Structural Variation and Levels of Water-Extractable Arabinogalactan-Peptide in European Wheat Flours

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ABSTRACT

Cereal Chem. 75(6):815–819

Water-extractable arabinogalactan-peptides (WE-AGP) were isolated from flour of eight different wheat cultivars (harvest year 1996). Little structural variation in WE-AGP of flour of the different wheat cultivars was observed. The arabinose-to-galactose (A/G) ratio of WE-AGP varied between 0.66 and 0.73. Methylation analysis showed that the proportion of β-1,3-galactopyranosyl residues is almost equal for the different WE-AGP samples (10.2–11.1%). More variation was observed for the proportion of the β-1,6-galactopyranosyl residues (9.4–13.0%) and β-1,3,6-galactopyranosyl residues (76.0–80.1%). The ^{1}H-nuclear magnetic resonance spectra (D_2O, 85°C, 300 MHz) were comparable, and gel permeation analysis consistently yielded a narrow peak with an apparent molecular weight between 5.0×10^4 and 10.0×10^4. Interpretation of the results was facilitated by α-L-arabinofuranosidase debranching of WE-AGP. For flour samples of 18 wheat cultivars (10 from 1994 harvest, eight from 1996 harvest), the variation in percentage of water-extractable arabinoxylan (WE-AX) (0.31–0.78% of dry matter) was much larger than the variation in percentage of water-extractable arabinogalactan (WE-AG) (0.24–0.33%). The ratio of WE-AX to WE-AG for flour samples of different wheat cultivars varied between 1.00 and 2.44.

Water-extractable nonstarch polysaccharides (NSP) of wheat consist of water-extractable arabinoxylan (WE-AX) and water-extractable arabinogalactan-peptide (WE-AGP). They can be fractionated by using ammonium sulfate precipitation (Fincher and Stone 1974). Other techniques are diethylaminoethylcellulose adsorption chromatography (Kündig et al 1961, Medcalf et al 1968, Lineback et al 1977, MacArthur and D'Appolonia 1980, Westerlund et al 1990) or ethanol precipitation (Suckow et al 1983, Cleemput et al 1993).

Previous research (Medcalf et al 1968, D'Appolonia and MacArthur 1975, Lineback et al 1977, Ciacco and D'Appolonia 1982, Izydorczyk et al 1991, Cleemput et al 1993) has shown structural variation in the WE-AX of different wheat cultivars, and much literature deals with their role in breadmaking (D'Appolonia 1971, Hoseney 1984, Meuser and Suckow 1986, Roels et al 1993).

Fincher and Stone (1974) found that the major part of the WE-AGP of wheat flour consists of a polysaccharide (92%) with an arabinose-to-galactose (A/G) ratio of 0.67. Water-extractable arabinogalactan (WE-AG) is covalently associated with a hydroxyproline-rich peptide (8%) (Fincher et al 1974). Methylation studies and optical rotation data suggested that the galactan chain is linked β-D-1,3 or β-D-1,6 (Neukom and Markwalder 1975). According to McNamara and Stone (1981) and Strahm et al (1981), a 4-hydroxyproline-galactoside linkage connects the arabinogalactan side chains to the peptide of a WE-AGP. However, less research was performed to study the structural variation in WE-AGP of flour from different wheat cultivars. Although it has recently been reported that little structural differences exist in WE-AGP in the different milling fractions of two wheat cultivars (Loosveld et al 1997), less insight into the structural characteristics and heterogeneity of isolated and purified WE-AGP of flour of different wheat cultivars is available. Futhermore, although from monosaccharide, protein, and gel filtration analysis, Izydorczyk et al (1991) concluded that little variation exists in WE-AGP structures between flour of eight Canadian wheat cultivars, a high variation in content and structure of WE-AGP from 20 white flour samples was noted (Andersson et al 1994).

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Publication no. C-1998-1006-03R.
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The purpose of this study was to investigate the structural variation in the WE-AGP of different wheat flour cultivars, using analysis of monosaccharide constituents, protein contents, gel permeation, methylation analysis, and ^{1}H-nuclear magnetic resonance (NMR) spectroscopy. In this work, NSP were fractionated into WE-AX and WE-AGP by ethanol precipitation. Percentages of WE-AX and WE-AG in wheat flours were calculated. Differences in total water-extractable NSP levels of flour from different cultivars are given in the literature (Hashimoto et al 1987, Shogren et al 1987, Izydorczyk et al 1991, Cleemput et al 1993), but percentages of the two components of water-extractable NSP (WE-AX and WE-AGP) are rarely listed separately. For 20 white flour samples, Andersson et al (1994) calculated percentages of WE-AX at 0.36–0.78% of dry matter and percentages of WE-AG at 0.15–0.21%.

