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RESEARCH PAPER

Effect of Water Soluble Non-starch Polysaccharides from Rye on Characteristics of Wheat Dough and Properties of Wheat Bread

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ABSTRACT

Present paper deals with crosslinking, oxidation, reduction, complex formation and enzymatic degradation of flour components like starch, protein and water soluble non-starch polysaccharides (WSNSP), contribute to the dough characteristics and bread properties. Peak viscosity and pasting viscosity of wheat starch showed 21% and 18% increase respectively, in presence of 1% RYE-WSNSP. Loaf volume of the wheat flour breads increased to a significant ($p<0.05$) level (12%) due to presence of 1.5% RYE-WSNSP. In presence of 10 units of xylanase, loaf volume of standard wheat flour bread increased to 44 ml. Evaluation of the effect of RYE-WSNSP on the baking loss showed no significant difference between samples. RYE-WSNSP delayed staling significantly ($p<0.05$) during storage as expressed by crumb firmness measured after 48 hours. Stress relaxation measurements showed that rate at which stress decayed was delayed by RYE-WSNSP in a wheat flour bread. RYE-WSNSP have a slight but significant ($p<0.05$) influence on transition enthalpy of gelatinization of a sample of starch as well as a sample of wheat flour. However, RYE-WSNSP did not cause any significant effect on retrogradation of starch. But at a water content of 43.4% transition enthalpy of a wheat flour sample decreased by 25% in presence of 0.25% RYE-WSNSP.

HIGHLIGHTS

- The WSNSP - water soluble non-starch polysaccharides from Rye (*Secale cereale*) was found to influence the dough characteristics and bread properties, primarily due to its water binding capacity.
- The viscoelastic properties of the dough as well as its ability to hold the gas during fermentation and maintain the shape of the loaf are affected by the amount of WSNSP and its properties.
- The loaf volume, the crumb structure, colour and taste of the crust are also affected positively by the WSNSP content of the flour, while enzymes like xylanase, which degrade the WSNSP, are found to act in the reverse direction.
- The falling number of the rye flour is affected not only by its amylase activity but also very much on the activity of non-starch polysaccharide degrading enzymes and it is possible to modulate the bread properties by adding WSNSP and/or enzymes which degrade WSNSP.

Keywords: WSNSP-Water soluble non starch polysaccharides, Pentosans, Dough Rheology, Rye *(cecale cereale)*, oxidative gelation, staling, crumb firmness

During the mixing process, water molecules come into contact with reactive chemical groups of the protein, starch, dextrins and pentosans. The time required for uniform and optimum hydration depends on many factors such as particle size, intensity of mixing, and presence of components

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like damaged starch, non-starch polysaccharides, salt and other additives. The large surface area of the flour (Bushuk and Winkler, 1957) makes the hydration of its particles quick and efficient. The intact starch granules absorb water up to 50% of their weight, whereas damaged starch is able to take up water twice its weight, as do the proteins. However, water soluble pentosans have a hydration capacity of about 11 times their weight (Kulp, K. 1968). After the mixing process, during the proofing of the dough, the properties of its components may change partly due to the interaction between them but also depending on the distribution and availability of water as well as the degree of degradation of starch caused by fermentation and the water holding capacity caused by that. The water holding capacity of the rye flours depend also on their content of NSP (Hoseney, 1984), amylase activity and activity of enzymes which may also act upon gel forming NSP (Neukom, H. 1976; Kulp, K. 1968; Kühn and Grosch, 1988; Shelton and D'Appolonia, 1985). In the absence of gluten, the NSP give rye bread its structure (Holas, 1992) and improve the eating qualities. The WSNSP are understood to exert their effect on the dough and bread properties primarily due to their ability to absorb high amounts of water (D'Appolonia and Schwarz, 1992). The published literature on the importance of WSNSP for the bread properties shows some disagreement, which might be due to the different methods used for the preparation of the sample and the experimental conditions adapted in each case.

