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Nonstarch Polysaccharides in Wheat Flour Wire-Cut Cookie Making

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Nonstarch polysaccharides in wheat flour have significant capacity to affect the processing quality of wheat flour dough and the finished quality of wheat flour products. Most research has focused on the effects of arabinoxylans (AX) in bread making. This study found that water-extractable AX and arabinogalactan peptides can predict variation in pastry wheat quality as captured by the wire-cut cookie model system. The sum of water-extractable AX plus arabinogalactan was highly predictive of cookie spread factor. The combination of cookie spread factor and the ratio of water-extractable arabinose to xylose predicted peak force of the three-point bend test of cookie texture.

KEYWORDS: Arabinoxylan; arabinogalactan; pentosans; flour; pastry quality

INTRODUCTION

Arabinoxylans (AX) and arabinogalactan peptides (AGP) are nonstarch polysaccharides in wheat flour that have significant capacity to affect dough properties and baked product quality. Nonstarch polysaccharides (NSPs) comprise approximately 75% of cell wall dry weight in wheat endosperm, and AX are predominant (~85%) among them [reviewed by Courtin and Delcour (*1*)]. Water-extractable AX (WE-AX), thought to be loosely bound at the cell wall surface, make up between 25 and 30% of the total flour AX. The behavior of AX derives primarily from the length of the xylan backbone, the degree of substitution of the xylan backbone with arabinose (indicated by the arabinose to xylose ratio, Ara/Xyl), the pattern of substitution (e.g., frequency of mono- and disubstituted xylopranosyl residues), and the coupling of ferulic acid to other AX molecules or cell wall components. AX can cross-link through ferulic acid residues and ultimately gel under oxidizing conditions; oxidative cross-linking increases the viscosity of AX in solution [recently reviewed in Bettge and Morris (*2*)]. Both water-unextractable AX (WU-AX) and WE-AX strongly absorb water. When AX is added to bread dough, resistance to mixing can be compensated for by addition of 2−10 times their weight in water (*1*).

Water absorption generally is undesirable in soft wheat flours because it increases baking time for low-moisture products (*3*). The solvent retention capacity test (SRC) of flour is used to partition the underlying components of flour water absorption. SRC is used for evaluation of wheat germplasm in development stages because of its low cost, high genetic heritability, and low genotype × environment interaction (*3*−*5*).

Most previous research on AX has focused on their effects on bread making, as previously reviewed by Courtin and Delcour (*1*) and extended in subsequent studies, particularly related to the formation of glutenin macropolymer (*6*−*10*). Fewer studies have explored effects of AX on pastry flour quality. Zhang et al. (*3*) reported a correlation of 0.78 between water-soluble AX (as measured by apparent xylose) and sucrose solvent retention capacity (SRC) in 17 Chinese wheat cultivars grown in six environments. The diameter of sugar-snap cookies, a high-sucrose model cookie system, was predicted by sucrose SRC or sucrose SRC in combination with flour protein in this study and others (*3*−*5*). Bettge and Morris (*11*) also reported that total AX and WE-AX were correlated negatively with sugar-snap cookie diameter of 13 Pacific Northwest U.S. soft white wheat flours.

Wire-cut cookies have lower sucrose/flour and sucrose/shortening ratios than the more widely used sugar-snap cookie method (*12*). Per gram of flour (14% mb), the AACC sugar-snap cookie formula (AACC 10-52) contains 0.3 g of shortening and 0.6 g of sucrose; the AACC wire-cut cookie formula (AACC 10-54) contains 0.4 g of shortening and 0.42 g of sucrose. Wire-cut cookies more closely resemble commercial product formulas than sugar-snap cookies and, therefore, are a particularly sensitive indicator of soft wheat flour baking quality (*12*−*14*). Yet, little research has been reported using the wire-cut formula. Genotype × environment interaction for wire-cut cookie parameters has been observed (*15*), but the underlying basis remains uncharacterized, and studies linking wire-cut cookie quality to flour quality parameters are limited. An early fractionation/interchange experiment (*16*) pointed to an important role for generic water-solubles plus starch tailings in increasing the hardness of wire-cut cookies.

