Extract Viscosity as an Indirect Assay for Water-Soluble Pentosan Content in Rye

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ABSTRACT

Viscosity of extracts from rye grain were tested to predict the water-soluble arabinoxylan content. The extracts tested were water extracts from raw or autoclaved rye and a low-pH extract from raw rye. Similar, but not identical, viscosity values were obtained from the three starting materials at extraction times of at least 1 hr and an extraction temperature of <50°C. In all cases, there was a linear relationship between dry matter, crude pentosan or crude arabinoxylan content of the extract, and viscosity ($r \geq 0.97$). The addition of purified or crude enzyme preparations to either rye extracts or pure substrates demonstrated that nearly all of the viscosity in the rye extracts was attributable to the arabinoxylans. Thus starch, protein, and β-glucans did not contribute to the viscosity of rye extracts. A high correlation existed between the viscosity of a rye extract and its water-soluble arabinoxylan content.

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Rye (*Secale cereale*) is a widely grown cereal in Europe. It has the potential to become an alternative crop in countries that mainly produce wheat. Rye is winter-hardy, very disease-resistant, and adaptable to marginal land (Wolski 1974). Rye nutrient content is similar to that of wheat (Rakowska et al 1985), but the use of rye in animal feeding is limited because of several antinutritive factors (Wieringa 1967, Fernandez et al 1973, Misir and Marquardt 1978). Water-soluble arabinoxylans are a major detriment in depressing nutrient digestibility, especially in chicks (Antoniou and Marquardt 1981; Fengler and Marquardt 1988a,b). In the broiler chick diet, as little as 20% rye decreases weight gains by 25% (Friesen et al 1991). Another characteristic of the arabinoxylans is the ability to form a highly viscous solution in water at a relatively low concentration (Bengtsson and Åman 1990).

The effects of the pentosans, and more specifically the arabinoxylans, can be counteracted by partial hydrolysis to less viscous polymers (Bedford et al 1991). The addition of xylanase to rye-based diets greatly improves chick performance and results in growth rates and feed efficiency equivalent to those obtained with a wheat-based diet (Fengler and Marquardt 1988b; Pettersson and Åman 1988, 1989; Grootwassink et al 1989; Friesen et al 1991; Teitge et al 1991).

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Although adding enzymes to rye-based diets is highly beneficial, it seems that the ultimate solution to improving the nutritional value of rye grain would lie in genetic manipulation. A few inbred lines do have low amounts of soluble nondigestible polysaccharides (Madej et al 1990). Because heritability of these undesirable polysaccharides is as high as 0.73%, these lines might be a good source of highly nutritive germ plasmas. However, it requires considerable effort to develop a rye cultivar with low amounts of polysaccharides that could demonstrate a nutritive value that was clearly superior to those of the rye cultivars that are currently available.

The availability of a rapid, indirect assay for viscous polysaccharides would greatly facilitate the screening of rye cultivars currently being used for feed that are low in this putatively antinutritive factor. Studies have demonstrated that barley contains a water-soluble and highly viscous β-glucan (Scott 1972, Gohl et al 1978, Hesselman and Åman 1986). There is a high correlation between the viscosity of acidic extracts of barley and its soluble β-glucan content (Aastrup 1979, Bhatty 1987, Bhatty et al 1991). Techniques that measure the viscosity of barley extracts as an indirect indication of soluble β-glucan content (Greenberg and Whitmore 1974, Morgan and Gothard 1977, Aastrup 1979) are routinely used in feed-barley breeding programs. However, similar procedures have not been developed for the quantitation of the viscous carbohydrates in rye grain.

The objective of this study was to develop a simple, sensitive, and reliable procedure, based on the viscosity of aqueous extracts of rye, for indirectly quantitating the water-soluble pentosan content. The results obtained with three different extract techniques were compared.