Kulp (1968) found that the addition of pentosans to a dough resulted in reduced mixing time and stiffer dough at constant water absorption, while the mixing time did not change significantly when the doughs were adjusted to constant farinograph consistency. However, Pence *et al.* (1950) reported that pentosan containing fractions gave a reduction in mixing time. They attributed an increased loaf volume obtained by the addition of water soluble WSNSP to the protein remaining attached to the pentosans. D'Appolonia *et al.* (1970) obtained an increase in loaf volume in a starch-gluten loaf with the addition of water soluble substances in the flour, whereas the pure arabinoxylans produced only an insignificant increase in loaf volume. The fractions from the DEAE-cellulose chromatography containing high amounts of protein caused an increase in loaf volume. However, Cowley (1964) reported that the effect of flour solubles on the loaf volume was destroyed by polysaccharide degrading enzymes, but not by active proteases. McCleary *et al.* (1986) used a highly purified endoxylanase in baking experiments with 16-250 units of added xylanase. The dough became sticky and after the fermentation step the doughs were very sloppy, sagging over the side of the baking pans at higher concentrations of xylanase. Kim and D'Appolonia (1977) observed that the pentosans had a definite effect in delaying the retrogradation of starch gels upon ageing and later they also found that pentosans decreased the bread staling rate. Michniewicz *et al.* (1992) found an increased specific loaf volume due to the addition of WSNSP from wheat and rye. In the present study, the effect of RYE-WSNSP on the characteristics of the dough was monitored by measuring the amylograph viscosity of a sample of wheat starch and a standard wheat flour after the addition of RYE-WSNSP. The effect of NSP on the farinograph water absorption of a standard flour was determined in the presence of NSP degrading enzymes and their effect on the gelatinization and retrogradation of starch was studied by differential scanning calorimetry. Baking experiments were also carried out to study the effect of RYE-WSNSP on the properties of the bread such as baking loss, loaf volume, crumb firmness and pore structure.

MATERIALS AND METHODS

Flour samples

Wheat flour used for studying effect of added RYE-WSNSP, in presence of enzyme and oxidizing agent, on the characteristics of wheat flour dough and the properties of the wheat flour bread was a standard bakery flour of type "normalvetemjöl" with no addition of ascorbic acid, from Nord Mills AB, Malmö", Sweden. It contained 9.4% protein, 0.48% ash, 14.9% moisture and its falling number was 307 sec.

Chemicals and enzymes

All chemicals used in this experiment were of pro analysi grade. Pure wheat starch of food quality was from Excelsior, Holland. Hydrogen peroxide (30%) and Horse-radish peroxidase (P-8125) were from

Sigma Chemical Company, St. Louis, Mo., USA. Xylanase from Trichoderma viride, 2.5 u/mg was from Fluka AG-9470 Buchs, Switzerland.

Preparation of the NSP

Isolation of WSNSP from whole grains of rye (var. Petkus from Svalöf AB, Svalöv, Sweden) was done as described by Girhammar and Nair (1992). Grains were milled to particles less than 1 mm in size using a sample mill. Flour was then refluxed with three volumes of 80% ethanol for a period of one hour. Slurry was cooled to room temperature and filtered by suction. Residue was washed with 95% ethanol and suspended in four volumes of distilled water for a period of 15 minutes. Extract was separated from the residue by centrifugation and it was treated with pancreatin to digest the starch and protein. After centrifugation and filtration, supernatant was adjusted to 80% ethanol for precipitation of WSNSP. Precipitate was washed with ethanol, ether and acetone before it was dried under nitrogen atmosphere at room temperature in a desiccator.

Chemical characterization of the NSP

(a) Moisture

Moisture content was determined by weighing and then drying at 135 °C for 75 min. Weight loss was regarded as the moisture content (NMKL, 1977).

(b) Ash

Samples were dry ashed at 550 °C over night and ash content was determined by weighing (NMKL, 1987).

(c) Protein and amino acids

Protein content of water soluble non-starch polysaccharide was determined by Kjeldahl method using 6.25 as conversion factor. Sample was digested (Digestion system 20, Tecator AB, Höganäs, Sweden) with concentrated H_2SO_4 and a catalyst ($CuSO_4$, Kjeltabs) at 400 °C for 60 minutes. After cooling digested material was diluted with water. Mixture was distilled after addition of NaOH solution and ammonia was absorbed into a 1% solution of boric acid. Amount of ammonia absorbed in the boric acid was determined by titration with HCl. Amino acid determination of WSNSP was carried out by ion-exchange chromatographic method (Model LC 5001, BIOTRONIK amino acid analyser GmbH, Germany) after acid hydrolysis as described by Nair (1977).

(d) Monosaccharides

Determination of monosaccharide content in the WSNSP was done according to Theander and Åman (1979). Polysaccharides were hydrolysed with sulphuric acid and monosaccharides were converted to alditol acetates before they were separated in a gas chromatograph (Model 3700, Varian, California, USA) equipped with a capillary column and a flame ionization detector, using fucose or allose as internal standard.

Amylograph viscosity

Effect of α-amylase on viscosity of a commercial starch at different concentrations of WSNSP as a function of temperature was measured in an Amylograph (Brabender OHG, Duisburg, Germany) by ICC method, standard No 126 (ICC-Standard 1984).

