Physicochemical and Functional Properties of Rye Nonstarch Polysaccharides. IV. The Effect of High Molecular Weight Water-Soluble Pentosans on Wheat-Bread Quality in a Straight-Dough Procedure

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ABSTRACT

Cereal Chem. 70(3):306–311

Addition of 2% high molecular weight rye water-soluble pentosans to European bread wheat flour greatly changed its rheological and functional breadmaking properties. When the rye fractions were added as dry powder, the changes in the mixograph curves were smaller than the changes of the fractions that were presoaked in water and then added. Under the latter conditions, the mixograph peak height and area under the curve were greatly increased. Response surface methodology showed that the loaf volume of breads obtained from wheat flour is strongly dependent on mixing time and water addition. The addition of the rye components as a fine powder to wheat flour increased the water-absorption level and the range of mixing times for obtaining a bread of constant loaf volume and crumb quality. At the same time, it was possible to incorporate more water and to mix for a longer time without impairing the dough-handling properties. In general, the loaf volume increased and the crumb structure was comparable to that of the control. When the high molecular weight water solubles from rye were presoaked and added as a solution, the range of mixing times and the water-absorption level again were increased. Mixing time and water-absorption level strongly influenced loaf volume. The rye components used in this study, therefore, obviously influenced the quality of the wheat flour.

Reports concerning the impact of water-soluble pentosans on the breadmaking potential of wheat and rye are rather contradictory. Their effects on dough characteristics such as absorption level, dough development time, dough consistency, extensibility, and resistance to extension or breakdown were investigated by several researchers (Cawley 1964; Jelaca and Hlynka 1971, 1972; Holas et al 1973; Kim and D'Appolonia 1977; Meuser and Suckow 1985). Although significant correlations exist in the results obtained from various instruments (farinograph, mixograph, extensigraph), some findings (the effect on dough development time, dough breakdown) are contradictory.

Early investigations showed that water-soluble pentosans from wheat flour contributed to loaf volume, but investigators were not able to separate the effects of carbohydrates from those of protein (Baker et al 1943). Further studies introduced more ambiguity than clarity about the functional role of wheat pentosans in breadmaking. Cawley (1964) observed that the volume of loaves baked from blends of gluten and starch increased upon addition of high molecular weight water solubles (HMWS) of wheat and that the increase was due to nonstarch polysaccharides. Enzymic hydrolysis confirmed that the increase was due to nonstarch polysaccharides and not influenced by the presence of protein. Reconstitution experiments by Hoseney et al (1969) established that the removal of the water solubles from wheat flour does indeed lead to a reduction of loaf volume. Denaturation of the protein in the water solubles by boiling revealed that the reduction could be ascribed to the water-soluble pentosans. Later, D'Appolonia et al (1970) reported that water solubles, crude and amylase-treated, from wheat had an improving effect on the volume of gluten-starch loaves. Fractionation on diethylaminoethyl-cellulose showed that pure arabinoxylans had only a very small impact on loaf volume; however, fractions high in protein content increased the loaf volume markedly.

Delcour et al (1991) studied the effects of a rye fraction containing water-soluble pentosans and proteins on gluten-starch loaves and showed that these components did indeed improve the loaf volume. The optimum concentration was 2–3%. The protein component appeared to have no effect.

According to Hoseney et al (1969) and Kim and D'Appolonia (1977), although water-soluble pentosans in wheat flour contribute to loaf volume of normal wheat loaves, adding an extra amount did not result in an increased volume. In contrast, Jelaca and Hlynka (1972) observed a marked increase of loaf volume (5–14%) when water-soluble pentosans from wheat were added to wheat flour. Shogren et al (1987), investigating the pentosan content and breadmaking characteristics of hard red winter wheat flours, concluded that water-soluble pentosans in wheat may have a small negative effect on loaf volume. Meuser and Suckow (1985) reported a positive effect on loaf volume for rye water-soluble pentosans. Jankiewicz and Michniewicz (1987), in their report on the impact of water-soluble rye pentosans on wheat-bread staling, did not mention any effect on wheat loaf volume.