MATERIALS AND METHODS

Plant Material

A fall rye (cultivar Prima) was used for all method development studies. Cereal samples (four wheat, two triticale, three rye) were obtained from the Manitoba Crop Variety Trials undertaken annually by the Department of Plant Science, University of Manitoba. Grain samples were obtained from three locations throughout the province of Manitoba in 1990 and from one location in 1991. Each cultivar was grown in four separate plots at each location. Two replicates were prepared by mixing 100 g of grain from plots 1 and 3 and plots 2 and 4. All samples were passed through a 0.5-mm screen in a grinding mill (Tecator Cyclotec 1093, Hoganas, Sweden). Both raw and autoclaved meal were used when the samples were extracted with water. The HCl-KCl buffer was used only with the raw meal. Autoclaved samples were heated at 121°C at 20 atm of pressure at a depth of 2 cm for 15 min; they were dried at room temperature and sieved to homogeneity.

Analytical Methods

Dry matter, crude protein (N × 6.25), and ash were determined by standard methods (AOAC 1984). Nonstarch polysaccharides were determined by gas-liquid chromatography (component neutral sugars) (Englyst and Cummings 1984, Slominski and Campbell 1990). Uronic acids were determined by the method of Scott (1979), as modified by Englyst and Cummings (1984). Starch was analyzed after gelatinization and enzymatic hydrolysis using thermostable α-amylase (Novo, Copenhagen) and amyloglucosidase (Boehringer, Germany) according to the procedures of Åman and Hesselman (1984). Free glucose and glucose derived from starch were determined spectrophotometrically by the glucose oxidase method (SIGMA Glucose[HK] kit, 16-UV).

Routine Procedures for the Preparation of Rye Extracts and Viscosity Analyses

The extraction procedure suitable for viscosity measurement is a modification of the method of Greenberg and Whitmore (1974) and was developed on the basis of results obtained in the studies outlined in this article. It involved the addition of 5 ml of either 0.1*M* HCL-KCL buffer, pH 1.5, or distilled water to 0.25 g of ground grain. The suspension was shaken for 1 hr at 25°C and then centrifuged for 10 min at 13,000 × *g* at 5°C. The resulting supernatant solutions were removed and assayed for viscosity. They are subsequently referred to as the *water-raw*, *water-autoclaved*, or *acid-raw* extracts. Viscosity measurements were carried out at 25°C using the Wells-Brookfield Cone/Plate Digital Viscometer, model LVTDV-1CP (Stoughton, MA), with a 0.8° cone spindle and shear rate of 4.5–450 sec^{-1}. Extracts of arabinoxylans at these shear rates exhibit Newtonian behavior: the viscosity is independent of shear rate (Izydorczyk et al 1991b). A 0.5-ml aliquot of grain extract was transferred into the viscometer chamber. After 1 min of operation, the results were recorded. All results were calculated in mPa·sec and expressed as values relative to that of water.

Optimal extraction conditions were investigated first by establishing the effect of autoclaving time on the viscosity of water extracts when assayed at different time periods after extraction. Rye grain samples were autoclaved for 0, 5, 10, 15, 20, or 25 min and extracted with water at 25°C for 60 min. The extracts were centrifuged, and the supernatants analyzed for viscosity after 0, 30, 60, or 180 min of storage at 25°C. A second study established the influence of extraction time (15, 30, 60, 90, 120, or 180 min) on the viscosity of water and acid extracts of rye assayed immediately after centrifugation. Water extracts were prepared from rye that had been autoclaved for 0, 5, 10, or 15 min. A third study established the effect of extraction temperature (20, 30, 40, 50, 60, or 70°C) on the viscosity of water and acid extracts of rye assayed immediately after centrifugation.

Effect of Enzyme on Extract Viscosity

Crude pentosans were isolated from rye (cultivar Prima) according to Fengler and Marquardt (1988a). Crude arabinoxylans were isolated as described by Izydorczyk et al (1991a). They were dissolved separately in 0.05*M* citric-phosphate buffer, pH 5.0, for 1 hr at 25°C. Extracts from nonautoclaved rye were also prepared using the same buffer and extraction conditions. Enzyme solutions were prepared by dissolving 100 mg of each enzyme in 1 ml of the same buffer. Bacterial xylanase from *Streptomyces lividans* (ICI Biological Product, Mississauga, ON, Canada) (xylanase activity 7746 IU/g) and a fungal enzyme from *Trichoderma viride* (Roxazyme G, Hoffmann-La Roche) (cellulase activity of 8,000 IU/g and xylanase activity of 43350 IU/g) were used in this study. The enzyme preparation from *S. lividans* contained neither cellulase nor β-glucanase activity. A 10-μl aliquot of enzyme solution or buffer was added to 0.5 ml of crude pentosans, crude arabinoxylans, or rye extract in the viscometer. Viscosities were measured at 37°C after 1, 2.5, 5, 7.5, or 10 min of incubation. A temperature of 37°C (rather than 25°C) was selected to enhance enzyme activity.