Dough making in the farinograph

A Farinograph (Brabender OHG, Duisburg, Germany) using a 50 g bowl (S 50) was used for dough preparation. Fifty gram of the wheat flour "normalvetemjöl" on 14% moisture basis was mixed for 6 min at 60 RPM with 15 ml of a suspension containing 2.65 g compressed baker's yeast, 5.5 ml of a solution containing 3.0 g sugar and 0.75 g salt. Final moisture content was adjusted by adding more water while mixing, until a consistency equivalent to 400 Brabender units (Bu) was attained. Solutions of RYE-WSNSP (0.025% to 1.5% heated to 90 °C for 3 min to be sure that the enzymes are inactivated), xylanase (10U, 20U and 60U), hydrogen peroxide (30 ppm), Horse-radish peroxidase (30 ppm) were added on flour weight basis whenever effect of each of these on mixing was being studied in duplicate. Temperature of suspension and solutions added to the mixture was adjusted to 38 ºC and temperature of dough reached 32 °C at the end of mixing procedure.

Test baking

Doughs were removed from mixer and placed in a beaker which was covered and placed in a fermentation cabinet at 30 °C for 55 min. Doughs

were then divided into portions of 12 g weight after punching by passing them through a couple of rotating rollers. Moulding was accomplished by rolling the doughs on the surface of the table 30 times. Dough pieces were placed in a baking pan and returned to fermentation cabinet and proofed at 38 °C for 60 min at a relative humidity of 85%. After proofing doughs were baked in the oven for 13 min at 235 °C. Steam was introduced into the oven during the first two minutes. After removal from oven loaves were placed on a grating for an hour before their quality was determined. Weights and volumes were determined using a rape seed displacement volumeter. Six loaves from each sample were cut and scored **(Fig. 4)** for symmetry, texture and grain.

Crumb firmness

Crumb firmness was measured with LFRA texture analyser (Stevens & Son Ltd., Great Britain) using constant speed (0.2 mm/sec) operational mode. In each test two loaves were sliced (13 mm thick) and they were evaluated 2, 24 and 48 hours after baking. A cylindrical probe (Ø 6.4 mm) was used and the distance of penetration was set at 2 mm (about 15% compression of 13 mm thick slices). Each slice was compared five times moving the cylindrical probe 3.2 mm in each direction around the centre of the slice. After penetrating preselected distance into slice probe returned to its resting position. Load (in grams) was read on a digital display or on a connected recorder.

Stress relaxation of each bread slice was studied in holding mode by holding probe at preselected distance (2 mm) and then relaxation was registered as a function of time on an XY-recorder. Relaxation curves were normalized and fitted into the equation:

$$Y(t) = \frac{F_0 - F(t)}{F_0} = \frac{abt}{1 + bt}$$

where F_o is the initial force, $F(t)$ is the force at time t and $Y(t)$ is the decay of the force. Constants **a** and **b** describe the level (a) to which the stress decay during relaxation and the rate (b) at which the stress relaxes, respectively (Peleg, 1979).

Gelatinization

Effect of WSNSP on gelatinization of a pure starch sample with a water to starch ratio of 1.60 and starch in wheat flour with a water to starch ratio varying between 0.80 and 1.10 was studied by using a differential scanning calorimeter (DSC-2, Perkin Elmer Corp, Norwalk, CT, USA). Duplicate dough samples, were prepared by mixing 10 g wheat flour with different amounts of water. After storage at 4 °C for a period of 12 hours, about 10-15 mg of the dough was weighed into the sample pans (DuPont sample pans). The endothermic heat flow was recorded by scanning from 20 °C to 99 °C at a rate of 10 °C/min. A sample pan containing silver was used as reference.

Retrogradation

Effect of WSNSP on retrogradation of starch was also studied using differential scanning calorimetry. Heated samples from the gelatinization experiment were stored under room temperature for four days in their respective DSC pans. Endothermic heat flow was recorded once again by scanning from 20 °C to 99 °C at a rate of 10 °C/min. Moisture content of samples was determined after the DSC measurements. Sealed sample pans were punctured to release the water vapor and dried overnight in an oven at 105 °C. Sample pans were weighed to determine the total water content in the samples. Peak area was determined by using a planimeter for calculation of transition enthalpy.

RESULTS

Composition of the RYE-WSNSP

Composition of WSNSP isolated from whole grain rye flour is shown in Table 1. The RYE-WSNSP contains about 9% protein and about 72 % sugars with xylose (50%) and arabinose (37%) as the major components. Aspartic acid and glutamic acid together contributed 30% of the protein.

