Available online at www.sciencedirect.com
ScienceDirect
Carbohydrate Polymers 68 (2007) 658–664
Carbohydrate Polymers
www.elsevier.com/locate/carbpol

Application of xyloglucan to improve the gluten membrane on breadmaking

Tomoko Maeda [a], Hisanobu Yamashita [b], Naofumi Morita [b,*]

[a] *Department of Life and Health Sciences, Hyogo University of Teacher Education, 942-1, Shimokume, Hyogo 673-1494, Japan*
[b] *Laboratory of Food Chemistry, Graduate School of Life and Environmental Sciences, Osaka Prefecture University, 1-1, Gakuen-cho, Sakai, Osaka 599-8531, Japan*

Received 1 March 2006; received in revised form 22 July 2006; accepted 31 July 2006
Available online 18 September 2006

Abstract

Effects of xyloglucan (XG) on the physical properties of dough and bread quality were studied. XG was fractionated to water-soluble (WS-XG) by enzymatic hydrolysis with cellulase, and the four kinds of WS-XG: WS-XG-A (average degree of polymerization; 17), WS-XG-B (32), WS-XG-C (78) and WS-XG-D (223) were obtained. XG without enzymatic hydrolysis was termed water-insoluble xyloglucan (WI-XG). Additions of WS-XG-A (3%), WS-XG-D (1–5%) and WI-XG (3%) increased the stability of the dough and improved the loaf and softness of bread samples. Especially, the WS-XG-D (1–5%) significantly improved the various factors of the final products, such as loaf volume, storage properties and good appearances with fine distribution of small size gas cells, and its addition of low level (1%) still showed improving effects, as compared with other additives. The more viscous gluten matrix could be observed in the mixed doughs with WS-XG-D, than the control sample without XG. WS-XG-D increased the water activity of the dough, and therefore the gluten matrix of dough became strong and uniform. Since the WS-XG-D had the higher degree of polymerization, it might be polymerized during mixing or fermentation, followed by the formation of new insoluble-XG after baking. Appropriate amount of the new WI-XG formed from WS-XG-D was considered to improve the storage properties with higher water holding property than WS-XG-D alone.

Keywords: Wheat flour; Xyloglucan; Breadmaking; Dough property; Bread quality

1. Introduction

Xyloglucan (XG) is a major polysaccharide in the primary cell walls of higher plants and has been reported to have a role of cross-linkage among the microfibril structures of cellulose (Hayashi, 1989). XG polysaccharide has the β-glucan structure of β-1,4-glucose main chains having branched xylose residue at the C-6 position. Tamarind (*Tamarindus indica L*) is one of the leguminous plants and its seed abundantly contains XG, which has branched β-D-galactose residues at the C-2 position of xylose residues. As the XG extracted from the tamarind has similar characteristics in water to those of starch, and stability against heat and acid, it has been extensively used for various processed-foods as a swelling agent or stabilizer in the food industry (Nishinari, Yamatoya, & Shirakawa, 2000; Yamatoya, 1998). In addition, XG is expected to be a functional foodstuff since the XG has physiological activity for animals (Yamatoya, Shirakawa, Kuwano, Suzuki, & Mitamura, 1996, 1997, 2000). Other kinds of polysaccharides, such as gums (Huebner & Wall, 1979; Sharadanant & Khan, 2003a, 2003b), oat β-glucan (Åman, Rimsten, & Andersson, 2004; Miller, Fulcher, Sen, & Arnason, 1995; Miller & Fulcher, 1995) and arabinoxylan (Courtin, Gelders, & Delcour, 2001) have been studied in terms of their physicochemical properties and widely used as improvers for breadmaking. Generally, addition of some polysaccharides as dietary fiber to bread ingredients would increase the nutritive

* Corresponding author. Tel.: +81 72 254 9459; fax: +81 72 254 9921.
E-mail address: morita@biochem.osakafu-u.ac.jp (N. Morita).

0144-8617/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.carbpol.2006.07.034

value, however decrease the qualities of final products giving an excessive viscosity or sticky property. In particular, they reduce the storage stability of bread. But, as celiac disease, a wheat allergy, is becoming quite serious, utilization of these polysaccharides in place of wheat flour to make the gluten-like dough is increasingly important for breadmaking. As arabinoxylan is a main polysaccharide in cell walls of wheat, barley, rye and oat, the effects of arabinoxylan on breadmaking have been reported (Cleemput, Roels, Oort, Grobet, & Delcour, 1993; Jelaca & Hlynka, 1972; Kuhn & Grosch, 1989; Vanhamel, Cleemput, Delcour, Nys, & Darius, 1993; Vinkx, Stevens, Gruppen, Grobet, & Delcour, 1995). In contrast, studies on the use of XG in breadmaking have not been reported. XG has not been found in cell walls of wheat or barley grain, however it appears to be significant components of rice endosperm though levels are small.

