WATER-SOLUBLE NONSTARCHY POLYSACCHARIDES OF COMPOSITE FLOURS. II. THE EFFECT OF POLYSACCHARIDES FROM YAM (*DIOSCOREA*) AND CASSAVA FLOURS ON THE RHEOLOGICAL BEHAVIOR OF WHEAT DOUGH

S. SEFA-DEDEH, B. MacDONALD, and V. F. RASPER, Department of Food Science, University of Guelph, Guelph, Ontario, Canada

ABSTRACT

Cereal Chem. 54(4): 813–819

Water-soluble nonstarchy polysaccharides (W.S.N.P.) extracted from flours milled from dried tubers of the two most common West African species of yam (*Dioscorea rotundata* Poir. and *D. alata* L.) and roots of cassava (*Manihot utilissima* Pohl., cv. Ankra) were tested for their effect on the rheological behavior of wheat dough during mixing and in simple tension. W.S.N.P. were prepared in the same way as water-soluble wheat "pentosans" of a typical bread flour which were used as a standard for comparison. While 1% replacement of wheat flour with an equal amount of cassava W.S.N.P. resulted in a reduced farinograph absorption of the mixture, yam W.S.N.P. as well as wheat pentosans exhibited an opposite effect. The highest increase in farinograph absorption (4.7%) followed the substitution of wheat flour with W.S.N.P. of *D. rotundata* Poir. origin. Analysis of data obtained in simple tension revealed that the tested materials (with the exception of *D. rotundata* Poir. W.S.N.P.) behaved as a rheologically inert material showing no significant effect on parameters other than those influenced by the changes in the water absorption characteristics. A distinct "strengthening" effect was noticed with doughs containing *D. rotundata* Poir. W.S.N.P., which was unrelated to the high water-binding capacity of this material. In rheological tests on bromated doughs, all W.S.N.P. appeared as an inert material with respect to the bromate reaction.

The chemical composition and oxidation gelation characteristics of water-soluble nonstarchy polysaccharides (W.S.N.P.) extracted from flours milled from dried tubers of several West African species of yam (*Dioscorea*) and roots of cassava (*Manihot utilissima* Pohl.) were the subjects of a study whose results were presented in Part I of this paper (1). The present study concerns the effect of some of these polysaccharides on the rheological quality of doughs prepared from untreated as well as bromated wheat flour. The impetus for this work arose from the results of earlier studies (2) in which marked differences in the baking characteristics were observed when the above-mentioned flours were used as partial substitutes for wheat flour in bread-baking tests. Yam flours, especially that of *D. rotundata* Poir. origin, exhibited a less detrimental effect on the baking performance of composite mixtures than other tested substitutes. Even at concentrations up to 10%, the addition of *D. rotundata* Poir. flour had an improving effect on loaf volume, in spite of the rather unfavorable characteristics of starch present in this flour. This effect was similar to that reported more recently for sweet potato flour (3).

Marked differences were found between the tested W.S.N.P. with respect to their chemical composition (1). While cassava W.S.N.P. were found to be predominantly polymers of D-glucose, other sugars were present in higher quantities in W.S.N.P. extracted from yam flours. Among them, *D. rotundata* Poir. W.S.N.P. were characterized by relatively high pentose (57% of the total carbohydrate content) and glucuronic acid (24.3%) contents in hydrolyzed material. Investigations described in Part II were undertaken to determine whether the differences in chemical composition are related to the effect of the individual W.S.N.P. on the rheological quality of supplemented wheat dough, and if there is any relation between this effect and the earlier reported baking characteristics.

MATERIALS AND METHODS

Materials

W.S.N.P. from peeled and sun-dried tubers of *D. rotundata* Poir. and *D. alata* L., and roots of *M. utilissima* Pohl., cv. Ankra, were prepared as described in Part I (1). Water-soluble wheat pentosans used for comparison were extracted from straight-run flour milled from Canadian hard red spring wheat.