It is generally accepted that pentosans have an impact on the water absorption of dough (Bushuk 1966, Kulp 1968, Jelaca and Hlynka 1971, Kim and D'Appolonia 1977, Meuser and Suckow 1985). Analytical figures on the water-binding capacity of pentosans vary widely (4.4–11 times their weight of water), but there is common agreement that they bind a substantial amount of dough water. Because of this high water-absorbing capacity, pentosans influence the relationship between loaf volume and water-absorption levels used in the baking process. Thus, they can strongly influence the breadmaking properties of wheat flours (Jelaca and Hlynka 1972, Hoseney 1984).

One of the reasons for the discrepancy of the conclusions reached by authors who studied the impact of water-soluble pentosans on the breadmaking potential of wheat flour could be that there has not been a systematic study in which the breadmaking potential of wheat (with and without added pentosan) was evaluated as a function of varying water additions and mixing times.

We here report on such work. We compared breads obtained by baking with or without the addition of 2% HMWS from rye. In each of our experiments we changed not only the water addition quantity but also the mixing time. We also studied the effect of presoaking the water solubles before addition. We compared optimum water-absorption levels and mixing times obtained by mixography with optimum baking results.

MATERIALS AND METHODS

Isolation of Rye HMWS

The Danko variety rye grain we used for our sample was grown in the Province Limburg, Belgium (1990 harvest). The sample was ground at a 12% moisture level with a D.D.D. President mill (President, Ieper, Belgium). The HMWS were separated from the rye whole meal by shaking one portion of meal with four portions of deionized water for 4 hr at 6°C and recovering the water solubles by centrifugation at 10,000 × g for 30 min at

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2°C. The supernatant was then dialyzed (molecular weight cutoff 12,000) for 48 hr against deionized water, shell-frozen with liquid nitrogen, and freeze-dried.

Analysis of the Rye HMWS

Protein content (Kjeldahl nitrogen) was estimated as outlined in Analytica (EBC 1987). The monosaccharide content and composition were determined by gas chromatography of the alditol acetates obtained by acid hydrolysis of the sample (Delcour et al 1989).

Mixograph Assay

Operating conditions and procedures followed the AACC methods (1983). The parameters of the mixogram curves were estimated as prescribed by Kunerth and D'Appolonia (1985). The moisture level of the HMWS was 10.3%. When HMWS (2% level) were tested, the weight of flour (14% moisture content) was reduced so that the total weight of flour and the sample material would still equal 10.0 g. The lyophilized preparations were homogenized with an Ultra-Turrax mixer (type A 10, Janke and Kunkel, Staufen, Germany) while being cooled with solid carbon dioxide. The resulting dry powder was blended with the flour by hand. The presoaked HMWS were obtained by stirring 200 mg of the lyophilized material overnight at 5°C in 5.0 ml of water. These presoaked pentosans, as well as the water quantity needed to obtain the desired absorption level, were added to the flour just before mixing.

Breadmaking Materials

A commercial European wheat flour (Surbi) was used, along with Crisco shortening (Proctor and Gamble, Cincinnati, OH); Gloria nonfat dried milk (Nestle, Vevey, Switzerland); and Fermipan dried yeast (Gist-Brocades, Delft, The Netherlands). The materials were analyzed by standard AACC methods (1983).

Loaf Production

The breadmaking test for 10 g of flour developed by Shogren and Finney (1984) was used. All baking trials were performed at least in triplicate. Nonfat dried milk (4.0%) and shortening (3.0%) were included in the formula. The fermentation was done with 76 mg of Fermipan. The addition of HMWS was as described for the mixograph experiments.

The bread loaves were placed on a wire grid for about 2 hr. Then loaf volumes were determined four times using the method of Vanhamel et al (1991), discriminating bread loaves of 1-cm^3 difference. The total standard deviation for the breadmaking process and the volume determinations was 1 cm^3.

Response Surface Methodology

For this study, a central-composite, rotatable, second-order experimental design was used. This type of design provides an efficient method of examining the loaf volume response to input variables (water addition, mixing time) during breadmaking (Box et al 1987, Montgomery 1984). Our first step was to determine the area of effect for mixing time and water addition to loaf volume that could be examined for doughs with and without added rye material. Although not critical for dough formation, the minimum absorption level used was 55%. The water addition was increased until sticky doughs were obtained. At different absorption levels, minimum (time necessary to obtain an even distribution of the dough ingredients) and maximum (the time during which a dough can be mixed without picking up stickiness) mixing times were evaluated. An experiment was set up to explore the response surface over this area (Table I).