Since XG is not hydrolyzed by the human digestive enzymes and its low *viscosity* might not affect our mouth feel (Yamatoya, Shirakawa, & Baba, 2000), the effective application to many processed foods is possible for improvements of nutritional value, taste and texture.

In this study, dough and bread with direct addition of XG to bread ingredients were studied, and the effects on dough and bread qualities were determined.

2. Materials and methods

2.1. Flours and chemicals

The flour used was "Hermes", commercial wheat flour obtained from Okumoto Flour Milling Co., Ltd. (Osaka, Japan). Its protein and ash contents were 11.8% and 0.38%, respectively. XG (Yamatoya et al., 1996) obtained from tamarind seed was provided by Dainippon Pharmaceutical Co., Ltd. (Tokyo, Japan). Cellulase (ONOZUKA 3S) whose origin and activity were *Trichoderma viride* and 3000 U/g (Yakult Pharmaceutical Ind. Co., Ltd., Japan), respectively were used for the hydrolysis of XG. Other chemicals were of analytical grade and used without further purification.

2.2. Fractionation of XG with various molecular weights

Hydrolyzed XG was prepared according to the modified procedures by Yamatoya et al. (1996) and York et al. (1990). Cellulase (24 mg) was dissolved in 4 mL of 20 mM acetic acid buffer (pH 4.0). 2.4 g of XG was suspended to 1.2 L of the same acetic acid buffer (pH 4.0) as the above and mixed with the cellulase solution described, followed by incubation for 4 h at 40 °C. After heating the solution at 100 °C for 10 min, the denatured precipitates were removed through glass filter G-3. The filtrate was concentrated to a total volume of 15 mL under reduced pressure, then the insoluble precipitate was removed by centrifugation (15,000*g*, 30 min, 4 °C). The separated supernatant was filled up to the final volume of 15 mL, and named water-soluble XG (WS-XG). Next, the WS-XG was separated by a Sephadex G-50 column (2.6 cm i.d. × 100 cm) according to molecular sizes. The column was equilibrated with distilled water, and each fraction of 7.5 mL was collected with distilled water at the flow speed of 60 mL/h. Amounts of reducing (RS) and total sugars (TS) in the eluted fractions were determined by Somogyi–Nelson (Nakamura, Takita, & Watanabe, 1995) and phenol-sulfuric acid methods (Dubois, Giles, Hamilton, Pebers, & Smith, 1956) as the glucose content (GC), respectively. The apparent total amount and degree of polymerization of XG were calculated using the formulas GC × 0.87, and TS/RS, respectively. To determine the enzyme protein, each fraction was photometrically measured at 280 nm. The 4 fractions with different molecular weights were obtained by the above fractionation using size-exclusion chromatography, and thus prepared fractions were purified by ion-exchange chromatography as follows. One gram of activated H^+ form of Dowex-50W × 8 (Cation exchanger, strongly acidic type, 100–200 mesh, Dow Chemical Japan, Osaka, Japan) was added to 100 mL of each fraction obtained above, stirred for 30 min, and filtered through a glass filter (G4). After the filtrate was concentrated to a small volume and frozen, the sample was freeze-dried. Thus prepared samples were used as additives for the following experiments. In addition, XG without enzymatic hydrolysis of cellulase was named water-insoluble XG (WI-XG), and also used for the experiments.

2.3. Breadmaking

Breadmaking was conducted by AACC method (10-10B, 2000) using lyophilized WS- and WI-XGs with various molecular weights as described above. Fifty grams of flour, 0.75 g of sodium chloride, 3 g of sucrose, 1 g of dry baker's yeast (Asahi Shokuzai Co., Ltd., Shizuoka, Japan) and appropriate amounts of water were mixed for 15 min using a KN-200 mixer (Taisho Denki Co., Ltd., Osaka, Japan). The optimum amount of water for a flour sample was determined by adding water to the flour in farinograph mixing with or without XGs (1–5% on a flour weight basis) until the consistency of the dough reached 500 B.U. The mixed dough was subjected to the first fermentation for 30 min in a cabinet maintaining a constant temperature of 30 °C and relative humidity of 85%. After fermentation, kneading was repeated 2 more times. Subsequently, the dough was divided into 3 pieces, rounded and moulded using a mechanical moulder SM-230 (Baker's Production Co., Ltd., Osaka, Japan), and placed in baking pans. The dough was subjected to the final proof in the cabinet maintaining a constant temperature of 38 °C and relative humidity of 90%, followed by baking at 200 °C for 12 min. The loaf volume was measured by the rapeseed displacement method.

