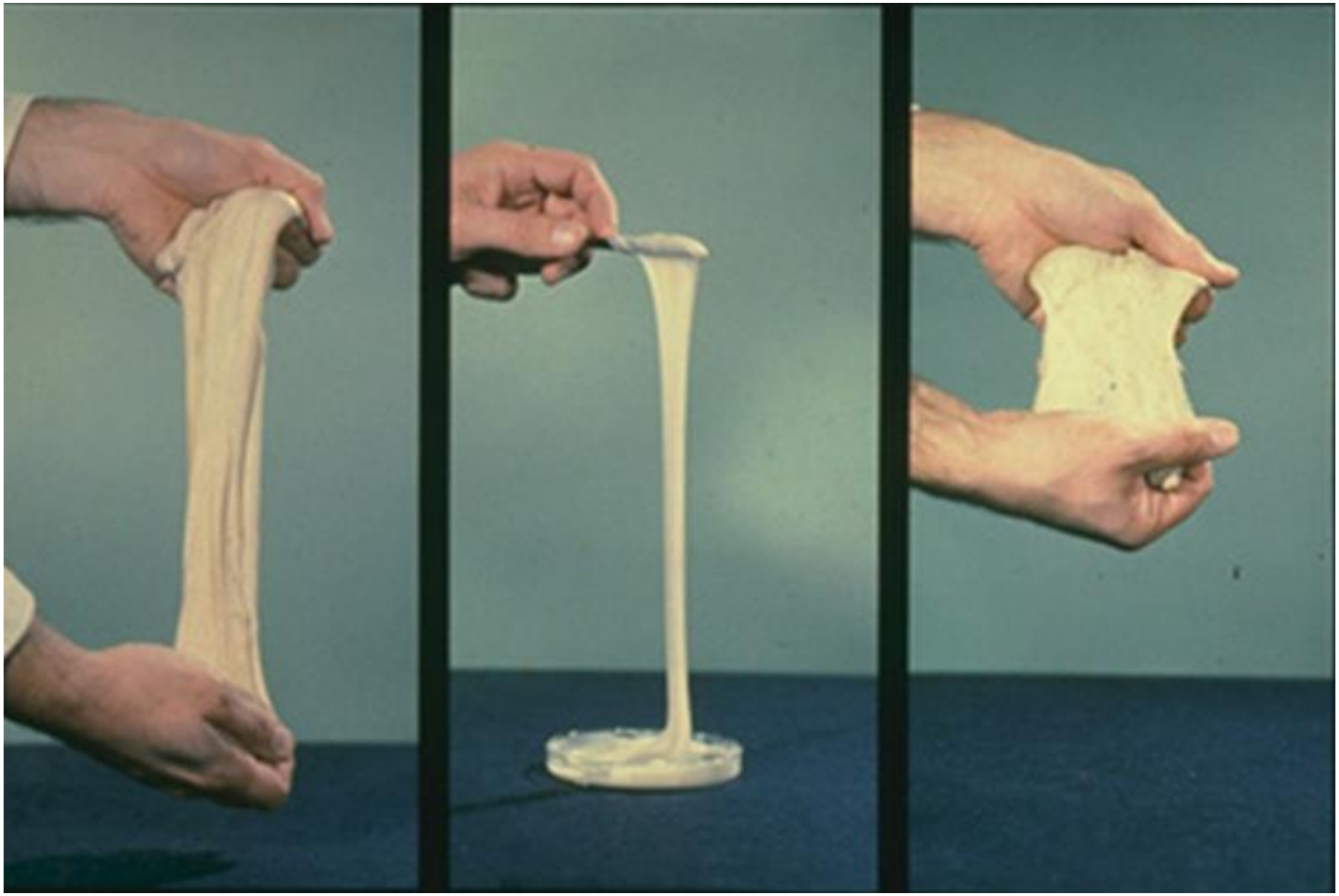
Results

Viscosity is a measure of the resistance to flow

Gluten

Gliadin
Low viscosity

Glutenin
High viscosity



Hoseney 1994

Regressed parameters for Dough using the Kelvin-Voigt generalized model (6 elements) of Creep test for *Glu*-1 loci.[a,b]

Glutenin Subunits	Maximum Deform (%)	J_0 (1/Pa) x 10^{-4}	J_1 (1/Pa) x 10^{-4}	J_2 (1/Pa) x 10^{-4}	λ_1 (s)	λ_2 (s)	G_0 (Pa)	G_1 (Pa)	G_2 (Pa)	η_0 (Pa.s) x 10^5	η_1 (Pa·s) x 10^3	η_2 (Pa·s) x 10^4
Glu-A1												
1	19.2 a	1.19 a	2.88 a	6.18 a	0.45 a	9.86 a	8459 a	3527 a	1647 a	1.10 a	1.57 a	1.62 a
2*	20.1 a	1.20 a	3.00 a	6.63 a	0.46 a	9.96 a	8444 a	3532 a	1669 a	1.17 a	1.57 a	1.60 a
Glu-B1												
7+8	19.1 a	1.21 a	2.89 ab	6.29 a	0.45 ab	9.92 a	8382 b	3579 b	1656 b	1.16 b	1.59 a	1.63 ab
7+9	21.2 a	1.21 a	3.10 a	6.91 a	0.47 a	10.09 a	8411 b	3408 b	1612 b	1.10 b	1.55 a	1.55 b
17+18	16.5 b	1.14 a	2.67 b	5.53 b	0.42 b	9.20 b	8915 a	3991 a	1978 a	1.43 a	1.61 a	1.79 a
Glu-D1												
2+12	26.0 a	1.33 a	3.62 a	8.52 a	0.53 a	10.9 a	7545 b	2802 b	1198 b	0.79 b	1.48 b	1.29 b
5+10	18.3 b	1.17 b	2.80 b	6.00 b	0.44 b	9.69 b	8687 a	3725 a	1788 a	1.25 a	1.59 a	1.69 a

[a] :Means (n=7 by cultivar) followed by different letter within a column and same group are significantly different (Duncan, $P < 0.05$).
[b] : Dough under 100 Pa of shear strain hold 100 s and recovery recorded during 100 s after creep phase.
J_0: instantaneous compliance; G_0: instantaneous shear modulus; G_1, G_2: shear modulus; Jr_1, Jr_2: retarded elastic compliances; η_1, η_2: viscosity coefficient associated to λ_1, λ_2: retardation times.

Hernández-Estrada Z.J., Rayas-Duarte, P., Figueroa, J.D.C and Morales-Sánchez E. 2014. Food Eng.

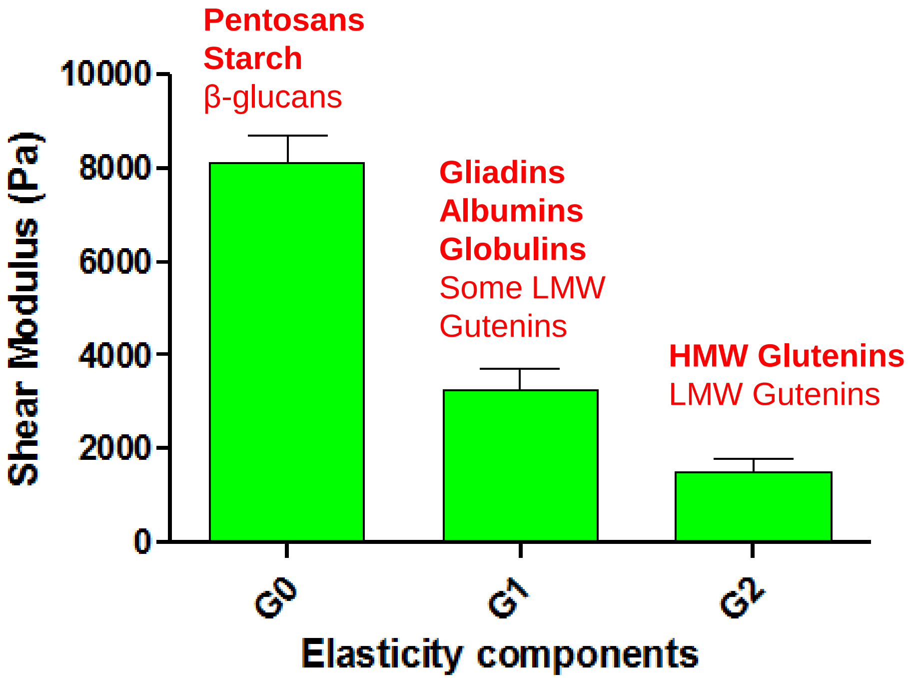
Regressed parameters for Wet Gluten using the Kelvin-Voigt generalized model (6 elements) of Creep test for *Glu*-1 loci.[a,b]