Data Analyses

All data are means of duplicate analyses, except for viscosity values, which, in some cases, were the result of up to quadruplicate determinations. Linear regression and correlation were calculated as described by Snedecor and Cochran (1967). The standard deviation in all analyses was less than 3% of the mean and, therefore, not presented with the data.

RESULTS AND DISCUSSION

Influence of Autoclave Treatment on Rye Composition and Extracts

Autoclaving did not affect the concentration of protein, ash, or total nonstarch polysaccharides in rye (Table I). Autoclaved rye, however, contained 6% more of the soluble nonstarch polysaccharides fractions than did raw rye (5.7 vs. 6.0%). Other researchers have also shown that treating grain at high temperatures (e.g., 96 or 125°C for 1 hr in an autoclave) did not change the total dietary fiber value but tended to solubilize some of the fiber (Asp et al 1983, Graham et al 1988).

Influence of Extraction Conditions on the Viscosity of Rye Extracts

The first objectives of the study were to determine how the

TABLE I
Protein and Ash Content and Nonstarch Polysaccharide Composition of Rye Grain (g/100 g of dry matter)

Constituent	Rye Grain	
	Raw	Autoclaved
Protein	12.30	12.26
Ash	1.93	1.92
Nonstarch polysaccharides		
Rhamnose		
total	0.18	0.11
soluble	...	...
Arabinose		
total	3.14	3.13
soluble	1.13	1.39
Xylose		
total	4.87	4.87
soluble	2.01	1.83
Mannose		
total	0.52	0.51
soluble	0.14	0.19
Galactose		
total	0.34	0.37
soluble	0.14	0.09
Glucose		
total	4.37	4.45
soluble	2.25	2.53
Uronic acid		
total	0.23	0.23
soluble	Trace	Trace
Total		
total	13.65 ± 0.51	13.67 ± 0.18
soluble	5.67 ± 0.13	6.03 ± 0.06

viscosity of an aqueous extract of rye grain was affected by the duration of the autoclaving period, by subsequent incubation, or by storing the extract after centrifugation. Results are presented in Figure 1.

The initial viscosity of the extract prepared from the 5-min autoclaved sample was higher than that obtained from the nonautoclaved sample. The values obtained when rye was autoclaved for 10 min, and particularly for 15 min, were substantially decreased and remained unaffected after 15–25 min of autoclaving. The viscosity values of the raw rye extracts (0 autoclaving time) decreased by 15% over the 180-min incubation period at 25°C, while the corresponding decrease for extracts obtained from rye that had been autoclaved for 5 min decreased by only 2%.

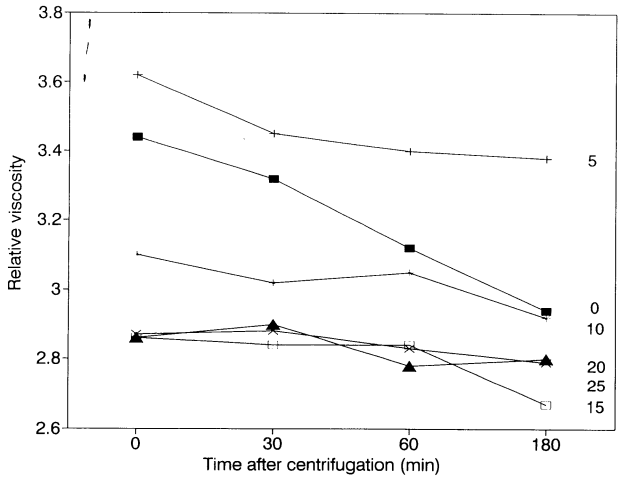

Fig. 1. Effect of autoclaving time (0, 5, 10, 15, 20, 25 min) of rye and incubation time (0, 30, 60, 180 min) on the viscosity of water-rye extracts. Viscosity measured at different time intervals on supernatants of centrifuged samples extracted with water (1:20, w/v) at 25°C for 1 hr.