2.4. Rheological tests

Effects of XG on the mixing properties of dough samples were determined by a Brabender farinograph equipped

with a 50 g stainless steel bowl at a temperature of 30 °C (AACC 54-21 2000). WS- and WI-XGs were directly added to the flour at 1–5% on the flour weight basis, and the mixing was done at 30 °C. Dough properties with WS- and WI-XGs were measured using a uni-axial compression-elongation type rheometer (Model RT-2002D·D, Rheotec Co., Ltd., Tokyo, Japan) as reported previously (Maeda, Maeda, & Morita, 2001). The dough samples were prepared using the same farinograph and the mixed dough samples having suitable water absorption to obtain dough consistency of 500 B.U. were placed in the plastic vessel (2.5 cm i.d. × 2.5 cm). After standing at 30 °C for 10 min, a cylindrical plunger (ϕ 1 cm × H 5 cm, Product No. 9) was used and the penetration force was defined as the force penetrated into the sample with the depth of 2 cm at the plunger speed of 30 cm/min and 30 °C. Firmness of breadcrumbs during storage for 3 days after baking was tested using the same Rheometer as described above (Maeda & Morita, 2003). Bread slices ($2 \times 2 \times 1\,cm^3$) were cut out from the central area of crumbs with a electronic bread cutter. Crumb samples were stored at 25 °C and the firmness was measured during storage for 3 days by the penetration of the plunger of a 1.0 cm diameter. The speed of penetration was 6 cm/min and the depth was controlled at 3 mm. The penetration points per one sample was 5, and 3 samples were used for one treatment. Data obtained from dough and bread properties were processed by the Rheosoft TR-06.

2.5. Image analysis of crumb grains

A computerized image analysis of gas cells of crumb was done using a PIAS LA555 Pias Computer Image Analyzer equipped with a PX-380 CCD camera and a AV-M160S Victor color monitor as reported previously (Maeda, Ohkura, & Morita, 1999). Photocopies of breadcrumbs (3 cm × 3 cm) were placed under the camera and gas cell size information was stored in computer memory. The area of $2 \times 2\,cm^2$ was used for analysis of mean diameter of gas cells. For one treatment, three samples were used.

2.6. Scanning electron microscopy (SEM)

SEM with a Hitachi SEM apparatus was conducted to observe starch granules and gluten matrix in the dough (Maeda et al., 1999; Maeda & Morita, 2000, 2001). The dough samples after mixing, the first fermentation and rounding were used for the observation with the SEM. The frozen dough was fractured into a size of $5 \times 5 \times 3\,mm^3$ with a cutter and then lyophilized using a freeze-drier. A portion of these samples was fixed in osmium tetraoxide over night and then rinsed in sufficient amount of water until the smell of osmium tetraoxide was completely removed. After the fixed dough was frozen at −80 °C, the samples were lyophilized again. These were fixed with silver paste on the sample stage, and then dried under reduced pressure. These prepared samples were coated with Pt–Pd for 4 min and observed by SEM at 10 kV at a magnification of 1500.

2.7. Water activity (a_w) of dough samples containing XG

Fifty grams of wheat flours and 1–5% of XGs were mixed with water whose amount was the same as measured by the Farinograph above. The mixing time was controlled until the central portion of farinogram curve arrived at the 500 B.U. at 30 °C depending on each sample. The dough samples with the consistency of 500 B.U. were packed in an official test case recommended by the company of the apparatus and the values of a_w were measured by Novasina IC-500 AW-LAB (Axair Ltd., Switzerland).

2.8. Change of XG in dough and bread samples on baking processes

2.8.1. Preparation of soluble extracts from dough and bread containing XG

Five grams of dough or bread samples and 100 mL of distilled water were stirred for 30 min at 4 °C, and centrifuged at 18,000*g*, 4 °C for 20 min. The supernatant was stored at 4 °C, and to the remaining precipitate was added 50 mL of distilled water, stirred for 15 min (4 °C), and then centrifuged at 18,000*g*, 4 °C, 20 min again. These separated supernatants were combined and boiled at 100 °C for 15 min to denature the enzyme. The clear supernatant was obtained by centrifugation (18,000*g*, 4 °C), and filled up to 150 mL with distilled water.

2.8.2. Change of structure of XG

Twenty milliliters of thus prepared soluble extracts from dough and bread samples as described in the before section were put on the equilibrated Sephadex G-15 column (2.6 cm i.d. × 100 cm) with distilled water. The fractionation was conducted with distilled water at the flow rate of 20 mL/h and effluent of 7.5 mL was collected. The apparent total amount and polymerization degree of XG were determined from the values of TS, RS and GC measured as glucose unit by the same methods as described above. In addition, the ratios of recovery of WS-XG extracted from mixed, fermented and baked samples were calculated from the TS amounts in original flours and dough or bread samples.

2.9. Statistical analysis

All tests were conducted at least three times for each sample and the data were independently analyzed by analysis of variance (ANOVA) and then performed using Duncan's multiple-range test to compare the means. Results were defined by SPSS (Version 11.0, SPSS Inc., Chicago, USA) at $P < .05$.

