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Effect of arabinoxylans on bread-making quality of wheat flours

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Two highly purified arabinoxylan preparations of different molecular weight (HMW, $[\eta] = 5{\cdot}48$ dl/g and LMW, $[\eta] = 3{\cdot}69$ dl/g) were used to study the effect of these water-soluble polysaccharides on the bread-making quality of two wheat flours: a Canada western red spring (CWRS) composite sample and a Canada prairie spring (CPS), cv. HY 368. Both preparations significantly increased the farinograph water absorption and the dough development time for the two flours; the HMW arabinoxylans exerted significantly ($P < 0{\cdot}01$) greater effects than the LMW preparation. The HMW arabinoxylans maximally improved the loaf volume of CWRS and CPS breads at a level of 0·5% (w/w) supplementation. The LMW arabinoxylans maximally increased the loaf volume of CWRS and CPS breads at 0·7 and 1·1% (w/w), respectively. Breads containing HMW arabinoxylans retained significantly ($P < 0{\cdot}01$) more water than the breads with LMW polymers at 0·5–0·9% (w/w) supplementation levels. Because of their higher moisture content the arabinoxylan-fortified breads exhibited a greater rate of starch retrogradation as assessed by calorimetry. Nevertheless, these breads had softer breadcrumbs than the controls; breads fortified (0·3–0·9% w/w) with HMW arabinoxylans were significantly ($P < 0{\cdot}01$) less firm than those with LMW polymers over the 7-day storage period.

INTRODUCTION

Water-soluble pentosans (arabinoxylans and arabinogalactans) are heterogeneous, non-starch polysaccharides of wheat flour. In spite of being relatively minor constituents (0·4–0·8%), pentosans are believed to have an impact on the bread quality parameters such as loaf volume, crumb texture and staling characteristics (Amado & Neukom, 1985; Meuser & Suckow, 1986). A great deal of uncertainty, however, remains as to the exact functional role and contribution of the individual pentosan components to the overall bread-making quality of wheat flours; several research reports in this area are contradictory. While Cawley (1964) and Jelaca and Hlynka (1972) reported that addition of pentosans improved the loaf volume and crumb quality, the data of Kim and D'Appolonia (1977*a*) did not concur with such a view. Moreover, the effect of pentosans on starch retrogradation remains rather obscure. Kim and D'Appolonia (1977*b*) and Jankiewicz and Michniewicz (1987) reported that pentosans decreased retrogradation of starches and staling of bread based on lower firmness values observed for starch gels and bread containing pentosans. When Longton and LeGrys (1981) measured the process of retrogradation by differential scanning calorimetry, however, they concluded that pentosans did not affect the retrogradation of starch, whereas Gudmundsson *et al.* (1991) and Biliaderis and Izydorczyk (1992) reported an increase in the crystallisation rate of amylopectin upon addition of arabinoxylans. The reasons for such conflicting results lie most likely in differences in the purity and composition of pentosan preparations (protein and starch content, ratio of arabinoxylans to arabinogalactans), levels of supplementation, as well as differences in the water content between control and pentosan-supplemented breads.

The purpose of the present investigation was, therefore, to study in a more systematic manner, the effect of arabinoxylans, the major high-molecular-weight constituents of pentosans, on breadmaking quality of wheat flours. The diverse physicochemical characteristics of arabinoxylans due to structure and molecular size variations (Izydorczyk *et al.*, 1991*a,b*) necessitated, in the authors' view, the use of two arabinoxylan preparations (differing especially in molecular weight) in the fortification experiments. To the authors' knowledge this is one of the very few attempts, if any, to clarify the functional role of arabinoxylans in dough and bread systems utilizing highly purified and structurally well-characterised arabinoxylan preparations. The effect of various levels of supplementation with arabinoxylans as well as the effect of using flours of diverse bread-making qualities were also considered in this study.

MATERIALS AND METHODS

Wheat flours and water-soluble arabinoxylans

The flours used for the baking studies belong to two different classes of wheat: Canada western red spring (CWRS, a composite flour) and Canada prairie spring (CPS, cultivar HY368). The extraction rate, protein, and ash contents of these two flours were 72%, 13·0%, 0·46% (14% mb) for CWRS flour and 67%, 11·5%, 0·35% for CPS flour, respectively. The total and water-soluble pentosan contents of these flours were 1·98 ± 0·04%, 0·74 ± 0·04% (CWRS), and 1·79 ± 0·05%, 0·65 ± 0·03% (CPS), respectively.