The objective of this study was to measure the relationship between nonstarch polysaccharides and wire-cut cookie quality

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with the intent to understand the variation in wire-cut cookie quality previously attributed to genotype × environment interaction and statistical factors.

EXPERIMENTAL METHODS

Grain Production. Wheats were grown as part of The Ohio State University wheat-breeding program yield trials. The six genotypes included the long-term standard soft red winter wheat cultivar 'Hopewell,' two recently released soft white winter wheats from Cornell University, 'Richland' and 'Caledonia Resel-L,' a soft white winter breeding line from Cornell University, NY92039-9065, and recently released soft white winter wheats from Michigan State University, 'Ambassador' and 'Coral.' The trials were planted at the Northwest Agricultural Research Station near Hoytville in northwestern Ohio and at the Horticulture and Crop Science Farm at the Ohio Agricultural Research and Development Center in Wooster, located in central Ohio. The soil type at the Northwest Station was Hoytville clay, and the soil type at Wooster was Canfield silt loam. Plots at the Northwest Station were seeded at commercial seeding rates of 69 seeds m^{-1} of row on October 10, 2006, and harvested on July 6, 2007. Plots at Wooster were seeded at 69 seeds m^{-1} of row on October 9, 2006, and harvested on July 9, 2007. Plots were fertilized with 78.5 kg of N ha^{-1} as liquid urea ammonium nitrate on March 30, 2007, at the Northwest Station and with 89.6 kg of N ha^{-1} as ammonium nitrate on April 4, 2007, at Wooster. Weeds were controlled with applications of registered herbicides at commercially labeled rates. No fungicide applications were applied to the trials.

Plots were harvested with a small plot combine. Grain samples were cleaned over a Carter-Day Dockage Tester to remove shriveled seed.

Experimental Milling. Grain (1200 g) was tempered to 14.0% moisture level for at least 24 h in order for the moisture to equilibrate throughout the grain. Wheat was introduced into the first break rolls of the Miag Multomat Mill at the U.S. Department of Agriculture Soft Wheat Quality Laboratory (SWQL) at a rate of 54.4 kg h^{-1}. The Miag Multomat Mill is a pneumatic conveyance system consisting of 8 pairs of 254 mm diameter × 102 mm wide rolls and 10 sifting passages. Three pairs of rolls are corrugated and employed as break rolls, and five pairs of rolls are smooth and utilized in the reduction process. Each sifting passage contains six separate sieves. The two top sieves for each of the break bolls are intended to be used as scalp screens for the bran. The third break sieving unit of the mill was modified so that the top four sieves are employed to scalp bran. That modification increased the final bran sieving surface by 100%. Straight grade flour was a blend of 10 flour streams: the 3 break flour streams and the 5 reduction streams, plus the grader flour resifting of the first 2 break streams and the duster flour resifting of the first 2 reduction streams. Flour generated by the SWQL Miag Multomat Mill very nearly represents that of commercially produced straight grade flour.

Cookie Evaluation. Wire-cut cookies were prepared using American Association of Cereal Chemists (AACC) method 10-54 (*12*), "Baking Quality of Flour—Micro Wire-Cut Formulation". This method predicts the quality of soft wheat flour for contemporary commercial wire-cut formulation cookies. Desirable quality is associated with larger cookie diameter, smaller cookie height (stack height), and increased tenderness. Duplicate batches for each flour were prepared, baked, and evaluated. Cookies were stored, covered, at room temperature overnight before being broken with a three-point-bend test essentially as previously described (*17*).