3. Results and discussion

3.1. Fractionation of XG

The elution pattern of WS-XG using Sephadex G-50 is shown in Fig. 1. Since the absorbance of eluted fraction at 280 nm showed peak value at the fraction number (FN) of 56,

most of enzymes were considered to be removed by the present fractionation. As shown in Fig. 1, the average degrees of polymerization of WS-XG in eluted fractions for FNs 42–54 (WS-XG-A), 35–41 (WS-XG-B), 26–34 (WS-XG-C) and 16–25 (WS-XG-D) were 17, 32, 78 and 223 and their recovered amounts of freeze-dried samples were 239, 365, 555 and 174 mg, respectively. These dried samples were added to the dough or bread ingredients for the following experiments.

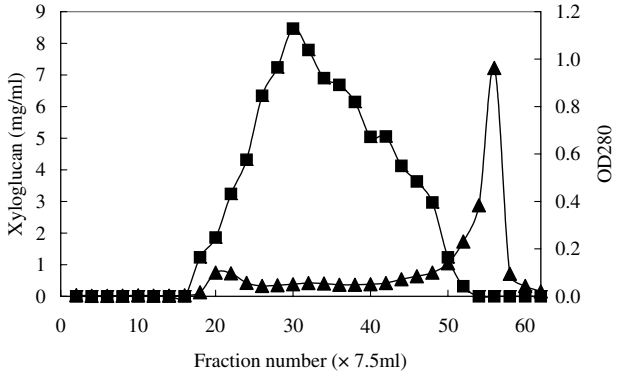

Fig. 1. Elution profile of xyloglucan on Sephadex G-50 column chromatography. –■–, xyloglucan; –▲–, OD_{280}.

3.2. Effect of WG on bread qualities

The WS-XG-A, -B, -C, -D and WI-XG significantly improved the specific volume with the additions of 2–3%, 1–2%, 1–3%, 1–5% and 2–3%, respectively and increased the loaf volume significantly, as compared with the control bread (Fig. 2). Storage properties of breadcrumbs were also significantly improved by the addition of XGs (Fig. 3). Particularly as to the results after storage for 3 days, the breadcrumbs with WS-XG-A (3–5%), -B (1–3%), -C (3%), -D (1–5%) and WI-XG (2–5%) were significantly softened more than that of the control sample. Therefore, bread qualities as shown in Figs. 2 and 3 suggested that additions of WS-XG-A (3%), -B (1%), -C (3%), -D (1–5%) and WI-XG (2–3%) especially improved the loaf and softness of bread samples.

3.3. Rheological results

3.3.1. Farinograph results

To determine the effects of XGs on the dough properties, WS-XG-A and -D that distinctly improved the bread qualities as shown in Figs. 2 and 3, and WI-XG were used for the following tests. The WS-XGs decreased the water

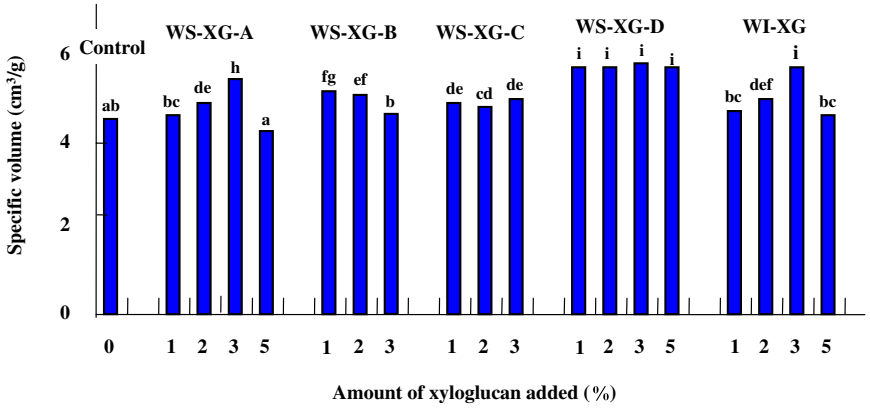

Fig. 2. Specific volume of bread containing various amounts of xyloglucan. WS-XG, water-soluble xyloglucan; WI-XG, water-insoluble xyloglucan. Degree of polymerization: WS-XG-A, 17; WS-XG-B, 32; WS-XG-C, 78; WS-XG-D, 223; WI-XG, >500. Values followed by the same letter in the same column are not significantly different at $P < .05$ using Duncan's multiple test.