Dough Preparation

W.S.N.P. were added at 1% concentration to an untreated, commercially milled wheat flour (13.82% protein, 59.2% farinograph absorption, both on 14% mb), replacing an equal amount of flour on a dry solids basis. The lyophilized polysaccharides were dissolved in water before they were added to flour. The doughs (without any addition of salt) were prepared by mixing them in a Brabender Farinograph® to maximum development consistency under the conditions of constant water absorption (59.2%) and constant optimum development consistency (500 BU), respectively. To obtain doughs with the same optimum development consistency, farinograph absorptions had to be adjusted depending on the type of W.S.N.P. All doughs were prepared using constant flour weight procedure. Bromated doughs were mixed from flour treated with 45 ppm of potassium bromate on a dry solids basis.

The doughs were rested and prepared for testing in simple tensile mode according to the procedure described earlier (4).

Rheological Measurements

Apart from farinographic data obtained in the process of dough mixing, stretching tests in simple tension at four different extension rates provided stress/strain curves which were analyzed in terms of isochronal constant strain rate modulus for 0.1 min extension time, F(0.1 min), and "exponent n," indicating the changes in the balance between the viscous and elastic response of the tested material. The procedure used for these measurements and the evaluation of the stress/strain curves in the aforementioned rheological terms were described in full detail earlier (4,5). The method is only applicable over a limited range of relatively small deformations; in all measurements, the strain ($\lambda - 1$) values did not exceed 1.2.

A Universal Testing Machine (Instron) with a special crosshead attachment was used for all stretching tests (5). The four arbitrarily chosen extension rates were 0.44, 0.22, 0.08, and 0.04 s^{-1}. At each extension rate, the measurements were repeated three times and all reported data were taken as averages of these triplicate tests.

RESULTS AND DISCUSSION

Farinographic tests revealed marked differences in the effect of the tested W.S.N.P. on the water absorption characteristics of the supplemented doughs (Fig. 1). When the water content in the doughs was kept at the same level as in the control dough without any added W.S.N.P., polysaccharides of cassava origin caused a marked decrease in the maximum development consistency, while both water-soluble what pentosans and tested yam W.S.N.P. exhibited an opposite effect. The highest increase in the consistency (25%) was recorded with the dough containing W.S.N.P. extracted from *D. rotundata* Poir. flour. As expected, the adjustments of farinograph absorption values to bring the maximum development consistency of all doughs to the 500-BU line were directly related to the respective changes in dough consistency recorded under the conditions of constant water content (Fig. 2). To determine whether the isolated materials were involved in any rheologically significant mechanisms other than binding water, the doughs were subjected to tests in simple tension which provided two parameters: isochronal constant strain rate modulus F(t*) and "exponent n." Isochronal modulus describes the measured material at any arbitrarily chosen fixed time of extension t* over the range of the method's applicability, while exponent n shows the time dependence of the time-dependent modulus F(t) as expressed by the following equation:

$$F(t) = F(t^*) (t^*/t)^n \qquad [1]$$

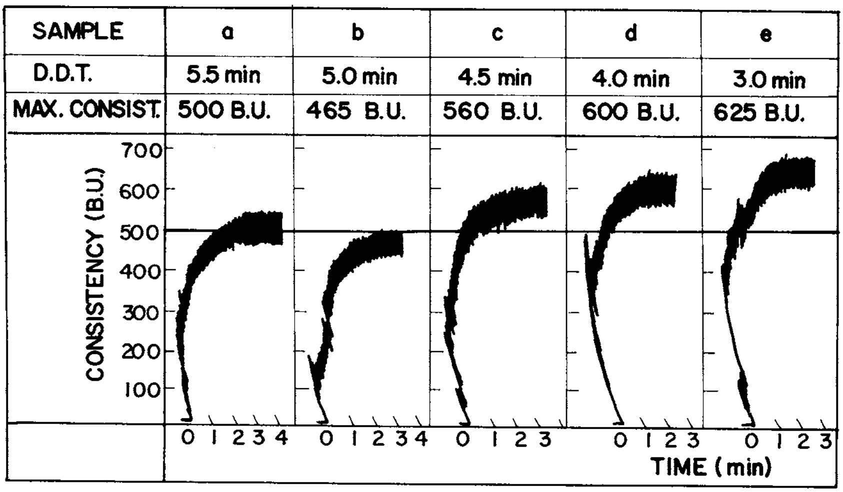

Fig. 1. Dough development curves for doughs prepared from wheat flour supplemented with 1% water-soluble nonstarchy polysaccharides (W.S.N.P.). Doughs mixed at constant water absorption of 59.2%. Origin of W.S.N.P.: a) control, b) straight-run H.R.S. wheat flour, c) *M. utilissima* Pohl. flour, d) *D. alata* L. flour, and e) *D. rotundata* Poir. flour.