Solvent Retention Capacity Tests. The SRC of flours were measured using AACC method 56-11 (*12*), modified by the SWQL to test 1 g of flour with 5 mL of solvent (water, 5% w/w sodium carbonate, 5% w/w lactic acid, 50% w/w sucrose) in 15 × 85 mm round-bottom glass tubes. Vortex agitation was used at 5 min intervals in place of the manual agitation specified in the AACC method. Determinations were made in duplicate.

Nonstarch Polysaccharide Characterization. Water-extractable nonstarch polysaccharides were prepared by conducting a water SRC test, as described above. A 2.5 mL aliquot of the supernatant after centrifugation was transferred to a screw-cap tube, and an equal volume of 4 N trifluoroacetic acid (TFA) was added. Hydrolysis was conducted in capped tubes for 1 h at 110 C. Hydrolysates were cooled briefly on ice, then transferred to centrifuge tubes and centrifuged at 3000*g* for 10 min at room temperature. An aliquot of the supernatant (3 mL) was transferred to a clean screw-cap tube for derivatization. Total polysaccharides were analyzed by hydrolyzing 50 mg of flour in 5 mL of 2 N TFA for 1 h at 110 C. The hydrolysate was centrifuged as described above, and a 3 mL aliquot of the supernatant was derivatized.

Alditol acetate derivatives of hydrolysates were prepared as described by Courtin et al. (*18*). Samples were analyzed in an Agilent 6850 gas chromatograph (Agilent Technologies, Santa Clara, CA) equipped with an autosampler, splitter injection port, and flame ionization detector. Injection and detection temperatures were 275 °C. Separation was conducted on a Supelco (Sigma-Aldrich Corp., Bellefonte, PA) 2380 column using He as a carrier gas at 250 °C and 9 psi for 12 min. Monosaccharide standards were calibrated to allose, which was used as an internal standard in analyses of hydrolysates. The AX concentration was calculated as 0.88 times the sum of xylose and arabinose concentrations (to correct for the water molecule that is lost when monosaccharides are bound) after correction of the arabinose concentration for the arabinogalactan peptide, as described in Courtin et al. (*18*) and Dornez et al. (*19*).

Statistical Analysis. Analyses of variance were conducted using mixed effects models in PROC MIXED in SAS with genotype and location as fixed effects and flour subsample and gas chromatograph injection (subsample) as random effects. Pearson correlation coefficients were calculated using PROC CORR in SAS applied to mean values for each flour ($n = 12$). Regression analyses with wire-cut cookie diameter, height, and spread factor as the dependent variables and monosaccharide concentration as the independent variable were selected on their ability to optimize the R^2 value of the regression model in PROC REG in SAS with the SELECTION = R-SQUARE option.

RESULTS

All six cultivars grown in both production environments had break flour extraction >20% and total flour extraction >70% on the Miag Multomat mill (**Table 1**). Therefore, all would be considered to be satisfactory milling cultivars by current standards in the eastern United States. For reference, Hopewell had the lowest flour extraction, near 72%, in both environments. At present, Hopewell is an older, widely grown, well-established cultivar considered to be satisfactory by the milling industry. Ambassador, when grown at Wooster, produced 76.5% flour extraction with 28.2% of the flour in the break roll and would be considered to be exceptionally good for milling. Flour protein and ash concentrations generally were lower from the Northwest Branch location than from the Wooster location, which would be preferred by the milling and baking industries.

Low water, sodium carbonate, and sucrose SRC values are desired for soft wheat flours because they are indicative of flours with lower water-holding capacity. Flours from the cultivars Richland, Hopewell, and Caledonia Resel-L, as a group, had greater water, sodium carbonate, and sucrose SRC values and would be less desirable than flours from the genotypes Ambassador, Coral, and NY92039-9065 (**Table 1**). Correlations among water, sodium carbonate, and sucrose SRC are self-evident in these data and were previously reported (*3, 4, 26*). Differences among these flours for water, sodium carbonate, and sucrose SRC are, however, small relative to those reported in previous studies (*3, 4, 26*). Lactic acid SRC provides an indication of flour gluten strength. Although these flours differed significantly, the differences observed are small relative to those previously reported. These flours would be considered to be relatively similar, moderate gluten strength for eastern U.S. soft winter wheat.