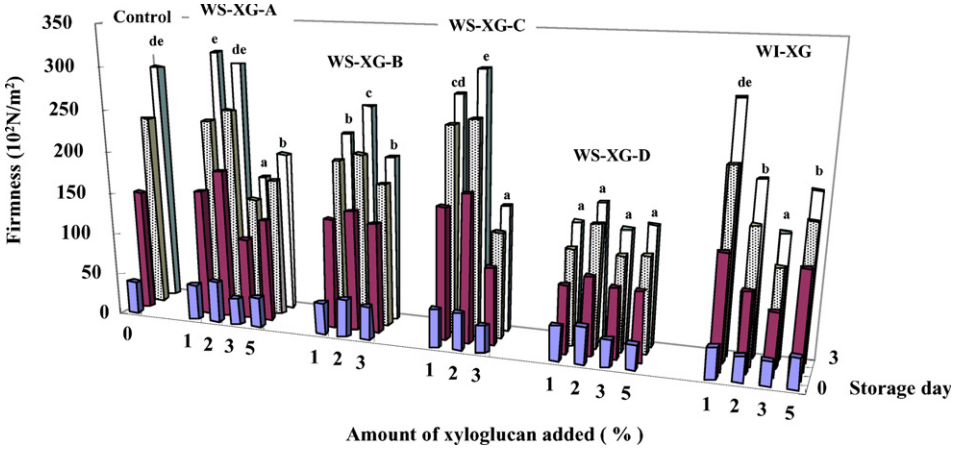

Fig. 3. Staleness of breadcrumbs containing various amounts of xyloglucan. Abbreviations are the same as in Fig. 2. Values followed by the same letter in the same column are not significantly different at $P < .05$ using Duncan's multiple test.

absorption without relation to the molecular weight, whereas the WI-XG increased (Table 1). This tendency might be due to the higher water-holding properties of WI-XG than those of WS-XG (Hayashi, Takeda, Ogawa, & Mituishi, 1994). Dough stability evaluated from the stability time, weakness and valorimeter values was significantly accelerated by additions of WS-XG-A (2–5%), WS-XG-D (1–3%) and WI-XG (1–2%). For the case of WI-XG, the 3% level addition to make the good baking qualities as shown in Figs. 2 and 3 could not show significant improvement in the present results, but the dough stability was more than that of the control. Therefore, from synthetic results of dough and bread qualities, the suitable amounts (1% or 3%) and excessive additions (5%) of WS-XG-A or WI-XG were done in the following experiments.

Table 2
Firmness of wheat dough containing various amounts of xyloglucan

Sample	Percent addition	Firmness[A] (*N*)
Control	0	157a
WS-XG-A	3	139a
	5	141a
WS-XG-D	1	145a
WI-XG	3	188b
	5	188b

Abbreviations are the same as in Table 1. Values followed by the same letter in the same column are not significantly different at $P < .05$ using Duncan's multiple test.

[A] Penetration force into the dough sample was controlled with the depth of 2 cm at the plunger speed of 30 cm/min.

3.3.2. Firmness of mixed doughs

The WS-XG-A and -D additions decreased the firmness of the mixed dough samples, but there were no significant differences in the values between the control and theses samples. Therefore, WS-XG-A and -D did not affect the firmness of doughs after mixing. In contrast, WI-XG significantly increased the value at the addition of 3% or 5% level, as compared with the control (Table 2). As a result, the doughs added with W1-XG became quite firm, therefore the handling properties of doughs were considered to be difficult as compared with the control.

3.4. SEM results

The images of dough samples with various XGs are shown in Fig. 4. The doughs with 3% additions of WS-XG-A, WS-XG-D and WI-XG exhibited the thick gluten matrix structure. These images were considered to produce improving bread qualities as shown in Figs. 2 and 3 Weak or thin gluten matrices were broken by extension during baking (Gan et al., 1990; Hoseney, 1984). However, the gluten matrix of the dough was improved by additions of XGs, and especially the matrices of doughs with WS-XG-A or -D were more viscous than that with WI-XG. The dough with WI-XG addition showed larger value on the firmness in Table 2, and therefore the dough with WI-XG addition had tight structure as compared to those with WS-XG-A or -D additions as observed by SEM.

3.5. Water activity of dough samples containing XG

Effects of XG additions on the water activity of the doughs are shown in Fig. 5 WS-XG-A addition (3%) to the wheat flour slightly increased the water activity of the dough, and a significant increase in the value was obtained from the dough sample with 5% addition, as compared with the control. In contrast, WI-XG decreased the water activity, but there were no significant differences in the value between the control and WI-XG added sample. The WS-XG-D (1% addition) significantly increased the water activity of the dough. Since the amount of water added to the WS-XG-D sample was slightly lower than that to the

Table 1
Farinograph data of wheat dough containing various amounts of xyloglucan

Xyloglucan	Percent of addition	Water absorption (%)	Development time (min)	Stability time (min)	Weakness (B.U.)	V.V.
Control	0	64.6	16.7^{ab}	15.3^{a}	39^{e}	93^{b}
WS-XG-A	1	63.8	20.5^{bc}	16.5^{a}	35^{de}	96^{bed}
	2	62.8	21.9^{bcde}	18.0^{ab}	38^{e}	97^{cde}
	3	62.8	26.5^{de}	29.3^{d}	22^{ab}	100^{ef}
	5	61.8	42.0^{f}	38.0^{e}	43^{e}	102^{ef}
WS-XG-D	1	64.0	21.8^{bcde}	27.0^{cd}	23^{bc}	97^{cde}
	2	63.2	27.0^{e}	29.0^{d}	21^{ab}	100^{ef}
	3	63.2	25.0^{cde}	26.0^{cd}	30^{d}	97^{cde}
	5	63.0	20.5^{bc}	14.9^{a}	50^{f}	94^{bc}
WI-XG	1	66.4	13.0^{a}	20.0^{ab}	15^{a}	88^{a}
	2	72.0	25.0^{cde}	22.5^{bc}	35^{de}	99^{def}
	3	78.2	18.3^{ab}	16.3^{a}	35^{de}	94^{bc}
	5	87.0	21.0^{bcd}	14.5^{a}	50^{f}	96^{bcd}

