Water-Binding Capacity of Wheat Flour Crude Pentosans and Their Relation to Mixing Characteristics of Dough[1]

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ABSTRACT

Water-soluble and water-insoluble crude pentosans were obtained from flours from a milling grade of Canadian hard red spring (CHRS), No. 5, and No. 2 Canada western amber durum (2 CWAD) wheats. The farinograph constant-dough method was used for determination of water-binding capacity (WBC) of pentosans. It has been estimated that the water-soluble pentosans (from CHRS wheat flour) absorb 6.3 times their weight of water, and the water- insoluble pentosans absorb 6.7 times their weight (dry basis). When the farinograph constant-flour method was used, these values were shown to be 9.2 for water-soluble and 8.0 for water-insoluble pentosans. The same fraction of water-soluble pentosans (from CHRS wheat flour) absorbed 4.8 its weight of water (on 14% m.b.) in gluten-water system; 6.9 in prime starch-water system; and 6.5 in reconstituted gluten-prime starch dough. In the range of mixing speed from 32.5 to 200 r.p.m. in the farinograph, the results show that for an increase in mixing speed of 56 r.p.m., there is an increase in WBC of water-soluble pentosans of 1 g. per g. pentosans. For water-insoluble pentosans the same result is shown for an increase in speed of 105 r.p.m. Pentosans added to dough increase dough development time and viscosity of dough; however, work-input requirement is decreased. Addition of pentosans to iodated doughs showed small changes in their mixing characteristics. There were no significant changes in the rheological properties of salted doughs with added pentosans.

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Present-day knowledge indicates that pentosans in flour play an important role in the "water balance" in dough, and in relation to its rheological properties. By water balance is meant the distribution of water in dough among the flour components.

Wheat flour contains about 2 to 3% of water-soluble and water-insoluble pentosans (1,2,3), of which the water-soluble pentosan fraction represents only about 0.5 to 0.8% of the total weight of wheat flour (2). It has been estimated that pentosans absorb about one-third of the total water (1,4) in a normal dough, which emphasizes the extremely high affinity for water and the general importance of these rather minor flour components.

Water-soluble pentosans have the property of dissolving in water to give an extremely viscous solution, whereas water-insoluble pentosans seem to be able to become highly hydrated in water without actually going into solution (2). It has also been reported that water-soluble pentosans are responsible for the remarkable property of oxidative gelation (2), and that oxidized polysaccharides at a certain concentration level have a distinct improving effect on dough properties in extensigram experiments (5).

Wheat flour pentosans have an important influence on baking properties as indicated by the increase in loaf volume and the finer texture of bread (1,5–12), although there are some conflicting results.

The object of our investigation was to examine more fully the role of both water-soluble and water-insoluble pentosans in water balance and their relation to mixing characteristics of dough. Although methods are now available for the preparation of pure fractions of pentosans (5,6,13,14), it was decided to use crude pentosans for these studies for the interest inherent in viewing the total effect of the pentosans as they exist in flour, rather than in their fractions. The test methods that were used included the farinograph, work-input meter, and the amylograph.

This paper summarizes our study of the water-binding capacity (WBC) of pentosans isolated from three different flours and their influence on mixing characteristics of dough.

MATERIALS AND METHODS

The flours used for isolating pentosans in the principal experiments discussed in this study were: unbleached, improver-free, straight-grade, and commercially milled from a blend of Canadian hard red spring (CHRS) wheat; laboratory-milled from No. 5 wheat; and untreated durum obtained as a by-product in commercial milling of semolina from No. 2 Canada western amber durum (2 CWAD) wheat. The protein contents of the respective flours were 13.7, 14.0, and 14.6%; the ash contents were 0.46, 0.50, and 1.01% (on a 14% m.b.).

The flour used for isolation of pentosans from CHRS wheat was also used for some auxiliary experiments. The absorption of this flour at a consistency of 500 farinograph units was 61.7%.

