Physical Properties of Water-Soluble Pentosans from Different Wheat Varieties[1]

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ABSTRACT

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The physical properties of water-soluble pentosans and their constituents, arabinoxylan and arabinogalactan, in solution or gels, were investigated using purified preparations from flours of eight wheat varieties: HY 355, HY 320, Oslo (Canada prairie spring), Glenlea (Canada utility), Fielder (Canada western soft spring), Norstar (Canada western hard red winter), Katepwa (Canada western red spring), and Marshall (a hard red spring variety unregistered in Canada). The intrinsic viscosities for arabinoxylans and arabinogalactans ranged between had ranges of 2.82-4.20 dl/g and 0.045-0.062 dl/g, respectively. Oxidative gelation of 2% (w/v) pentosan and arabinoxylan solutions (H_2O_2 and peroxidase) was probed by dynamic rheometry. The most rigid gel networks, as

assessed by the storage modulus (G') and tanδ (G''/G'), were obtained for the preparations derived from Katepwa, followed by those from HY 355, HY 320, and Fielder. Relatively weak gels were obtained for pentosans from Oslo, Marshall, Norstar, and Glenlea. The storage modulus of arabinoxylan and pentosan gels (2%, w/v) were positively correlated with the intrinsic viscosity of the polymers ($r = 0.85$ and $r = 0.83$, respectively; $P < 0.01$). Cross-linked pentosans and arabinoxylans held up to 100 g of water per gram of carbohydrate. Although both arabinoxylans and arabinogalactans reduced the surface tension of water, only arabinoxylans effectively stabilized protein foams on heating.

Water-soluble pentosans of wheat exhibit some unique physical properties that have been the subject of many studies. The ability to bind large quantities of water (Bushuk 1966) and to form viscous solutions or gels via covalent cross-linking (Geissmann and Neukom 1973), are important attributes that also can have direct functional implications during mixing, dough development, and baking of bread. Although the water absorption properties of native pentosans have been reported in previous investigations (Jelaca and Hlynka 1971, Patil et al 1975), no studies have been done on water absorption of isolated cross-linked pentosans and their polymeric constituents. The water-holding capacity of polymerized pentosans probably would affect the distribution of moisture among dough constituents and thereby alter the rheological properties of dough systems. Of the many reports on different aspects of gelation of wheat pentosans (Neukom and Markwalder 1978, Hoseney and Faubion 1981, Crowe and Rasper 1988, Izydorczyk et al 1990), only one (Ciacco and D'Appolonia 1982) suggested that the gelling ability of pentosans depends also on their varietal origin.

Another important functional property of fermented dough systems is their ability to hold gas. In fact, air occlusion during the mixing and formation of gas cells during fermentation plays an important role in the rheology of dough and consequently affects the final texture of baked products (MacRitchie 1986). In this respect, dough and bread can be viewed as examples of classic foams. The stability of these systems relates to how gas cells resist rupture on baking, especially during the initial oven heating and before the surrounding fluid network (the viscosity of dough at 60°C is only one fifth of its viscosity at 25°C) is transformed into a solid structure. This stability depends on the initial gas distribution, and, most important, on the nature of the compounds stabilizing the film around gas cells. Although the involvement of gluten proteins in film formation is generally acknowledged, evidence also indicates that some polysaccharides, such as xanthan, locust bean, and guar gums possess similar properties (Hoseney 1984, McCleary 1986).

This article presents information on the gelling potential and flow behavior of purified pentosans and their constituents in aqueous solutions, as probed by small-deformation mechanical measurements and steady shear rheometry. Furthermore, the surface properties of these polysaccharides are examined in the context of imparting stability to heated foam systems.

MATERIALS AND METHODS

Water-Soluble Pentosans

Water-soluble pentosans and their polysaccharide components, arabinoxylan and arabinogalactan, were isolated and purified from eight wheat flours representing five distinct Canadian classes, as previously described (Izydorczyk et al 1991).

Enzymes and Chemicals

Horseradish peroxidase, type II, EC 1.11.1.7, 220 purpurogallin units (PU) per milligram of solid, bovine serum albumin (fraction V, 96-99% albumin), xanthan gum, and gum arabic were obtained from Sigma Chemical Co, St. Louis, MO. Hydrogen peroxide (30%) was a product of Mallinckrodt, Inc., Paris, KY.

Rheological Measurements

Viscosity measurements of aqueous solutions of pentosans (0.15-0.25%, w/v), arabinoxylans (0.05-0.15%, w/v), and arabinogalactans (0.20-0.40%, w/v) were performed using Ubbelohde viscometers (International Research Glassware, Kenilworth, NJ) at 25 ± 0.05°C. The reduced viscosities (using distilled water as the solvent) were plotted against polymer concentration and extrapolated to zero concentration, using the Huggins equation (Huggins 1942), to obtain the intrinsic viscosities.

A Bohlin rheometer (Bohlin Reologi, Edison, NJ) was used to determine viscosity as a function of shear rate and concentration. All measurements were taken at 25 ± 0.1°C using a concentric cylindrical geometry; the radii of the inner rotor and outer container were 7.0 and 7.7 mm, respectively; the rotor length was 21 mm. The samples were subjected to shear sweeps between 5 and 924 per sec. The reported results are averages of three replicates. Viscosity measurements were performed for aqueous solutions of 0.5-3.0% (w/v) pentosans and arabinoxylans isolated from Katepwa. Concentrations of 2.0% (w/v) and 1.5% (w/v) of pentosans and arabinoxylans, respectively, were adopted for comparative intervarietal measurements.