MATERIALS AND METHODS

Flour Milling

Eighteen European wheat cultivars (Skirlou, Torfrida, Gaspard, Tribun, Estica, Génésis, Hereward, Ritmo, Soissons and Camp Remy, harvest 1994, and Skirlou, Ritmo, Versailles, Soissons, Clan, Torfrida, Estica and Biscot, harvest 1996) (AVEVE, Landen, Belgium) were conditioned to a final moisture content of 14.5%. The samples were milled on a MLU-202 laboratory mill (Bühler, Uzwil, Switzerland) according to Approved Method 26-31 (AACC 1995). The milling yields varied between 70 and 74%.

Ash (method 08-01, AACC 1995) varied between 0.51 and 0.65% (dry basis) and protein content (Jones 1991) varied between 10.9 and 13.6% (dry basis), averaging 0.52 and 10.1%, respectively.

Isolation and Purification of WE-AX, WE-AGP, and WE-GP

The isolation was done as described by Loosveld et al (1997). Flour refluxed with 80% ethanol (Fincher and Stone 1974) was extracted with deionized water. The extracts were heated at 90°C to precipitate soluble protein; starch was removed by hydrolysis with α-amylase and amyloglucosidase and dialysis. WE-AGP and WE-AX were precipitated by stepwise addition of ethanol (95%) to a final concentration of 80%. Precipitates obtained were dissolved by shaking in 300 mL of deionized water for 60 min at room temperature. Ethanol was added to a final concentration of 65% (v/v) to separate WE-AX and WE-AGP. WE-AX was then precipitated and recovered according to Cleemput et al (1993), while WE-AGP was recovered from the supernatants (vacuum rotary evaporation, 40°C).

WE-AGP (300 mg) isolated from the flour of the wheat cultivar Versailles was dissolved in 20.0 mL of 25 m*M* sodium acetate

buffer (pH 4.5). To the solution, 5 µL of *Aspergillus niger* α-L-arabinofuranosidase (Megazyme, Bray, Ireland) was added. After incubation at 40°C for 12 hr, the solution was heated at 100°C for 15 min to inactivate the enzyme. After dialysis (48 hr, 4°C) and centrifugation (10,000 × *g*, 15 min, 4°C), the solution was lyophilized. The fraction obtained was called a water-extractable galactan-peptide (WE-GP).

Estimation of WE-AX and WE-AG in Wheat Flours

The monosaccharide composition of flour extracts was estimated by gas-liquid chromatography of alditol acetates following hydrolysis and reduction with sodium borohydride. Flour (2.00 g) was shaken (2 hr, 30°C) in water (1:10 w/v) and centrifuged (3,000 × *g*, 15 min). Supernatants were hydrolyzed for 60 min in 4.0*M* trifluoroacetic acid (TFA) at 110°C (Cleemput et al 1993). For the estimation of the monosaccharide composition of isolated WE-AX and WE-AGP, samples (15 mg) were directly hydrolyzed in 2.0*M* TFA for 60 min at 110°C. Alditol acetates (Englyst and Cummings 1984) were separated on an SP-2380 column (30 m, 0.32 mm i.d., 0.2-µm film thickness) (Supelco, Belleforte, PA) in a 9011 chromatograph (Chrompack, Middelburg, The Netherlands) equipped with a flame-ionization detector. Separation was at 225°C, with injection and detection temperatures of 275°C, and β-D-allose (A6390, Sigma Chemicals Co., St. Louis, MO) as internal standard.

The percentages of WE-AX and WE-AG in the different wheat flours were calculated as outlined previously (Loosveld et al 1997).

Protein Estimation

Protein contents of isolated WE-AX and WE-AGP were determined by the method of Lowry et al (1951) with bovine serum albumin as standard.