Preparation of Water-Soluble and Water-Insoluble Pentosans by Modified Baker's Procedure

The general procedure for isolation of the pentosan fractions is outlined in Fig. 1. The first step was similar to that described by Doguchi and Hlynka (15) for the preparation of gluten. Flour was mixed with water to make a batter and the batter slurried by the addition of more water; this gluten was washed out from the slurry

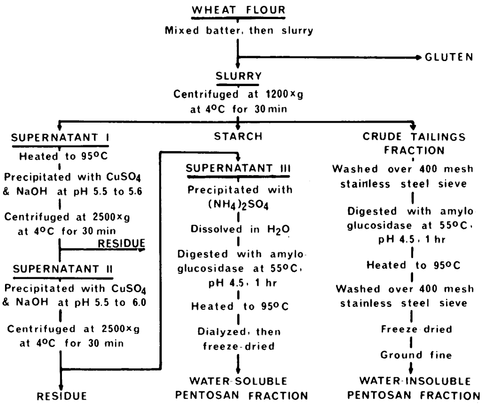


Fig. 1. Flow diagram for isolation of crude pentosans from wheat flour.

and washed by hand for 10 min. These washings were then combined with the starch slurry and centrifuged at 1,200 X g at 4°C. for 30 min. Two fractions were taken: the supernatant (containing water-soluble pentosans) and the crude tailings (containing water-insoluble pentosans).

Supernatant I was boiled, to inactivate any enzymes present and to heat-coagulate the proteins, and then cooled to room temperature. The proteins in supernatant I were precipitated with saturated $CuSO_4$ (16.7 ml. per 100 ml. supernatant) and 5N NaOH (6 ml. per 100 ml. supernatant) as described by Baker et al. (16). After addition of $CuSO_4$ and NaOH to supernatant I, the solution was stirred until a homogeneous mixture was obtained.

The solution was adjusted to pH 5.5–5.6 and then centrifuged at 2,500 X g at 4°C. for 30 min. Supernatant II was precipitated and centrifuged in the same way as supernatant I except that the pH was adjusted to 5.5–6.0. Supernatant III was obtained.

Ammonium sulfate (70 g. per 100 ml. supernatant) was added to supernatant III and stirred at high speed to saturate the solution and thus precipitate the water-soluble pentosans. The solution was left standing for several hours until a white layer of pentosans was consolidated on top. This layer was removed, washed once lightly with a small amount of distilled water to remove most of the ammonium sulfate, and then dissolved in distilled water by high speed stirring for further purification.

This pentosan solution contained a small amount of occluded starch, which has a high WBC (17). To remove it, 10 mg. amyloglucosidase (Grade III, Sigma Chemical Co., St. Louis, Mo.) was added to each 100 ml. of pentosan solution at 55°C. The enzyme reaction was stopped after 1 hr. of stirring by bringing the solution to a boil. The clear solution was then dialyzed for 72 hr., with several changes of distilled water each day, and freeze-dried.

For the preparation of water-insoluble pentosans, the crude tailings fraction was washed with distilled water over a 400-mesh stainless-steel sieve. The washing was repeated many times until as much starch as possible was removed. The material remaining on the sieve (water-insoluble pentosans) was gathered and reacted with amyloglucosidase in the same way as described above for soluble pentosans. The pentosans were again washed several times, freeze-dried, and finely ground.

Quantitative Chromatographic Analysis

Chromatographic analyses were done mainly to show that starch had been eliminated from the crude pentosan material.

A 10-mg. sample of water-soluble or water-insoluble pentosans was hydrolyzed with 1 ml. 1N H_2SO_4 at 120°C. for 1 hr. in a sealed test tube. The hydrolysate was made up to 50 ml. and filtered. Two and one-half milliliters of the filtered solution was mixed with 2.5 ml. of 0.2M borate buffer, pH 8.0. Two milliliters of this solution was used for quantitative determination of borate derivatives of the sugars by ion-exchange chromatography on an anion polystyrene resin column (18).

The chemical composition of pentosan fractions used in this study is shown in Table I.

Pentosan fractions isolated from durum wheat flour contained more protein than the fractions from CHRS and No. 5 wheat flours.