Table 1: Composition of water soluble non-starch polysaccharides isolated from whole grain rye flour (Mean ± sd)

Moisture	7.0 ± 1.7 %
Ash	4.0 ± 1.4 % of dry weight
Protein	8.6 ± 1.3 % of dry weight
Sugars	72.0 ± 14.0 % of dry weight
Monosaccharides	**% of the total sugars (Mean ± sd)**
Arabinose	36.5 ± 0.5

Xylose	49.7 ± 3.4
Mannose	2.5 ± *
Galactose	3.5 ± 0.7
Glucose	7.7 ± 1.4
Amino acids	**Mg/g dry weight ***
Aspartic acid	11.3
Threonine	3.9
Serine	5.2
Glutamic acid	10.0
Proline	4.0
Glycine	6.2
Alanine	4.5
Valine	5.0
Methionine	0.7
Isoleucine	3.7
Leucine	4.9
Phenylalanine	2.4
Lysine	4.3

**single observation.*

Amylograph viscosity

Effect of added RYE-WSNSP on amylograph viscosity of starch is as shown in Fig. 1. Peak viscosity of wheat starch was found to be 947 Brabender units and final viscosity of the paste after holding at 50 °C for a period of 30 minutes was 2119 Brabender units. Peak viscosity increased to 1122 BU and final paste viscosity to 2430 BU as a result of addition of 1% (w/w) RYE-WSNSP.

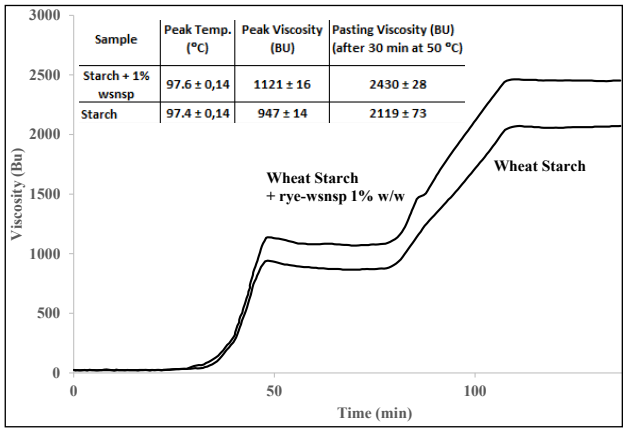


Fig. 1: The effect of water soluble non-starch polysaccharides from rye on the amylograph viscosity of wheat starch

Amylograph viscosity of wheat flour without any addition of RYE-WSNSP (Fig. 2) shows a peak viscosity of 1755 Brabender units and it increased to 2225 Brabender units in the presence of 1% RYE-WSNSP. Paste viscosity of the wheat flour could also be increased from 2996 BU to 3103 BU.

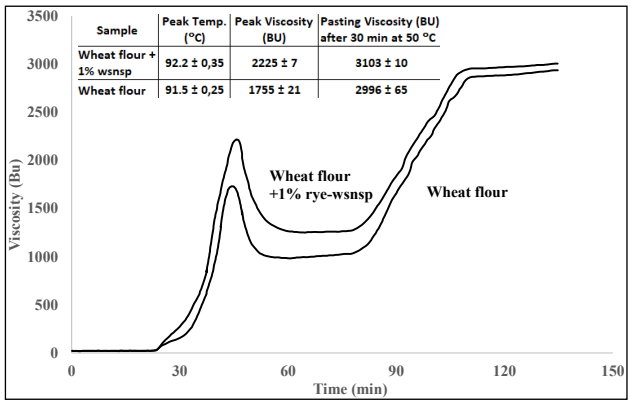


Fig. 2: The effect of water soluble non-starch polysaccharides from rye on the amylograph viscosity of a wheat flour.

Farinograph water absorption

Effect of RYE-WSNSP on the farinograph water absorption of wheat flour dough in presence of xylanase is presented in Fig. 3. It shows that water absorption increases significantly ($p<0,05$) with increasing amount of WSNSP and that presence of xylanase reduces water absorption in doughs.

The farinograph water absorption of a standard wheat flour dough (Fig. 3) increases in the presence of various amounts of RYE-WSNSP.