Solutions of increased viscosity and/or gels were obtained by adding horseradish peroxidase (0.11 PU/ml) to aqueous solutions of pentosans and arabinoxylans (2.0%, w/v, using deionized distilled water) and, after mixing, hydrogen peroxide (2 ppm). The development of gel structure was monitored by small amplitude shear stress measurements using a Bohlin rheometer operated in the oscillatory mode. Immediately after the oxidant was added, the samples were placed between the parallel plates (30-mm diameter, 1-mm gap thickness); excess material was removed, and a thin layer of light mineral oil (Mallinckrodt, Inc.) was added to cover the upper plate and thus prevent evaporative losses throughout the experiment (Biliaderis and Zawistowski,

1990). All measurements were performed at $15 \pm 0.1°C$ using a torsion bar of 19.3 g·cm. Data were collected at regular time intervals at a frequency of 1.0 Hz and 4% strain. Values for the storage modulus (G′), loss modulus (G″), and tan δ were obtained using the software of the Bohlin rheometer. The data reported are the means of at least triplicate runs. Differences among samples were assessed using analysis of variance in conjunction with Duncan's multiple range test.

Kinetics of Feruloyl Group Disappearance

The rate of disappearance of feruloyl groups from pentosan solutions (0.5%, w/v) on addition of H_2O_2 (0.3 ppm) and peroxidase (0.11 PU/ml) was followed by spectrophotometry. Periodically, aliquots were mixed with glycine-NaOH buffer (0.07M, pH 10), and the absorbances at 375 nm were recorded. The apparent first-order rate constant, k_{app}, was determined from the equation log $[(A_t - A_\infty)/(A_o - A_\infty)] = k_{app}t$, where A_o, A_t, and A_∞ were absorbances initially, at time t, and at infinity, respectively (Thibault and Garreau 1987).

Hydration Capacity of the Cross-Linked Polymers

Cross-linked pentosans and arabinoxylans were prepared by adding horseradish peroxidase (0.15 PU/ml) and H_2O_2 (3 ppm) to 2% (w/v) polysaccharide solutions. The gels were allowed to set for 15 min; they were then disrupted, washed with excess water, and centrifuged at $20,000 \times g$ for 10 min. Washing and centrifugation was repeated to remove soluble (non-cross-linked) material. The water-insoluble cross-linked products were then washed with excess ethanol (80%, v/v) and the precipitates were filtered, dried, ground, and sieved into two particle diameter sizes (>0.8 mm and 0.4–0.5 mm). The dried products (50 mg) were

mixed with an excess of distilled water and allowed to swell for 24 hr at room temperature. The hydrated gel was recovered by filtration and weighed. The degree of hydration is expressed as grams of water absorbed per gram of dry cross-linked polysaccharide.

Surface Tension Measurements

The decrease of the surface tension of water with addition of soluble pentosans, arabinoxylans, and arabinogalactans was monitored with a Fisher Surface Tensiomat (model 21, Fisher Scientific, Winnipeg, MB). Solutions of various concentrations were placed in a dish (diameter 5.5 cm, depth 4 cm); the changes in surface tension were recorded every 5 min for 120 min at $25 \pm 0.5°C$.

Foam Stabilization

The effects of arabinoxylans and arabinogalactans on the formation and stabilization of foam formed by a surface-active protein (bovine serum albumin) were studied according to the procedure of Susheelamma and Rao (1979). One milligram of a 2% (w/v) bovine serum albumin, 0.25 ml of 5% $NaHCO_3$, and 0.25 ml of arabinoxylan or arabinogalactan solution (1.2%, w/v) were mixed well for 30 sec in a 15-ml graduated test tube. The volume of foam was measured immediately. Then 0.25 ml of 5% citric acid solution was added, the mixture was agitated again for 30 sec, and the foam volume was recorded immediately and after 10 min. The test tube was subsequently placed in a water bath at 95°C, and the changes in foam volume were noted after 3 and 5 min of heating.

RESULTS AND DISCUSSION

Viscosity

Substantial differences in limiting viscosities between arabinoxylans (2.81–4.23 dl/g) and arabinogalactans (0.045–0.062 dl/g) of various wheat flours were observed (Table I). Compared with the intrinsic viscosities [η] of other polysaccharides (Mitchell 1979), the arabinoxylans are similar to guar gum (2.3–6.75 dl/g) and pectin with a low degree of esterification (3.38 dl/g) but were more viscous than other neutral polysaccharides such as dextran (0.214 dl/g), beet arabinan (0.195 dl/g), or gum arabic (0.12–0.25 dl/g). These results indicate that the arabinoxylan is the main contributor to the high viscosity of pentosans in aqueous solution. In contrast, the arabinogalactan

TABLE I
Limiting Viscosities of Pentosans and Their Fractions (dl/g)