RESULTS AND DISCUSSION

Effect of Added Crude Pentosans on Farinograms at Constant Absorption and at Constant Consistency

At the beginning of this project it is important to point out that the constant-flour farinograph method is satisfactory for flours which differ slightly in water absorption. But if the components which have a high water-binding capacity, e.g., pentosans, are tested, then the increase in volume of the dough itself has an influence on the farinograph mixing characteristics. Hence the constant-dough method (19,20) should be used as a more accurate procedure.

Farinograms were obtained by the constant-dough method, using the 50-g. bowl (19,20). The difficulty caused by mixing the cotton-like water-soluble pentosan material with flour was solved by prior rehydration of the pentosans as suggested by Kulp (1).

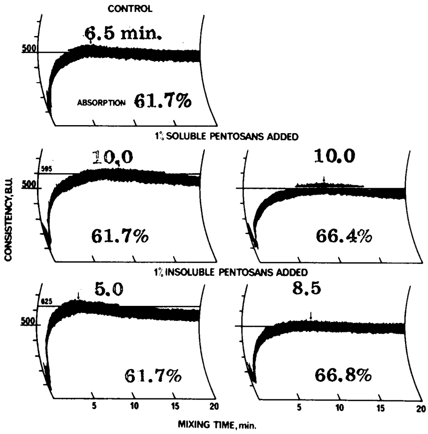
A summary of the results obtained by the constant-dough farinograph method is shown in Fig. 2.

At the left, farinograms are shown for control dough (top) and doughs

TABLE I. CHEMICAL COMPOSITION OF PENTOSAN FRACTIONS USED IN THIS STUDY, ISOLATED BY BAKER'S PROCEDURE (11)

Flour Used for Pentosan Isolation	Pentosan Fraction	Yield (flour basis)	Chemical Composition (dry basis)[a]					Ratio L-arabinose D-xylose
			D-xylose	L-arabinose	Glucose	Mannose	Protein	
			%	%	%	%	%	
CHRS	Water-soluble	0.71	53.5	32.8	9.5	trace	4.1	0.61:1.0
	Water-insoluble	2.00	55.3	35.8	5.9	trace	2.9	0.64:1.0
No. 5	Water-soluble	0.77	64.0	33.0	trace	trace	2.8	0.51:1.0
	Water-insoluble	2.18	52.2	31.6	7.9	1.5	6.8	0.60:1.0
2 CWAD	Water-soluble	0.60	51.0	32.5	trace	trace	16.5	0.64:1.0
	Water-insoluble	1.87	44.8	30.2	9.0	2.5	13.4	0.67:1.0

[a]Sugars such as maltose, rhamnose, ribose, and galactose were found in crude pentosan fractions in traces.



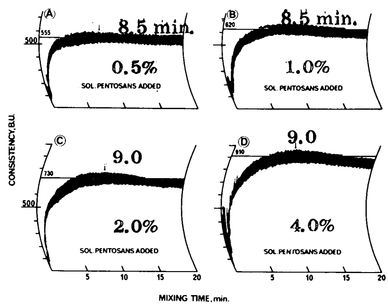


Fig. 2 (left). Farinograms showing changes in consistency for control dough (top left), with 1% water-soluble pentosans added (center row), and with 1% water-insoluble pentosans added (bottom row).

Fig. 3 (right). Farinograms A to D showing changes in consistency with the addition of 0.5 to 4.0% water-soluble pentosans (from CHRS flour). Control farinogram for these doughs is identical with that shown in Fig. 2.

containing 1% added water-soluble (center) and water-insoluble (bottom) pentosans from CHRS wheat flour. The effect of added pentosans is shown clearly by the marked increase in dough consistency. The two farinograms shown in the right column were made at 500 B.U. consistency. The dough development time (DDT), at consistency of 500 B.U., when pentosans were added to flour was longer from 2 to 3.5 min. than for the control. The amount of water required to obtain farinograms with a maximum consistency of 500 B.U. is shown in the diagram for both pentosan fractions. From these data the water absorption based on the pentosan content added to the flour was also calculated, and will be discussed together with other data in a later section.

Effect of Amount of Pentosans on Farinograms at Constant Absorption

In the next set of experiments it was important to show the change in dough consistency with increasing amounts of water-soluble pentosans added at a constant absorption.