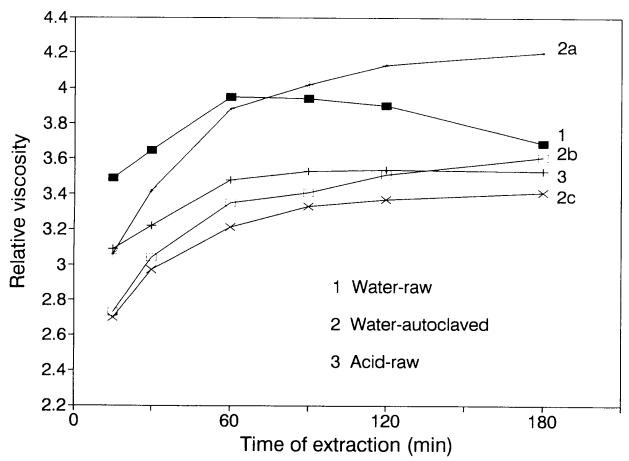

Fig. 2. Effect of extraction time on the viscosity of rye extracts. Viscosities determined at times indicated for raw or autoclaved grain extracted 1:20, w/v, at 25°C. 2a–c: autoclaved for 5, 10, and 15 min, respectively.

TABLE II
Quantity (mg/ml) of Some Soluble Compounds in Different Rye Extracts and Corresponding Relative Viscosities[a]

Compound	Rye Extract[b]		
	Water-Raw	Water-Autoclaved	Acid-Raw
Soluble mass, %	15.6	11.1	15.9
Viscosity	3.51	2.86	3.45
Arabinose	0.47	0.34	0.39
Xylose	0.50	0.41	0.43
Total NSC[c]	2.82	2.31	2.50
Protein (N × 6.25)	2.31	0.83	2.42
Ash	0.46	0.15	0.43

[a]All samples were extracted with 20 volumes of solvent for 1 hr at 25°C.
[b]Values represent yield of soluble compounds in the extracts after lyophilization. The acid-raw extract was corrected for amount of added salt. The arabinose plus xylose values were obtained following acid hydrolysis.
[c]Nonstarch carbohydrates.

Endogenous hydrolytic enzymes may have been most responsible for the decrease in viscosity of extracts prepared from raw rye during the time course of the study. The much slower loss of viscosity by the autoclaved samples may be due to the hydrolysis of the viscous components. Similar changes in the viscosity were reported by Pawlik et al (1990) in extracts prepared from raw rye and by Moore and Hoseney (1990) in wheat flour extracts incubated for up to 6 hr. In the latter study, the relative viscosity of aqueous extracts for samples incubated at different pH levels (pH 2–8) gave parallel curves. The absence of a pH optimum for viscosity reduction suggested that the viscosity change in the wheat extract was attributable to nonenzymatic hydrolysis of the arabinose side chain. Further studies are required to confirm this hypothesis, including changes in the molecular weight of the arabinoxylans and the release of free arabinose and xylose. Overall, these results indicate that both autoclaving time and the time of viscosity assay after the preparation of the extract, particularly in the case of raw rye, affect the viscosity of the extract.

The second objective of the study was to determine the influence of extraction time on the viscosity values of raw or autoclaved (5, 10, 15 min) rye. The results (Fig. 2) demonstrated that the viscosity of the different extracts increased curvilinearly for all but one extract up to 180 min, with near-maximum value being obtained within 60 or 120 min. The viscosity of water-raw extract, however, decreased when the extraction time was >1 hr, although it had the highest viscosity values compared to other extracts when samples were extracted for the short period (15–60 min). Corresponding extracts prepared from rye autoclaved for 10 or 15 min had the lowest viscosities, while extracts prepared from rye autoclaved for 5 min was of intermediate value. After 180 min of extraction, the same relative pattern was retained for all extracts, except the water extract prepared from raw rye. Under those conditions, the viscosity of this extract decreased considerably so that it was much lower than that prepared from rye autoclaved for 5 min. This decrease, as discussed above, was probably caused by the hydrolytic action of endogenous enzyme. Interestingly, the pattern observed in Figure 1 for the extracts that were subjected for viscosity measurement 180 min after centrifugation was almost identical to that obtained in Figure 2 after 180 min of extraction. The reason for the reduction in viscosity with increasing autoclaving time, particularly with the short extraction period, was not established, but it may be attributed to an apparent reduction in the extractability of the viscous pentosans (Table II) or other viscous components in autoclaved as compared to raw rye. The heat-labile components, such as protein, in the extract may also have contributed to its