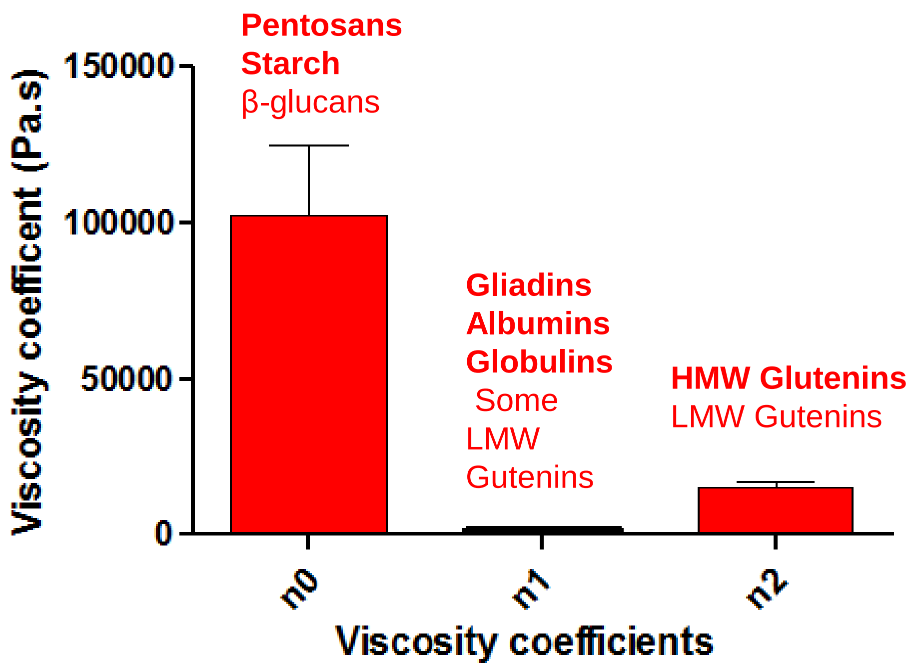
Glutenin Subunits	Maximum Deform (%)	J_0 (1/Pa) x 10^{-4}	J_1 (1/Pa) x 10^{-4}	J_2 (1/Pa) x 10^{-3}	λ_1 (s)	λ_2 (s)	G_0 (Pa)	G_1 (Pa)	G_2 (Pa)	η_0 (Pa.s) x 10^5	η_1 (Pa·s) x 10^3	η_2 (Pa·s) x 10^4
Glu-A1												
1	-	7.00 a	9.84 a	1.06 a	1.11 a	14.4 b	1500 a	1121 a	1101 a	1.22 a	1.21 a	1.56 a
2*	-	7.32 a	10.9 a	1.27 a	1.20 a	15.0 a	1530 a	1125 a	1052 a	1.20 a	1.29 a	1.55 a
Glu-B1												
7+8	-	7.29 a	10.7 ab	1.19 ab	1.16 a	14.7 a	1518 b	1121 b	1059 b	1.20 b	1.27 b	1.54 b
7+9	-	7.67 a	11.6 a	1.36 a	1.22 a	15.1 a	1410 b	1012 b	944 b	1.04 b	1.17 b	1.38 b
17+18	-	5.24 b	6.93 b	0.74 b	1.10 a	14.6 a	2027 a	1613 a	1587 a	1.87 a	1.71 a	2.28 a
Glu-D1												
2+12	-	8.97 a	14.42 a	1.79 a	1.33 a	15.8 a	1193 b	787 b	661 b	0.70 b	1.02 b	1.03 b
5+10	-	6.79 b	9.71 b	1.07 b	1.14 b	14.7 b	1611 a	1213 a	1170 a	1.33 a	1.34 a	1.69 a

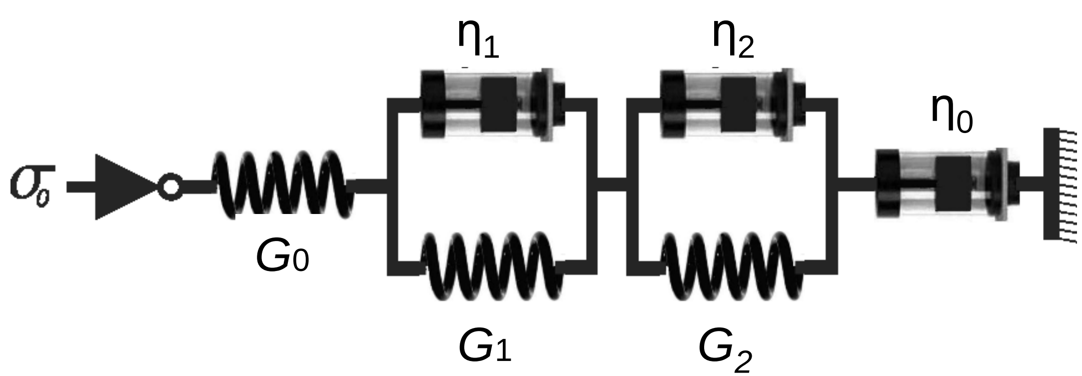
[a] :Means (n=7 by cultivar) followed by different letter within a column and same group are significantly different (Duncan, $P < 0.05$).
[b] : Dough under 100 Pa of shear strain hold 100 s and recovery recorded during 100 s after creep phase.
J_0: instantaneous compliance; G_0: instantaneous shear modulus; G_1, G_2: shear modulus; Jr_1, Jr_2: retarded elastic compliances; η_1, η_2: viscosity coefficient associated to λ_1, λ_2: retardation times.

Hernández-Estrada Z.J., Rayas-Duarte, P., Figueroa, J.D.C and Morales-Sánchez E. 2014. Food Eng.

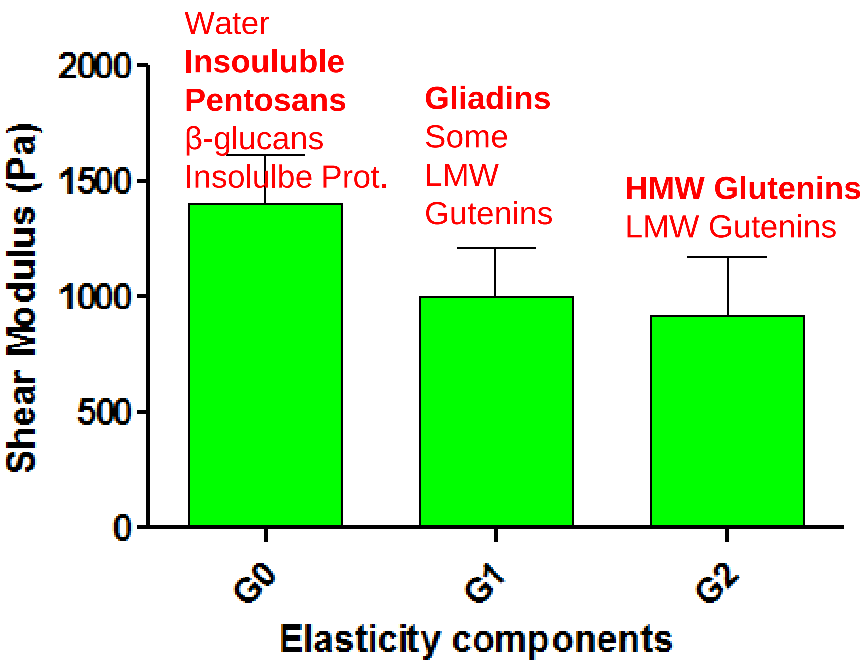
Viscoelastic properties of Wheat Dough
Creep using a Kelvin-Voigt model