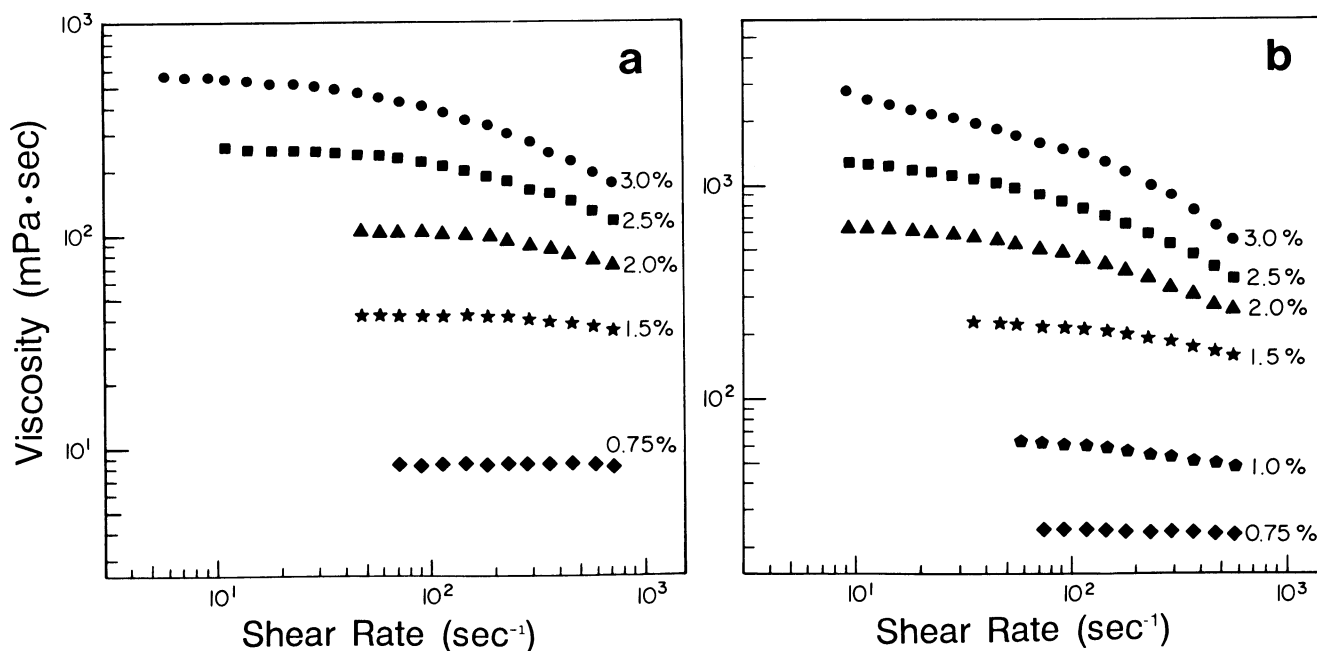| Variety	Pentosan	Arabinoxylan	Arabinogalactan
HY 355	2.78	3.98	0.047
HY 320	2.76	3.40	0.045
Oslo	2.07	3.15	0.062
Glenlea	2.00	3.12	0.053
Fielder	2.37	2.75	0.050
Norstar	2.08	3.14	0.060
Marshall	1.47	2.81	0.058
Katepwa	3.11	4.23	0.057

Fig. 1. Effect of shear rate on the apparent viscosity of pentosan (a) and arabinoxylan (b) solutions (Katepwa) at concentrations between 0.75 and 3.00% (w/v) at $25 \pm 0.1°C$. Standard error of the means of duplicate analyses were <7% of the absolute values.

is a component of very low intrinsic viscosity. Among the eight arabinoxylans isolated from different wheat flours, the Katepwa sample showed the highest intrinsic viscosity, followed by HY 355 and HY 320. The lowest viscosity was that of Marshall. Our values are somewhat higher than those reported by Medcalf et al (1968) for arabinoxylans of hard red spring wheat (2.5–3.1 dl/g) and by D'Appolonia and MacArthur (1975) for arabinoxylans from flours of conventional and semidwarf hard red spring wheats (0.8–3.1 dl/g).

The effect of shear rate on the apparent viscosity of soluble pentosans and arabinoxylans isolated from Katepwa at concentrations between 0.75 and 3.0 (w/v) is shown in Figure 1. At low concentrations, the viscosity remained relatively constant over the entire shear rate range tested, indicative of a Newtonian behavior. However, at concentrations above 1.0%, the flow curves exhibited a plateau region at low shear rates as well as a region of decreasing viscosity (shear thinning) with increasing shear rate. Such a flow pattern is typical of pseudoplastic materials. Figure 2 presents the shear dependence of viscosity for arabinoxylans and pentosans from different flours. At 1.5% (w/v), arabinoxylans from Katepwa, HY 355, and HY 320 exhibited higher viscosity values as well as more shear-thinning properties than did the other samples (Fig. 2a). The same pattern was observed for the respective pentosan solutions (Fig. 2b). Such behavior could reflect differences in molecular size and/or conformation of these polymeric constituents. Gel filtration profiles of the soluble pentosans and arabinoxylans from these varieties did indeed reveal differences in the molecular weight distributions of these materials (Izydorczyk et al 1991).