WS-XG, water-soluble xyloglucan; WI-XG, water-insoluble xyloglucan; Degree of polymerizations is 17 (WS-XG-A), 223 (WS-XG-D) and more than 500 (WI-XG), respectively. V.V. and B.U. are valorimeter value and brabender unit, respectively. Values followed by the same letter in the same column are not significantly different at $P < .05$ using Duncan's multiple test.

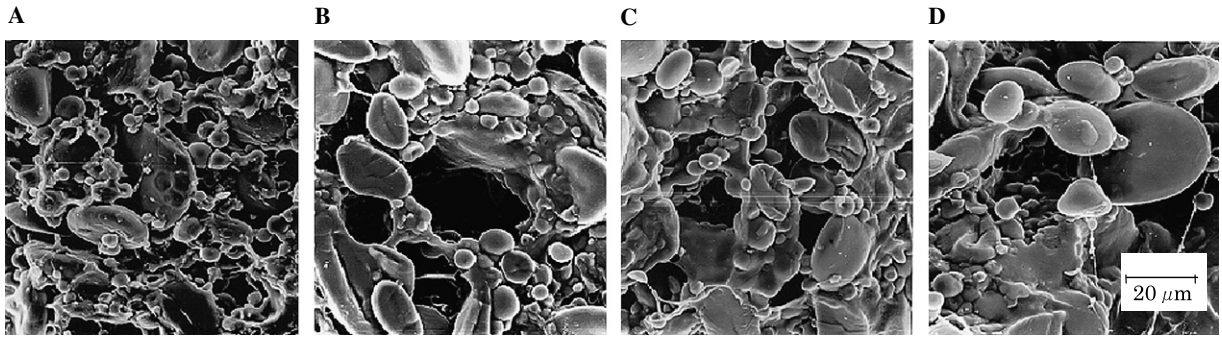

Fig. 4. SEM images of wheat dough containing various amounts of xyloglucan. A, Control; B, +3% WS-XG-A; C, +3% WS-XG-D; D, +3% WI-XG. Abbreviations are the same as in Fig. 2.

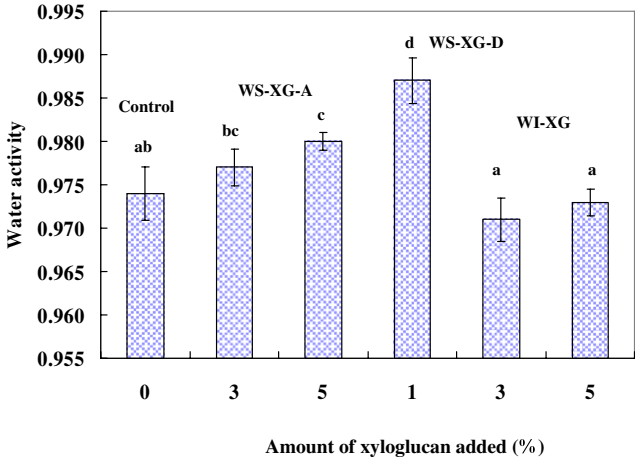

Fig. 5. Water activities of wheat dough containing various amounts of xyloglucan. Abbreviations are the same as in Fig. 2. Values followed by the same letter in the same column are not significantly different at $P < .05$ using Duncan's multiple test.

control in the farinograph mixing as shown in Table 1, the amount of free water in the WS-XG-D-added dough distinctly increased, resulting in the formation of extensible gluten structure to produce breads of sufficient qualities.

3.6. Gas cell distribution of breadcrumbs

Effects of these additives on the gas cell distribution in breadcrumbs were determined by the image analysis as shown in Table 3. The additions of WS-XG-A, -D and WI-XG decreased the gas cell size in inverse proportion to increasing numbers of gas cells, and the distribution of crumb grains was improved by the additions. Especially, WS-XG-D made the breadcrumbs with large numbers of fine crumb grains with the minimum amount of 1.0% among all additives. From these baking results, WS-XG-D (1–5%) significantly improved the various factors of final products, such as loaf volume, storage properties and the final appearance with fine distribution of small size gas cells, and its addition with small level (1%) still showed the improving effects, as compared with other additions.