Methylation Analysis

The method of Hakomori (1964), modified by Sandford and Conrad (1966), was used for methylation analysis. After methylation, the samples were dialyzed against water, dried by evaporation, hydrolyzed (2.0*M* TFA, 1 hr, 121°C), and converted to alditol acetates (Gruppen et al 1992). Identification of the compounds was confirmed by gas chromatography-mass spectroscopy using a CP Sil 19 CB capillary column (25 m, 0.25-mm i.d., 0.2-µm film thickness) (Chrompack) in an HP 6890 gas chromatograph coupled to an HP 5973 mass-selective detector and using an HP Chem Station (Hewlett-Packard, Amstelveen, The Netherlands). The temperature program was 160–185°C at 0.5°C/min, 185–230°C at 10°C/min, and 230°C for 5.5 min.

^{1}H-Nuclear Magnetic Resonance Spectroscopy

^{1}H-NMR spectra were recorded on a 300-MHz Fourier transform-spectrometer (Bruker, Karlsruhe, Germany) at 85°C. Samples were dissolved in D_2O (Acros Chimica, Geel, Belgium), stirred for 120 min, and lyophilized. This step was repeated, and the resulting deuterium-exchanged dry material was finally dissolved in D_2O (1.0 mg/mL). Pulse repetition time was 2 sec; in a typical experiment, the number of scans was ≈7,000.

Gel-Permeation Chromatography

Aliquots of the isolated WE-AGP of the different wheat flour cultivars were solubilized in 0.3% NaCl (1.0 mg/mL) and centrifuged (10,000 × *g*; 10 min). Solutions obtained (100 µL) were separated on a Jordi aqueous gel-permeation chromatograph (Alltech, Bellingham, MA) glucose-bound column (100 nm, 250 × 10 mm) by elution with 0.3% NaCl (1.5 mL/min at room temperature). The eluate was monitored by using a R-400 refractive index detector (Waters Associates, Milford, MA). Molecular weight markers were Shodex standard P-82 pullulans (1.0 mg/mL) (Showa Denko K.K., Tokyo, Japan) with molecular weights of 78.8×10^4, 40.4×10^4, 21.2×10^4, 11.2×10^4, 4.73×10^4, 2.28×10^4, 1.18×10^4, and 0.59×10^4.

RESULTS AND DISCUSSION

Structural Variation of WE-AGP

Isolation and purification of WE-AGP. Analysis of the monosaccharide composition of WE-AGP from the flour of eight 1996 harvest wheat cultivars (Table I) showed that, apart from arabinose and galactose, only traces of xylose, mannose, and glucose were present. Of the samples, 61.1–74.5% were pure WE-AG. The isolated WE-AGP samples were contaminated with only traces of WE-AX (2.7–3.7%), except for the wheat cultivar Estica (7.7% WE-AX). For the calculation of the A/G ratio (w/w), the presence of traces of WE-AX was taken into account. The result is therefore referred to as the corrected arabinose-to-galactose ratio (A/G_{corr}). There is little variation in the A/G_{corr} ratios (w/w) (Table I), which range from 0.66 to 0.73 among the different wheat flour cultivars. Izydorczyk et al (1991) found similar A/G ratios for eight different Canadian wheat cultivars, except for one cultivar with a less-branched WE-AGP (0.66–0.75). A protein content of 10.3–12.7% was found in the WE-AGP fractions (Table I). WE-AX were also isolated from flours of different cultivars (monosaccharide composition not shown). The arabinose-to-xylose ratios (A/X, w/w) (0.47–0.55) are given in Table II.

The monosaccharide composition of the WE-GP (Versailles) is shown in Table I. The main component is galactose (70.7%). Part of the arabinose (7.2%) is not hydrolyzed.

Methylation analysis. From the methylation analysis results, relative proportions of the different galactose linkages were deduced (Table III). Removal of the arabinose residues resulted in a large increase in the relative proportion of the β-1,6-galactopyranosyl residues and an decrease in the β-1,3,6-galactopyranosyl residues. This showed that, in WE-AGP, most of the arabinofuran-

TABLE I
Monosaccharide Composition[a] (wt proportion, %), Protein Content (%), and Arabinose-to-Galactose Ratio (w/w) of the Water-Extractable Arabinogalactan-Peptide (WE-AGP) Isolated from Flours of Eight Wheat Cultivars (Harvest 1996) and Monosaccharide Composition of the Water-Extractable Galactan-Peptide (WE-GP) of Versailles