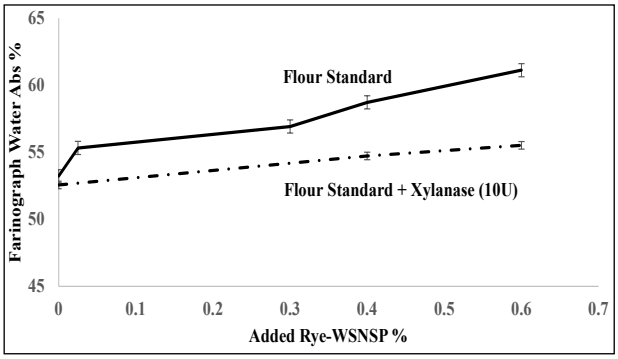


Fig. 3: The effect of water soluble non-starch polysaccharides from rye on the farinograph water absorption of wheat flour dough

Loaf volume and crumb structure

Effect of RYE-WSNSP on the loaf volume of wheat flour bread is given in Fig. 4 which shows that volume increases with increased addition of RYE-WSNSP. An increase from 0.03% of dry matter to 1.5% gave an increase in loaf volume from 35 ml to 39 ml, which is a significant ($p<0.05$) increase of

12%. In presence of 10 units of xylanase, loaf volume of standard wheat flour bread increased to 43.5 ml (P<0.05), while 20 units of xylanase increased the loaf volume of standard wheat flour bread to 41 ml (p<0.05). Increased addition of xylanase (60 units) to standard wheat flour dough without any WSNSP gave a loaf volume of 42 ml. In presence of 60 units of xylanase, loaf volume of bread with 0.03% WSNSP in dough decreased and form and crumb structure showed significant deviation from standard with overflowing crust and uneven pore structure. Effect of WSNSP on loaf volume of a wheat flour bread in presence of oxidizing agents can be seen in Fig. 4, which shows that loaf volume increases from 35 ml for a standard wheat flour bread without any WSNSP to 37 ml for a wheat flour bread containing WSNSP at a level of 0.3 %. However, at 0.6% WSNSP loaf volume decreased to 34 ml in comparison with a standard loaf. Evaluation of the effect of WSNSP on baking loss in these experiments shows no significant difference between samples in this regard.

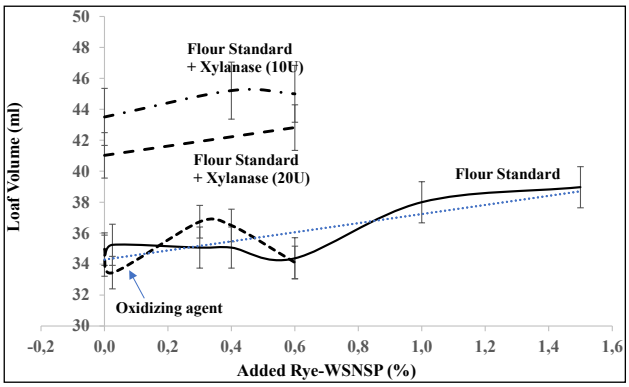


Fig. 4: The effect of water solublr non-starch polysaccharides from Rye, xylanase and oxidizing agents on the loaf volume of a wheat flour bread.

Addition of RYE-WSNSP, however, produced a crust which was dark brown in appearance and xylanase made it darker in colour and caused a somewhat uneven and shrinky surface compared to standard wheat flour bread. Both crumb and crust of the bread baked with oxidizing agent were light in colour.

Shape of the bread was also affected by the presence of RYE-WSNSP, xylanase and oxidizing agents. The RYE-WSNSP improved the shape significantly (p<0.05) by making it round with even and smooth surface. Addition of xylanase made the crust deform and overflow at higher concentrations (60 U), to some extent losing volume. Porosity of crumbs showed a significant (p<0.05) increase in the Dallman scale; and makes the pores finer and more uniform with increased addition of WSNSP.

Crumb firmness

Effect of RYE-WSNSP on staling of a wheat flour bread after 2, 24, and 48 hours of storage is shown in Fig. 5. It shows that WSNSP delays staling significantly (p<0.05) during storage as expressed by crumb firmness measured after 48 hours. Addition of xylanase increases the staling measured as crumb firmness it degrades the WSNSP in the dough. Oxidizing agent retards the staling of the breads to a significant (p<0.05) extent.

Stress relaxation measurements carried out, Fig. 6, after three days of storage show that presence of increased amounts of RYE-WSNSP decreases rate at which stress decays as well as level to which stress decays in wheat bread crumbs. Similar effect was observed in breads baked with oxidizing agents. Addition of xylanase seems to produce opposite effect in wheat bread crumbs.

Gelatinization of starch

Gelatinization of pure wheat starch in presence of various amounts of RYE-WSNSP was measured by differential scanning calorimetry. It shows that RYE-WSNSP gave a slight but significant (p<0.05) decrease in the transition enthalpy of sample compared to that of starch.

Transition enthalpy (cal/g starch) increases significantly (p<0.05) due to increased (41.5% to 48.4%) water content in dough. In presence of RYE-WSNSP (0.25%) transition enthalpy decreases from 11 % at moisture content 41.5% to 4% at a moisture content of 45%. However, at a moisture content of 48% enthalpy increases to 9%.