In Fig. 3, farinograms A to D show the effect of the addition of 0.5 to 4.0% of water-soluble pentosans (from CHRS flour) on the consistency of dough. The control farinogram for these doughs was identical with that already shown in Fig. 2 with water absorption of 61.7%.

The results show that, at constant absorption, dough consistency increased markedly with increase in amount of pentosans added. At these high consistencies, a longer development time and greater stability than for control dough were obtained.

The effect of water-insoluble pentosans (farinograms not shown) was also studied. Even higher dough consistency but shorter development time was obtained at corresponding levels of pentosans added.

Water-Binding Capacity of Pentosans

To estimate the WBC of pentosans, the constant-dough farinograph method (19,20) was used as described above. This study was extended to include all pentosan fractions from three different flours, and the results obtained are summarized in Table II.

The results show that the highest WBC was found for pentosans from No. 5 wheat flour and the lowest for those from durum flour. It is estimated that the water-soluble pentosans from CHRS wheat flour absorb 6.3 times their weight of water, and the water-insoluble pentosans absorb 6.7 times their weight (dry basis). On a 14% m.b. these values are 5.3 g. H_2O per g. water-soluble and 6.1 g. H_2O per g. water-insoluble pentosans.

Experiments were also done by mixing pentosans with gluten, or prime starch, or mixture of gluten and prime starch in the farinograph. When gluten was mixed, the farinograph lever linkage was set at a 1:5 ratio; for the other two tests the linkage was set at 1:1, as commonly used for flour. Gluten and prime starch, when mixed together, were in the same proportions as found in the CHRS flour which was used for isolating pentosans, i.e., 13.7 and 69.2% (on 14% m.b.).

It was found that the same fraction of water-soluble pentosans from CHRS flour absorbed 4.8 g. H_2O per g. pentosans (14% m.b.) in the gluten-water system; 6.9 g. in the prime starch-water system; and 6.5 g. in reconstituted gluten-prime starch dough. These experiments show that the WBC of pentosans depends not only on the amount of pentosans present, but also on the nature of the flour components.

In 1968 Kulp (1) reported that water-soluble pentosans absorb 11 times their weight of water and water-insoluble pentosans 10 times their weight. He also showed that when absorption by the doughs with added pentosans was adjusted to give farinograms with a peak consistency of 500 B.U., the dough development time was comparable to that of the controls. It was of interest to confirm these observations using the constant-flour farinograph method that Kulp had used. Results showed that the water-soluble pentosans from CHRS wheat flour absorb 9.2 times and the water-insoluble pentosans 8.0 times their weight of water (dry basis). These results in general confirm those of Kulp (1), although they are slightly lower. It is obvious that the constant-flour method gives somewhat higher results than the constant-dough farinograph method.

Measuring the viscosity of thin doughs with the amylograph revealed that pentosans from CHRS wheat flour absorb 10 to 18 times their weight of water (discussed in a later section). This result also indicates that there is no single value for the WBC of pentosans.

TABLE II. FARINOGRAPH DATA FOR PENTOSAN FRACTIONS USED IN THIS STUDY (at a consistency of 500 B.U. by constant-dough method)

Dough	Absorption (14% m.b.) %	Water-Binding Capacity (14% m.b.) g. H_2O/g. pentosan	Water-Binding Capacity (dry basis) g. H_2O/g. pentosan	DDT min.	Stability min.
Control	61.7	...	...	6.5	17
With 1% soluble pentosans, CHRS	66.4	5.3	6.3	10	13
With 1% insoluble pentosans, CHRS	66.8	6.1	6.7	8	17
With 1% soluble pentosans, No. 5	67.9	5.9	7.0	10.5	10
With 1% insoluble pentosans, No. 5	67.6	5.6	6.6	11	16
With 1% soluble pentosans, CWAD	65.6	3.8	4.5	11	17
With 1% insoluble pentosans, CWAD	66.7	4.8	5.5	11	17

Influence of Speed of Mixing on Some Rheological Properties of Dough with Added Pentosans

It has already been shown (21) that at constant maximum dough consistency, a higher speed of mixing gave a higher apparent consistency or farinograph absorption.