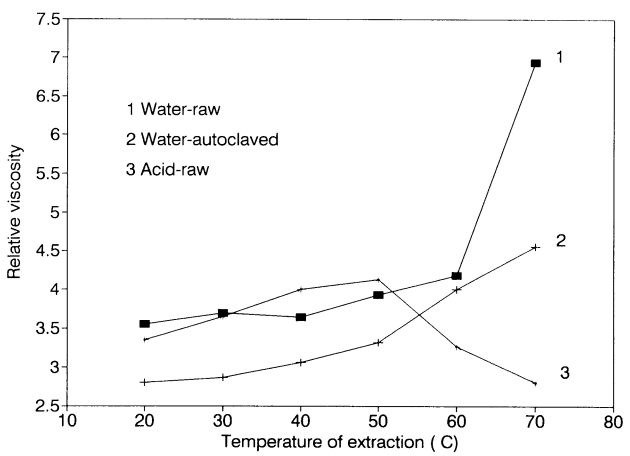

Fig. 3. Effect of extraction temperatures on the viscosity of rye extracts. Extraction time: 1 hr.

viscosity, but they would have been relatively insignificant (3.5%), as indicated by comparing results obtained with raw-extract and raw-extract that had been heated to 99°C. Components of rye grain that are not heat-labile, such as starch, did not affect the viscosity of the extract, provided extraction temperatures were <50°C. The results obtained with water-raw or acid-raw extracts were similar to the results obtained by Moore and Hoseney (1990) for raw wheat extracted at pH 2–8. The results of this study demonstrated that maximum viscosities from rye extracts can be obtained when rye is autoclaved for a short period of time (5 min) and extracted with water for longer periods of time (180 min). Presumably, autoclaving time should be long enough to inactivate endogenous enzymes but brief enough to reduce its effect on the extractability of the pentosans. For standard assay, intent on establishing the relative amount of extractable pentosans, it would be advisable to use an autoclaving time of approximately 15 min and an extraction period of approximately 1 hr. Under such conditions, viscosity values tend to be independent of the heating and extraction period and, therefore, should result in more uniform analyses. Overall, this study demonstrated that the viscosity of an aqueous extract of rye is influenced to a certain degree by heat treatment of the grain, by the type of solvent, and by the duration of the extraction period.

The effect of extraction temperature on the viscosity of three rye extracts is shown in Figure 3. The viscosity of all three extracts increased gradually, between 20 to 50°C; the water-raw rye extract increased up to 60°C. The increases in viscosity between 20 and 50°C for the water-raw, water-autoclaved, and acid-raw extracts were 11, 19, and 23%, respectively. The viscosity of the extract prepared from raw rye was dramatically increased when the temperature of the water was increased from 60 to 70°C (66%). The significant increase in the viscosity of water-raw extract at 70°C (but not in that of autoclaved rye) was probably caused by gelatinization of the starch in raw rye. Presumably, prior changes in the structural nature of starch during the autoclaving process affected its gelatinization. It is well-known that gelatinization of starch occurs at high temperatures, and that the resulting product becomes highly viscous (Ring 1985). Data supporting these conclusions is given in Table III. The increase in the amount of soluble starch was greater in rye extracted at 70°C than it was in rye extracted at 20°C. Also, the effect was much greater for the water-raw rye and the acid-raw extract than it was for the water-autoclaved extract.