Retrogradation of starch

Presence of RYE-WSNSP in starch at levels between 0.03% and 6% does not have any significant effect on DSC transition enthalpy (cal/g starch) of the samples. Effect of RYE-WSNSP on retrogradation of starch in a wheat dough at different water content shows that, at a water content of 43.4%, there is a decrease (34%) in transition enthalpy due to presence of 0.25% RYE-WSNSP. However,

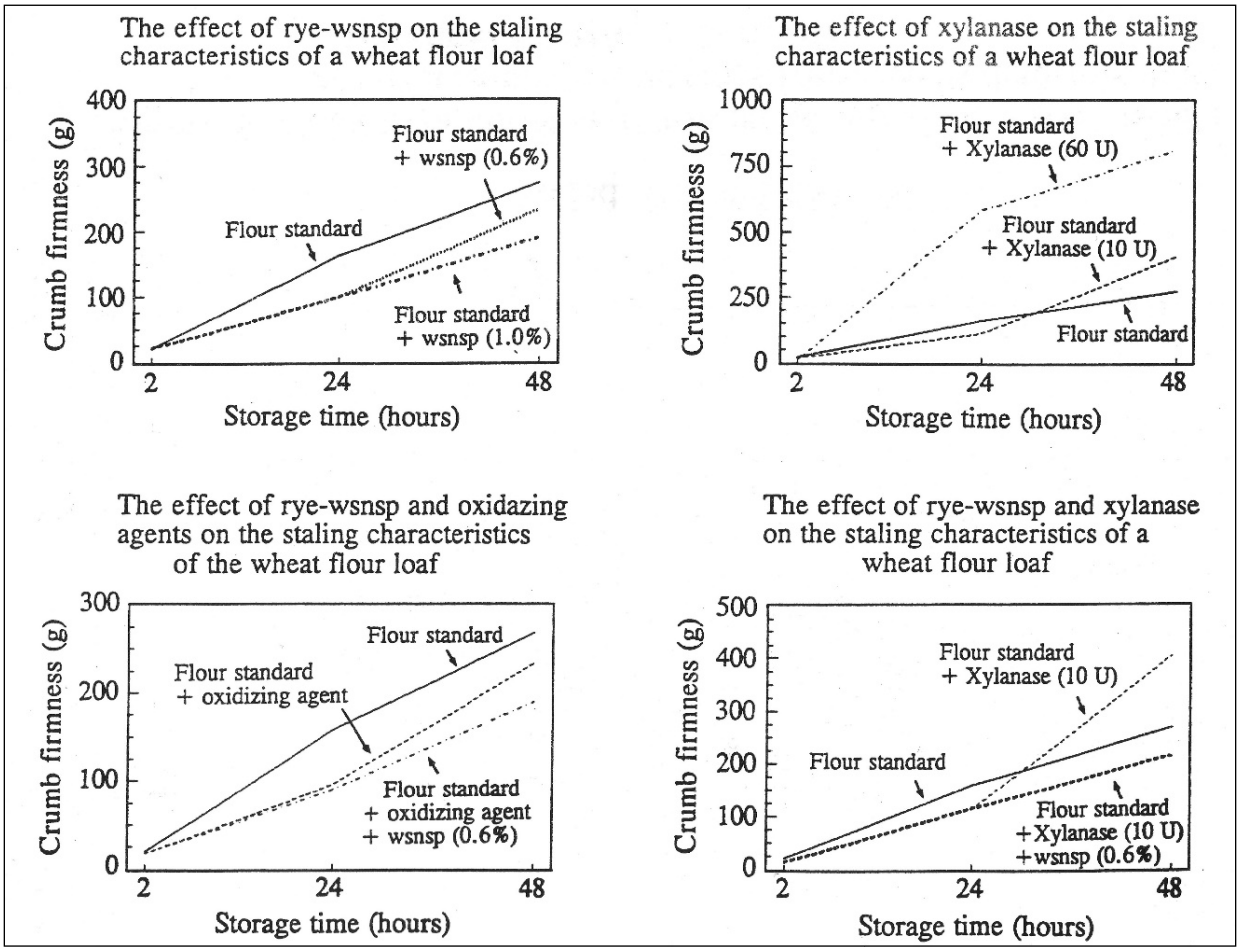


Fig. 5: The effect of water soluble non-starch polysaccharides from rye, xylanase and oxidizing agents on the staling properties of a wheat flour dough bread

at a water content of 45.2% there was an increase in enthalpy by 3%.