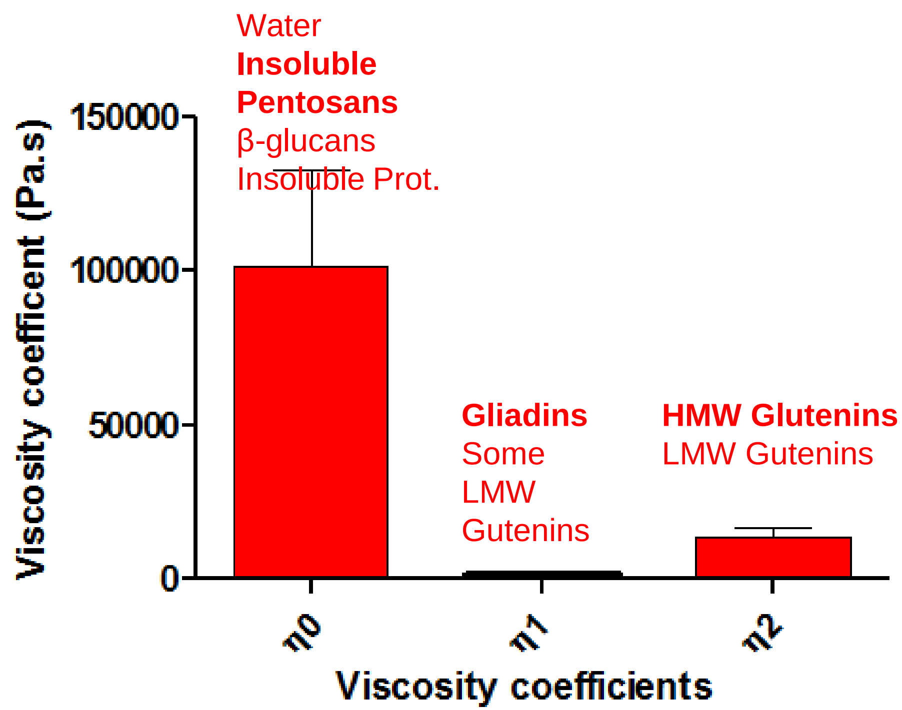


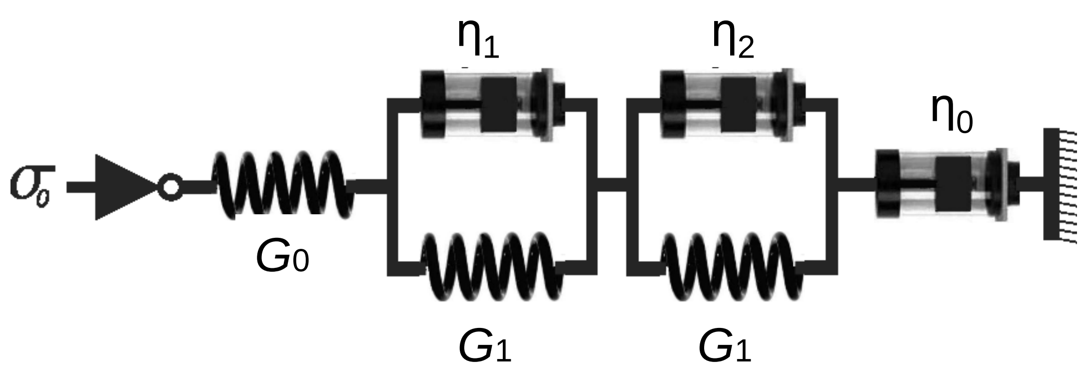


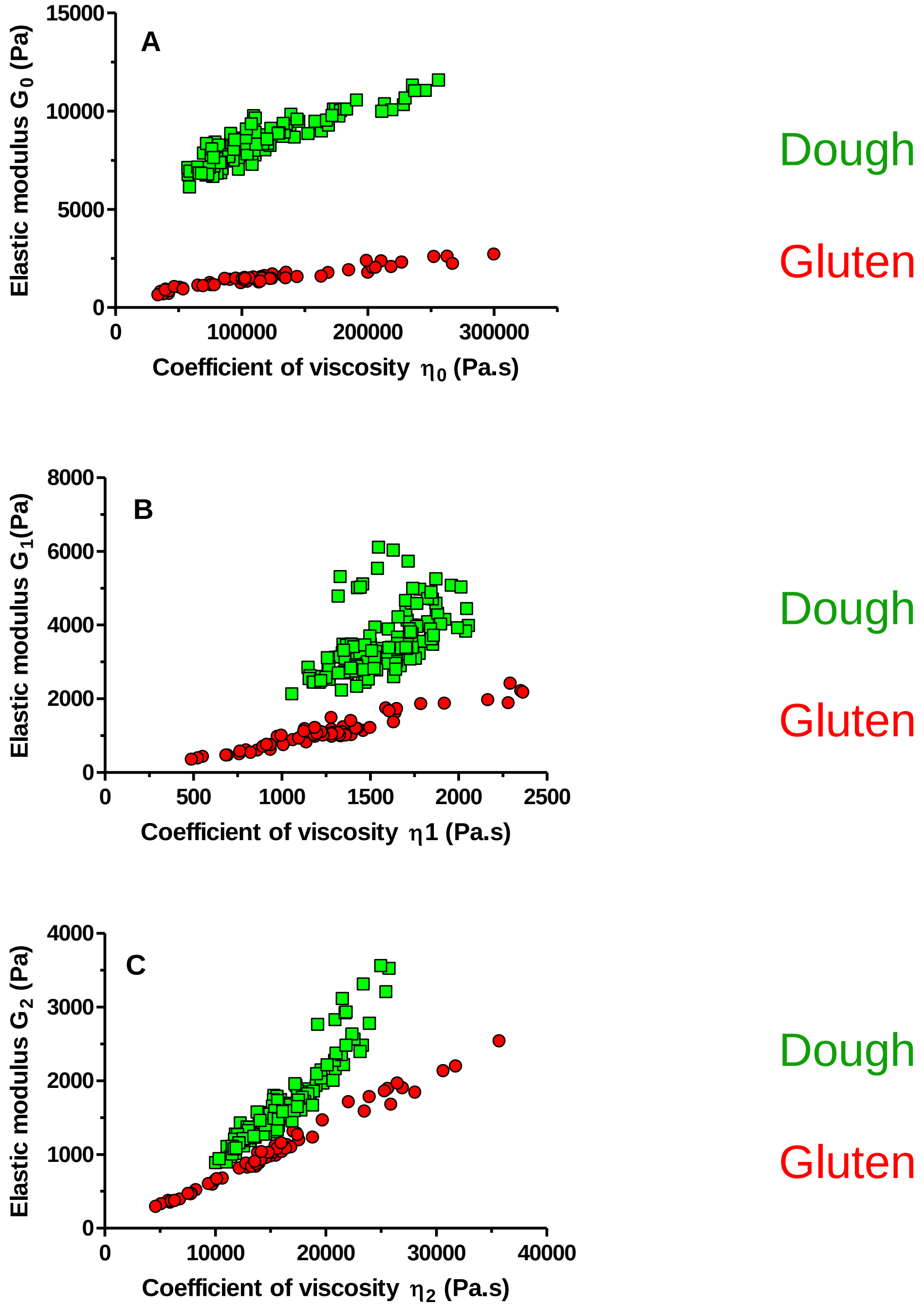


Viscoelasticity of Wet Gluten









Hernández-Estrada, Z.J., Rayas-Duarte, P., Figueroa, J.D.C. (2017). Cereal Chem.

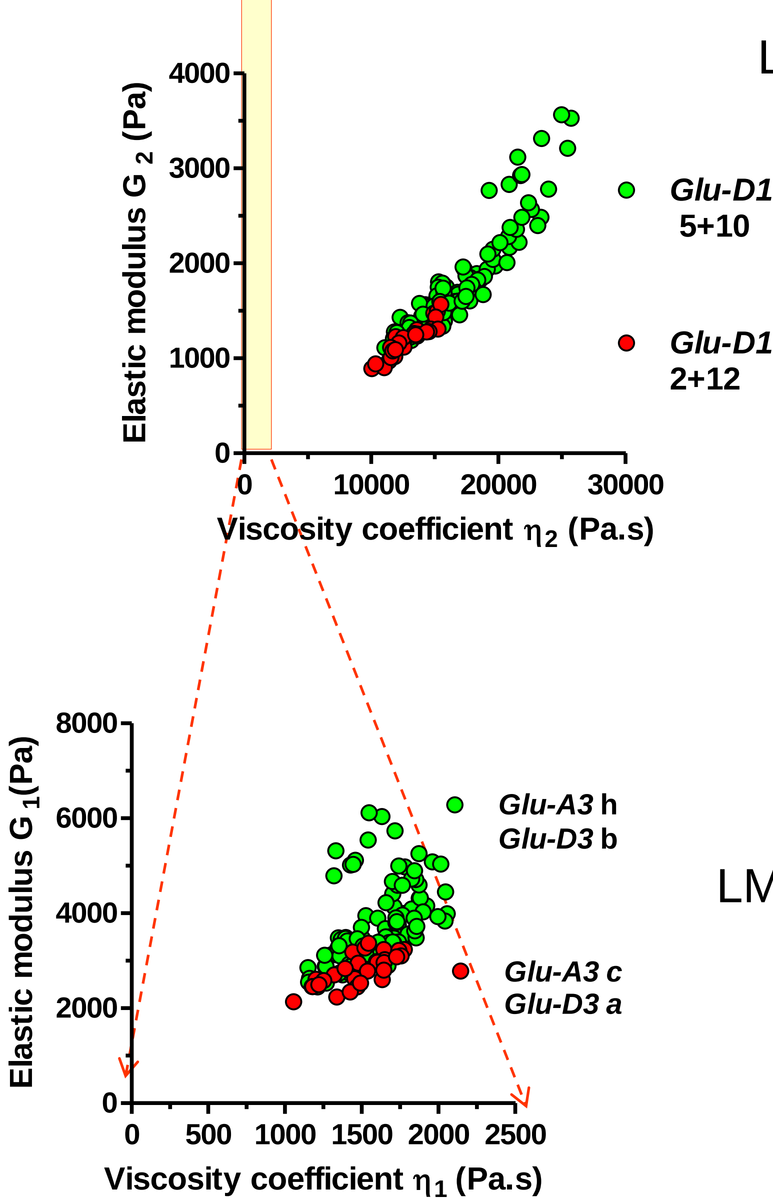
Effect HMW-GS background on dough viscoelasticity

2nd element
Large-chain size
HMW-GS

MW

90,000 to

70,000 Da



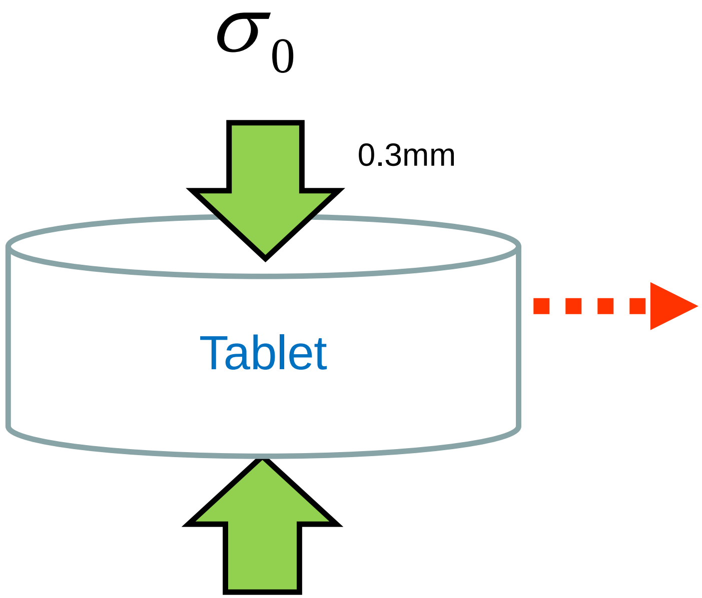
Expanded scale
First element
Short-chain size
LMW-GS and Gliadins