A significant relationship between break flour yield and sodium carbonate SRC was observed in these flours (Pearson *r*

Table 1. Break Flour Yield, Straight Grade Flour Yield, and Protein and Ash Concentrations of Flours Milled on a Miag Multomat Mill from Six Soft Winter Wheat Genotypes Grown at Two Ohio Locations in 2007 and Solvent Retention Capacities (AACC 56-11) of the Flours

location	genotype	break flour yield (%)	straight grade flour yield (%)	flour protein concn (%)	flour ash concn (%)	solvent retention capacity (%)			
						water	5% (w/w) sodium carbonate	50% (w/w) sucrose	5% (w/w) lactic acid
Northwest Branch	Richland	27.8	75.9	9.9	0.38	53.2	70.5	94.0	105.0
	Caledonia Resel-L	23.9	73.9	9.0	0.36	52.2	68.7	91.9	103.4
	Ambassador	26.7	75.7	8.8	0.37	51.3	67.4	88.8	99.2
	Coral	25.6	74.8	8.8	0.39	51.0	66.3	86.2	100.4
	NY92039-9065	25.6	76.0	9.0	0.40	50.5	66.0	86.8	97.9
	Hopewell	28.0	72.2	8.7	0.39	52.4	70.0	91.7	102.6
Wooster	Richland	31.3	74.4	9.4	0.40	53.3	72.4	92.9	100.1
	Caledonia Resel-L	29.1	73.6	9.6	0.38	52.2	70.6	89.1	99.4
	Ambassador	28.2	76.5	9.3	0.38	51.6	67.8	88.8	95.1
	Coral	28.0	75.9	9.4	0.36	49.2	67.6	85.9	95.3
	NY92039-9065	28.1	75.7	9.5	0.40	49.6	66.9	85.5	91.0
	Hopewell	30.7	72.1	9.4	0.39	52.1	70.3	88.8	100.3
standard error				0.1	0.002	0.3	0.2	0.7	0.6

Table 2. Shape and Peak Force in Three-Point Bend Test of Wire-Cut Cookies (AACC 10-54) Prepared from Flours Milled from Six Soft Winter Wheat Genotypes Grown at Two Ohio Locations in 2007

location	genotype	cookie diameter[a] (cm)	stack height[b] (cm)	spread factor[c]	peak force (g)
Northwest Branch	Richland	7.60	1.08	7.03	3180
	Caledonia Resel-L	7.74	1.04	7.41	2880
	Ambassador	7.76	1.03	7.51	2740
	Coral	7.69	1.02	7.54	3020
	NY92039-9065	7.78	1.01	7.70	2890
	Hopewell	7.93	1.01	7.87	2800
Wooster	Richland	7.93	1.03	7.73	2810
	Caledonia Resel-L	7.92	1.04	7.65	3130
	Ambassador	8.01	0.98	8.16	2550
	Coral	7.89	0.99	7.94	2700
	NY92039-9065	7.77	1.01	7.60	3060
	Hopewell	7.90	1.01	7.79	2970
standard error		0.03	0.01	0.11	160

[a] Average diameter of one cookie. [b] Height of one cookie, determined on a stack of two cookies. [c] Spread factor = cookie diameter/stack height.

= 0.68, $p < 0.05$). As break flour yield increased, sodium carbonate SRC also increased. Greater break flour yield generally is considered to be desirable by the industry; however, among this set of flours, it was associated with increased water absorption characteristics at high pH, which is undesirable in soft wheat flour. No relationship between flour ash or flour protein and any of the SRC parameters was observed.