DISCUSSION

Viscosity of the starch slurry increased both at peak and at pasting viscosities to a significant ($p<0.05$) level as shown in Fig. 1. This increase in viscosity at the expense of 1% reduction in starch content could be due to the limitation in the availability of water in relation to the amount of starch caused by the RYE-WSNSP. The same effect could be observed in Fig. 2 in the case of the peak viscosity of the wheat flour which shows an increase, while its pasting viscosity after holding the temperature at 50 °C for 30 min did not show any significant increase as in the case of starch as observed in Fig. 1. The endogenous enzymes of the wheat flour may degrade the added water soluble non-starch polysaccharides and thus reduce their effect on water holding. Even though the starch content of the wheat flour was the same as in the previous experiment, the maximum viscosity at the peak as well as on pasting was much higher than that of the pure starch, clearly due to the presence of other components like protein, non-starch polysaccharides and also damaged starch. El-Wakeil *et al.* (1975) have also found a significant increase of amylograph viscosity in the wheat flour on addition of 0.5-1.5% water soluble pentosans. Similar observations of increasing viscosity due to addition of pentosans were also reported by Jelaca and Hlynka (1971).

Jelaca and Hlynka (1971), Michniewicz *et al.* (1991) and Henrik Johansson (1978) have also found increasing farinograph water absorption following addition of WSNSP in the wheat flour dough. The reduction in the farinograph water absorption due to the effect of xylanase, which is a non-starch polysaccharide degrading enzyme, shows clearly the importance of non-starch polysaccharides in the water absorption capacity of a flour. Kühn and

Grosch (1988) studied the effect of soluble and insoluble NSP on the baking properties of the rye flour. They also found that the addition of enzymes which hydrolysed the WSNSP decreased the water binding capacity of the water soluble components of the flour to a significant extent. Dahliwal *et al.* (1988), on the other hand, found no significant correlation between the amount of WSNSP and water absorption capacity of the wheat flour or dough development time. Michniewicz *et al.* (1991) found a marked effect of WSNSP on the dough development time. McCleary *et al.* (1986) showed that the addition of as little as 28 units of xylanase / 10 g wheat flour was sufficient to cause a significant decrease in peak height in the farinograph and the immediate loss of consistency and dough strength was observed on addition of excess of xylanase. The loss of consistency and ability to absorb water could be restored by an addition of non-starch polysaccharides. Thus, it seems that the degree of polymerization of the WSNSP is important in its ability to absorb water. Oxidizing agents are generally used to improve the baking quality of the flours to an optimum beyond which the effect was negative (Yamada and Preston, 1992), as also observed in this study. In the case of WSNSP the oxidizing agents help developing crosslinks (Girhammar and Nair, 1995) and gelformation and thus give a further increase in the water binding capacity of the WSNSP as well as that of the bread. Ability of the WSNSP to respond to oxidizing agents and produce gels is well documented (Neukom and Markwalder, 1978). Hoseney and Faubion (1981), who tried to understand the mechanism of oxidative gelation by water soluble pentosans using oxidizing agents like ascorbic acid, bromate and hydrogen peroxide, found a mechanism involving the addition of protein to ferulic acid which is esterified to the arabinoxylan. The resultant crosslinking was implied to be responsible for the oxidative gelation of wheat flour. Patil *et al*. (1975) have found that the pentosans under the influence of oxidizing agents play an important role in hydrogen bonding between major protein and carbohydrate components of the dough.

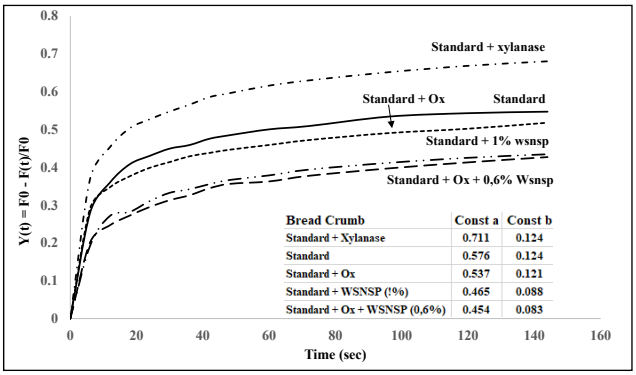
The water absorption and dough consistency are important in relation to mixing, dividing, panning and proofing steps. The dough making process is largely designed to create colloidal conditions that favor a desirable water absorption of the flour, dough consistency and cell structure, which are related to baking quality. For optimum development, the dough must attain balance between viscous and elastic properties. The dough should not be too extensible nor too elastic. During molding, for proper sheeting and during panning, for proper adjustment to the pan shape, the dough should have an appropriate extensibility or viscous flow (Pyler, 1988).

The loaf volume, which is generally regarded as an important quality criterion, is affected by WSNSP, as shown in Fig. 4.