TABLE I
Absorption Levels (A) and Mixing Times (T) Chosen in the Initial Experiments and Corresponding Codes for the Variables

Experiment No.	Control Flour		High Molecular Weight Water Solubles from Rye Added (Dry or Presoaked)			
	A (%)	*T* (sec)	*A* (%)	*T* (sec)	*A* Coded	*T* Coded
1	60.0	330	61.5	330	0.00	1.41
2	60.0	255	61.5	255	0.00	0.00
3	55.0	255	55.0	255	−1.41	0.00
4	65.0	255	68.0	255	1.41	0.00
5	60.0	180	61.5	180	0.00	−1.41
6	56.5	203	56.9	203	−1.00	−1.00
7	60.0	255	61.5	255	0.00	0.00
8	56.5	307	56.9	307	−1.00	1.00
9	63.5	203	66.1	203	1.00	−1.00
10	63.5	307	66.1	307	1.00	1.00
11	60.0	255	61.5	255	0.00	0.00

RESULTS AND DISCUSSION

Composition of Rye Water Solubles

Dialysis removed 45% of the original water-soluble material from rye, yielding 5.4% HMWS. The isolated material contained 4% Kjeldahl nitrogen and 75% carbohydrates. These carbohydrates consisted of 73.1% pentoses (L-[+]-arabinose and D-[+]-xylose), 22.7% D-(+)-glucose, and minor traces of D-(+)-galactose and D-(+)-mannose. Starch is a common contaminant in rye extracts (Fengler and Marquardt 1988). According to Anderson et al (1978) and Prentice et al (1980), the contribution of β-glucan to the D-(+)-glucose content is negligible. These authors reported that the rye grain contains small amounts of β-glucan, but β-glucan is insoluble in water at low temperatures. The ratio of L-(+)-arabinose to D-(+)-xylose was 0.69 and is in line with previous observations (Delcour et al 1991).

Impact of Rye Water Solubles on Mixing Characteristics

Because rye pentosans have a high water-absorbing capacity, the influence of varying water additions on the mixograph characteristics was examined.

Control flour. The mixograph curves of the control flour at different absorption levels were compared to determine the optimum water addition. The subjectively determined optimum absorption level was 58%. The height of the mixograph peak for the control doughs decreased linearly with decreasing dough-water content (Fig. 1, $r^2 = 0.83$, $P < 0.01$). The overall shape of the mixograph curve was not affected. Swanson (1941) noted that an absorption of 2% above or below optimum had little effect on the mixogram shape but did affect peak height. Higher absorption levels resulted in a linear increase ($r^2 = 0.96$, $P < 0.01$) of the time to peak (Fig. 2). This merely indicated that, as more water was added to the system, more time was needed to obtain an uniform dough. The results were in agreement with the reports of Jasberg et al (1989), Kunerth and D'Appolonia (1985), and Larsen and Greenwood (1991). Higher absorption levels resulted

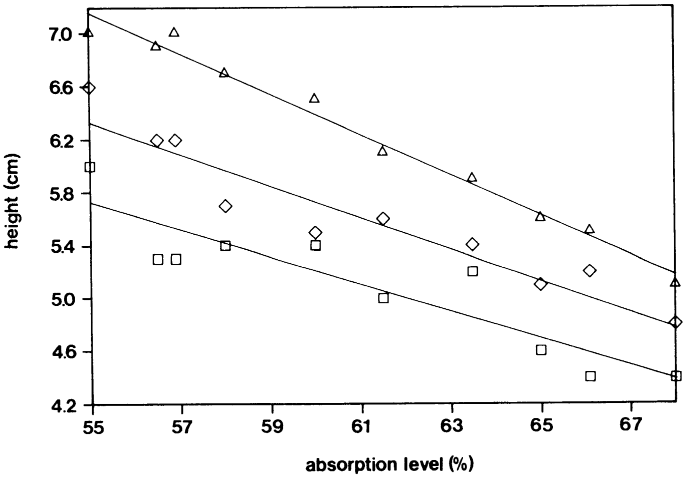

Fig. 1. Effect of the powdered (◇) and presoaked (△) high molecular weight rye water-soluble pentosans on mixogram peak height of wheat flour (□) at different absorption levels.

in lower areas under the mixogram curve (Fig. 3, $r^2 = 0.90$, $P < 0.01$). At all absorption levels tested the doughs were resistant to overmixing.