	Flour	Ara	Gal	Xyl	Man	Glc	Protein	AG[b]	AX[c]	A/G_{corr}[d]
WE-AGP	Skirlou	34.5	48.0	2.8	1.4	2.1	10.3	72.2	3.7	0.69
	Ritmo	33.4	45.2	2.7	0.4	1.2	10.6	68.8	3.5	0.71
	Versailles	33.9	44.9	2.0	0.4	0.5	12.7	69.3	2.7	0.73
	Soissons	36.1	48.8	2.1	0.3	1.4	11.0	74.5	2.9	0.72
	Clan	31.6	44.4	2.5	0.5	1.6	12.6	66.4	3.3	0.68
	Torfrida	33.5	48.7	2.5	0.6	2.1	10.8	72.0	3.3	0.66
	Estica	31.5	40.1	5.8	0.6	1.4	12.1	61.1	7.7	0.71
	Biscot	32.0	44.9	2.1	0.2	0.9	10.6	67.5	2.7	0.69
WE-GP	Versailles	7.2	70.7	2.0	0.4	0.5	…	…	…	…

[a] Ara = arabinose; Xyl =xylose; Man = mannose; Gal = galactose; Glc = glucose.
[b] AG = arabinogalactan = 0.89 × [(%Ara – A/X × %Xyl) + %Gal]. A/X = arabinose-to-xylose ratio.
[c] AX = arabinoxylan = 0.88 × [(%Ara – 0.7 × %Gal)+ %Xyl].
[d] A/G_{corr} = arabinose-to-galactose ratio (corrected for water-extractable arabinoxylan present in the isolated fractions) = (%Ara – A/X × %Xyl)/Gal.

osyl residues are linked to position 3 of the β-1,6-galactopyranosyl residues. As a result of the α-L-arabinofuranosidase action, the proportion of β-1,3-galactopyranosyl residues did not increase, indicating that no arabinose residues are linked to position 6 of the β-1,3-galactopyranosyl residues. The decrease in β-1,3-galactopyranosyl residues and the relatively high proportion of terminal galactopyranosyl residues measured in the galactan-peptide indicated that the galactose chain must be branched.

Two structural models for wheat flour WE-AGP (Type II arabinogalactans, Aspinall 1973) were proposed by Fincher et al (1974) and Strahm et al (1981). Fincher et al (1974) assumed the galactan chains to be unbranched, with the arabinofuranosyl units present either as single residues or as short side chains distributed along the galactan chains. Strahm et al (1981) proposed a model with branched galactan chains and arabinofuranosyl units present as single residues. Our data support the latter. Methylation analysis of WE-AGP also showed that all arabinose is present as terminal arabinofuranosyl moieties.

For the WE-AGP samples of the different wheat cultivars, little variation was noted in the distribution of the different glycosidic linkages of the galactopyranosyl residues. The proportion of β-1,3-galactopyranosyl residues was almost equal for the different wheat samples (10.2–11.1%). More variation was observed for the proportion of the β-1,6-galactopyranosyl residues (9.4%–13.0%).

The proportion of β-1,3,6-galactopyranosyl residues varied between 76.0 and 80.1%. The lowest level of β-1,3,6-galactopyranosyl residues (76.0%) was observed for Torfrida and the highest (80.1%) for Versailles. The WE-AGP of these cultivars had the lowest (0.66) and highest (0.73) A/G_{corr} ratios (Table I), respectively.