In contrast to the results obtained with the water extract, the viscosity of the acid-raw extract was dramatically reduced (32%) when the extraction temperature was above 50°C. This is in spite of the fact that the total amount of soluble starch in the extract increased (Fig. 3 and Table III). Heat lability of β-glucan has been reported by Morgan (1971) and Aastrup (1979). Acid lability of the hemiacetal bonds of arabinose has been reported by Fincher et al (1974). Also, Moore and Hoseney (1990) associated the decrease in viscosity of wheat flour extract at low pH with the hydrolysis of the arabinose side chains. In vitro studies also demonstrated that the viscosity of arabinoxylans was affected by the solvent. In this study, there was a more pronounced reduction in viscosity when a crude rye arabinoxylan preparation was dissolved in the low pH buffer at a concentration of 0.2% and kept for 1 hr at 70°C than there was for the same procedure at 20°C. The corresponding viscosities were 1.36 and 3.36, respectively, in the low pH buffer and 2.56 and 2.81, respectively, in water. The difference in viscosities between the two solvents at 20°C is attributed in part, to a pH effect on intrinsic viscosities. These results suggest that the decrease in viscosity during extraction at a low pH and elevated temperatures is attributable to hydrolysis of the arabinoxylans and the presence of gelatinized starch. Consequently, extraction temperatures should not be above 50°C in studies involving the solubilization of viscous arabinoxylans from rye. Below 50°C there was a slight and parallel increase in viscosities of all three extracts with increasing extraction temperatures.

TABLE III
Glucose and Starch Content in Rye Extracts as Influenced by Extraction Temperature (mg/ml)[a]

	20°C		70°C	
Rye Extract	Glucose	Starch	Glucose	Starch
Water-raw	0.34	1.90	0.44	8.46
Water-autoclaved	0.28	2.04	0.34	3.80
Acid-raw	0.33	2.43	1.10	10.80

[a]Free glucose and glucose derived from starch was measured using procedures described in Materials and Methods. Rye was extracted with 20 volumes of solvent for 1 hr at 25°C.

Influence of Extraction Conditions on Extract Composition and Viscosity

The water-raw and acid-raw extracts, as indicated earlier, yielded similar and somewhat higher viscosities than those obtained with the water-autoclaved extracts (Table II). The yield of arabinose plus xylose (arabinoxylan), total carbohydrates, and total soluble mass also varied in a similar manner. The total protein and ash content of water-autoclaved extract, however, was much less than that of the other two extracts. Overall, these results would suggest that there is a positive relationship between viscosity of the extract and the total amount of arabinose, xylose, and noncarbohydrate components extracted by all three procedures.

Relationship Between Arabinoxylan Content and Extract Viscosity

Figure 4 shows a linear relationship between the amount of solids in the extract and its viscosity. The effect was independent of the extraction procedure. Similar results were obtained with different concentrations of crude pentosans and crude arabinoxylans (Fig. 5). Crude pentosans had lower viscosity values than those of pure arabinoxylans because the crude pentosans also contain arabinogalactans with very low viscosities (Izydorczyk et al 1991b). The data in Figures 4 and 5 suggest that the amount of the soluble arabinoxylans in rye extracts are linearly associated with viscosities when these values are converted to logarithmic values.

Contributions of Arabinoxylans to Total Viscosity of Rye Extracts

The final series of studies were designed to test whether the viscosity of the aqueous extract was mainly attributable to its water-soluble pentosan content. In the first experiment, the influence of two enzyme preparations on the viscosity of four concentrations of crude pentosans and crude arabinoxylans in buffer solution were investigated. The xylanase from *S. lividans* did not cause changes in viscosity of a β-glucan extract, but the fungal enzyme, which contained both xylanase and β-glucanase activity, greatly reduced its viscosity. In contrast, when added to either the crude pentosans or arabinoxylans, both enzymes

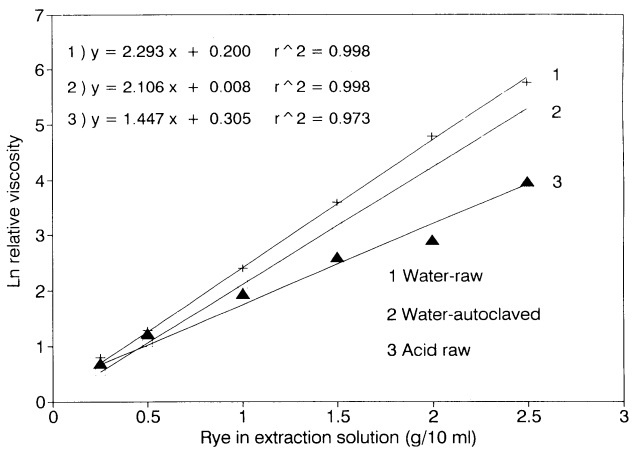

Fig. 4. Relationship between increased amount of rye in extraction solutions and the corresponding logarithmic viscosity values of three extracts. Extraction time: 1 hr at 25°C. Concentration of arabinoxylans: 0.79, 1.58, 3.16, 4.74, 6.32, and 7.90 mg/ml.