Gelation

Treatment of water-soluble pentosans with oxidizing agents, such as H_2O_2/peroxidase, results in substantial increase in viscosity and/or development of a three-dimensional network, depending on the initial concentration of polymer and oxidant. It was shown previously (Izydorczyk et al 1990) that only the arabinoxylan component of pentosans participates in the gel structure, whereas the arabinogalactan is not affected by the oxidant. In the present study, the gelling potential of pentosans

and arabinoxylans was investigated by small-amplitude shear stress oscillatory testing. Figure 3 shows the evolution of storage modulus (G') of pentosan solutions (2.0%, w/v) after addition of peroxidase (0.11 PU/ml) and H_2O_2 (1.5 ppm). The results indicate that the pentosans of all varieties were affected by the oxidant, although with substantial intervarietal differences. The greatest increases in G' were observed for the soluble pentosans of Katepwa, followed by those of HY 355, HY 320, and Fielder. Relatively small responses to H_2O_2/peroxidase were found for the pentosans of Oslo, Marshall, Norstar, and Glenlea. The mode of establishment of the gel structure appears to differ among varieties. Pentosans of Katepwa, HY 355, HY 320, and Fielder showed an initial rapid rise in modulus, followed by a plateau region. In contrast, the pentosans of Norstar, Marshall, Glenlea, and Oslo exhibited gradual increases in the G' throughout the entire reaction time. These results are not in agreement with the findings of Ciacco and D'Appolonia (1982), who reported the highest gelling potential (as assessed by capillary viscometry) for pentosans derived from flours of hard red winter wheat, followed by western white, hard red spring, and durum wheats.

The rheological parameters G', G", and tan δ of the cross-linked pentosans are summarized in Table II. Significant differences ($P < 0.05$) in G' and G" occurred among the gels of different pentosan samples. Strong gels, such as those of Katepwa, HY 355, and HY 320, were characterized by low tan δ values, indicative of networks in which the elastic modulus (G') predominates over the viscous modulus (G"). In the case of gels from pentosans of Oslo, Glenlea, Norstar, and Marshall, the ratios of G" to G' were much higher. The variation in tan δ among samples reflects differences in the viscoelastic character of the gels, namely, the relative contribution of the elastic and viscous components. Similar trends in the G' and tan δ values were also obtained for the arabinoxylan gels.

A relationship between intrinsic viscosity (mainly reflecting molecular size) and the pentosan gel strength was also found; the elastic modulus G' (i.e., gel rigidity) (Table II) and intrinsic
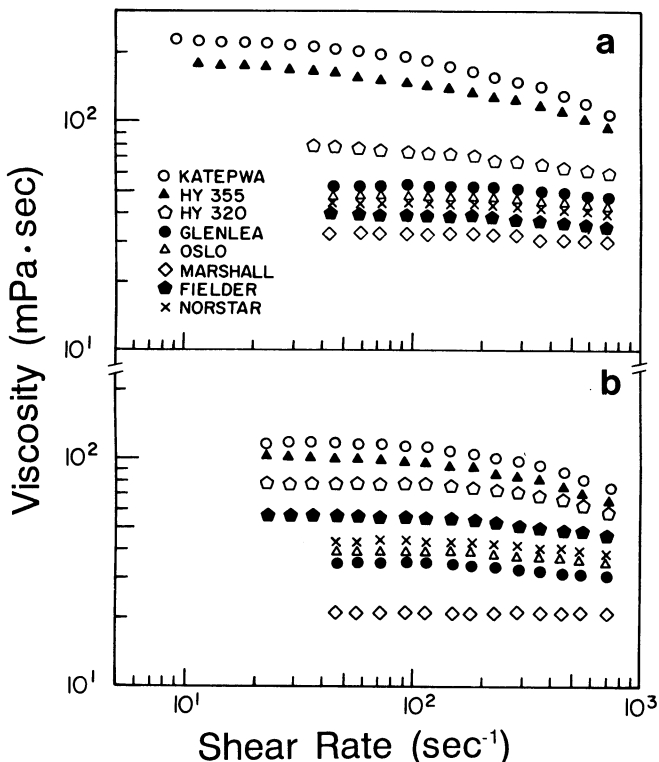

Fig. 2. Flow curves at 25 ± 0.1°C of arabinoxylans (1.5%, w/v) (a) and pentosans (2.0%, w/v) isolated from different wheat flours (b).
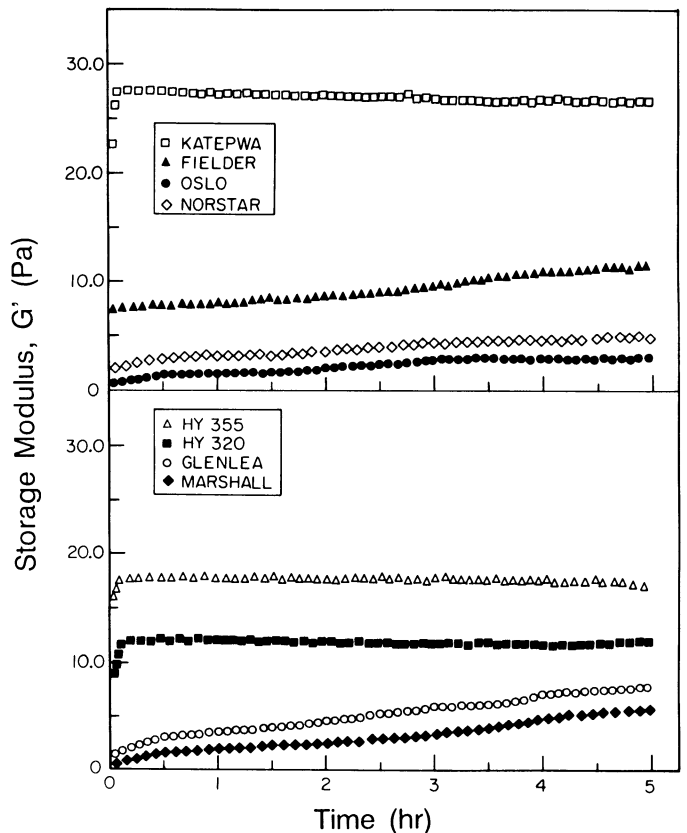