Significant genotype × environment variation was evident in the cookie quality data (**Table 2**). For example, flour from the cultivar Richland grown at the Northwest Branch baked small-diameter, high stack height wire-cut cookies that required relatively large force to snap. Yet flour from Richland grown at Wooster baked relatively large-diameter cookies that required less force to snap. In contrast, Hopewell produced flours from both environments that baked cookies with similar diameter and stack height and required less force to snap. The similarity of SRC values for water, sodium carbonate, and sucrose for Hopewell, Richland, and Caledonia Resel-L flours is consistent with the similar cookie performance of these flours from the Wooster location, but the similar SRC values fail to predict the range in variation in cookie performance at the Northwest Branch location. Flour ash and flour protein were not correlated with cookie diameter, height, or snapping force.

Total AX concentration in flour in this study averaged 13.6 mg g^{-1} of flour (**Table 3**). In a study of AX distribution in commercial wheat mill streams using gas chromatographic methods, Dornez et al. (*19*) calculated that total AX content in straight-run flour, which most closely would approximate the Miag-milled flours of this study, was 21.3 mg g^{-1}. Both genotype and genotype × environment interaction effects were important sources of variation in total AX concentration in flour. For example, the genotypes Ambassador and NY92039-9065 had relatively low total AX concentration (lower than Hopewell) in flours from both environments, but the genotype Coral had lower total AX concentration than Hopewell in flour from the Northwest Branch and higher total AX concentration in flour from Wooster. Ara/Xyl ratios in the total flour AX did not vary among the genotypes evaluated, and these genotypes responded similarly to the two test environments: the Ara/Xyl ratio was significantly lower ($p < 0.05$) at the Northwest Branch (0.73) than at Wooster (0.77). Location and genotype did not significantly affect total AG or the sum of AX + AG. However, the sum of AX + AG varied among genotypes in response to the two environments as the Richland flour from the Northwest Branch had a notably high concentration of total AX + AG. In a previous study, the soft white spring wheat, 'Fielder', which was developed in the 1970s in the western United States (*20*), had a total NSP concentration of 18.7 mg g^{-1} and an Ara/Xyl ratio (uncorrected for arabinogalactans) of 1.23 (*21*). Applying the correction for arabinogalactan to the data for comparison to values in this study, the corrected Ara/Xyl ratio is 0.68. This low value may be due to differences in the experimental methods or the wheat cultivar. Fielder now is considered to be a poor-quality soft wheat cultivar.

Water-extractable AX concentration was affected by location and genotype. Moreover, genotypes responded differently to the two locations (**Table 3**). The Richland flour from the Northwest Branch had a particularly high concentration of WE-AX (5.19 mg g^{-1}), yet the genotype Ambassador produced flours with relatively low concentrations of WE-AX in both environments (3.58 and 3.75 mg g^{-1}). A survey of 19 bread wheat flours grown in France (*22*) had an average WE-AX concentration of 4.9 mg g^{-1}. In the commercial mill stream study (*19*), the WE-AX concentration in straight-run flour was calculated to be 4.4

Table 3. Total and Water-Extractable (WE) Arabinoxylan (AX), Arabinose/Xylose Ratio (Ara:Xyl), Arabinogalactan (AG), and Arabinoxylan plus Arabinogalactan (AX+AG) in Flours of Six Wheat Cultivars Grown at Two Ohio Locations in 2007, Expressed on a Dry Weight Basis as the Mean ± SD