Table 3
Effects of various amounts of xyloglucan on the size of gas cells in breadcrumbs

Xyloglucan	Cell size (mm)	Number of cells	Total cell size (mm)
0 (Control)	0.647	219	142
WS-XG-A (3%)	0.604	243	147
WS-XG-A (5%)	0.613	249	153
WS-XG-D (1%)	0.565	281	159
WS-XG-D (5%)	0.577	277	160
WI-XG (3%)	0.589	254	150
WI-XG (5%)	0.635	261	166

Abbreviations are the same as in Table 1.

3.7. Characteristics of XG on the various baking processes

The average degrees of polymerization of WS-XG-A and -D stepwisely decreased after the proofing process, but the value increased after baking (data not shown). Recovery of WS-XG obtained from the sample containing WS-XG-A was not changed during mixing, fermentation and baking. On the other hand, the recovery from WS-XG-D was the same after mixing and fermentation, but the value distinctly decreased after baking (ca. 10%). WS-XG-A with low degree of polymerization was considered to be soluble in the bread sample after baking. In contrast, WS-XG-D had the higher degree of polymerization, during mixing or fermentation, and it might be polymerized, followed by the formation of new insoluble-XG after baking, and lowering the recovery. These phenomena have been reported for the arabinoxylan as one of polysaccharide in the wheat grain (Courtin et al., 2001).

From these results, additions of WS-XG-A, -D and WI-XG at suitable levels to wheat flour increased the stability of the dough and improved the loaf volume and softness of breads during storage. Especially, WS-XG with longer polymerization (WS-XG-D) could improve the dough and bread qualities, though only at low level (1%). The improvement of WS-XG-D was related to the larger free water amount in the dough than that in other samples, and the enough amount of free water accelerated to make better gluten structure with the viscous or extensible properties. In addition, the sufficient fluidity of the dough accelerated to interact with all components in the dough. Namely, the presence of much water would improve the gelatinization of starch and strengthen the membrane of breadcrumbs during baking. As a result, after

taking out from baking oven, the contraction of bread caused by the lowering of pressure in the gas cell could be suppressed (Matsumoto & Tanaka, 1997). In addition, the appropriate amount of new WI-XG formed from WS-XG-D during baking increased the holding ability of water and retarded staleness of breadcrumbs during storage.

4. Conclusion

Effects of xyloglucan (XG) on the breadmaking were studied and the additions of WS-XG-A (3%), WS-XG-D (1–5%) and WI-XG (3%) to wheat flour improved the bread qualities. The more *viscous* gluten matrix could be observed in the mixed doughs with WS-XG-A and -D, than that with WI-XG. Especially, the low level addition (1%) of WS-XG-D still showed more improving effects, as compared with other additions. The water activity of dough containing WS-XG-D (1% addition) significantly increased, and therefore the enough amount of free water in the WS-XG-D-added sample resulted in the formation of extensible gluten structure to produce the sufficient bread qualities. In addition, the WS-XG-D with higher degree of polymerization (223) might be polymerized during mixing or fermentation, and the new WI-XG formed from WS-XG-D after baking was considered to improve the softness of breadcrumbs during storage with the higher water holding property than the WS-XG-D alone.

Acknowledgments

The authors wish to thank the Okumoto Flour Milling Co., Ltd. (Osaka, Japan) for supplying wheat flour; and the J.T. Foods Co., Ltd. (Shizuoka, Japan) for providing dry yeast, and the Dainippon Pharmaceutical Co., Ltd. (Tokyo, Japan) for providing tamarind XG.

References

American Association of Cereal Chemists. (2000). Approved methods of the AACC (10th ed.). Methods 10-10B, 54-21. St. Paul, MN: The Association.

Åman, P., Rimsten, L., & Andersson, R. (2004). Molecular weight distribution of β-glucan in oat-based foods. *Cereal Chemistry, 81*, 356–360.

Cleemput, G., Roels, S. P., Oort, M. V., Grobet, P. J., & Delcour, J. A. (1993). Heterogeneity in the structure of water-soluble arabinoxylans in European wheat flours of various bread-making quality. *Cereal Chemistry, 70*, 324–329.

Courtin, C. M., Gelders, G. G., & Delcour, J. A. (2001). Use of two endoxylanases with different substrate selectivity for understanding arabinoxylan functionality in wheat flour breadmaking. *Cereal Chemistry, 78*, 564–571.

Dubois, M., Giles, K. A., Hamilton, J. K., Pebers, P. A., & Smith, F. (1956). Colorimetric method for determination of sugar and related substances. *Analytical Chemistry, 28*, 350–356.

Gan, Z., Angold, R. E., Williams, M. R., Galliard, T., Ellis, P. R., & Vaughan, J. G. (1990). The microstructure and gas retention of bread dough. *Journal Cereal Science, 12*, 15–24.

Hayashi, T. (1989). Xyloglucans in the primary cell wall. *Annual Review of Plant Physiology and Plant Molecular Biology, 40*, 139–168.