Water-soluble arabinoxylans from several flours of Canada western red spring wheats (Rattan *et al.*, 1994) were isolated and purified according to the procedure of Izydorczyk *et al.* (1990). Two preparations (from cultivars Katepwa and Columbus), greatly differing in their molecular size, were employed in the fortification experiments.

Chemical analysis

The content of total and water-soluble pentosans in wheat flours was determined by the phloroglucinol method (Douglas, 1981). The monosaccharide composition of arabinoxylans was determined by gas–liquid chromatography (GC) (Hewlett Packard Corp., fused silica column SP 2330, 30 × 0·75 mm i.d., 0·75 μm film thickness) of alditol acetates (Englyst *et al.*, 1982). The content of feruloyl groups in arabinoxylans was determined spectrophotometrically by direct absorbance measurements, at 375 nm, of freshly prepared solutions of arabinoxylan in 0·07 M glycine–NaOH buffer (pH 10·0), using a molar extinction coefficient of 31 600 (Izydorczyk *et al.*, 1990). Protein content was determined by the method of Lowry *et al.* (1951) using bovine serum albumin as a standard.

The apparent viscosities of aqueous solutions of arabinoxylans were measured with Ubbelohde viscometers (International Research Glassware, Kenilworth, NJ, USA) at 25°C. The limiting viscosities were calculated from the Huggins equation (Huggins, 1942).

Farinograph absorption

A microfarinograph was used to determine the water absorption of the flours with added arabinoxylans (0·5–1·3%), according to the approved AACC method (method 54–21, AACC, 1983). Arabinoxylans in a dry form were mixed well with 10 g of flour prior to the water absorption test.

Bread baking

The GRL remix method (Kilborn & Tipples, 1981) with some minor modifications was employed for all baking studies. The bread formula was as follows: flour (14% mb) (100·0 g), yeast (3·0 g), salt (1·0 g), sucrose (2·5 g), potassium bromate (15 ppm), ammonium phosphate (0·1%), malt syrup (0·6%), arabinoxylan (amount varied), water (microfarinograph absorption). Arabinoxylans (pulverised, dried form) were mixed with the flours (CPS and CWRS) at different levels (0·3–1·1% of the flour weight) and doughs were made by adding water equivalent to the farinograph absorption value (500 BU). The doughs were fermented for 2 h and 45 min, remixed, and allowed to set again for additional 25 min. The doughs were then sheeted, moulded, and cut into two halves of equal weight. Each half was placed into a separate baking pan (8 cm × 3·5 cm × 4·7 cm) for proofing (55 min). Baking was performed at 430°F (~220°C) for 25 min. Loaf volumes were measured after 25 min of cooling with a pup loaf volumeter (National Mfg Co.) using wheat grain. The loaves were then vacuum-packed in plastic bags using a commercial vacuum sealer Decosonic (Decosonic Inc., Montreal, Canada) and stored at 7°C.

Moisture content determination

The moisture content of control and arabinoxylan-supplemented (at various levels) breadcrumbs stored for 1, 3, 5, and 7 days (at 7°C) were determined according to the AACC approved method (method 44-15A, AACC, 1983).

Bread firmness measurements

The Ottawa Texture Measuring System (OTMS, Engineering and Statistical Research Institute, Ottawa) equipped with Apple software (Personal Computer Products Inc., San Diego, CA, USA) was used to measure bread firmness of control and arabinoxylan-fortified breadcrumbs. Bread slices of 12 mm thickness were cut out from the centre of the loaves with a commercial bread cutter (TEFAL, model 220, Germany). These slices were compressed to a 40% compression (4·4 mm) using a 28 mm (area $6{\cdot}15 \times 10^{-2}$ m^2) diameter plunger with a load cell of 11·36 kg and crosshead speed of 100 mm/min. The compression curves (time (s) versus force (N)) were plotted using the Apple software. Using these curves, the force readings at 25% compression were taken for comparison purposes.