reduced the viscosity of both preparations. The reduction was greater with the arabinoxylans than with pentosans (Fig. 6). This reflects the purity of the polysaccharides. Similar results were obtained by adding xylanase to rye extracts (Fig. 7). Taken together, the ability of the enzyme from *S. lividans* to reduce the viscosities of purified arabinoxylans and a rye extract to values roughly equal to those obtained with a fungal enzyme possessing β-glucanase activity; the lack of effect on β-glucans (2.52 vs. 2.49, SE 0.07), oat extracts (2.74 vs. 2.54, SE 0.02), or barley (3.41 vs. 3.03, SE 0.04); and the relatively small effect of amylase (2.53 vs. 2.50, SE 0.06) or protease (2.53 vs. 2.48, SE 0.01) on the viscosity of rye extracts suggest that most of the viscosity of the water-soluble extracts of rye is attributable to the soluble arabinoxylans. (The values given above are the relative viscosities of the extract in the absence of enzyme versus those in the presence of added enzyme.)

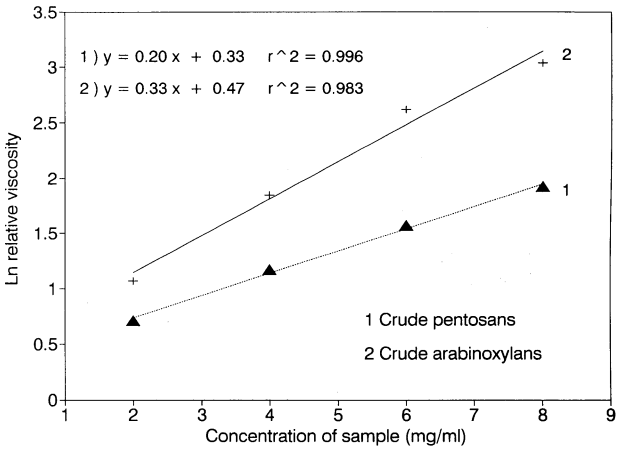

Fig. 5. Relationship between concentrations of crude pentosan and crude arabinoxylans in water and the corresponding logarithmic viscosity values. Correlations (r^2) without logarithmic conversion were 0.982 (1) and 0.943 (2).

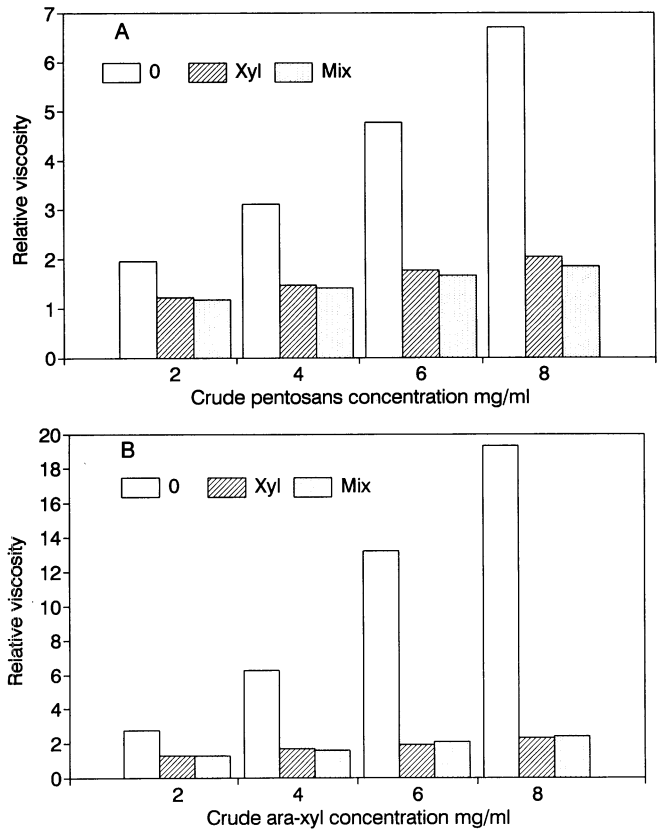

Fig. 6. Changes in viscosity of crude pentosans (**A**) and crude arabinoxylans (**B**) solutions with enzymes added. xyl = xylanase from *Streptomyces lividans*. mix = a preparation from *Trichoderma viride* with multiple enzyme activities. Viscosity values determined 5 min after addition of enzyme.