To see to what extent pentosans influence the rheological properties of dough mixed in the farinograph, two series of experiments on a constant-absorption and a constant-consistency basis were done for a range of speed from 32.5 to 200 r.p.m. The constant-dough farinograph method was used.

The results obtained are summarized in Table III.

It was found (21) that at higher mixing speeds there was an increase in the temperature of the dough which could not be maintained at 30°C. Therefore the changes in consistency, absorption, and development time per 1°C. of temperature found previously (21) were checked on a control dough and the values in Table III were corrected to 30°C.

These results generally confirm those of Hlynka (21) and obviously show that the average rate of work (consistency/DDT) increases with the increase of shear rate (mixing speed). These values for doughs with added pentosans were smaller than for the control because of longer development time. This is in agreement with the work-input requirement which will be discussed later.

The changes in consistency and farinograph absorption vs. rate of shear are

TABLE III. DOUGH CHARACTERISTICS AS A FUNCTION OF SPEED OF MIXING

Dough	Speed of Mixing r.p.m.	Consistency (at constant abs. of 61.7%) B.U.	Values at Consistency of 500 B.U.			
			Absorption %	DDT min.	Stability min.	Rate of work consist./DDT B.U. × min.$^{-1}$
Control 47.5	32.5	375	56.7	8	20	62.5
	47.5	450	60.7	7	20	71.5
	63	500	61.7	6.3	20	79.4
	90	610	64.8	5.8	16.5	86.2
	105	670	66.6	5.0	16	100.0
	123	700	70.0	4.5	14	111.1
	150	790	72.0	3.5	12	142.9
	175	850	72.7	3.5	9	142.9
	200	890	73.9	2.7	9	185.2
With 1% soluble pentosans	32.5	460	60.8	9.2	20	54.3
	47.5	550	64.4	9	20	55.5
	63	580	65.8	8.8	20	56.8
	90	725	71.9	6.8	9	73.5
	105	785	73.4	6.7	8	74.6
	123	850	75.3	6.0	8	83.3
	150	890	77.7	3.9	8	128.2
	175	950	79.2	3.2	7	156.2
	200	1015	80.7	2.8	5	178.5
With 1% insoluble pentosans	32.5	520	61.8	11	20	45.5
	47.5	610	64.7	9.8	20	51.0
	63	650	68.3	8.8	20	56.8
	90	780	69.8	8.7	15	57.5
	105	875	73.4	8.6	14	58.1
	123	920	75.1	7.4	11	67.6
	150	1010	77.3	3.9	9	128.2
	175	1060	78.7	3.2	8	156.2
	200	1115	80.5	2.7	5	185.2

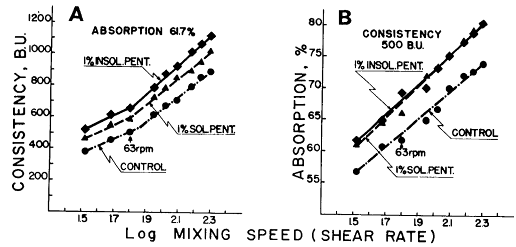


Fig. 4. Plots showing changes in consistency (A), and farinograph absorption (B) vs. log mixing speed (shear rate).

plotted in Fig. 4, which shows a plot of the logarithm of farinograph speed (shear rate) against consistency (A) and against absorption (B). For a given absorption of 61.7%, an increase in the speed of mixing results in changes in consistency. Hlynka (21) pointed out that rheologically consistency may be regarded as a measure of shear stress. For a given consistency of 500 B.U., the relation between the logarithm of shear rate and absorption was linear and the lines for both pentosan fractions were very similar. In other words, it is evident that dough containing pentosans during mixing obeys the power law (22). In the range of mixing speed that has been studied, the results show that for an increase in mixing speed of 56 r.p.m., there is an increase in the WBC of water-soluble pentosans of 1 g. per g. pentosans. For water-insoluble pentosans, the same result is shown for an increase in speed of 105 r.p.m. It has already been shown (21) that farinograph absorption may be regarded as a function of shear stress, as absorption is related to dough mobility or consistency.