Fig. 3. Storage modulus (G') versus time for 2% (w/v) solutions of pentosans treated with horseradish peroxidase (0.11 PU/ml) and H_2O_2 (1.5 ppm) at 15°C. Data were obtained at 1.0 Hz and 4% strain.

TABLE II
Storage (G′) and Loss (G″) Moduli, and tan δ for Pentosan and Arabinoxylan Gels[a]

	Pentosans			Arabinoxylans		
Variety	G′ (Pa)	G″ (Pa)	tan δ	G′ (Pa)	G″ (Pa)	tan δ
HY 355	16.5 ± 1.5[b] b	4.4 ± 0.5 cd	0.27	19.9 ± 3.3 b	10.1 ± 0.9 b	0.51
HY 320	11.5 ± 2.3 c	5.2 ± 0.7 d	0.45	9.2 ± 0.8 cd	6.6 ± 0.5 d	0.71
Oslo	2.6 ± 0.2 e	2.2 ± 0.1 e	0.87	5.9 ± 0.1 ef	5.1 ± 0.1 e	0.85
Glenlea	5.9 ± 0.6 d	3.8 ± 0.1 d	0.64	7.5 ± 0.5 de	5.7 ± 0.1 de	0.76
Fielder	11.4 ± 1.5 c	6.6 ± 0.6 a	0.58	11.1 ± 1.0 c	8.1 ± 0.1 c	0.73
Norstar	4.2 ± 0.1 de	3.7 ± 0.1 d	0.89	3.2 ± 0.2 f	4.9 ± 0.1 e	1.52
Marshall	5.9 ± 0.2 d	5.1 ± 0.1 bc	0.85	4.6 ± 0.4 f	4.9 ± 0.1 e	1.05
Katepwa	27.6 ± 2.5 a	4.8 ± 0.2 bc	0.17	36.7 ± 3.5 a	12.9 ± 1.3 a	0.35

[a]2% (w/v) solutions were treated with horseradish peroxidase (0.11 PU/ml) and H_2O_2 (1.5 ppm); the reported values are those obtained after 5 hr of reaction.
[b]N = 3 ± SD; values not followed by a common letter in a column are significantly different ($P < 0.05$).

TABLE III
Apparent Rate Constant (k_{app}) of Disappearance of Feruloyl Groups from Pentosan Solutions Treated with H_2O_2/Peroxidase[a]

Pentosans	$k_{app} \times 10^3$ (sec^{-1})
HY 355	9.4 ± 0.9[b]
HY 320	7.9 ± 0.7
Oslo	2.4 ± 0.3
Glenlea	3.0 ± 0.3
Fielder	7.3 ± 0.8
Norstar	2.9 ± 0.3
Marshall	2.6 ± 0.4
Katepwa	11.1 ± 0.9

[a]0.5% (w/v) pentosan solutions, 0.3 ppm H_2O_2 0.11 PU/ml horseradish peroxidase.
[b]n = 3 ± SD.

Fig. 4. Storage modulus (G′) versus time for 2% (w/v) solutions of arabinoxylans treated with horseradish peroxidase (0.11 PU/ml) and H_2O_2 (1.5 ppm) at 15°C. Data were obtained at 1.0 Hz and 4% strain.

viscosity [η] (Table I) were positively correlated ($r = 0.83$ for pentosans and r = 0.85 for arabinoxylans, $P < 0.01$). The content of feruloyl groups in pentosans or arabinoxylans (Izydorczyk et al 1991) does not appear to be related to their gelling ability. Nonetheless, the rate of disappearance of feruloyl groups on addition of H_2O_2/peroxidase appeared to correspond with the trend of G′ development. The values of rate constant, k_{app}, characterizing the kinetics of oxidative cross-linking reactions, are given in Table III. Pentosans that exhibited a rapid rise in the elastic modulus (G′) such as Katepwa, HY 355, HY 320, and Fielder, also showed high k_{app} values. On the other hand, pentosans of Norstar, Glenlea, Oslo, and Marshall, which exhibited a gradual increase in G′ and reached the plateau values at much longer reaction times, had lower rate constants.

Figure 4 compares the gelation profiles of arabinoxylans derived from various flours. In general, similar patterns of G′ development were observed for arabinoxylans and their pentosan counterparts. Although greater differences were expected, since arabinoxylan is the sole contributor to gel network development (Izydorczyk et al 1990), arabinoxylans attained only slightly higher values for G′ than did the respective pentosan solutions of equal polymer and oxidant concentration. In some cases, the G′ values were even lower than those obtained for pentosan gels (Table II). Such behavior might have its origin in the structural and/or conformational characteristics of these macromolecules as well as in the nature of the gelation process. It would appear that because of the stiff, rodlike chain conformation of arabinoxylans (Andrewartha et al 1979), initial formation of relatively few cross-links could cause rapid "freezing" of chains throughout the network structure, thereby restricting the chain diffusion that is essential for further cross-linking and additional modulus increases.