Comparison of Viscosity of Rye, Wheat, and Triticale

Three cultivars of wheat, two triticale, and one rye, all from three locations, and two fall rye cultivars from two locations were tested for viscosity. Water-raw extracts from rye were more viscous than those from wheat and triticale (Table IV). Both fall cultivars had higher viscosity than that of the spring rye. These results agree with the data obtained by Pettersson and Åman (1987), Rybka et al (1988), and Bengtsson et al (1992), which showed that viscosity of extracts of these cereals were related to their soluble fiber content. The viscosity in wheat, and probably that of triticale, may be attributed mostly to the effect of arabinoxylans (Izydorczyk et al 1991b, Moore et al 1990).

CONCLUSIONS

The results of these studies demonstrated that there is a high correlation between the viscosity of a rye extract and its content of water-soluble pentosans (arabinoxylans). All three extraction procedures used in this study yielded similar, but not identical, viscosity values. They appear to be suitable predictors of the content of soluble arabinoxylans in rye. However, the water-rye extraction procedure is probably the simplest. The presence of

TABLE IV
Viscosities[a] of Water-Raw Extracts Prepared from Wheat, Triticale, and Rye Harvested in 1990 and 1991 from Several Locations in Manitoba

	Location				
		Waskada			
Cereal	Winnipeg 1990	1990	1991	Dauphin 1990	Portage la Prairie 1990
Wheat					
Katepwa	1.13	1.31	1.44	1.15	NA[b]
Genesis	1.13	1.23	1.31	1.16	NA
Oslo	1.11	1.18	1.20	1.10	NA
Glenlea	1.11	1.13	1.18	1.11	NA
Triticale					
Wapiti	1.36	1.28	1.60	1.33	NA
Frank	1.41	1.40	1.60	1.43	NA
Rye					
Gazelle	2.83	2.73	3.14	2.94	NA
Prima	3.36	NA	NA	NA	2.92
Musketeer	3.78	NA	NA	NA	2.99

[a]Values relative to those of water at 25°C.
[b]Not applicable.

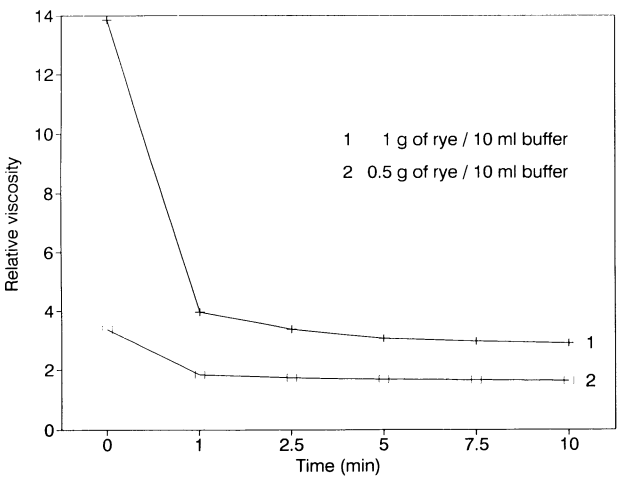

Fig. 7. Effect of xylanase from *Streptomyces lividans* on the viscosity of citric-phosphate buffer extracts prepared from different amounts of rye. Respective corresponding logarithmic values for the 0.5 and 1.0 g rye extracts: 1.33 and 2.64 (0 time); 0.59 and 1.10 (10 min).

endopentosanases does not seem to greatly interfere with this assay, provided it is carried out within one hour of extraction. Therefore, it should be possible to predict the soluble pentosan content in rye grain from the viscosity of rye extract.

ACKNOWLEDGMENTS

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