45,000 to

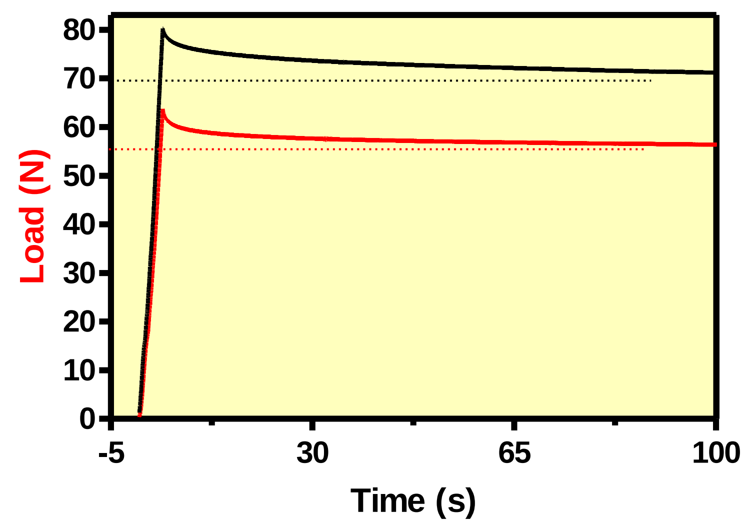
20,000 Da

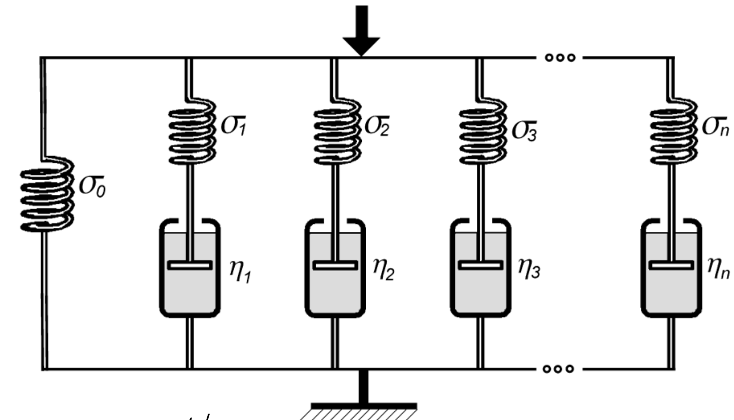
Hernández-Estrada, Z.J., Rayas-Duarte, P., Figueroa, J.D.C. (2017). Cereal Chem.

Compressional tests with texturometer



Texturometer TA-XT2





Stress Relaxation:
General Maxwell Model

$$\sigma(t) = \sigma_0 + \sigma_1 e^{-t/\tau_1} + \sigma_2 e^{-t/\tau_2} + \sigma_3 e^{-t/\tau_3} \ldots + \sigma_n e^{-t/\tau_n}$$

Figueroa, J.D.C., Hernández, Z., Rayas-Duarte, P., and Peña R.J. **2013**. Cereal Foods World.58(3):139-144

Figueroa, J.D.C., Escalante-Aburto, A., Véles-Medina, J.J., Hernández-Estrada, Z.J., Rayas-Duarte, P., Simsek S., and Ponce-García, N**. 2016**. Journal of Cereal Science. 69:207-212.

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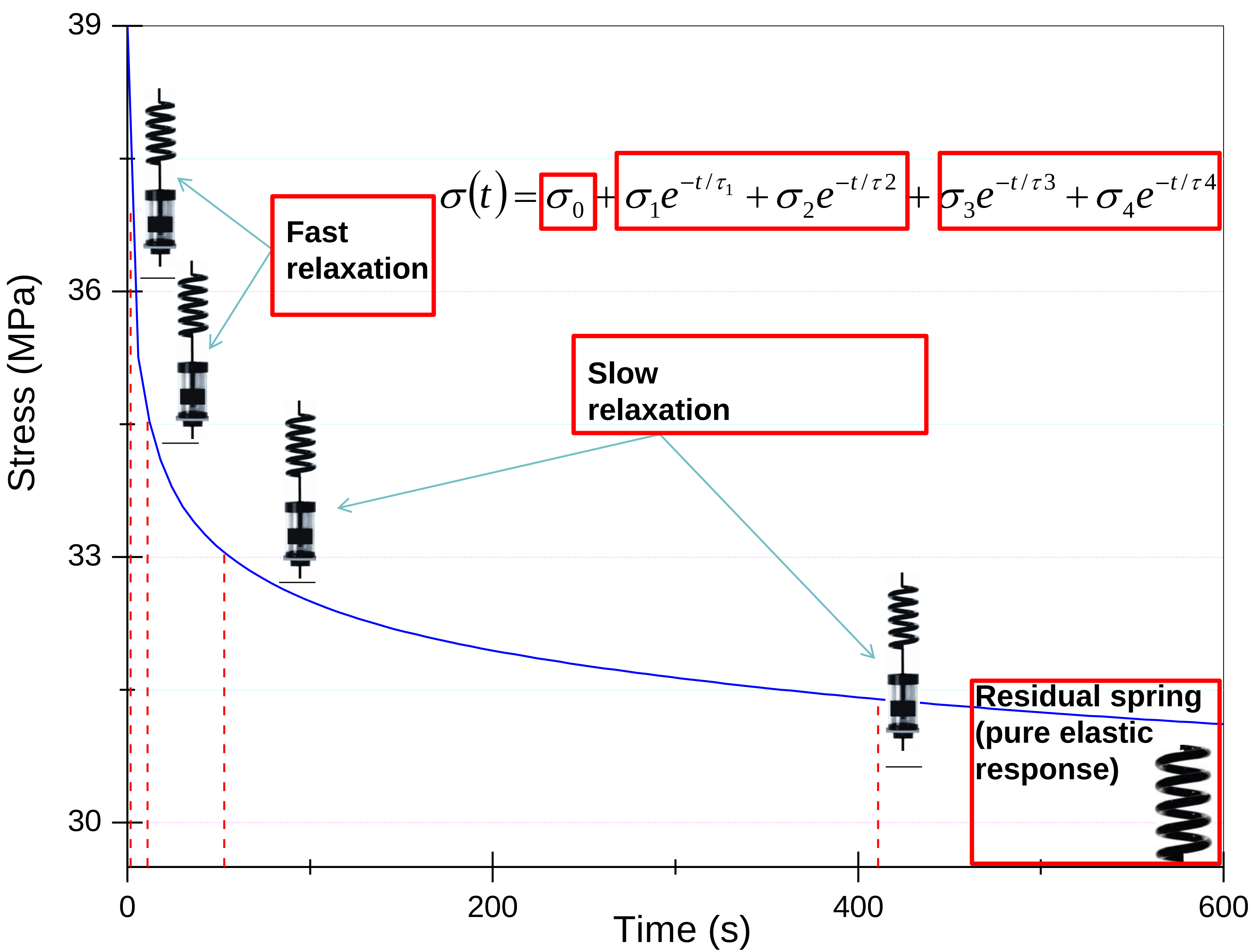


39
36
33
30
Stress (MPa)
0
200
400
600
Time (s)
$\sigma(t) = \sigma_0 + \sigma_1 e^{-t/\tau_1} + \sigma_2 e^{-t/\tau 2} + \sigma_3 e^{-t/\tau 3} + \sigma_4 e^{-t/\tau 4}$
Fast relaxation
Slow relaxation
Residual spring (pure elastic response)