Differential scanning calorimetry

The staling of bread was assessed by DSC following storage of the breadcrumbs at 7°C for a designated time period. The crumb samples were freeze-dried and analysed with a DuPont 9900 Thermal Analyser equipped with a Dupont 910 cell base and a low-pressure differential scanning calorimeter cell, according to the method of Biliaderis *et al.* (1985). Triplicate measurements were performed on samples weighing 3–3·5 mg (30% aqueous suspensions of freeze-dried crumb). The samples were heated in the calorimeter at a rate of 10°C/min.

Statistics

Statistical analyses were made using the procedures of the SAS software system, release 6·04 (SAS Institute, Cary, NC, USA).

RESULTS AND DISCUSSION

Arabinoxylan preparations

The composition and physicochemical characteristics of the two arabinoxylans used in this study are presented in Table 1. Both preparations contained very little proteins and consisted essentially of two monosaccharides, arabinose and xylose. The apparent molecular weights, calculated from the limiting viscosity values, were substantially different for these two arabinoxylan preparations. Moreover, the low-molecular-weight (LMW) arabinoxylan extracted from the cultivar Columbus was slightly more branched but contained lower amounts of ferulic acid than the high-molecular-weight (HMW) arabinoxylan preparation from Katepwa.

Farinograph absorption and dough development time

The changes in water absorption of the base flours caused by addition of arabinoxylans (various levels) were assessed by a microfarinograph. Both arabinoxylan preparations (HMW and LMW) significantly ($P<0\cdot01$) increased the farinograph water absorption at a fixed dough consistency (500 BU) (Table 2). There were also significant ($P<0\cdot01$) differences between the two arabinoxylans in the effects they exerted on the water absorption of the two flours; the HMW arabinoxylan increased the farinograph absorption to a greater extent than the LMW preparation. Significant correlations were found between farinograph absorption and the amount of arabinoxylan added (r = 0·99 and r = 0·90, $P\leq0\cdot05$ for the HMW arabinoxylans in CWRS and CPS flours, respectively; r = 0·98 and r = 0·97, $P\leq0\cdot05$ for the LMW arabinoxylans in CWRS and CPS flours, respectively). Similar relationships have been reported previously by Michniewicz *et al.* (1991) who added water-soluble wheat and rye pentosans to various wheat flours.

It is evident from Table 2 that arabinoxylans added to the base flours also increased the dough development time. Again, significant differences were found between LMW and HMW arabinoxylans in their effects on dough development time.

Effect of arabinoxylans on bread loaf volume

The impact of different levels of the two arabinoxylans

Table 1. Physicochemical characteristics of two arabinoxylan preparations (means ± SD, *n* = 3)

Arabinoxylan source (cultivar)	Limiting viscosity (dl/g)	Molecular weight[a]	Protein (%)	Ferulic acid (mg/g)	Ara : Xyl
Katepwa	5·43	201 600	1·20 ± 0·02	1·11 ± 0·02	1 : 1·56
Columbus	3·69	134 600	0·93 ± 0·02	0·93 ± 0·01	1 : 1·49

[a] Calculated from $[\eta] = KM^{\alpha}$ ($K = 3\cdot47 \times 10^{-3}$, $\alpha = 0\cdot98$; data taken from Anger *et al.*, 1986).

Table 2. Farinograph absorption and dough development time for arabinoxylan-supplemented CWRS and CPS wheat flours (means, *n* = 3)

Sample	Farinograph absorption[a] (%)		Dough development time[a] (min)	
	CWRS	CPS	CWRS	CPS
Control	60·0 g	58·0 f	5·0 e	4·0 f
+0·5% AX (HMW)	62·5 e	60·0 d	5·5 d	5·0 d
+0·9% AX (HMW)	65·0 c	63·0 c	6·0 c	6·0 c
+1·3% AX (HMW)	67·0 a	65·6 a	8·5 a	7·0 a
+0·5% AX (LMW)	62·0 f	59·6 e	5·5 d	4·5 e
+0·9% AX (LMW)	64·6 d	63·0 c	6·5 b	6·5 b
+1·3% AX (LMW)	66·5 b	65·0 b	8·5 a	7·0 a

[a] The coefficient of variation was less than 5·0% of the mean values in all cases. Values followed by different letters (columns) are significantly different (LSD α = 0·01).