The above findings suggest that the gelling ability of pentosans is related to their structure. The observed differences in the final values of the elastic modulus (Table II) among the samples can be explained, at least in part, by the variation in the molecular size ([η] values, Table I). However, an explanation for the different modes of gel network formation (rapid vs slow G′ development)
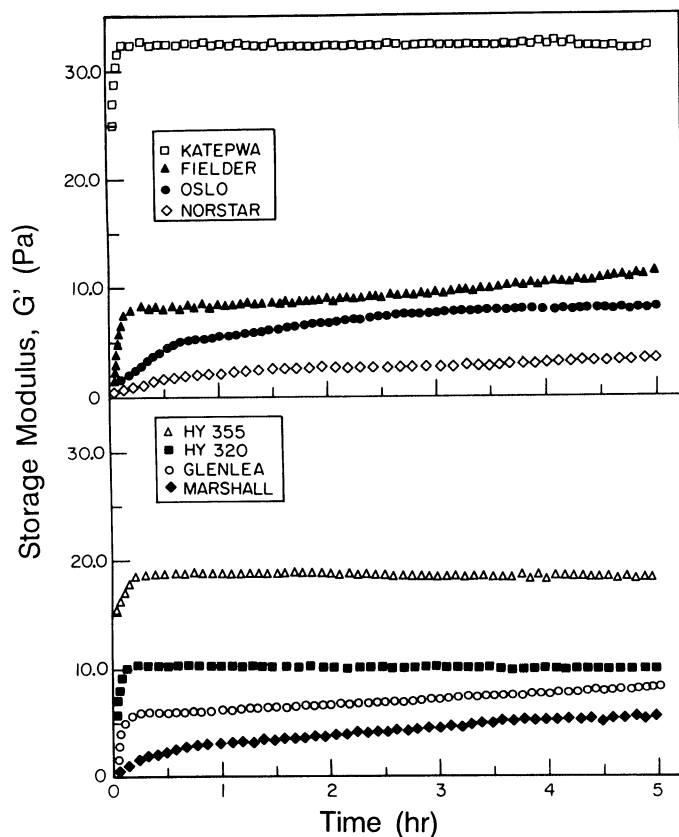
should be sought in the fine structure of arabinoxylans and, more specifically, in the location of feruloyl groups. The different rates of feruloyl group disappearance found in this study (Table III) suggest that some of them cannot participate in oxidative cross-linking initially but become accessible only after certain changes take place in the conformation of the arabinoxylan backbone. With respect to arabinoxylan structure, it is also noteworthy that the arabinoxylans with poor gelling ability (Table II) are characterized by high ratios of arabinose to xylose (i.e., they are more branched) (Izydorczyk et al 1991). Clearly, further studies on the distribution of arabinose and feruloyl groups along the polymer chain backbone are needed to establish relationships between the molecular structure and gelling ability of wheat pentosans.

Hydration Capacity of Cross-Linked Pentosans

The ability of cross-linked, polymerized pentosans and arabinoxylans to swell and retain water was examined after oxidative gelation of these polymers (Table IV). The quantity

TABLE IV
Hydration Capacity of Cross-Linked Pentosans and Arabinoxylans

Variety	Pentosans			Arabinoxylans		
	Cross-Linked Material (%)[a]	Particle Size		Cross-Linked Material (%))[a]	Particle Size	
		>0.8 mm	0.4-0.5 mm		>0.8 mm	0.4-0.5 mm
HY 355	56.2 ± 0.5	58.9[b] ± 5.0	60.4 ± 5.1	87.2 ± 0.6	46.4[b] ± 4.5	47.2 ± 4.0
HY 320	59.9 ± 0.5	70.3 ± 6.2	96.4 ± 5.1	85.4 ± 0.5	61.1 ± 5.0	81.4 ± 4.0
Oslo	42.7 ± 1.5	93.5 ± 5.6	100.6 ± 6.0	77.2 ± 1.0	66.4 ± 4.0	109.9 ± 5.5
Glenlea	45.4 ± 0.9	67.7 ± 3.0	105.8 ± 7.0	79.6 ± 1.0	67.6 ± 3.4	104.6 ± 6.0
Fielder	57.0 ± 1.0	46.1 ± 2.9	112.4 ± 6.7	79.6 ± 1.1	51.8 ± 4.5	113.2 ± 7.8
Norstar	48.6 ± 1.7	75.6 ± 4.0	84.8 ± 4.4	81.4 ± 1.8	52.7 ± 4.2	90.0 ± 4.6
Marshall	51.6 ± 1.0	79.1 ± 3.0	108.4 ± 6.5	75.0 ± 1.0	54.4 ± 3.0	81.3 ± 5.1
Katepwa	57.0 ± 1.5	75.0 ± 5.6	99.0 ± 5.9	87.1 ± 1.7	64.9 ± 2.0	99.8 ± 3.0