Tablet sinterization

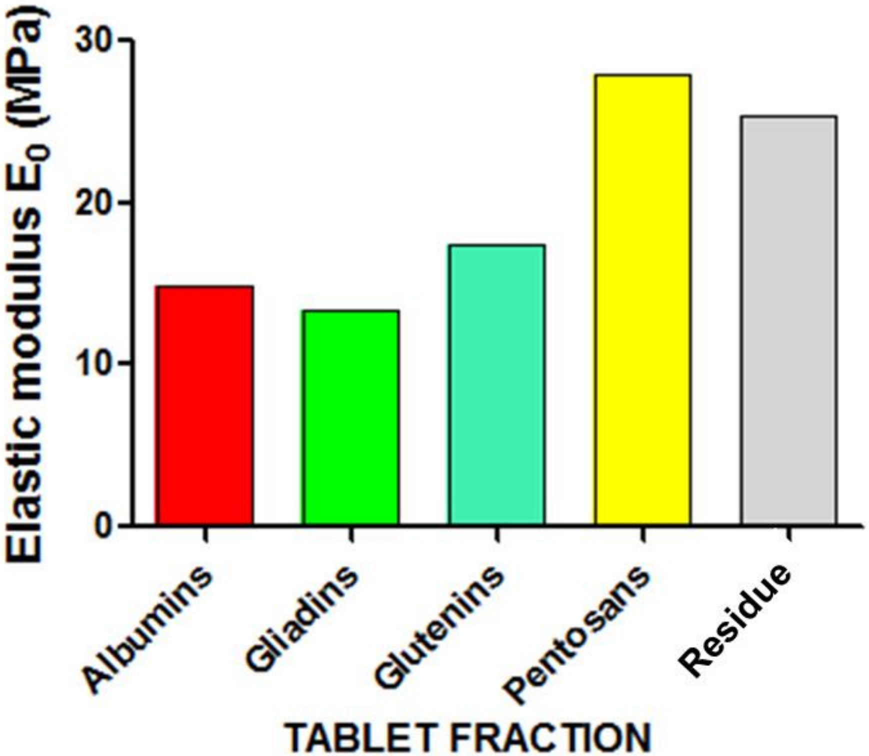
Hydraulic Press

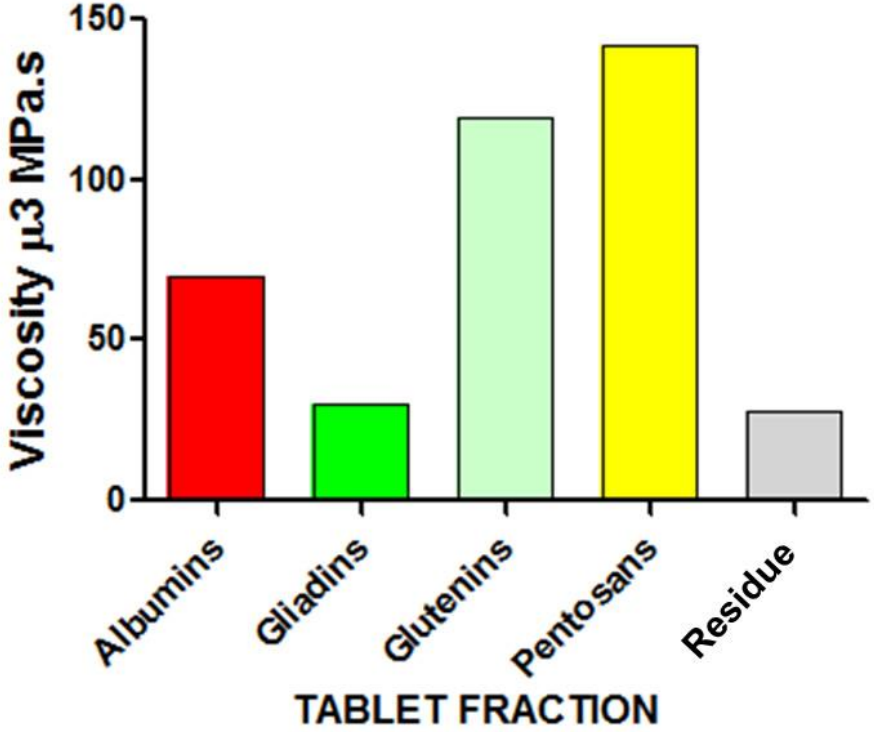
25 tonnes for 5 min

Osborne fractions
Albumins
Globulins
Gliadins
Glutenins
Residue
Pentosans
Starch

1% of water

Stress relaxation data

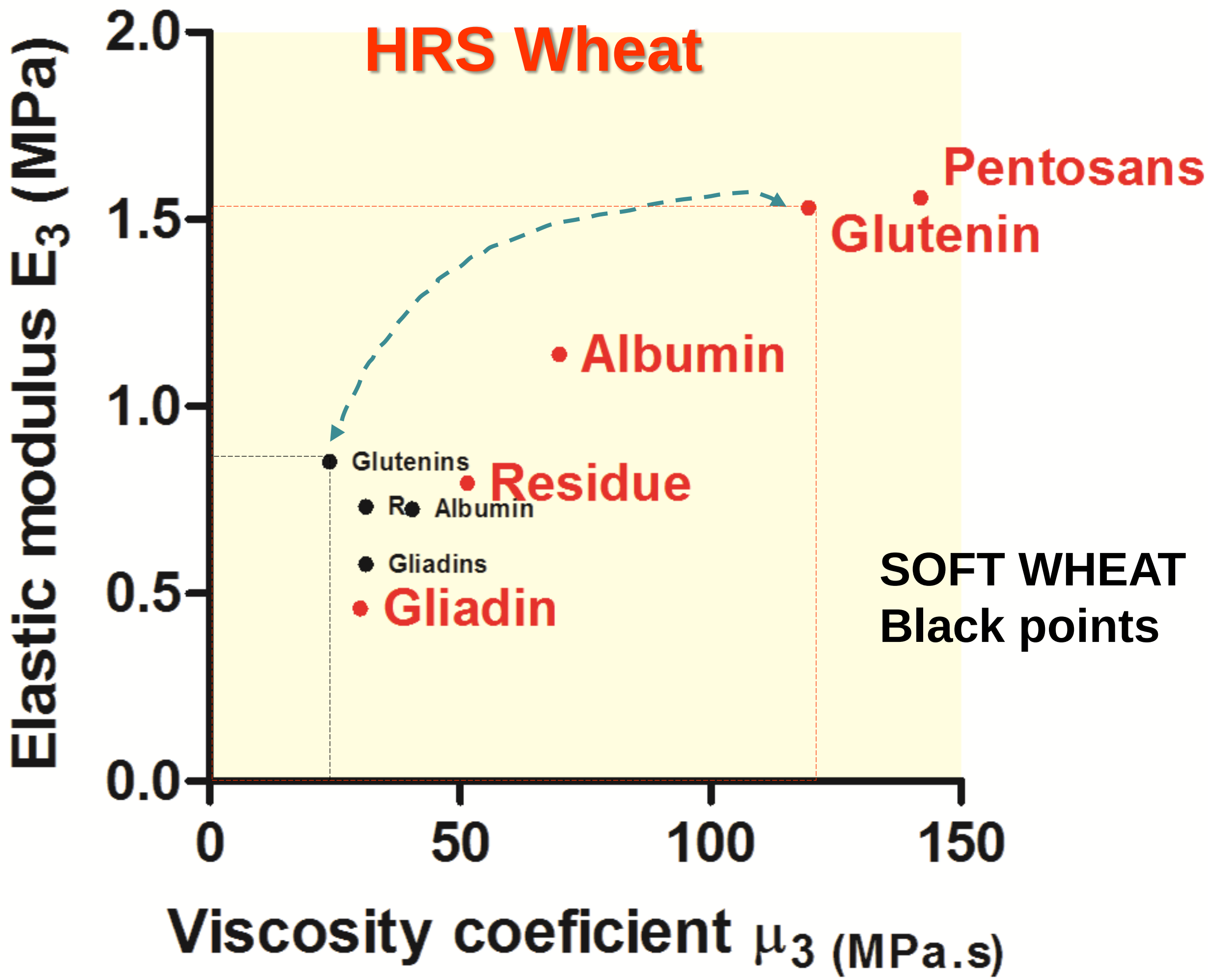




Figueroa, J.D.C., Escalante-Aburto A.,Veles-Medina J.,Hernandez-Estrada Z., Rayas-Duarte, P., Simsek, S., and Ponce-García N. (2016) J Cereal Sci. 69:2017-2012.

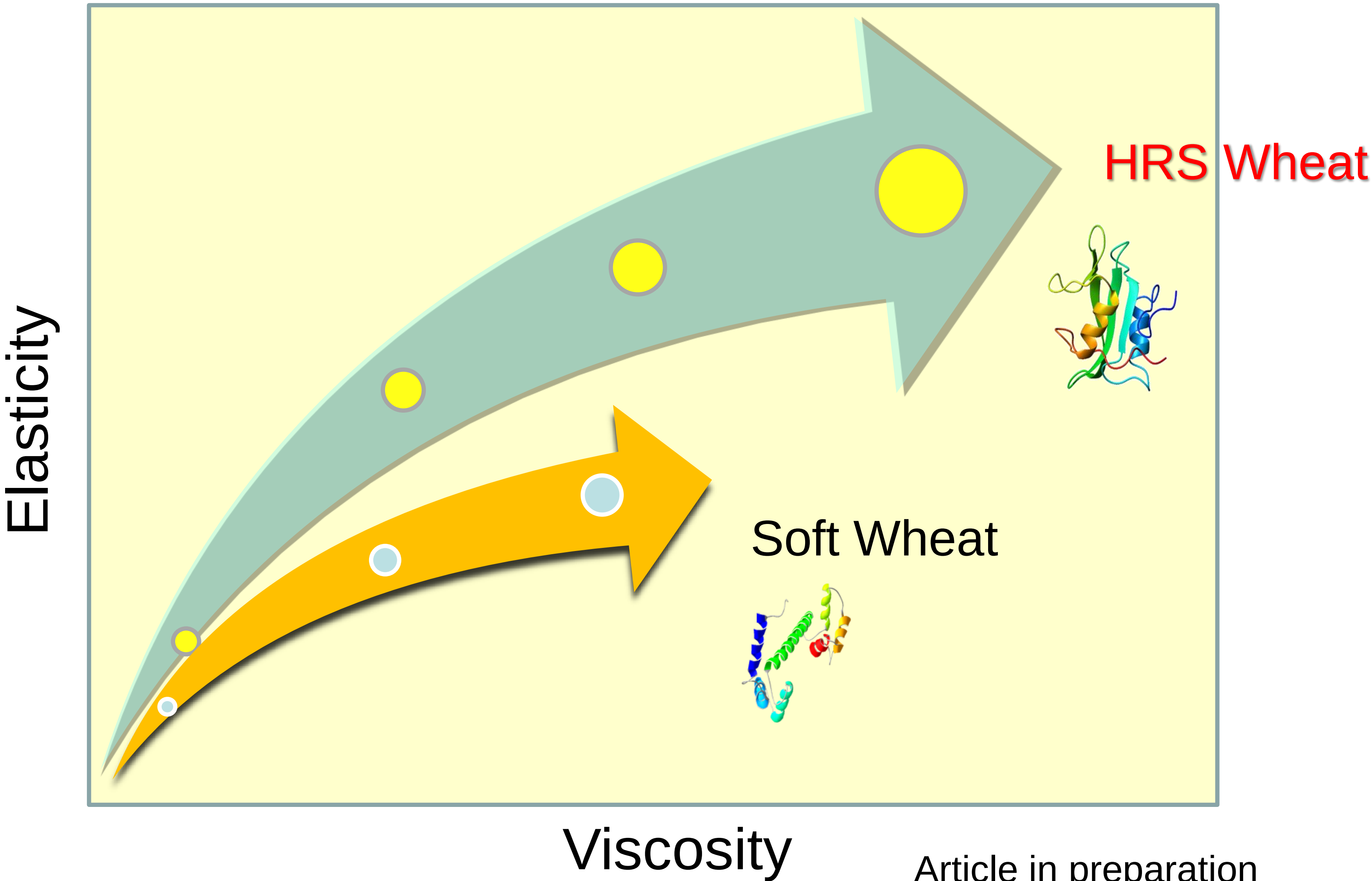
Viscelasticity of HMW-GS in Tablet Fractions