The lines obtained for doughs with added pentosans are shifted upward from the control dough line. Also the slope of these lines is greater than for the control. From these lines the changes in dough consistency or farinograph absorption corresponding to a given speed of mixing could be evaluated.

Properties of Dough with Added Pentosans in the Presence of Iodate

Studying the effect of iodate on the mixing tolerance of dough, Meredith and Bushuk (23) found that when iodate-treated doughs were mixed in air, the development time and maximum consistency increased with increasing iodate concentration, reaching a maximum of 1.2 μeq per g. flour. However, they found that the rate of decrease in consistency or "drop-off" after maximum development was much faster than for the control dough.

In this investigation it was of interest to see what effect iodate might have on the mixing characteristics of dough containing added pentosans.

Both water-soluble and water-insoluble pentosan fractions from CHRS wheat flour were studied with iodate added at concentrations of 1.2, 2.4, and 4.8 μeq per g. flour. The results obtained at consistency of 500 B.U. by the constant-dough farinograph method are presented in Table IV.

The results show that the maximum development time for control dough was reached at iodate concentration of 2.4 μeq per g.; for the dough with water-soluble pentosans added, at 1.2 μeq per g.; and for the dough with water-insoluble pentosans added, at 0 μeq per g. The results for control doughs with iodate

TABLE IV. MIXING CHARACTERISTICS FOR IODATED DOUGHS WITH ADDED PENTOSANS (at constant consistency of 500 B.U.)

Dough	Iodate Concentration µeq/g.	Absorption (14% m.b.) %	DDT min.	Stability min.	Time to Breakdown min.
Control	0	61.7	6.5	17	20
	1.2	64.8	7.5	15	20
	2.4	65.2	10	9	16
	4.8	65.6	10	6	13
With 1.5% soluble pentosans	0	69.3	8	14	20
	1.2	71.6	9	10.5	17
	2.4	72.0	9	6	12.5
	4.8	72.6	9	5.5	12.5
With 1.5% insoluble pentosans	0	68.5	8	18	20
	1.2	70.4	8	20	20
	2.4	71.6	8	10	17
	4.8	71.8	7	7.5	13.5

generally agree with those obtained by Meredith and Bushuk (23). For all doughs absorption increases with increasing iodate concentration. Doughs with added water-soluble pentosans appear to have a lower stability and a slightly faster breakdown than doughs containing water-insoluble pentosans.

Experiments were also carried out to determine whether NaCl effect in dough was influenced by the presence of added pentosans. No significant change in the rheological properties of salted doughs was found with added pentosans.

Work-Input Measurement

In recent years, the measurement of work-input into dough has been used for assessing optimum dough development. Chamberlain et al. (24) suggested that 2 Wh per lb. of work is optimum for mechanical dough development to produce the best bread. It was of interest to know to what extent pentosan material added to dough might influence the work-input requirement. For this study the GRL mixer with a work-input meter (25) was used. In these tests, the water absorption was at least 3% more than farinograph absorption.

Figure 5 shows the work-input curves for control dough (left), for dough with 1% water-soluble pentosans added (center), and for dough with 1% water-insoluble pentosans added (right). Both pentosans were obtained from CHRS wheat flour. Dough consistency is expressed in arbitrary units and adjusted to be approximately

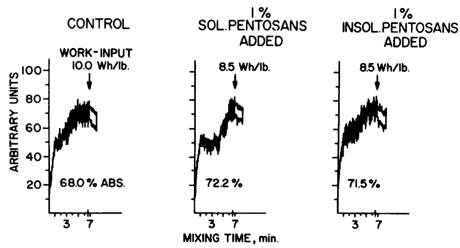


Fig. 5. Representative work-input curves for control dough (left), for dough with 1% water-soluble pentosans added (center), and for dough with 1% water-insoluble pentosans added (right).

the same for all three tests. Immediately after peak consistency was reached, the amount of work-input and development time was read from the meter.

The work-input for the control dough was 10 Wh per lb. and 8.5 Wh per lb. for both doughs with 1% of soluble and insoluble pentosans added. The same work-input for the control (10 Wh per lb.) was obtained by using two different water levels (65.8 and 68.0%). These results are rather high in comparison with the optimum work suggested above by Chamberlain et al. (24). A more significant observation, however, is that the presence of pentosans appears to reduce the work-input requirement and that this effect appears to be independent of the water content of dough.