Michniewicz *et al.* 1992 also found an increase in loaf volume on addition of WSNSP to the wheat flour. McCleary *et al.* (1986) found an increase in loaf volume of 12% by adding 16 units of xylanase to 10 g flour. Johansson *et al.* (1971) obtained a significant increase in loaf volume by adding a commercial pentosanase to the flour. The crumb structure was not affected by the addition of pentosanase at this level. However, increased amounts of this enzyme caused a decrease in loaf volume while the crumb became coarse, losing its elasticity, as also shown in this study. McCleary *et al.* (1986), on the other hand, found a reduction in loaf height with a crust which was brittle with a total loss of silkiness in crumb texture with greater air cells than in the control bread. The crumb was yellowish and waxy in colour due to the presence of xylanase. Kühn and Grosch (1988) also found a decrease in loaf volume, but an improvement of crumb structure due to the addition of xylanase to the dough.

The right degree of firmness of the crumb is an important quality of the bread, as it is related to the organoleptic properties through its physico-chemical characteristics. The crumb firmness depends on moisture content, presence of surfactants, salts, sugars, protein, non-starch polysaccharides and the degree of gelatinization of the starch (Inagaki and Seib, 1992). In a bread the crumb firmness increases with duration of storage due to retrogradation of its starch, which is an effect of the recrystallization of amylopectin. However, the rate of increase of firmness is affected by factors other than recrystallization of amylopectin (Persaud *et al.* 1990). In the present study the effect of WSNSP on the crumb firmness was measured by using a penetrometer, and the stress relaxation was analyzed

by determining the level to which the stress decays as well as its rate. The measurement of crumb firmness in a loaf without extensive variability is a difficult problem (Ponte and Faubion, 1985). The results are affected by the porosity, thickness of the slice, depth of compression, presence of crust and location of measurement. This is especially true in the case of small loaves. Nevertheless the development of crumb firmness of the different bread samples during storage could be monitored with sufficient accuracy. It shows that the initial crumb firmness of the loaves was not significantly affected by the addition of WSNSP, oxidizing agents or xylanase at the levels used in the experiment. But the development of firmness after 48 hours storage showed significant ($p<0.05$) differences, especially in the increase of firmness of loaves baked with 60 units of xylanase, decrease of firmness due to the presence of RYE-WSNSP and the effect of oxidizing agents (Fig. 5).



Bread Crumb	Const a	Const b
Standard + Xylanase	0.711	0.124
Standard	0.576	0.124
Standard + Ox	0.537	0.121
Standard + WSNSP (1%)	0.465	0.088
Standard + Ox + WSNSP (0,6%)	0.454	0.083

Fig. 6: The effect of water soluble non-starch polysaccharides, xylanase and oxidizing agents on the rheological, characteristics of the bread crumb

The analysis of the stress relaxation curves (Fig. 6) show the stress decay and the rate of decay in some bread samples. The values *a* **(**the level to which the stress decays during relaxation) and value *b* (the rate at which the stress relaxes) for various samples are not significantly different from each other??. The structure of the crumb at the end of the storage gives way to the probe of the penetrometer, probably due to the hard but thin walls of the pores; in a rheological sense the crumb behaves as if it were a liquid without any elasticity as it is presented in the Fig. 6. It seems that a penetrometer probe with greater diameter and a larger loaf would have given different results. Nevertheless, the measurement of the development of firmness in this experiment seems to be valid for estimating the effect of WSNSP, xylanase and oxidizing agents.

ABBREVIATION

Abbreviation	Full name
DSC	Differential Scanning Calorimetry
WSNSP	Water soluble non starch polysaccharides

CONCLUSION

The RYE-WSNSP was found to influence the dough characteristics and bread properties. This seems to be primarily due to its water binding capacity. The viscoelastic properties of the dough as well as its ability to hold the gas during fermentation and maintain the shape of the loaf are found to be affected by the amount of WSNSP and its properties. The loaf volume, the crumb structure and the colour and taste of the crust are also affected by the WSNSP content of the flour. The enzymesα which degrade the WSNSP, like xylanase, are found to act in the reverse direction. Thus, an optimum amount of WSNSP along with optimum enzyme activity is required to produce an optimum dough and optimum bread. The falling number of the rye flour is affected not only by its α-amylase activity but also very much on the activity of non-starch polysaccharide degrading enzymes. The optimum content of WSNSP and optimum level of activity of the enzymes depend mainly on the properties of the major components like starch, protein, damaged starch and falling number. However, it is possible to modulate the bread properties by adding WSNSP or enzymes which degrade WSNSP as found in the above experiments.

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