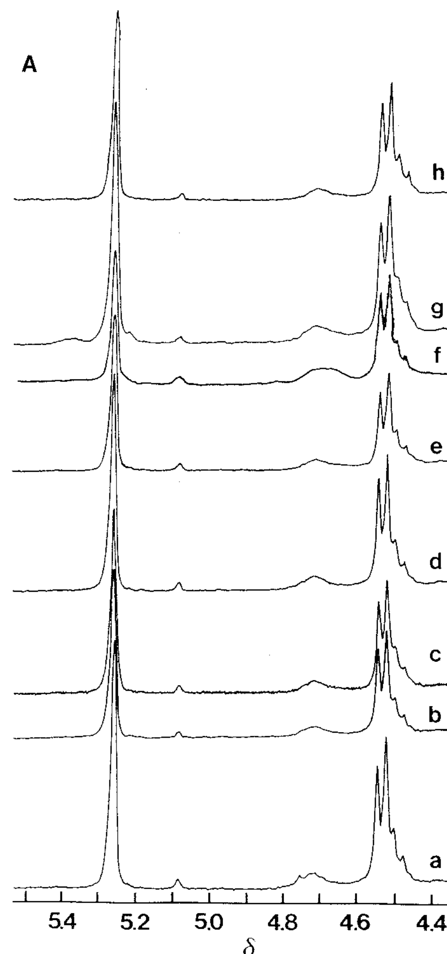
^{1}H-nuclear magnetic resonance spectroscopy. The ^{1}H-NMR spectra for WE-AGP fractions of flour from the eight cultivars were comparable (Fig. 1A). The spectra of the different WE-AGP samples confirmed the purity of the WE-AGP. No signals of WE-AX (Bengtsson and Aman 1990) and polymeric glucose (Gidley 1985) were present.

In Fig. 1B, the ^{1}H-NMR spectrum of the WE-GP is compared with the spectrum of the parent WE-AGP fraction from the wheat cultivar Versailles. The signal at δ 5.26 ppm was ascribed to terminal arabinose residues in WE-AGP (Westerlund et al 1990). The signal

TABLE II
Arabinose, Xylose, and Galactose Contents[a] (wt% of flour, dry basis) of the Water-Extracts of Flours from Different Wheat Cultivars; the A/X[b] Ratio (w/w) of Isolated Water-Extractable Arabinoxylan; and Arabinoxylan and Arabinogalactan Contents (% dry basis) and Ratios in Water Extracts

Flour	Ara	Xyl	Gal	A/X	AX[c]	AG[d]	AX/AG
1996							
Skirlou	0.41	0.52	0.24	0.51	0.69	0.33	2.09
Ritmo	0.30	0.35	0.21	0.49	0.46	0.28	1.64
Versailles	0.41	0.50	0.24	0.51	0.66	0.33	2.06
Soissons	0.27	0.23	0.24	0.54	0.31	0.31	1.00
Clan	0.31	0.37	0.20	0.55	0.50	0.24	2.08
Torfrida	0.29	0.35	0.19	0.47	0.46	0.26	1.77
Estica	0.28	0.33	0.19	0.50	0.44	0.24	1.83
Biscot	0.36	0.42	0.20	0.53	0.56	0.30	1.87
Minimum	0.27	0.23	0.19	0.47	0.31	0.24	1.00
Maximum	0.41	0.52	0.24	0.55	0.69	0.33	2.09
Average	0.33	0.38	0.21	0.51	0.51	0.29	1.67
1994							
Skirlou	0.45	0.58	0.23	0.52	0.78	0.32	2.44
Torfrida	0.37	0.50	0.16	0.49	0.66	0.27	2.43
Gaspard	0.31	0.35	0.19	0.53	0.47	0.27	1.74
Tribun	0.41	0.55	0.20	0.49	0.72	0.30	2.40
Estica	0.36	0.42	0.20	0.53	0.57	0.29	1.97
Génésis	0.37	0.46	0.21	0.51	0.61	0.29	2.10
Sidéral	0.35	0.43	0.20	0.52	0.58	0.27	2.15
Hereward	0.33	0.39	0.20	0.53	0.53	0.26	2.04
Ritmo	0.34	0.41	0.21	0.50	0.54	0.29	1.86
Soissons	0.28	0.27	0.22	0.55	0.37	0.28	1.32
Minimum	0.28	0.27	0.16	0.49	0.37	0.26	1.32
Maximum	0.45	0.58	0.23	0.55	0.78	0.32	2.44
Average	0.36	0.44	0.20	0.52	0.58	0.28	2.05

[a] Ara = arabinose, Xyl = xylose, Gal = galactose.
[b] A/X = arabinose-to-xylose ratio of isolated water-extractable arabinoxylan.
[c] AX = arabinoxylan = 0.88 × [(%Xyl × A/X)+%Xyl].
[d] AG = arabinogalactan = 0.89 × 〈[%Ara – (%Xyl × A/X)] + {[%Ara – (%Xyl × A/X)]/A/G}〉.