[a]Numbers refer to yield of cross-linked material (%) obtained from the respective native polysaccharides.
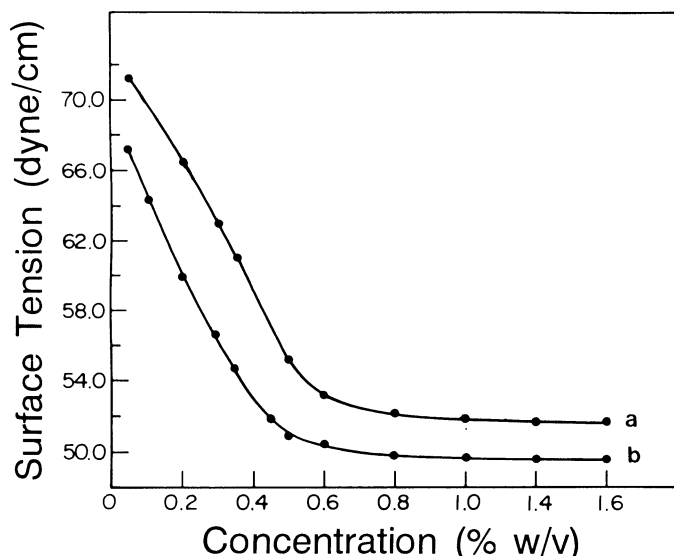[b]Grams of water per gram of polymerized material, n = 3 ± SD.

Fig. 5. Reduction of the surface tension of water by arabinoxylan (a) and arabinogalactan (b) (HY 355) at various concentrations; the surface tension of distilled water was 72.0 ± 0.5 dyne/cm at 25.0 ± 0.5°C.

TABLE V
Surface Tension of Pentosan, Arabinoxylan, and Arabinogalactan Soultions[a]

Variety	Pentosan	Arabinoxylan	Arabinogalactan
HY 355	55.2[b] ± 1.6	55.4 ± 1.8	50.8 ± 2.0
HY 320	58.5 ± 1.8	56.0 ± 1.9	51.0 ± 2.0
Oslo	48.9 ± 1.5	48.5 ± 1.4	50.7 ± 1.6
Glenlea	48.0 ± 2.0	48.6 ± 1.5	50.9 ± 1.8
Fielder	47.3 ± 1.9	44.8 ± 2.0	50.2 ± 1.9
Norstar	50.8 ± 1.7	47.3 ± 1.6	49.6 ± 1.9
Marshall	46.4 ± 1.9	42.0 ± 2.0	46.0 ± 1.0
Katepwa	50.3 ± 1.8	49.9 ± 2.0	50.3 ± 2.0

[a]0.5% (w/v).
[b]Dynes per centimeter; n = 3 ± SD. The surface tension of water was 72.0 ± 0.5 dynes/cm at 25.0 ± 0.5°C.

of the cross-linked materials, obtained by gelation, varied considerably among the pentosan preparations from various cultivars. Samples exhibiting good gelling ability yielded higher amounts of cross-linked materials. The hydration capacity of polymerized pentosans and arabinoxylans was dependent on the size of the particles. Small particles (0.4-0.5 mm) exhibited greater water absorption than large ones (>0.8 mm). Some differences also were noted in the hydration capacity among pentosans and arabinoxylans derived from different wheat flours. The HY 355 samples had markedly lower hydration capacity than the other samples. From a functionality viewpoint, the high water-holding capacity of cross-linked pentosans may have a direct bearing on the distribution of water among dough constituents as well as on the retention of water in baked items. In both cases, the rheological properties of dough and bread systems would be significantly altered.

Interfacial Properties of Pentosans and Their Fractions

The surface tension of water decreased rapidly with increasing concentration of arabinoxylan and arabinogalactan (HY 355) and then leveled off to a constant minimum value at concentration above 0.6% (Fig. 5). For intervarietal comparison, Table V gives the surface tension values for pentosan concentration of 0.5% (w/v). All the preparations were surface active. The activity of the samples from different wheat varieties showed considerable variation. The reason for this is not clear, but it may be related to the variable content of proteins present in all these preparations (Izydorczyk et al 1991).

The protective action of arabinoxylans against thermal

disruption of foam formed by a surface-active protein (bovine serum albumin) is evident from the results shown in Table VI. The bovine serum albumin in the presence of $NaHCO_3$ and citric acid, used as an in-situ source of CO_2, gave rise to a high foam volume, which initially increased significantly on subsequent heating but diminished completely after 3 min of heating. Adding arabinoxylans decreased substantially the initial foam volume (presumably due to increased viscosity of the system), but it prevented the disruption of gas cells during thermal expansion of CO_2. Furthermore, for the arabinoxylan-containing systems, the foam volume increased on heating, and a good cellular structure was preserved even after standing at 95°C for 5 min. Xanthan gum and gum arabic, examined for comparison, also stabilized the foam at higher temperatures. Arabinogalactans, on the other hand, reduced the initial foam volumes to a lesser degree than did arabinoxylans but failed to stabilize the foam at higher temperatures.