		total				water-extractable				
location	genotype	AX[a] (mg g^{-1} of flour)	Ara/Xyl	AG[a] (mg g^{-1} of flour)	AX + AG[b] (mg g^{-1} of flour)	AX[a] (mg g^{-1} of flour)	Ara/Xyl	AG[a] (mg g^{-1} of flour)	AX + AG[b] (mg g^{-1} of flour)	WE/total AX
Northwest Branch	Richland	16.4 ± 1.2	0.70 ± 0.06	3.3 ± 1.4	19.7 ± 2.0	5.19 ± 0.08	0.63 ± 0.03	2.33 ± 0.30	7.52 ± 0.38	0.32
	Caledonia Resel-L	14.3 ± 0.7	0.72 ± 0.05	3.9 ± 1.0	17.8 ± 1.6	4.25 ± 0.10	0.60 ± 0.01	2.77 ± 0.13	7.03 ± 0.04	0.29
	Ambassador	12.7 ± 0.4	0.72 ± 0.01	3.8 ± 1.2	16.5 ± 1.6	3.75 ± 0.09	0.57 ± 0.01	2.77 ± 0.02	6.53 ± 0.07	0.30
	Coral	12.6 ± 0.6	0.76 ± 0.09	3.0 ± 1.3	15.6 ± 1.9	3.65 ± 0.02	0.59 ± 0.01	2.72 ± 0.14	6.37 ± 0.16	0.29
	NY92039-9065	12.3 ± 1.7	0.76 ± 0.03	3.5 ± 1.1	15.8 ± 2.8	3.71 ± 0.05	0.73 ± 0.04	2.06 ± 0.24	5.77 ± 0.30	0.30
	Hopewell	13.7 ± 0.1	0.75 ± 0.04	2.9 ± 0.2	16.6 ± 0.3	4.64 ± 0.23	0.92 ± 0.11	1.35 ± 0.17	5.99 ± 0.06	0.34
Wooster	Richland	14.1 ± 0.8	0.77 ± 0.10	2.5 ± 0.6	16.6 ± 0.1	4.21 ± 0.06	0.75 ± 0.04	1.81 ± 0.13	6.02 ± 0.19	0.30
	Caledonia Resel-L	13.6 ± 0.2	0.76 ± 0.04	3.3 ± 1.0.	16.9 ± 1.3	4.42 ± 0.64	0.94 ± 0.03	1.73 ± 0.36	6.15 ± 0.99	0.33
	Ambassador	12.8 ± 0.7	0.76 ± 0.04	3.5 ± 1.5	16.3 ± 2.1	3.58 ± 0.10	0.89 ± 0.06	1.61 ± 0.10	5.19 ± 0.02	0.28
	Coral	14.8 ± 0.5	0.80 ± 0.08	3.5 ± 1.4	18.3 ± 1.9	3.52 ± 0.10	0.93 ± 0.06	1.69 ± 0.15	5.21 ± 0.05	0.24
	NY92039-9065	12.6 ± 0.8	0.76 ± 0.01	3.9 ± 1.0	16.5 ± 1.8	4.34 ± 1.20	1.13 ± 0.06	1.53 ± 0.49	5.87 ± 1.68	0.34
	Hopewell	13.1 ± 1.6	0.78 ± 0.03	3.6 ± 1.5	16.7 ± 3.1	4.02 ± 0.01	0.91 ± 0.12	1.57 ± 0.36	5.60 ± 0.35	0.34
standard error		0.5	0.02	0.48	0.9	0.18	0.03	0.11	0.27	

[a] Calculated as described in Courtin et al.(*18*), correcting for loss of water when monosaccharides are bound. [b] Calculated as the sum of the arabinoxylan concentration and arabinogalactan concentration.