Hayashi, T., Takeda, T., Ogawa, K., & Mituishi, Y. (1994). Effects of the degree of polymerization on the binding of xyloglucans to cellulose. *Plant and Cell Physiology, 35*, 893–899.

Hoseney, R. C. (1984). Gas retention in bread doughs. *Cereal Foods World, 29*, 305–308.

Huebner, F. R., & Wall, J. S. (1979). Polysaccharide interaction with wheat proteins and flour doughs. *Cereal Chemistry, 56*, 68–72.

Jelaca, S. L., & Hlynka, I. (1972). Effect of wheat flour pentosans in dough, gluten, and bread. *Cereal Chemistry, 49*, 489–495.

Kuhn, M. C., & Grosch, W. (1989). Baking functionality of reconstituted rye flours having different nonstarchy polysaccharide and starch contents. *Cereal Chemistry, 66*, 149–154.

Maeda, T., Maeda, N., & Morita, N. (2001). Effect of polished-graded hard-type wheat flour substitution for commonly milled hard-type wheat flour on the properties of dough and bread. *Journal Applied Glycoscience, 48*, 27–36.

Maeda, T., & Morita, N. (2000). Effect of polished-graded flour substitution to commonly milled wheat flour on the properties of dough and bread. *Journal Applied Glycoscience, 47*, 1–12.

Maeda, T., & Morita, N. (2001). Effect of quality of hard-type polished-graded flour on breadmaking. *Journal Applied Glycoscience, 48*, 63–70.

Maeda, T., & Morita, N. (2003). Flour quality and pentosan prepared by polishing wheat grain on breadmaking. *Food Research International, 36*, 603–610.

Maeda, T., Ohkura, M., & Morita, N. (1999). Characterization of wheat flour graded by polishing and its application to breadmaking. *Journal Applied Glycoscience, 46*, 413–422.

Matsumoto, H., & Tanaka, Y. (1997). *Science of breadmaking process.* Tokyo, Japan: Kourin Publishing Co. pp. 189–224 (in Japanese).

Miller, S. S., & Fulcher, R. G. (1995). Oat endosperm cell walls: II. Hot-water solubilization and enzymatic digestion of the wall. *Cereal Chemistry, 72*, 428–432.

Miller, S. S., Fulcher, R. G., Sen, A., & Arnason, J. T. (1995). Oat endosperm cell walls: I. Isolation, composition, and comparison with other tissues. *Cereal Chemistry, 72*, 421–427.

Nakamura, N., Takita, S., & Watanabe, T. (1995). *Basic experimental textbook for food science*. Tokyo, Japan: Sankyo Publishing Co. p. 110 (in Japanese).

Nishinari, K., Yamatoya, K., & Shirakawa, M. (2000). In G. O. Phillips & P. A. Williams (Eds.), *Handbook of Hydrocolloids* (pp. 247–267). Cambridge: Woodhead Publishing Ltd.

Sharadanant, R., & Khan, K. (2003a). Effect of hydrophilic gums on frozen dough. I. Dough quality. *Cereal Chemistry, 80*, 764–772.

Sharadanant, R., & Khan, K. (2003b). Effect of hydrophilic gums on quality of frozen dough: II. Bread characteristics. *Cereal Chemistry, 80*, 773–780.

Vanhamel, S., Cleemput, G., Delcour, J. A., Nys, M., & Darius, P. L. (1993). Physicochemical and functional properties of rye nonstarch polysaccharides. IV. The effect of high molecular weight water-soluble pentosans on wheat-bread quality in a straight-dough procedure. *Cereal Chemistry, 70*, 306–311.

Vinkx, C. J. A., Stevens, I., Gruppen, H., Grobet, P. J., & Delcour, J. A. (1995). Physicochemical and functional properties of rye nonstarch polysaccharides. VI. Variability in the structure of water-unextractable arabinoxylans. *Cereal Chemistry, 72*, 411–418.

Yamatoya, K. (1998). In A. Tanimura (Ed.), *Handbook of physiological functional materials in plant origin* (pp. 307–311). Tokyo, Japan: Science Forum.

Yamatoya, K., Shirakawa, M., Kuwano, K., Suzuki, J., & Mitamura, T. (1996). Effects of hydrolyzed xyloglucan on lipid metabolism in rats. *Food Hydrocolloids, 10*, 369–372.

Yamatoya, K., Shirakawa, M., Kuwano, K., Suzuki, J., & Baba, O. (1997). Hypolipidemic effects of hydrolyzed xyloglucan. *Macromolecular Symposia, 120*, 231–236.

Yamatoya, K., Shirakawa, M., & Baba, O. (2000). Effect of xyloglucan on lipid metabolism. *Hydrocolloids–part 2*, 405–410.

York, W. S., Halbeek, H. V., Darvill, A. G., & Albersheim, P. (1990). Structural analysis of xyloglucan oligosaccharides by 1H-NMR spectroscopy and fast-atom-bombardment mass spectrometry. *Carbohydrate Research, 200*, 9–31.