Thus, this exponent may serve as an indicator of the viscoelastic character of the measured material; a limit value of 0 signifies a purely elastic material, whereas a purely viscous material will be characterized by the value −1. Any value between these two limits indicates that the material is both viscous and elastic, and any change in the balance between its viscous and elastic response should be reflected in the value of this exponent. While isochronal modulus was found dependent on both the inherent quality of flour and water content in the dough, exponent n appeared not to be affected by the latter over a limited range (5). Within this range, the exponent could be considered a useful tool in studies where the effect of water should be separated from other factors influencing the rheological character of the tested material.

To determine the validity of this statement, exponent n values were evaluated for a series of doughs, all prepared from the same wheat flour but with water absorption ranging from 54 to 60% (Table I). The value of the exponent decreased from −0.295 to −0.335 over the whole 6% range. It will be shown later that changes in this parameter due to the addition of W.S. N.P. to wheat flour which were considered statistically significant either exceeded the above difference or were of approximately the same magnitude over a considerably narrower range of water absorption. Therefore, they could be attributed at least partially to factors other than water content or water-binding capacity of the dough.

All changes in the water-binding capacity of the doughs upon the addition of tested W.S.N.P. were well demonstrated by the values of isochronal modulus F(0.1 min). From comparison of data given in Figs. 1 and 2 and Table II, it

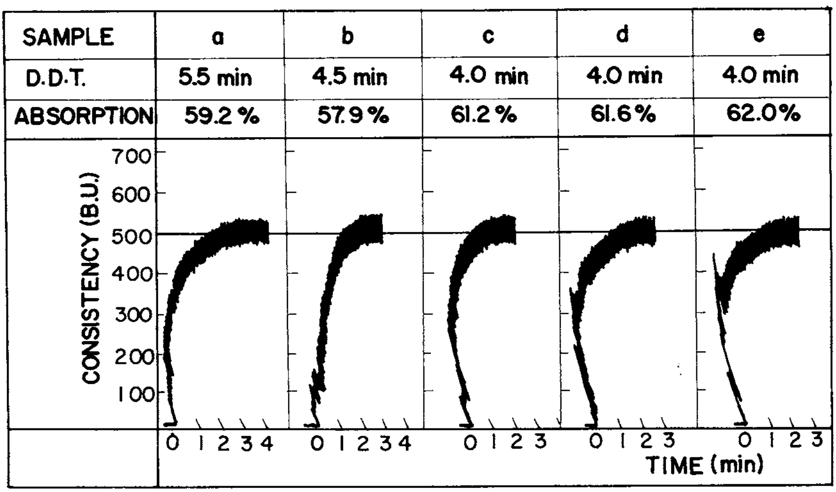

Fig. 2. Dough development curves for doughs prepared from wheat flour supplemented with 1% water-soluble nonstarchy polysaccharides (W.S.N.P.). Doughs mixed to constant maximum development consistency of 500 BU. Origin of W.S.N.P.: a) control, b) straight-run H.R.S. wheat flour, c) *M. utilissima* Pohl. flour, d) *D. alata* L. flour, and e) *D. rotundata* Poir. flour.

became evident that, under the conditions of constant water content, the isochronal moduli followed similar patterns as farinograph maximum development consistencies. On the other hand, when all doughs were mixed to the same maximum development consistency, the changes in the modulus were inversely related to the adjustments of farinograph absorption. However, it was noticed that the isochronal modulus of dough containing W.S.N.P. from *D. rotundata* Poir. flour did not reach the lowest value in the series of samples, in

TABLE I
Effect of the Water Content in Dough on Isochronal Modulus F (0.1 min) and Exponent n

	Sample No.						
	1	2	3	4	5	6	7
Water absorption, %	54	55	56	57	58	59	60
Isochronal modulus F (0.1 min) (kg cm^{-1} s^{-2})	17.0	16.6	15.7	13.7	11.2	10.5	8.7
Exponent n	−0.295	−0.292	−0.295	−0.317	−0.320	−0.330	−0.335

TABLE II
Rheological Parameters of Unbromated and Bromated Doughs Supplemented with 1% Tested W.S.N.P.