(HMW and LMW) on the loaf volumes of breads baked from the CWRS and CPS flours is presented in Fig. 1. Both arabinoxylan preparations have brought about similar effects on the loaves made from the CWRS flour (Fig. 1a). For example, when HMW arabinoxylan was added to the base flour up to a level of 0·5% (w/w), an increase in loaf volume was observed. However, upon further addition of arabinoxylans, a decrease in loaf volume was noticed. Similar responses were also shown for the LMW arabinoxylan-supplemented CWRS flour, except that the maximum volume enhancement took place at slightly higher concentration (0·7% w/w). It appears, therefore, that there is an optimum concentration at which these polysaccharides exert the most beneficial effect on the loaf volume. The initial expansion of dough and consequently bread volume upon addition of arabinoxylans is probably due to increased strength and elasticity of the gluten–starch composite network. Further addition of arabinoxylans, however, builds up the viscosity of the dough system and consequently hinders or even decreases the volume of the final baked products. Figure 1(b) shows the influence of HMW and LMW arabinoxylans on the loaves baked from the CPS flour. In this case, the two arabinoxylan preparations behaved differently. The HMW arabinoxylans maximally improved the loaf volume at a level of 0·5%, and further additions resulted in reduction of the loaf size. In contrast, with addition of the LMW arabinoxylans, a continuous increase in loaf volume was observed over the entire range of arabinoxylan concentrations tested. The above results indicate, therefore that, in addition to the nature of the base flour, differences in the molecular weight of arabinoxylans have a pronounced effect on the loaf volume of the final products. It appears that a maximal loaf volume can be achieved with much lower concentration of the HMW arabinoxylans than with the LMW counterparts. These results also show that it is possible to improve the poor bread-making quality of wheat flours by supplementation with small amounts of water-soluble arabinoxylans.

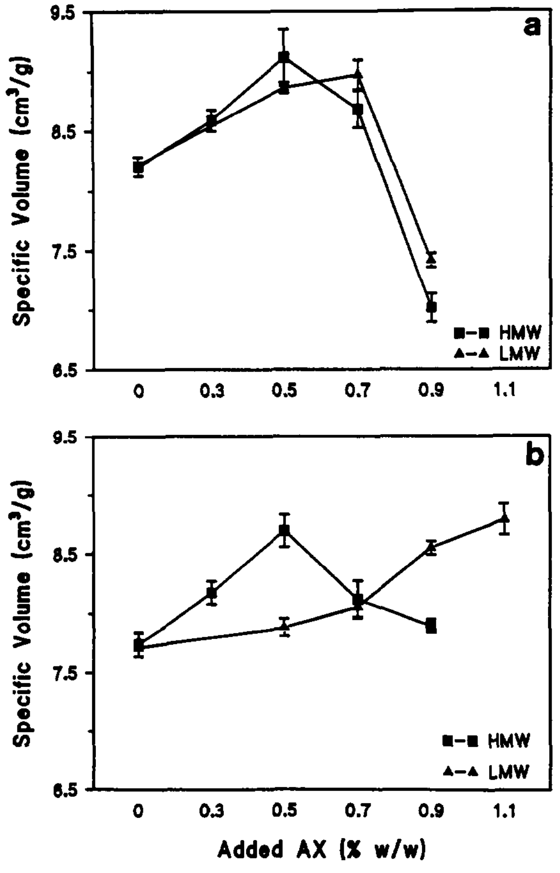

Fig. 1. Effect of added arabinoxylans (HMW and LMW) on the specific volume of breads made from the (a) CWRS, and (b) CPS flours.

Studies done in the past had shown a steady increase in the loaf volume with the addition of water-soluble pentosans at concentrations 1–2% (Tao & Pomeranz, 1967; D'Appolonia *et al.*, 1970; Jelaca & Hlynka, 1972; Michniewicz *et al.*, 1992). However, these authors dealt with the entire pentosan preparations which contain approximately 30% of arabinogalactan, the low-molecular-weight component (Izydorczyk *et al.*, 1991*a*). Delcour *et al.* (1991) also found that the water-soluble pentosans (mostly arabinoxylans) from rye were the most effective in enhancing the volume of gluten–starch loaves at concentrations of 2–3%.