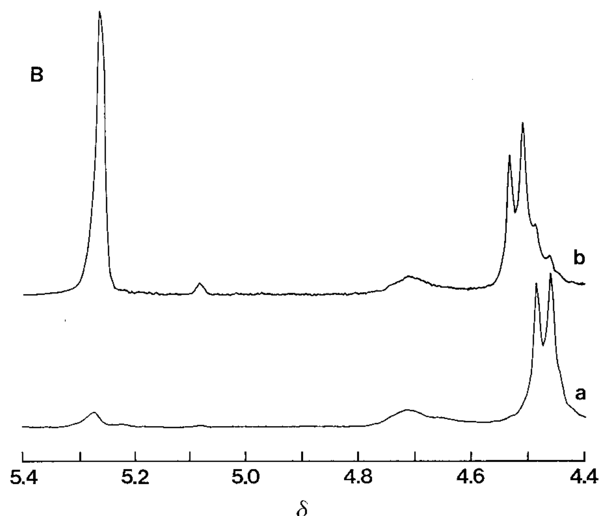


Fig. 1. Anomeric proton regions in the ^{1}H-nuclear magnetic resonance spectra. **A,** the water-extractable arabinogalactan-peptide fraction from Skirlou (a), Ritmo (b), Versailles (c), Soissons (d), Clan (e), Torfrida (f), Estica (g), and Biscot (h). **B,** water-extractable galactan-peptide (a) and water-extractable arabinogalactan-peptide (b) from Versailles.

at δ 5.26 ppm was initially absent in the WE-GP spectrum. The doublet (peaks at δ 4.54 and 4.51 ppm) could be ascribed to the anomeric protons in β-1,3,6-galactopyranosyl residues since the doublet is almost missing in the WE-GP profile. The doublet with peaks at δ 4.49 and 4.46 ppm probably arises from the anomeric protons in β-1,3- and β-1,6-galacopyranosyl residues, as it is more intense in the WE-GP profile. From the methylation analysis data (Table III), it is clear that, following treatment with an α-L-arabinofuranosidase, the level of β-1,3,6-galactopyranosyl residues decreased and that of β-1,6-galactopyranosyl residues increased. The small peak at δ 5.11 ppm probably originates from α-arabinofuranose (Saulnier et al 1992).

Gel-permeation analysis. The gel-permeation profiles of the WE-AGP fractions of flour from the eight wheat cultivars were comparable. In Fig. 2, only the profiles for two wheat cultivars, Ritmo and Soissons are shown. All fractions yielded one peak in the molecular weight range from 5×10^4 to 10×10^4 when the column was calibrated with pullulan standards. Izydorczyk et al (1991) also found similar apparent molecular weights for AGP-fractions of eight Canadian flours (Sephacryl S-300 gel filtration). We were further surprised to note that α-L-arabinofuranosidase debranching of WE-AGP did not change the gel-permeation profile (results not shown).

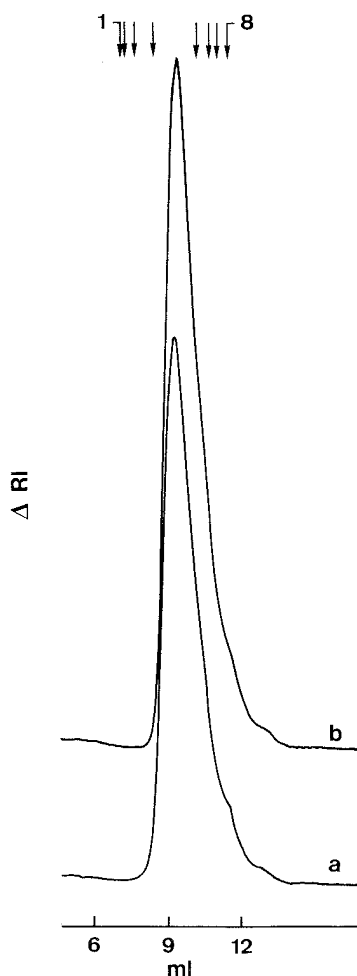


Fig. 2. Gel-permeation profile of the water-extractable arabinogalactan-peptide fraction from Ritmo (a) and Soissons (b). Elution volumes of pullulan standards of molecular weights 78.8×10^4, 40.4×10^4, 21.2×10^4, 11.2×10^4, 4.73×10^4, 2.28×10^4; 1.18×10^4, and 0.59×10^4 (arrows 1–8, respectively).