Measurement of Viscosity of Thin Doughs

The results already discussed indicate that the WBC of pentosans depends on the water available in dough. For additional information on this effect, thin doughs were mixed for 15 min. at constant temperature of 30°C. using the amylograph. The weight of the thin dough was kept constant at 250 g., but the absorption was varied (flour-water ratio changed from 106.5:143.5 to 99:151 g.). Viscosity was measured in amylograph units (A.U.).

The curves obtained at absorption of 135% (on 14% m.b.) are shown in Fig. 6. The curve for control thin dough is shown at the left; then follow the curves with 1% water-soluble pentosans (center), and with 1% water-insoluble pentosans from CHRS wheat added to flour (right).

The curves obtained with pentosans added show an increase in the viscosity of thin dough as compared with the control experiment. For a constant viscosity of 500 A.U., the absorption of the dough with water-soluble pentosans added had to be increased to 144% and with water-insoluble pentosans added to 153%. From these data the water absorption based on the pentosan content added to flour was calculated. By this method it was estimated that the water-soluble pentosans from CHRS wheat flour absorb 10 times their weight of water, and the water-insoluble pentosans absorb 18 times their weight, which has been already noted in the section on WBC.

Amylograph Experiments

It is known that starch gelatinization, from a practical point of view, is related to "alpha-amylase activity" of flour (26).

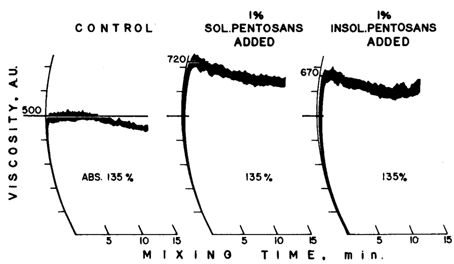


Fig. 6. Representative curves for thin doughs mixed in the amylograph for control (left), for dough with 1% water-soluble pentosans added (center), and for dough with 1% water-insoluble pentosans added (right).

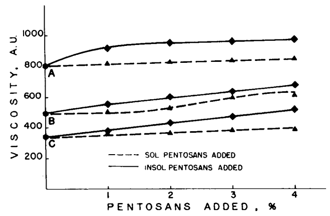


Fig. 7. Plots showing changes in amylograph viscosity for three flours A, B, and C with the addition of 1 to 4% water-soluble pentosans (from CHRS flour). Dashed lines represent water-soluble pentosan addition, while solid lines represent water-insoluble pentosan addition.

In the amylograph, as the temperature rises, starch gelatinizes, and its WBC increases very markedly. One would thus expect a competition for water between gelatinized starch and pentosans in the flour. It has been known that alpha-amylase reduces the viscosity of the starch, but has no effect on the properties of pentosans. It was therefore of interest to see what effect pentosans might have on amylograph viscosity.

For these tests three flours, A, B, and C with peak amylograph viscosity of 805, 495, and 340 A.U., respectively, were chosen and to each of them pentosan fractions from CHRS wheat flour added in amounts of from 1 to 4% (by replacing the same amount of flour with pentosans).

Figure 7 summarizes the data for the amount of pentosan added vs. amylograph viscosity. The dashed lines represent results of the addition of water-soluble and the solid lines of water-insoluble pentosans.

The viscosity values for control flours are marked on the ordinate of Fig. 7 as A, B, and C. The results show that viscosity increased with increasing amount of pentosans added to flour. This effect was greater when the water-insoluble pentosan fraction was used.

DISCUSSION

Experiments in this study indicate that pentosans in flour play an interesting role in the WBC and in relation to the mixing characteristics of dough. It is evident from the results presented that WBC of pentosans cannot be defined as a constant value. Rather, it depends on the available water in dough, on speed of mixing, on the flour components present, and on the method used for its evaluation.

It was found that pentosans at constant dough consistency increase dough development time. The results also suggest that the presence of pentosans appears to reduce the work-input requirement for optimum dough development.

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