Addition of presoaked HMWS. Replacing 2% of the flour with rye HMWS did not affect the shape of the mixograph curve, although it strongly affected mixogram characteristics. When presoaked in water and then added to the flour, the rye HMWS caused a marked increase in peak height and area under the curve (Figs. 1 and 3), indicating a much stronger dough. The subjectively determined optimum absorption level of the dough increased to 61.5%. At low absorption levels (<58%), the optimum mixing time was increased because the components were hydrated with more difficulty. The addition of presoaked rye HMWS had a negative effect on the dough's resistance to overmixing.

Addition of dry HMWS. The dry material did not change the general shape of the mixogram. Addition of the dry HMWS created changes in peak height and area under the curve that were similar to those described for the presoaked material, but to a lesser extent. The effect on mixing time was almost the same. The optimum absorption level of the wheat dough was not influenced. The dough weakening was more pronounced at all absorption levels.

All of the above findings are in line with the data of Jelaca and Hlynka (1971) and Michniewicz et al (1991), who used the farinograph to study the water-binding capacity of crude dissolved wheat-flour pentosans and their impact on dough mixing.

Other authors reported that doughs with added water-soluble wheat or rye pentosans have lower stability and a slightly faster breakdown (Jelaca and Hlynka 1971, Jankiewicz and Michniewicz 1976, Kim and D'Appolonia 1977).

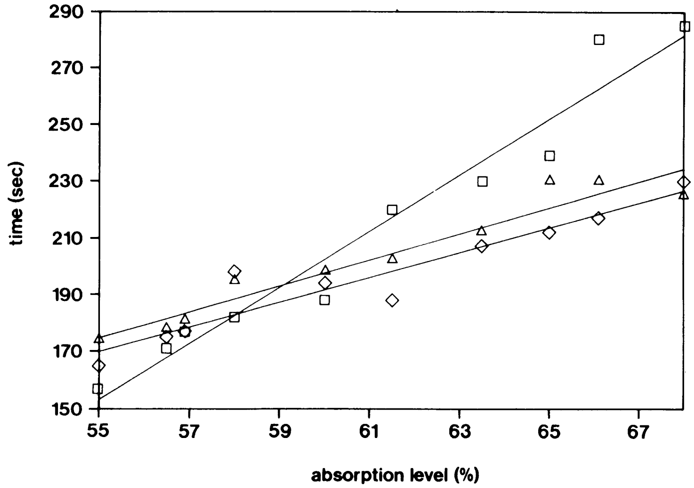

Fig. 2. Effect of the powdered (◇) and presoaked (△) high molecular weight rye water-soluble pentosans on mixogram time to peak of wheat flour (□) at different absorption levels.

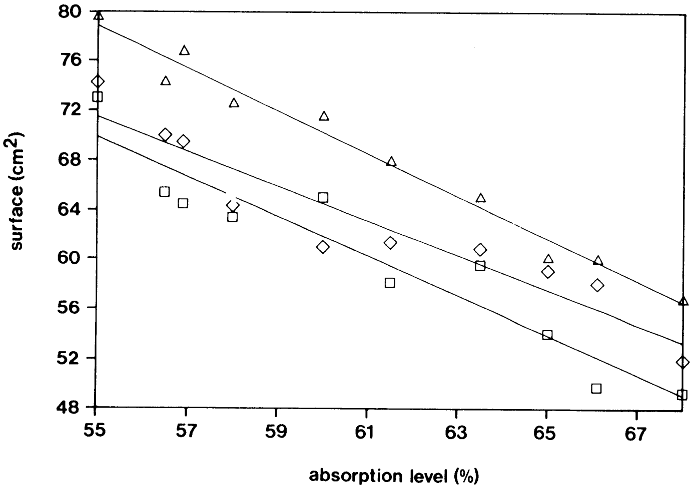

Fig. 3. Effect of the powdered (◇) and presoaked (△) high molecular weight rye water-soluble pentosans on area under mixograph curve of wheat flour (□) at different absorption levels.

Impact of Rye Water Solubles on Wheat-Bread Quality

A minimum mixing time of 3 min was necessary to distribute the ingredients evenly in the dough. With the addition of 2% rye HMWS, an additional 3% water could be added before the doughs became sticky. This is in line with the findings of Jelaca and Hlynka (1972), who reported that baking absorption levels were raised by 2–3% for doughs with water-soluble wheat pentosans at a 1% level. The doughs were less sticky than those from the control flour after a long mixing time.