Moisture content of bread crumbs

The texture of breadcrumb, one of the most important quality indicators of baked products, is related to the mechanical properties of bread and is greatly affected by the amount of water present after baking. The moisture contents of control and arabinoxylan-fortified (LMW and HMW) breadcrumbs from the two base flours (CWRS and CPS) are presented in Tables 3 and 4. In each case, the moisture content of control breadcrumbs was found to be lower than those supplemented with arabinoxylans over the 7-day storage period. This obviously reflects the higher water absorption values of the arabinoxylan-fortified flours. The molecular weight of arabinoxylans had a significant influence on the moisture content of breadcrumbs. Breads containing HMW arabinoxylans retained significantly ($P < 0·01$) more water than breads with LMW polymers at all lev-

Table 3. Moisture content (%) of arabinoxylan-fortified breadcrumbs (CWRS flour), stored at 7°C over a period of 7 days (means, *n* = 3)

Sample	Moisture content (%)[a]			
	Day 1	Day 3	Day 5	Day 7
Control	35.4 f	33.1 g	30.8 g	29.4 g
+0·5% AX (HMW)	39·5 d	37·5 c	36·0 c	35·4 c
+0·7% AX (HMW)	41·0 c	38·0 b	36·6 b	35·6 b
+0·9% AX (HMW)	44·7 a	41·1 a	39·4 a	38·2 a
+0·5% AX (LMW)	37·8 e	35·4 f	32·4 f	31·8 f
+0·7% AX (LMW)	40·1 c	36·7 e	34·1 e	33·0 e
+0·9% AX (LMW)	42·3 b	37·3 d	34·9 d	33·6 d

[a] The coefficient of variation was less than 1% of the mean values in all cases. Values followed by different letters (columns) are significantly different (LSD $\alpha = 0·01$).

Table 4. Moisture content (%) of arabinoxylan-fortified breadcrumbs (CPS flour), stored at 7°C over a period of 7 days (means, n = 3)

Sample	Moisture content (%)[a]			
	Day 1	Day 3	Day 5	Day 7
Control	33·0 g	31·0 g	30·1 f	28·4 g
+0·5% AX (HMW)	35·1 e	33·3 d	32·1 d	30·4 e
+0·7% AX (HMW)	39·6 b	37·5 b	36·4 b	34·8 b
+0·9% AX (HMW)	42·6 a	39·4 a	37·4 a	36·1 a
+0·5% AX (LMW)	34·6 f	32·4 f	31·0 e	29·3 f
+0·7% AX (LMW)	36·2 d	33·2 e	32·0 d	30·5 d
+0·9% AX (LMW)	38·0 c	36·5 c	34·5 c	33·4 c

[a]The coefficient of variation was less than 1% of the mean values in all cases. Values followed by different letters (columns) are significantly different (LSD α = 0·01).

els of supplementation. Moreover, analysis of variance confirmed highly significant effects ($P < 0{\cdot}01$) of supplementation levels on the amount of water retained in the crumbs. Generally, there was a continuous loss of moisture with time of storage although the rate of moisture loss slowed as storage time progressed.

Crumb firmness

The increase in breadcrumb firmness has been used by many researchers to follow the bread staling process. In this study, staling of control and arabinoxylan-fortified breadcrumbs was monitored by measuring crumb firmness by the Ottawa Texture Measuring System. The firmness measurements are plotted as a function of storage time (at 7°C) in Figs 2 and 3. Although firmness increased (almost linearly) over the 7-day storage for both control and arabinoxylan-fortified breadcrumbs, the latter were found to be less firm in all cases. Again, the molecular weight of arabinoxylans significantly affected the firmness of crumbs. Breads fortified with HMW arabinoxylans were significantly ($P < 0{\cdot}01$) less firm than those with LMW polymers at all levels of supplementation throughout the 7-day storage period. The crumb firmness also significantly ($P < 0{\cdot}01$) decreased with increasing amounts of arabinoxylan added in all cases, presumably due to increasing moisture content of the crumb matrix. For example, after 7 days of storage, the CWRS breadcrumbs containing 0·9% HMW arabinoxylans were found to be 22% less firm than those containing only 0·5%. Similarly, breadcrumbs with LMW arabinoxylans at 0·9% supplementation were found 20% less firm than those at 0·5% after 7 days of storage. In comparing the firmness between the two base flours, similar trends in staling rates were observed. However, the firmness values of control and fortified breadcrumbs of the CPS flour were generally higher than those of the CWRS flour.