	Unbromated Doughs			Bromated Doughs		
	Isochronal modulus F (0.1 min)		Exponent n	Isochronal modulus F (0.1 min)		Exponent n
	kg cm^{-1} s^{-2}	%[a]		kg cm^{-1} s^{-2}	%[a]	
Control dough (unsupplemented)	9.8	...	−0.350	11.3	...	−0.270
Constant Water Absorption (59.2%)						
Dough supplemented with W.S.N.P. from:						
H.R.S. wheat	10.1	+ 3.1	−0.353	11.8	+ 4.4	−0.260
Cassava	9.3	− 5.1	−0.350	10.4	− 8.0	−0.260
Yam—*D. alata* L.	10.1	+ 3.1	−0.352	11.7	+ 3.5	−0.260
D. rotundata Poir.	11.2	+14.3	−0.310**	12.9	+14.1	−0.225**
Constant Max. Development Consistency (500 B.U.)						
HR.S. wheat	8.1	−17.3	−0.360	9.2	−18.6	−0.260
Cassava	10.6	+ 8.2	−0.350	12.5	+10.6	−0.272
Yam—*D. alata* L.	7.6	−22.4	−0.360	10.1	−12.2	−0.267
D. rotundata Poir.	8.8	−10.2	−0.315**	11.2	− 1.0	−0.204**

[a]Change in isochronal modulus expressed as percentage of the modulus of control dough.

spite of the highest addition of water. A rather exceptional character of dough containing these W.S.N.P. was further confirmed by the values of exponent n. The doughs supplemented with *D. rotundata* Poir. W.S.N.P. were the only ones characterized by a statistically significant change in this parameter. A shift closer to 0 (*i.e.*, closer to the elastic end of the viscoelastic continuum) was observed. The elucidation of this phenomenon calls for a more detailed study, but it is of interest to note that the shift occurred under the conditions of both constant water absorption and constant maximum development consistency.

The same tests were run with bromated doughs prepared from wheat flour treated with 45 ppm $KBrO_3$. The interaction of nonstarchy polysaccharides with oxidizing agents in the process of dough development has drawn the attention of several researchers. Bushuk and Hlynka (6) concluded from their structural relaxation studies that wheat pentosans did not play any direct role in the bromate reaction other than as a relatively inert diluent similar to starch. More recently, Patil *et al.* (7) observed a significant change in the proportion of various DEAE cellulose fractions of wheat pentosans during mixing of doughs treated with oxidizing agents, which they related to an intensified association between carbohydrate and protein in the presence of the agent.

Measured rheological parameters of bromated doughs are compared with those of unbromated ones in Table II. Since both isochronal modulus and exponent n respond with a high sensitivity to the strengthening effect of the oxidizing agent (4), they could be used as indicators of any stimulation or inhibition of bromate action in the presence of added W.S.N.P. In order to separate the changes in isochronal modulus due to such interaction from the water absorption effect, all changes in this parameter as a result of adding W.S.N.P. to either untreated or bromated flour were expressed as percentages of the isochronal moduli of respective controls (without added W.S.N.P.). From these data, it became evident that the changes in isochronal modulus of bromated doughs due to the addition of W.S.N.P. of cassava origin and water-soluble wheat pentosans were practically of the same magnitude as those recorded with unbromated doughs. All of the differences were within the experimental error. Therefore, these two materials appeared to have no effect on bromate action. However, a marked difference was observed with doughs containing W.S.N.P. of *D. rotundata* Poir. flour under the conditions of constant maximum development consistency. With unbromated dough, the adjustment of farinograph absorption after the addition of W.S.N.P. resulted in a 10.2% decrease of the isochronal modulus (compared with the control). This decrease was practically negligible (1.0) with bromated dough. The same phenomenon, though manifested to a lesser extent, was recorded with dough containing W.S.N.P. from *D. alata* L. flour. Since this more pronounced strengthening effect of bromate was only recorded with doughs having a considerably increased water content, it appeared that it was this factor which was primarily responsible for the higher values of isochronal moduli, rather than any interaction between the polysaccharides and the oxidizing agent. It has previously been shown that the capacity of the improver to change the measured parameters can be markedly enhanced by an increased water content (4).