The defined region for the fitted second-order model for the control wheat doughs was 180–330 sec of mixing time and a 55–65% absorption level. When rye HMWS (dry or presoaked) were added, the region for obtaining a manageable dough increased to 180–384 sec of mixing time and a 55–68% absorption level. The mixing time and absorption level variables were coded to an interval of −1.41 to +1.41 and may be expressed in terms of the natural variables as follows.

Control:

$$T = (\text{mixing time} - 255)/52$$

$$A = (\text{absorption level} - 60.0)/3.5$$

Dry and presoaked rye HMWS:

$$T = (\text{mixing time} - 282)/72$$

$$A = (\text{absorption level} - 61.5)/4.6$$

with time in seconds, percent of absorption level, and T and A as the coded variables for mixing time and absorption level, respectively.

TABLE II

Equations for Bread Quality in Relation to Response Surface Mixing Time (T)[a] and Absorption Level (A)[a]

Dependent Variables

Volume (cm³)

Control

$65.83 + 1.52 \times T + 0.81 \times A - 0.84 \times T^2 - 0.82 \times A^2 + 0.75\ T \times A$

P-HMWS[b]

$63.32 - 2.52 \times T + 4.16 \times A - 0.54 \times T^2 - 0.81 \times A^2 + 0.77\ T \times A$

D-HMWS[c]

$67.80 - 0.79 \times T + 1.37 \times A - 1.00 \times T^2 - 1.32 \times A^2 + 1.68\ T \times A$

Specific loaf volume (cm³/g)

Control

$5.03 + 0.12 \times T + 0.00 \times A - 0.07 \times T^2 - 0.05 \times A^2 + 0.07\ T \times A$

P-HMWS

$4.97 - 0.21 \times T + 0.27 \times A - 0.05 \times T^2 - 0.07 \times A^2 + 0.05\ T \times A$

D-HMWS

$5.17 - 0.07 \times T + 0.05 \times A - 0.09 \times T^2 - 0.11 \times A^2 + 0.16\ T \times A$

Bread weight (g)

Control

$13.090 - 0.034 \times T + 0.159 \times A + 0.013 \times T^2 - 0.020 \times A^2 - 0.032\ T \times A$

P-HMWS

$12.751 + 0.049 \times T + 0.131 \times A + 0.026 \times T^2 + 0.030 \times A^2 - 0.035\ T \times A$

D-HMWS

$13.124 + 0.029 \times T + 0.146 \times A + 0.034 \times T^2 + 0.022 \times A^2 - 0.072\ T \times A$

[a] T and A are the coded variables for mixing time and absorption level, respectively.

[b] P-HMWS = addition of 2% presoaked high molecular weight water-solubles from rye.

[c] D-HMWS = addition of 2% dry high molecular weight water-solubles from rye.

Second-order models for the dependent variables of loaf volume, specific loaf volume, and bread weight were fitted to the coded data by least squares. The fitted models are given in Table II.

Control flour. The contour plot for loaf volume of the control flour is shown in Figure 4. The contour lines correspond to the mixing times and absorption levels that yield breads of equal loaf volume. We found that the loaf volume of the breads depended significantly on mixing time ($P < 0.001$), absorption level ($P < 0.05$), and the quadratic terms (mixing time)^2 and (absorption level)^2 ($P < 0.05$). The loaf volume varied from 61 to 66 cm^3 (8%). Maximum loaf volumes were obtained under operating conditions closely situated to the handling constraints. The maximum loaf volume of the model was situated at an absorption level of 63.8% and a mixing time of 325 sec. The resulting dough was sticky and difficult to handle. Harrel (1926), Micka and Child (1928), and Skeggs (1985) reported a parabolic relation between absorption level and loaf volume at a constant mixing time. We confirmed this relation, suggested by the fitted model, by additional baking experiments (results not shown). The crumb structure of different loaves did not change drastically at higher absorption levels or increased mixing times. As absorption level increased, the loaf corners became sharper and the crumb cells larger.