EFFECT OF GENOTYPE



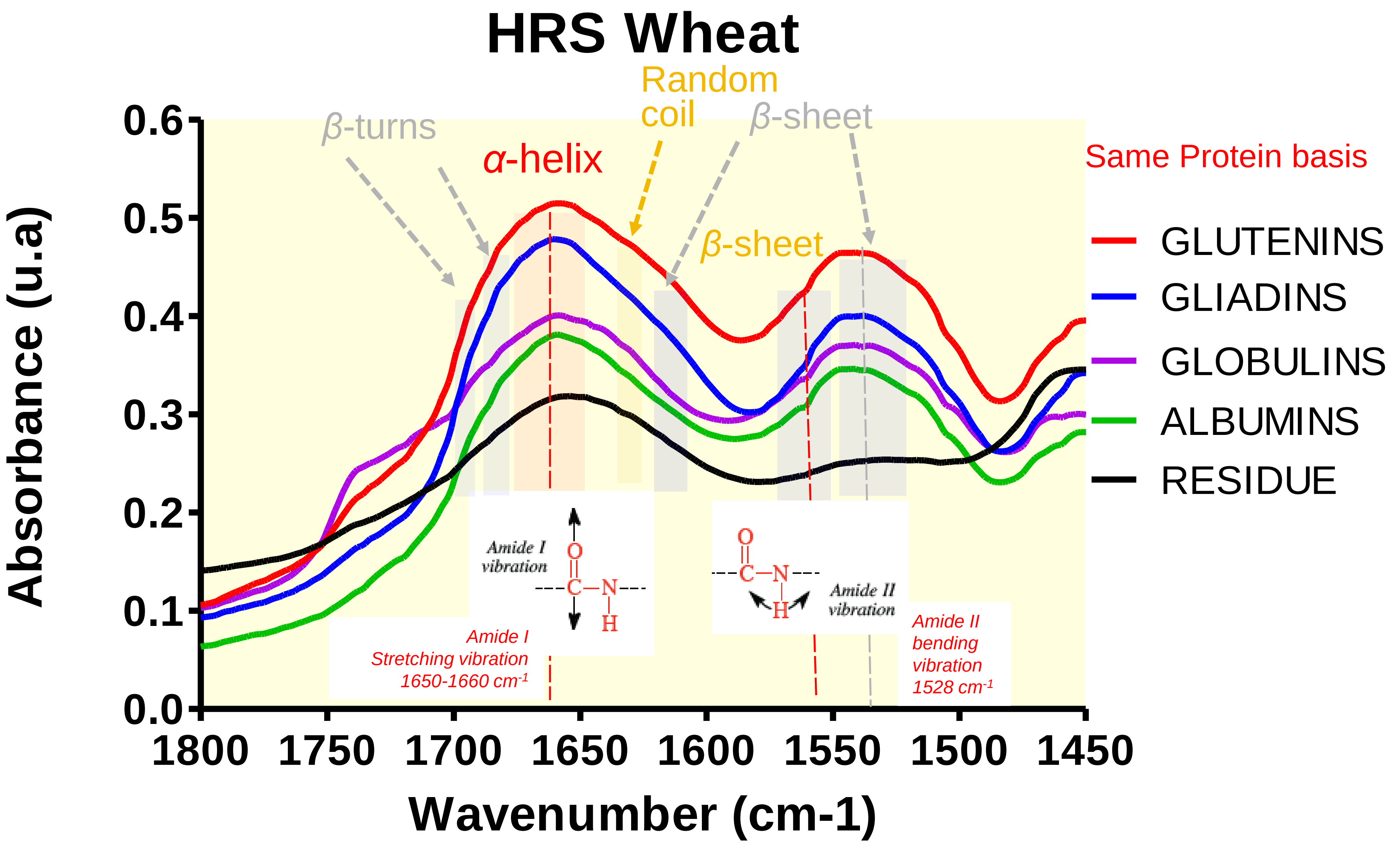
Article in preparation

Effect of Genotype on Viscoelasticity of Dough and Bread



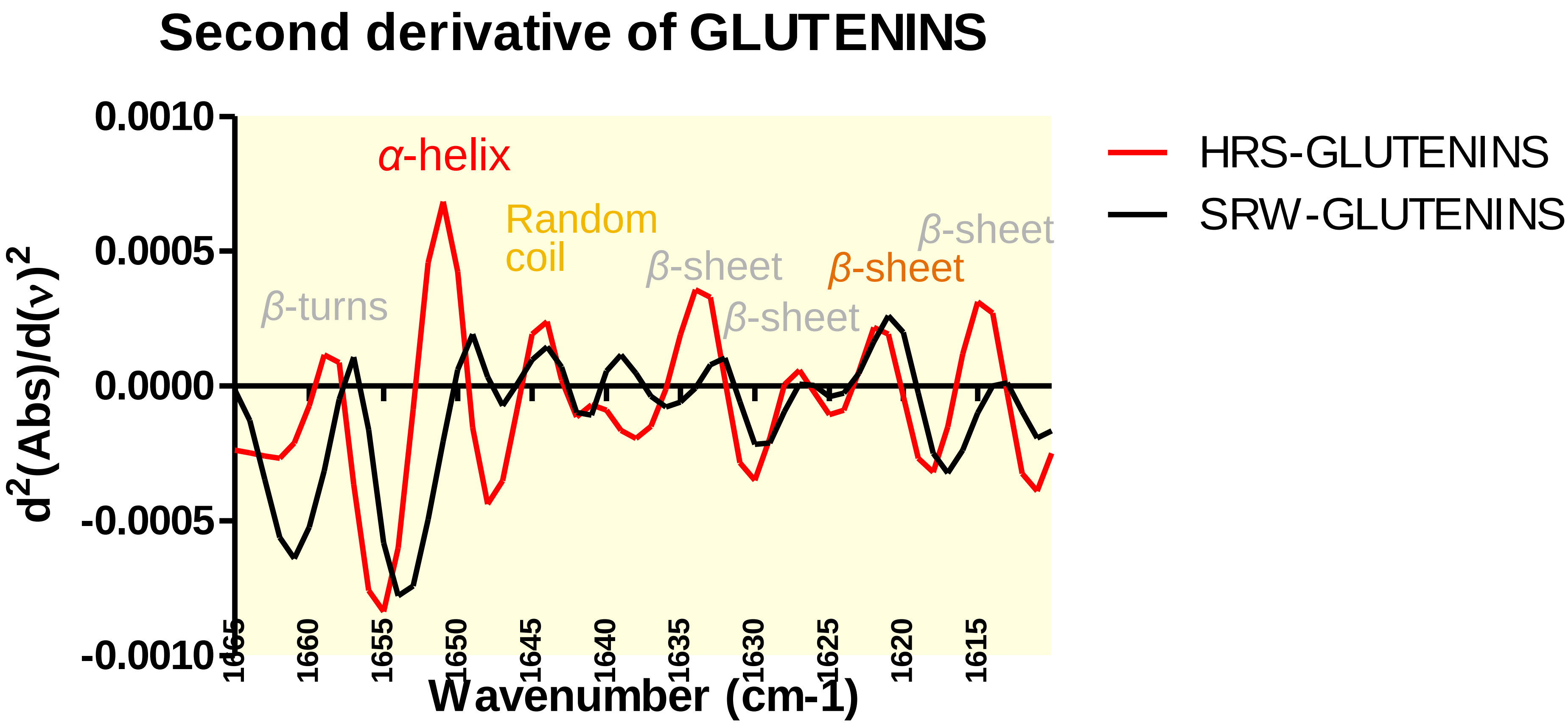
Article in preparation

ATR-FT-IR SPECTOSCOPY



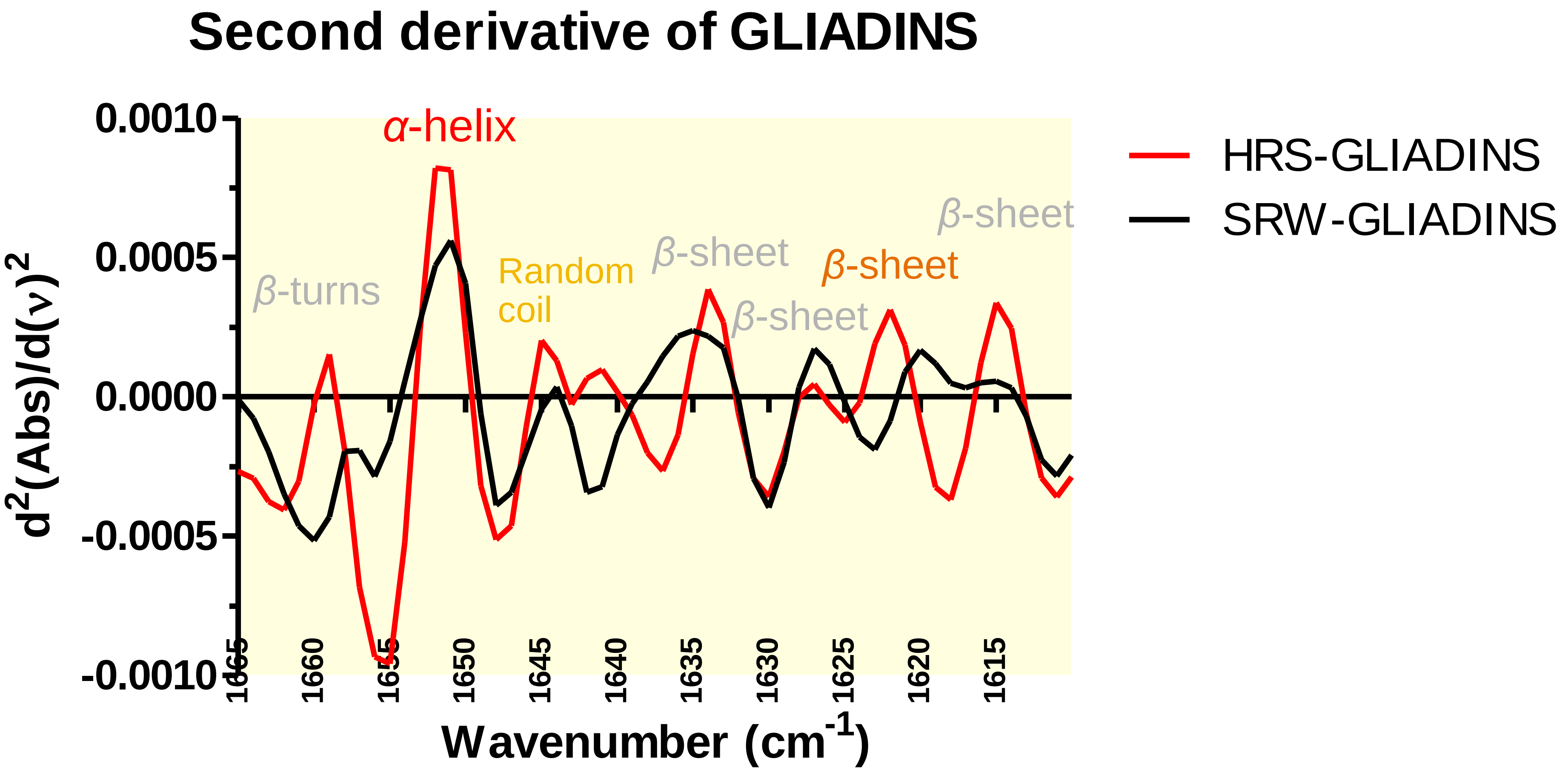
Luo et al., 2016. Food Chem

ATR-FT-IR SPECTOSCOPY



Article in preparation

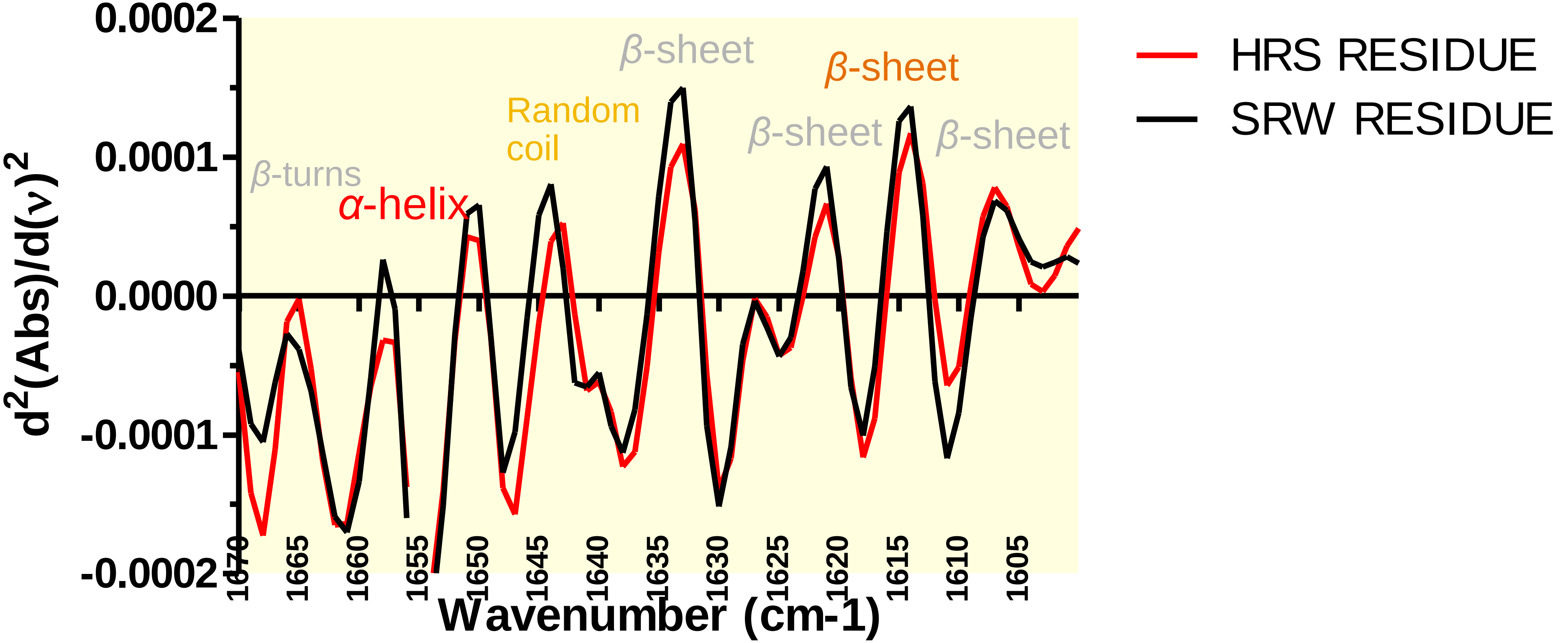
ATR-FT-IR SPECTOSCOPY

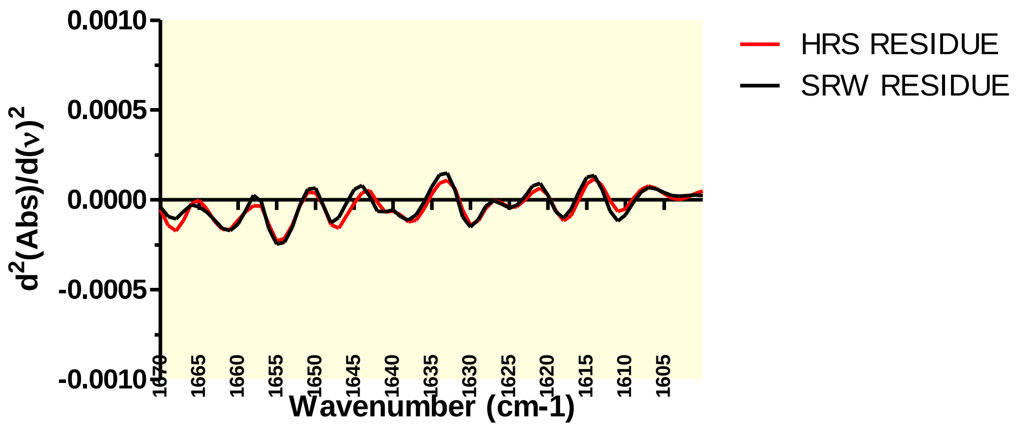


Article in preparation

Second derivative of RESIDUE