It has been suggested that pentosans influence the texture of breadcrumb by interacting with the gluten to form composite hydrated film networks and also by increasing the water absorption of dough which in turn contributes to the texture of breadcrumbs (Michniewicz *et al.*, 1991). Water acting as a plasticiser of the gluten–starch matrix lowers the rigidity of the composite network (Levine & Slade, 1990). The lower firmness values observed for breadcrumbs fortified with the arabinoxylans are most likely due to their higher moisture content.

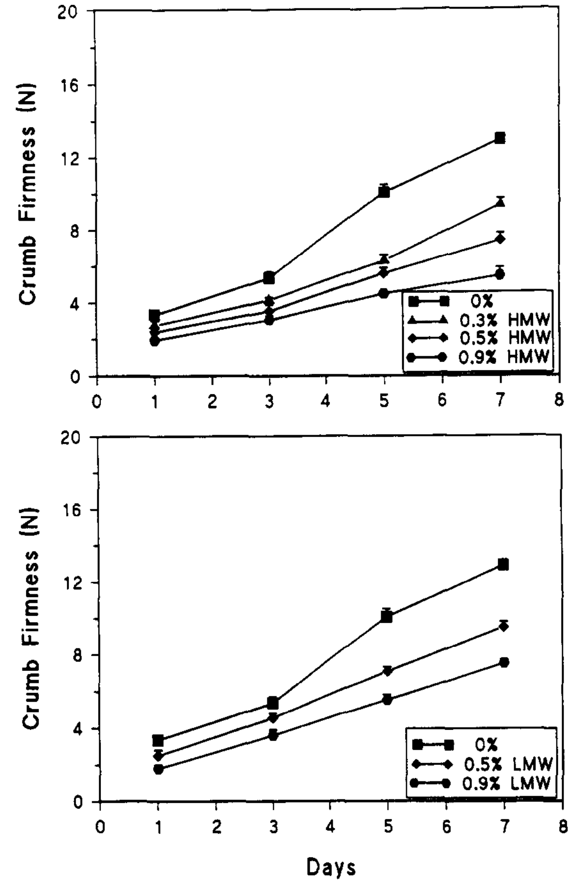

Fig. 2. Effect of added arabinoxylans (HMW and LMW; 0–0·9%, w/w flour basis) on crumb firmness during storage of breads made from the CWRS flour.

Bread staling studies by DSC

Starch recrystallisation is considered a major factor contributing to bread staling. Fearn and Russell (1982) and Russell (1983) applied differential scanning calorimetry (DSC) to measure the structural changes of starch in bread during ageing. They observed that when staled bread was heated in the DSC, a prominent endotherm peak was present around 50°C, which was absent in the fresh bread, and notably increased with storage time. This endotherm peak was due to the melting of retrograded amylopectin. In the present study, staling of control and arabinoxylan-fortified breadcrumbs (with LMW preparations at 0·5% and 0·9% levels) made from the two base flours (CWRS and CPS) was studied with DSC by monitoring the changes in melting enthalpies of recrystallised amylopectin during storage at 7°C. The results are compiled in Table 5. The enthalpy values (ΔH) of arabinoxylan-supplemented breadcrumbs were found to be