Addition of dry HMWS. Figure 5 shows that the maximum loaf volume (66 cm^3 plus) can be obtained at several combinations of absorption levels and mixing times situated in the center of the defined area, making mixing time and water addition less critical than they were for the control flour. Depending on the breadmaking conditions, loaf volumes varied from 58 to 68 cm^3 (17%). The bread loaf volume was significantly dependent on absorption level ($P < 0.001$), mixing time ($P < 0.05$), (absorption level)^2 ($P < 0.01$), and (mixing time)^2 ($P < 0.05$). Also significant was the interaction term ($P < 0.01$). The maximum loaf volume predicted by the model was situated at the same absorption level as that of the control wheat breads (64.2%) but at a lower mixing time (289 sec). At low absorption levels mixing time was critical. Loaf volume continuously decreased as mixing time increased. The rye pentosans, with a high water-absorbing capacity, probably withdrew water from other flour components during the longer mixing times, resulting in incompletely hydrated gluten. At the lowest absorption levels (55%) the doughs were obviously too dry. The breads obtained at high absorption levels had pitted bottoms but their internal structure was normal.

Addition of presoaked HMWS. When the water solubles were presoaked before addition, the loaf volumes obtained were significantly lower, ranging from 48 to 66 cm^3. The loaf volume was significantly dependent on mixing time ($P < 0.001$) and absorption level ($P < 0.001$). An isovolume contour plot (Fig. 6) shows that the maximum loaf volume moves to higher absorption levels. At constant absorption levels, loaf volume decreased as mixing time increased. Maximum loaf volumes can be obtained at high absorption levels and low mixing times. This is probably due to the fact that arabinoxylans can bind the added water strongly in the hydration step. Not enough water is available for other flour constituents during breadmaking; therefore, gluten and starch are not properly hydrated and developed, leading to lower loaf volumes.

The optimum combination of water absorption and mixing time (70.7%, 216 sec), according to the response surface methodology model, resulted in a very sticky dough. Therefore, the optimum absorption level was limited by the constraints (68%). Crumb structure was the same as it was for the addition of dry HMWS.

Validating the Model

In our second step, baking experiments were carried out to validate the model. Control breads were baked at several combinations of mixing times and absorption levels situated on a diagonal through the isovolume lines in the defined area. The resulting loaf volumes were compared with the theoretical value. The regression equation of the volume (cm^3) was:

$$\text{Experimental value} = 7.40 + 0.89 \times \text{predicted value}$$

with $r^2 = 0.94$, $n = 8$.

The model for loaf volume of breads prepared with presoaked rye HMWS was also tested for different absorption levels at constant mixing time (216 sec). The regression equation of the loaf volume (cm^3) was:

$$\text{Experimental value} = -7.68 + 1.11 \times \text{predicted value}$$

with $r^2 = 0.96$, $n = 6$.

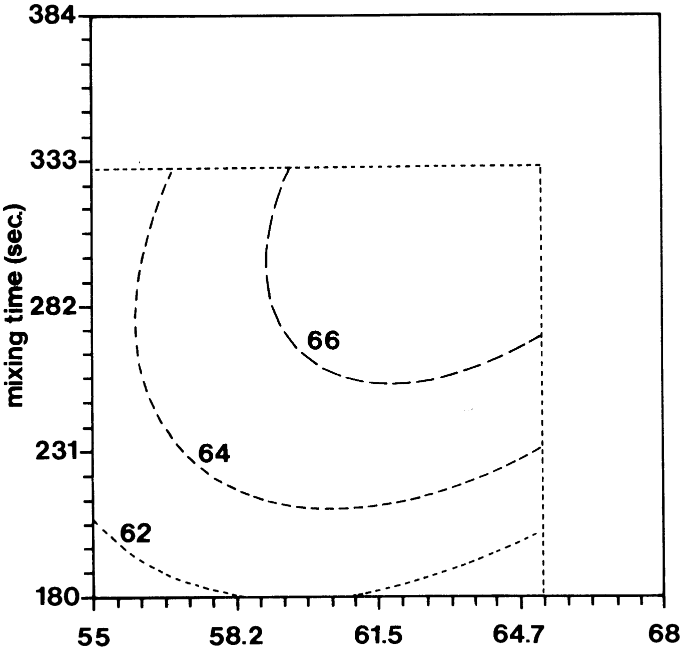

Fig. 4. Absorption levels, mixing times, and resulting loaf volumes for the wheat flour control.