ATR-FT-IR SPECTOSCOPY





Article in preparation

Wheat Nixtamalization

Flash drying for obtaining wheat flours

Processing temperatura, time-genotype
Lime ($Ca(OH)_2$, (Ca^{2+}, OH^{1-})
Ca-Salts (ions Cl^{1-}, CO_3^{2-},SO_4^{2-}),
Ashes ($Ca^{2+,}CO_3^{2+}$, K^{1+}, Na^{1+} ions)

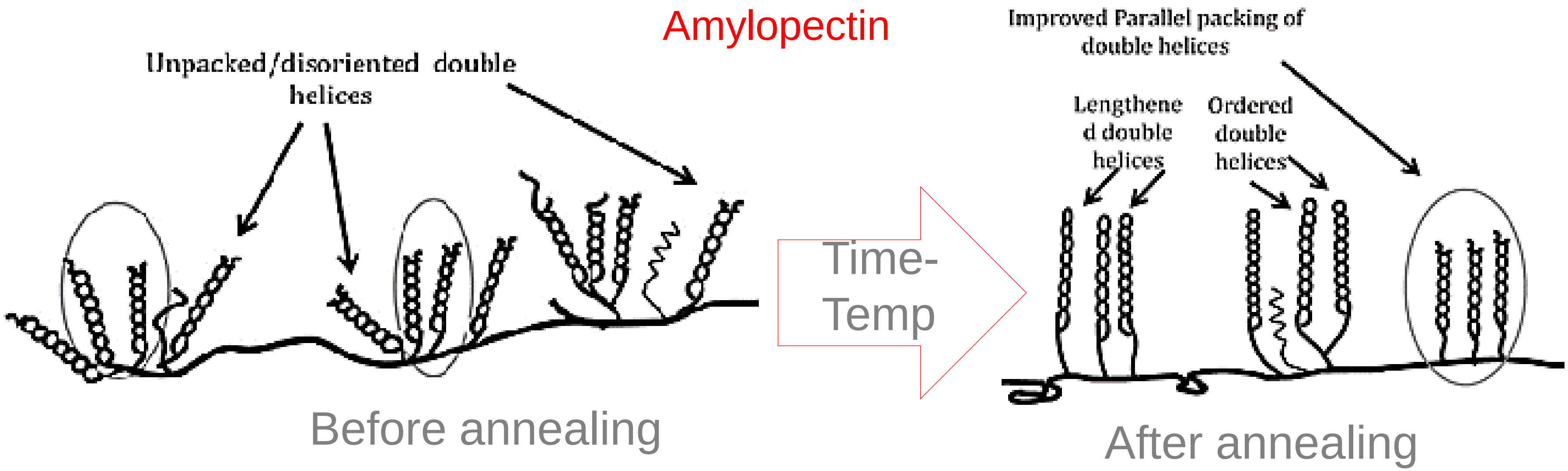
Protein and starch annealing
(Avoid Prot denaturation and starch Gelatinization)
Protein structural changes
(α-helix, β-sheet)
Gums hydrolysis
Water absorption

