A Comparison of the Rheology of Four Wheat Flour Doughs via a Damage Function Model

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Abstract:
The basic rheological properties of two Persian wheat flours - Tajan (11 % protein) and Back Cross Roshan (8 % protein) and two Australian wheat flours-JANZ (12.9 % protein) and Rosella (8.6 % protein) have been characterized. These properties have been interpreted via a damage function model. All samples could be reasonably well described by the damage function model with a power-law relaxation spectrum. Although the shear stresses in the Australian samples were higher, the relaxation parameter *G*(1) and power-law exponent *p* for the Australian varieties were lower than those for the Persian samples and the damage functions were different. Since protein contents were different, this indicates that the amount of protein is not the sole determinant of softness in the samples. The damage function *f* was also calculated for all samples. This function gives a measure of the softening due to working or kneading of the samples at a given strain level.

Zusammenfassung:
Die grundlegenden rheologischen Eigenschaften von zwei persischen Weizenmehlsorten, Tajan (11 % Eiweiß) und Back Cross Roshan (8 % Eiweiß) sowie zwei australische Weizensorten, Flours-JANZ (12.9 % Eiweiß) und Rosella (8.6 % Eiweiß) werden im Rahmen dieses Beitrags geschildert. Das damage-Funktionsmodell interpretiert die Eigenschaften der Proben. Alle Proben konnten durch die damage-Funktion mit einem Potenzgesetz-Relaxationszeitspektrum recht gut beschrieben werden. Obwohl die Schubspannungen in den australischen Proben höher waren, waren die Entspannungsparameter *G*(1) und Potenzgesetz-Exponenten für die australischen Sorten niedriger als die für die persischen Proben. Weiterhin wiesen die damage-Funktionen ebenfalls Unterschiede auf. Die damage-Funktion *f* wurde ebenfalls für alle Proben berechnet. Diese Funktion gibt ein Maß für die Anpassung der Verarbeitung sowie des Knetens der Proben bei einem bestimmten Belastungsniveau an.

Résumé:
Les propriétés rhéologiques de deux farines de blé persanes - Tajan (11 % de protéines) et Back Cross Roshan (8 % de protéines) et de deux farines de blé australiennes-JANZ (12,9 % de protéines) et Rosella (8,6 % de protéines) ont été caractérisées. Ces propriétés ont été interprétées par le biais d'un modèle d'endommagement. Tous les échantillons ont pu être raisonnablement bien décrits par le modèle d'endommagement avec une loi puissance du spectre de relaxation. Bien que les contraintes de cisaillement soient plus élevées pour les échantillons australiens, le paramètre de relaxation *G*(1) et l'exposant p de la loi de puissance des échantillons australiens sont inférieurs à ceux des échantillons persans et les fonctions d'endommagement sont différentes. Puisque la quantité de protéines est différente, cela indique que celle-ci n'est pas le seul critère déterminant le comportement des échantillons. La fonction d'endommagement *f* a également été calculée pour tous les échantillons. Cette fonction donne une mesure de l'assouplissement dû au malaxage de l'échantillon pour une déformation donnée.

Key words: dough rheology, wheat flour, relaxation, steady shear, elongation, damage function, power-law

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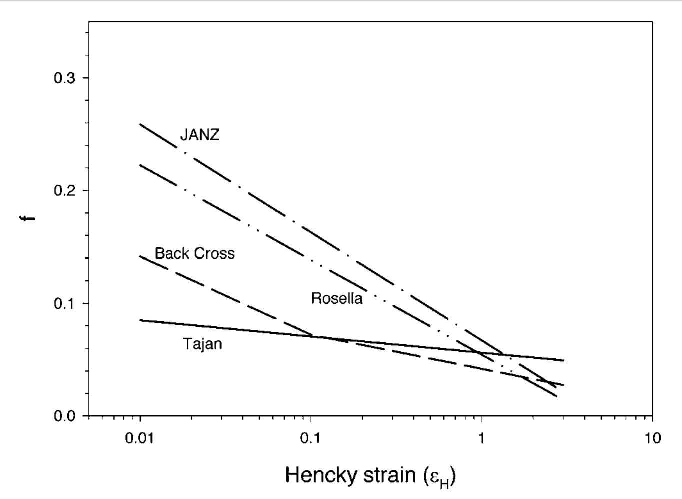