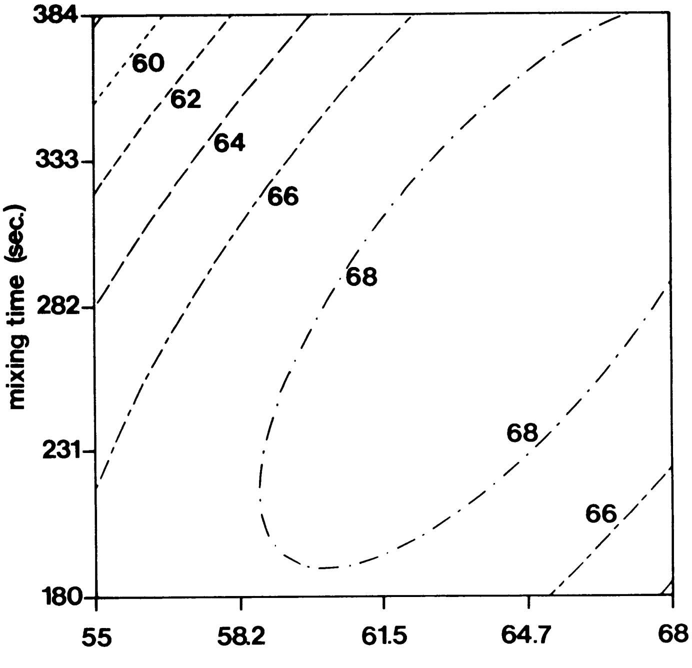

Fig. 5. Absorption levels, mixing times, and resulting loaf volumes for wheat flour when powdered high molecular weight rye water-soluble pentosans are added.

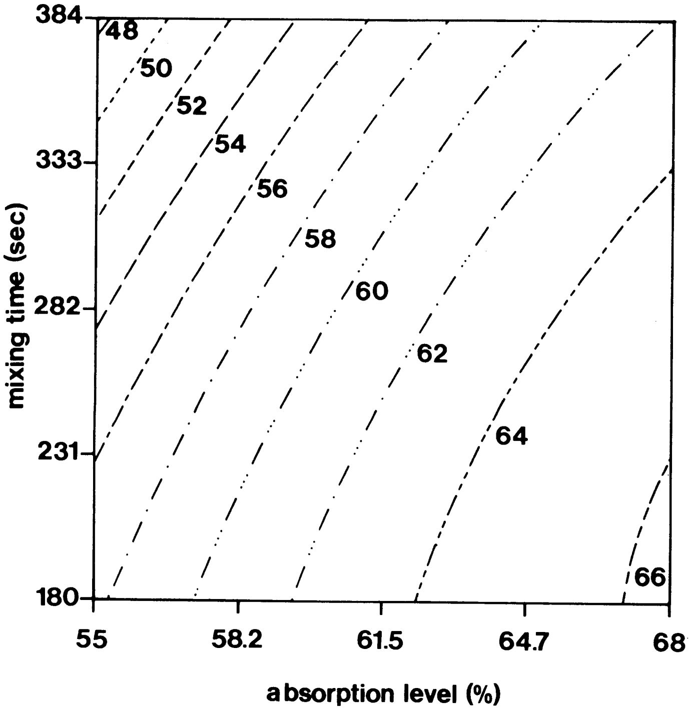

Fig. 6. Absorption levels, mixing times, and resulting loaf volumes for wheat flour when presoaked high molecular weight rye water-soluble pentosans are added.

These data show good correlation between the experimental and theoretical values. The significance level for both equations was 99%.

Mixograph and Baking Results

Optimum water absorption and mixing time, as determined by the mixograph procedure, did not result in maximum loaf volume. The absorption levels obtained by the mixograph were 6% lower than the values from the response surface methodology equations, which were calculated to obtain maximum loaf volume and take into account the constraints of handling properties. No correlation for mixing time was found.

CONCLUSIONS

From our results, it is clear that hydration during mixing causes the most important effect in breadmaking. When the dry water solubles are added to the wheat flour, they compete with the original flour constituents for the available water. This results in rye material with a different (more positive) influence on the dough and breadmaking properties than the presoaked rye HMWS has.

Therefore, a discussion of the impact of water-soluble pentosans on wheat loaves should always include the pretreatment of the pentosans and the mixing time and absorption level conditions during the experiment.

ACKNOWLEDGMENTS

Helpful discussion with R. C. Hoseney (Kansas State University) and excellent technical assistance by Luc Van den Ende (K. U. Leuven) are gratefully acknowledged.

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[Received December 30, 1991. Accepted October 7, 1992.]