Dough viscoelasticity

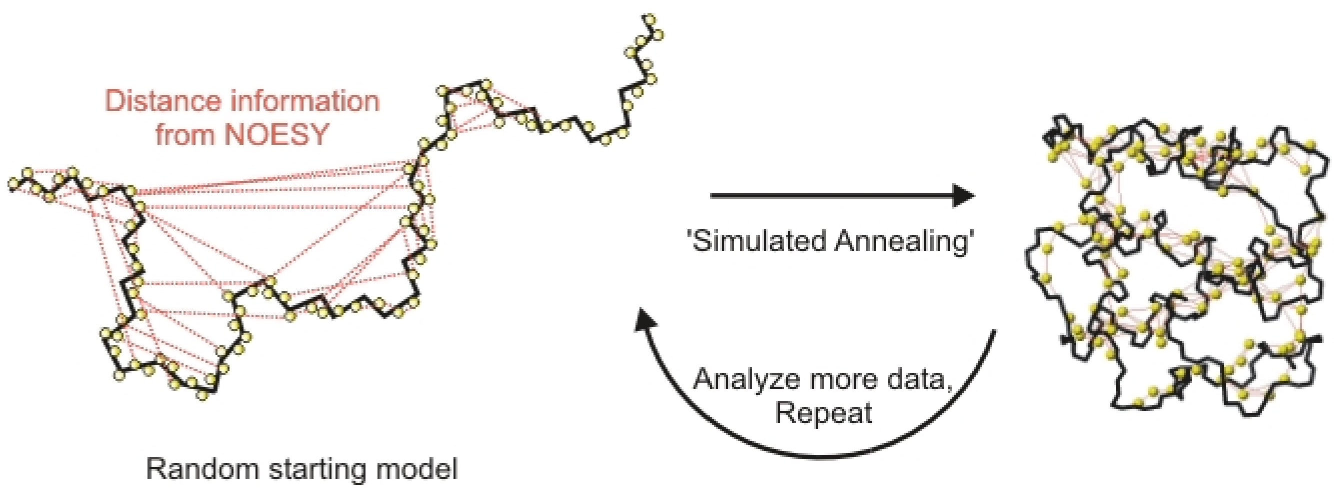
$$G(t) = G_0 + G_1 e^{-t/\tau_1} + G_2 e^{-t/\tau_2} + G_3 e^{-t/\tau_3}$$

$$\tau_i = \eta_i / G_i$$

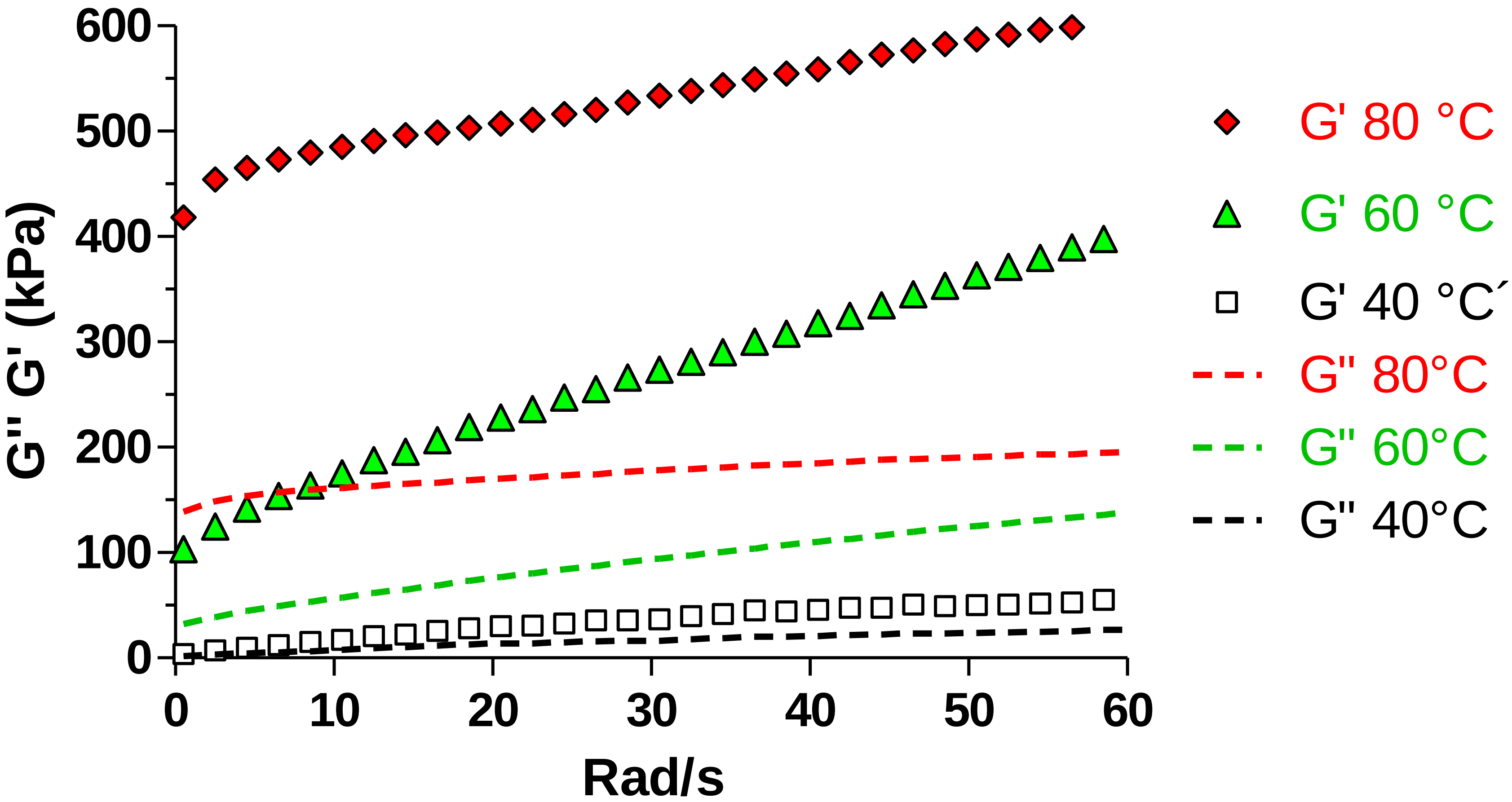
Amylopectin



Proteins

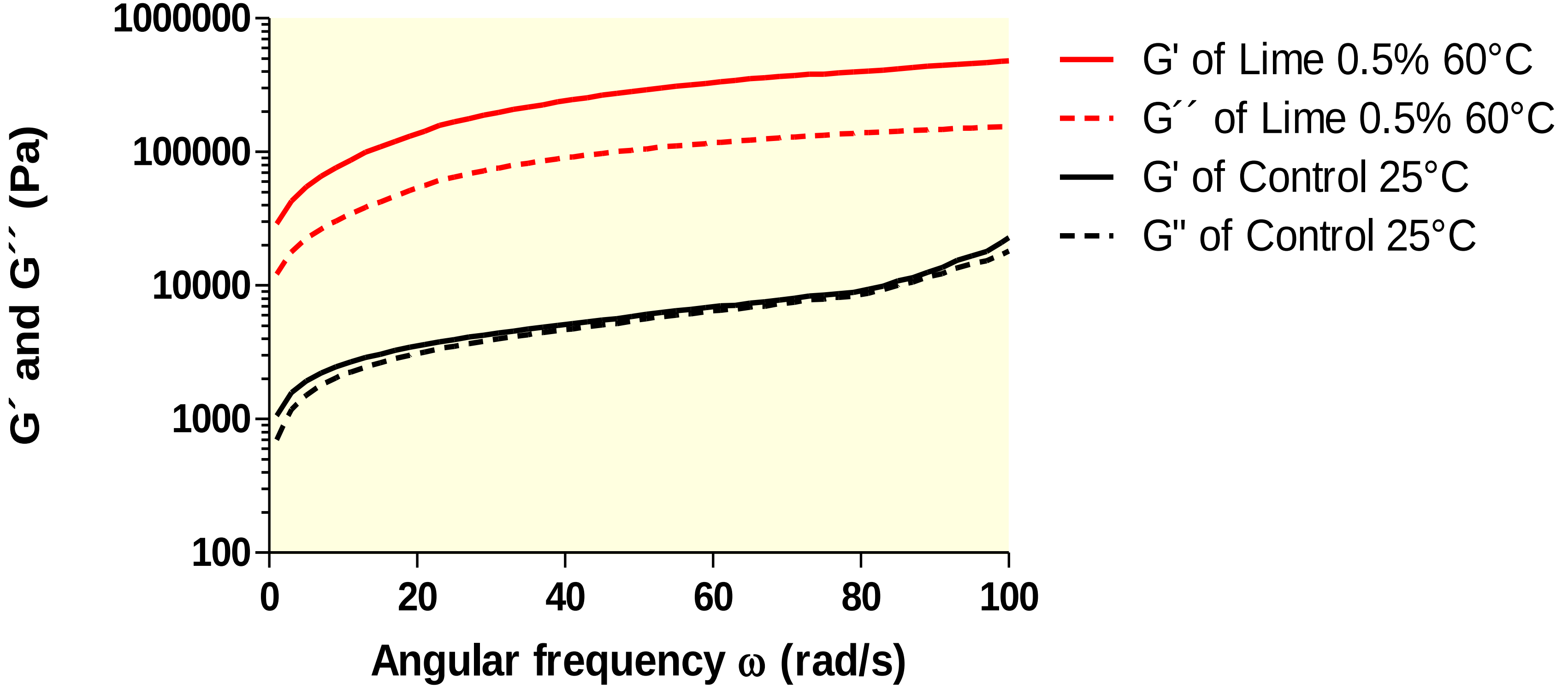


Effect of temp on wet gluten (1 mm gap)



Article in preparation

Nixtamalization Tech on GLIADINS from HRS Wheat 2mm gap



Article in preparation

Closing Remarks

•Glu-D1 5+10 of good breadmaking quality showed higher viscoelasticty compared to Glu-D1 2 + 12.

•Dough components presented higher viscoelasticity than gluten. Due to pentosans.

•Pentosans, starch, and non-gluten components play a major role in determining the viscoelastic nature of flour and bread.

Entanglements and agglomeration of glutenin of long chain sizes had major quality effect compared to short sizes (First element).

HRS wheat had higher viscoelasticity and α-helix and β-sheet compared to SRW-wheat.

Preliminary Nixtamalization results using wheat increase the viscoelasticity in dough and can be interesting approach to increase the quality of poor wheat quality.