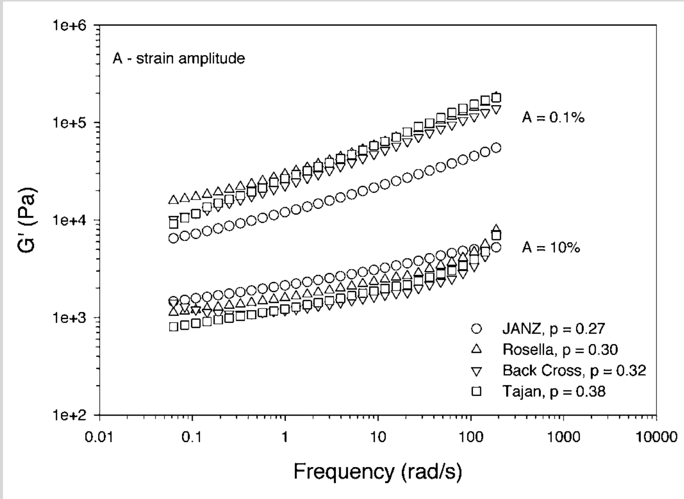

Figure 11 (left): Damage function f as a function of Hencky strain for elongation measurements of four varieties. The f function for JANZ: $f = -0.0958 \log \epsilon_H + 0.0669$, Rosella: $f = -0.0841 \log \epsilon_H + 0.0542$, Tajan: $f = -0.0144 \log \epsilon_H + 0.0561$ and for Back Cross: $f = -0.0695 \log \epsilon_H + 0.0025$ ($\epsilon_H \leq 0.1$) and $f = -0.0303 \log \epsilon_H + 0.0417$ ($\epsilon_H > 0.1$). The rise in f for ϵ_H is not shown; clearly f(0) = 1.0.

Figure 12: G' versus frequency at two strain amplitudes (0.1 and 10 %) for Australian and Persian samples. The slope of power-law fitted curves has been shown for each flour.

is not shown in this figure. This rapid change is discussed in [15]. The sudden drop is possibly due to reduced starch particle-protein network interaction at quite low stresses. Figure 11 shows that the Persian samples are softer at Hencky strains less than unity.

We also conducted *G'* and *G''* measurements at strain amplitudes of 0.001, 0.01, 0.05 and 0.1 for all samples. As it has been shown in different studies the range of maximum strain that results in a linear response is very small for dough [8]. For wheat flour, the maximum shear strain permitted in the linear range is around 0.001 (0.1 %). We used this value in our (linear) oscillatory tests. Results for storage module $G'(\omega)$ as a function of applied frequency ω (rad/s) are shown in Figure 12. The slope of the curves here is again *p* for small amplitudes (Eq. 3). Exponent *p* is close to the value of p from relaxation as it has been shown in Figure 12. It is in the range of 0.2 - 0.3 for Australian samples and 0.3 - 0.4 for Persian samples and $G' > G''$ indicating soft solid behavior.

5 DISCUSSION

We have shown that it is possible to differentiate between different flours by subjecting the doughs to different rheological tests. It seems that stress relaxation experiments at a strain of 0.1 % and determination of power-law *p* and *G*(1) could be good indices for dough behaviour in that stronger and more elastic flours show lower *G*(1) and *p*, but it seems that these differences are not solely related to protein content. The damage function *f* is also clearly different for the various flours. Another relatively high strain deformation that brings out subtle differences between different flour types is the constant shear rate flow between two parallel plates [22], where the strain increases linearly with the time of deformation. Typically Australian flours have higher values of stress than Persian samples, so it seems that they have stronger matrices. Of course in shear flow, it should be mentioned that the value of the stress peaks are strain-rate dependent. They are consistent with the assumption of a finite elastic network in gluten.

In oscillation, with a strain amplitude of 0.1 %, the power-law index is very close to the value in relaxation but we believe oscillation tests are not as convenient as data from relaxation tests, so that they were not used as a criterion for discriminating flours with similar protein qualities. We note that stress relaxation tests at various strain amplitudes are a convenient way of finding the damage function [4]. Testing of the samples by extensional testing seems to be a good way for determination of sample differences since extensional properties of the flours in constant elongation rate are quite different. Elongation rate is very important in dough reactions and baking so that at lower elongation rates the reaction of dough is related to the protein matrix strength, protein quantity and sample behaviour.

Typically, the wheat breed has a significant effect on dough rheology so that in all experiments Australian flours showed stronger resistance and a more elastic protein network. It should be noticed that determination of optimum water absorption and working are very important factors for producing reliable and reproducible data in experiments.

6 CONCLUSION

Comparing four rheological tests for these four samples reveals that the breed has a remarkable effect on the protein quality but differences in protein quantity cannot be the sole reason for having different rheological behaviour. It seems that using chemical and analytical information about the wheat protein besides rheological characteristics can give a good perspective of the protein efficiency for producing special products. Finding a correlation between rheological and

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analytical data may permit one to define some indices for each variety as a control factor, although it might be very hard to characterize such flours. As data showed the damage model seems quite useful for the description and comparison of the rheological behaviour of different doughs. With an overall look at different experiments, it seems that relaxation and elongation and steady shear are reliable tests for ranking flours but oscillatory tests also give useful complementary information.

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