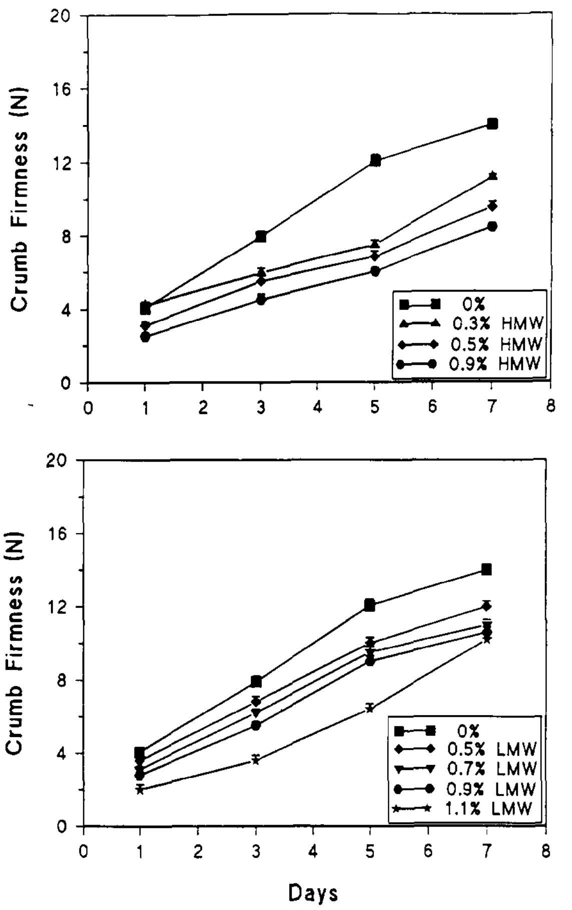

Fig. 3. Effect of added arabinoxylans (HMW and LMW; 0–1·1%, w/w flour basis) on crumb firmness during storage of breads made from the CPS flour.

higher than the controls for both flours. Also, the ΔH values increased with increasing level of arabinoxylan added. These increases in starch retrogradation are most likely the result of higher moisture content of the arabinoxylan-supplemented crumbs (Tables 3 and 4). It has been shown that the moisture content of the sample is critical in determining the kinetics of amylopectin retrogradation (i.e. recrystallisation of outer short chains of the molecule). Water increases chain mobility in the amorphous regions and, therefore, promotes recrystallization. There is an acceleration of the retrogradation rate with increasing moisture, especially in the range of 20–45% water content (Zeleznak & Hoseney, 1986). In the present study, the obtained enthalpy values (for the amylopectin endotherm) were higher than those reported earlier (Zeleznak & Hoseney, 1986; Czuchajowska & Pomeranz, 1989). This can be attributed to the relatively low storage temperature (7°C) adopted in our studies; it is known that with decreasing temperature there is an acceleration in the retrogradation events (Longton & LeGrys, 1981).

Table 5. Enthalpy values of staling endotherm for arabinoxylan-fortified breadcrumbs stored at 7°C

Sample	ΔH (J/g)[a]			
	Day 1	Day 3	Day 5	Day 7
Control (CWRS)	3·5 a1	3·7 a2	4·5 a3	4·7 a4
+0·5% AX (LMW)	4·1 b1	4·3 b1	4·7 b2	5·1 b3
+0·9% AX (LMW)	4·4 c1	5·0 c2	5·3 c2	5·8 c3
Control (CPS)	3·7 a1	3·8 a1	3·9 a1	4·6 a2
+0·5% AX (LMW)	3·8 a1	4·6 b2	5·3 b3	5·5 b3
+0·9% AX (LMW)	4·9 b1	5·5 c2	5·7 c3	5·8 c3

[a] The coefficient of variation was less than 5% of the mean values in all cases. Values followed by different letters (columns) or numbers (rows) are significantly different (LSD $\alpha = 0{\cdot}05$).

At first glance, the results of bread staling studies by DSC seem to contradict those obtained by the firmness measurements. There are many variables affecting the complex nature of the staling phenomenon and, as such, there is no single technique that can provide a complete view of all events related to this process. For example, the DSC and mechanical testing do not monitor the same properties of the composite network structure in breadcrumbs. Calorimetry measures only the amount of recrystallised amylopectin; in the range of moisture contents for the bread samples of the present study (Tables 3 and 4), retrogradation kinetics are accelerated with increasing moisture content. On the other hand, crumb firmness measurements provide information on the mechanical properties of the baked products which are also dependent on the water content; water acts as a plasticiser of gluten and starch and thereby decreases the firmness of the crumb. Overall, while starch retrogradation (determined by DSC) and firming occur concurrently upon storage, they do not exist in a cause–effect relationship as both processes are influenced in different ways by the moisture content of the bread system.

CONCLUSIONS

The results of these studies showed that the addition of highly purified water-soluble arabinoxylans to wheat flour significantly affects farinograph water absorption, dough development time, loaf volume of bread, moisture content and firmness of breadcrumbs. Although only two arabinoxylan preparations and two wheat flours for the baking tests were used in this study, the results clearly indicated that the magnitude of these effects is dependent on the amount of arabinoxylans added, molecular size of these polymers, and the bread-making quality of the base flour. Further studies, using arabinoxylans from other sources and flours with diversified bread-making qualities, would be useful to fully unravel the functional role of these polysaccharides in dough and bread systems.

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