Quantities of WE-AX and WE-AG in European Wheat Flours

The arabinose (0.27–0.45%), xylose (0.23–0.58%), and galactose (0.16–0.24%) contents (% of dry matter) of the water-extracts of wheat flour are given in Table II. The A/X ratios (w/w) of the isolated WE-AX, ranged from 0.49 to 0.55 (1994 harvest) and from 0.47 to 0.55 (1996 harvest) (Table II).

For flour of the eight 1996 harvest wheat cultivars, WE-AGP was isolated (Table I). By combining the data of the monosaccharide composition of the water-extracts, the A/X ratios (w/w), and the A/G_{corr} ratios (w/w), the values for WE-AX levels were calculated. They ranged from 0.31% (Soissons) to 0.69% (Skirlou) (Table II). The different wheat cultivars show less variability in WE-AG content, which ranged from 0.24% (Estica, Clan) to 0.33% (Skirlou, Versailles). Since there is little variation in A/G_{corr} ratio (w/w) (0.66–0.73), we recalculated WE-AG percentages by taking into account an average A/G ratio of 0.70. Little differences were observed when calculating WE-AG either with a varying or a constant (0.70) A/G ratio. The minimum WE-AX to WE-AG ratio was found for Soissons (1.00) and the maximum value for Skirlou (2.09) (Table II).

For flour of the 10 1994 harvest wheat cultivars, percentage WE-AG values were calculated assuming an average A/G ratio of 0.70. The values for WE-AX (0.37–0.78%) and WE-AG (0.26–0.32%) are given in Table II. AX/AG ratios ranged from 1.32 (Soissons) to 2.44 (Skirlou).

Comparison of the AX/AG ratios for wheat flour of the same cultivars from a different harvest year shows the lowest AX/AG ratio for the cultivar Soissons and the highest AX/AG ratio for Skirlou. Andersson et al (1994) calculated percentage WE-AX and WE-AG values for 20 samples of white flour by combining ^{1}H-NMR and sugar analysis data. The content of WE-AX varied between 0.36 and 0.78%, in agreement with our results. The WE-AG percentage values were lower (0.15–0.21%) than the values in this work.

CONCLUSIONS

Structures of WE-AGP fractions from different wheat cultivars were comparable. Little variation in A/G_{corr} ratio was observed. Methylation analysis and NMR spectral data led to similar conclusions. Gel-permeation profiles were almost identical. A large variation was observed in the content of WE-AX among wheat flours of different breadmaking quality. WE-AG showed less variation in content between wheat flour cultivars. For some wheat cultivars, the WE-AG percentage was of the same order as the WE-AX percentage. Hence, WE-AG probably cannot be neglected as a quality-determining factor in breadmaking.

TABLE III
Glycosidic Linkage Composition (relative mol %)[a] of the Water-Extractable Arabinogalactan-Peptide (WE-AGP) Fractions of Flour from Eight Wheat Cultivars and of the Water-Extractable Galactan-Peptide (WE-GP) Fraction from the Wheat Cultivar Versailles

	WE-AGP								WE-GP
Residues[b]	Skirlou	Ritmo	Versailles	Soissons	Clan	Torfrida	Estica	Biscot	Versailles
t-gal*p*	…	…	…	…	…	…	…	…	11.4
1,3-gal*p*	10.2	11.1	10.5	10.5	10.5	11.0	10.7	10.3	2.5
1,6-gal*p*	11.0	10.5	9.4	10.6	12.4	13.0	11.1	12.9	70.3
1,3,6-gal*p*	78.8	78.4	80.1	78.9	77.1	76.0	78.3	76.9	15.8

[a] Molar proportion relative to total galactosyl residues.
[b] t-gal*p* = terminal galactopyranosyl; 1,3-gal*p* = β-D-(1-3)-galactopyranosyl; 1,6-gal*p* = β-D-(1-6)-galactopyranosyl; 1,3,6-gal*p*-= β-D-(1,3,6)-galactopyranosyl.

ACKNOWLEDGMENTS

A. Loosveld wishes to acknowledge the receipt of a scholarship from the Vlaams Instituut voor de Bevordering van het Wetenschappelijk-Technologisch Onderzoek in de Industrie (Brussels). We thank L. Van Den Ende for technical assistance.

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[Received November 24, 1997. Accepted July 13, 1998.]