Polysaccharides are believed to stabilize foams by retarding the gas diffusion and/or by acting as steric stabilizers of the films surrounding the gas bubbles (Prins 1988). The initial formation and expansion of foam is impeded by the addition of polysaccharides due to an increase in viscosity of the liquid medium. However, the viscosity and elasticity of the thin film surrounding the gas bubbles are important for foam stability. The data in Table VI are consistent with this view; the arabinoxylans of Katepwa, HY 355, and HY 320, having high [η], were the most effective in stabilizing the foam during heating. As such, arabinoxylans together with gluten may play an important role in slowing down the rate of CO_2 diffusion from dough during the initial stages of baking and thereby may affect loaf volume and final crumb structure; fineness and homogeneity of crumb structure is directly related to the extent to which gas cells combine or collapse during heating. The effects of arabinoxylan on loaf characteristics have been discussed by McCleary (1986), who elegantly demonstrated that doughs prepared with depolymerized arabinoxylans (using a purified xylanase) result in loaves of collapsed structure with very large air cells. The possible involvement of pentosans in reducing the

TABLE VI
Stabilization of Foam by Pentosan Constituents

| Polysaccharide | Initial | Acidification[b] | | Heating[c] | |
		Immediate	After 10 min	After 3 min	After 5 min
Control[d]	5.0 ± 0.5	9.5 ± 0.5	6.5 ± 0.5	1.0 ± 0.3	...[e]
Arabinoxylan[f]					
HY 355	2.3 ± 0.4	2.4 ± 0.3	2.4 ± 0.4	4.5 ± 0.4	4.0 ± 0.3
HY 320	2.0 ± 0.3	2.4 ± 0.3	2.2 ± 0.2	4.0 ± 0.3	4.0 ± 0.3
Oslo	2.3 ± 0.4	2.5 ± 0.2	2.4 ± 0.2	3.0 ± 0.2	3.0 ± 0.2
Glenlea	1.5 ± 0.2	2.1 ± 0.2	1.7 ± 0.2	2.5 ± 0.2	2.2 ± 0.2
Fielder	1.5 ± 0.2	2.6 ± 0.2	2.3 ± 0.3	3.0 ± 0.3	2.8 ± 0.2
Norstar	1.8 ± 0.2	2.8 ± 0.3	2.7 ± 0.2	3.5 ± 0.2	3.1 ± 0.2
Marshall	1.5 ± 0.2	2.5 ± 0.2	2.1 ± 0.2	3.0 ± 0.2	2.8 ± 0.2
Katepwa	2.0 ± 0.2	3.5 ± 0.2	3.3 ± 0.2	4.5 ± 0.3	4.5 ± 0.3
Arabinogalactan[f]					
HY 355	2.8 ± 0.4	3.7 ± 0.4	3.0 ± 0.4	1.5 ± 0.4	...
HY 320	2.2 ± 0.2	3.5 ± 0.2	3.4 ± 0.2	1.0 ± 0.2	1.0 ± 0.2
Oslo	2.8 ± 0.4	4.0 ± 0.4	3.8 ± 0.2	1.5 ± 0.4	0.5 ± 0.2
Glenlea	2.5 ± 0.3	5.0 ± 0.5	4.5 ± 0.5	1.0 ± 0.3	...
Fielder	2.7 ± 0.3	3.7 ± 0.2	3.5 ± 0.2	1.5 ± 0.2	...
Norstar	2.6 ± 0.3	4.0 ± 0.3	3.3 ± 0.3	1.0 ± 0.2	...
Marshall	2.8 ± 0.2	3.8 ± 0.3	3.5 ± 0.2	2.0 ± 0.5	...
Katepwa	3.5 ± 0.2	4.5 ± 0.2	4.0 ± 0.3	1.5 ± 0.2	1.0 ± 0.3
Xanthan Gum[g]	2.0 ± 0.3	4.5 ± 0.2	3.9 ± 0.3	8.0 ± 0.4	7.0 ± 0.3
Gum Arabic[g]	2.2 ± 0.2	6.5 ± 0.3	6.0 ± 0.3	5.0 ± 0.4	4.5 ± 0.3

[a] Means ± SD (n = 3).
[b] Acidification by addition of 0.25 ml of citric acid solution (5%).
[c] Heating in a 95° C water bath.
[d] Control foam formed by mixing well (30 sec) 1 ml of 2% (w/v) bovine serum albumin and 0.25 ml of 5% $NaHCO_3$.
[e] Foam completely disrupted.
[f] Concentration of arabinoxylan and arabinogalactan in foam mixture of 0.2% (w/v).
[g] Concentration of xanthan gum and gum arabic in foam mixture of 0.1% (w/v).

rate of CO_2 diffusion have also been considered by Hoseney (1984).

The role of arabinogalactans in the formation and stabilization of foams is rather minor (Table VI). Although this constituent reduced the surface tension of water significantly, it was not as effective in foam formation (for the model system used in this study) as was the bovine serum albumin. Slight differences were noted in the volume of foam obtained after addition of arabinogalactan from various varieties. This may be related to the fine structure of the arabinogalactan, especially as it pertains to the location of the peptide on the macromolecular structure and its ability to position itself at the interface.

The above results as well as the studies of the report by Izydorczyk et al (1991) clearly indicate that water-soluble non-starch polysaccharides, isolated from flours of various wheat cultivars, differ greatly in their molecular size, structure, and physicochemical properties in aqueous environments. More detailed studies on structure-property relationships of these flour constituents are required to fully elucidate their functional role in bread-making and the quality of baked products. From the viewpoint of breeders and processors, it is also essential to identify the genetic and environmental factors contributing to the amount and fine structure of these polymeric carbohydrates in the wheat endosperm.

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