Similar to unbromated doughs, those containing *D. rotundata* Poir. W.S.N.P. were the only bromated ones characterized by a significantly increased exponent n. However, there was no significant difference between the magnitude of this increase for bromated and unbromated doughs. Thus, the experiments showed no evidence for involvement of the tested polysaccharides in the bromate reaction which could affect the measured parameters. This observation did not necessarily lead to a conclusion that there was no possibility of any interaction between the oxidizing agent and the polysaccharides. It was reported in Part I of this paper that all polysaccharide solutions upon oxidation with H_2O_2 exhibited a gelation effect with variable intensity similar to that of wheat pentosans. However, it appeared that there was no direct relation between these oxidative gelation characteristics and rheological parameters measured in this study. This was best demonstrated by the behavior of W.S.N.P. of *D. alata* L. origin. While solutions of these polysaccharides previously gave a very strong gelation response to the oxidizing agent in terms of viscosity increase, they appeared equally inert with respect to bromate reaction in the dough as all other tested materials.

CONCLUSIONS

The effect of all tested nonstarchy polysaccharides on the rheological quality of wheat dough was mainly attributed to their role in changing the water-binding capacity of the system. Nevertheless, an indication of a mechanism other than water-binding was observed with material extracted from *D. rotundata* Poir. flour. Though the elucidation of this effect calls for more detailed studies, it is of interest to note that it was recorded with a material which was previously found to possess rather unique chemical characteristics among the tested nonstarchy polysaccharides. The fact that it was extracted from a flour which was found to have a less detrimental effect on the baking performance of a composite mixture than any other flour used in this study may lead to a suggestion that there is a close relation between the reported baking characteristics and the nature of this nonstarchy fraction.

Literature Cited

1. SEFA-DEDEH, S., and RASPER, V. F. Water-soluble nonstarchy polysaccharides of composite flours. I. Chemical nature and oxidative gelation of polysaccharides from yam (*Dioscorea*) and cassava flours. Cereal Chem. 54: 746 (1977).
2. RASPER, V., RASPER, J., and MABEY, G. L. Functional properties of nonwheat flour substitutes in composite flours. I. The effect of nonwheat starches in composite doughs. Can. Inst. Food Sci. Technol. J. 7: 86 (1974).
3. HAMED, M. G. E., REFAI, F. Y., HUSSEIN, M. F., and EL-SAMAHY, S. U. Effect of adding sweet potato flour to wheat flour on physical dough properties and baking. Cereal Chem. 50: 140 (1973).
4. RASPER, V., RASPER, J., and DEMAN, J. M. Stress-strain relationships of chemically improved unfermented doughs. I. Evaluation of data obtained at large deformations in simple tensile mode. J. Texture Studies 4: 438 (1974).
5. TSCHOEGL, N. W., RINDE, J. A., and SMITH, T. L. Rheological properties of wheat flour doughs. II. Dependence of large deformation and rupture properties in simple tension on time, temperature and water absorption. Rheol. Acta 9: 223 (1970).
6. BUSHUK, W., and HLYNKA, I. The bromate reaction in dough. V. Effect of flour components and some related compounds. Cereal Chem. 38: 316 (1961).
7. PATIL, S. K., TSEN, C. C., and LINEBACK, D. R. Water-soluble pentosans of wheat flour. II. Characteristics of pentosans and glycoproteins from wheat flour and doughs mixed under various conditions. Cereal Chem. 52: 57 (1975).

[Received July 23, 1976. Accepted January 14, 1977]