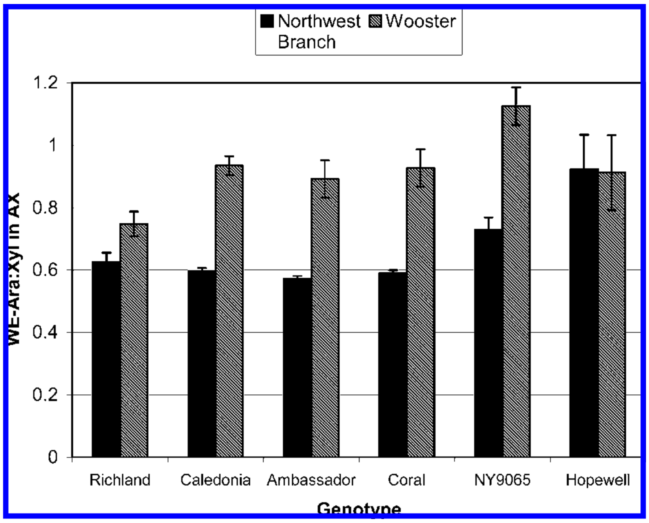

Figure 1. Ratio of arabinose to xylose in water-extractable arabinoxylan in flour of six wheat genotypes grown at two Ohio locations, Northwest Branch and Wooster, in 2007.

mg g^{-1}. The soft white spring wheat Fielder was reported to have 6.0 mg g^{-1} WE-AX (*21*).

Water-extractable AX represented between 24 and 34% of total flour AX (**Table 3**). WE-AX was not well predicted by total AX: a regression model with WE-AX as dependent variable and total AX as independent variable explained only 38% of the variation in WE-AX. Similarly, in a survey of 22 French bread wheat cultivars, WE-AX was not correlated with total AX in the grain (*23*).

The arabinose/xylose ratio in WE-AX varied significantly with location: WE-Ara/Xyl of flour from the Northwest Branch averaged 0.67; in contrast, WE-AX in flour from grain grown at Wooster was much more highly substituted, with an average Ara/Xyl ratio of 0.92. Moreover, the Ara/Xyl ratio of WE-AX of the six genotypes responded differently to the two test environments (**Table 3**; **Figure 1**). For example, the WE-Ara/Xyl ratio of the cultivar Hopewell was relatively unaffected by production environment compared to the genotype Ambassador. In this study, WE-Ara/Xyl ratios ranged from 0.57 to 1.13, averaging 0.80 across cultivars and environments. In a survey of French bread wheat flours (*23*), WE-Ara/Xyl ratios ranged from 0.7 to 1.1, averaging 0.9. These WE-Ara/Xyl ratios were negatively related to flour extract viscosity (*23*). Increasing substitution of the xylan backbone decreased flour extract viscosity. Viscosity is undesirable in some soft wheat applications, such as wafers, and desirable in other applications, such as batters and coatings. The full effects of the variation in AX structure illustrated in **Figure 1** may not be fully expressed in the present study, which evaluated only one baked product among many uses of soft wheat.

The apparent genotype × environment interaction of the WE-Ara/Xyl ratio illustrates one of the deficiencies in using colorimetric methods (*24, 25*) to estimate WE-AX concentration from apparent xylose concentration: the assumption that arabinose concentration is a relatively constant function of xylose concentration is invalid in this data set. Moreover, the values reported from colorimetric studies previously reported for soft wheat do not align well with chromatographic results. The mean total and WE-AX contents of 13 Pacific Northwest soft white spring, soft white winter, and club wheat flours were reported to be 73 and 27 μg of xylose equivalents per gram of flour, respectively (*11*), approximately 150-fold less than in this study. The mean total and WE-AX contents of 17 Chinese soft wheat flours were reported to be 1.97 and 0.84 mg g^{-1} (*3*), about one-fifth the concentration in this study.

Flour yield was not correlated with any of the SRC values or with any of the AX concentration measurements (data not shown). However, break flour yield, as discussed above, was positively correlated with sodium carbonate SRC and was negatively correlated with water-extractable galactose concentration (Pearson $R = -0.68$, $p < 0.05$). The potential relationship of arabinogalactan peptides with milling quality merits further investigation.

Flour protein and flour ash concentration are traditional industrial predictors of manufacturing quality and generally are included in purchasing specifications. Within this set of flours, protein and ash concentrations were not correlated with wire-cut cookie diameter, spread factor, or snapping force (**Table 4**). This may reflect the low level and narrow range of protein and ash concentrations of the samples. Among the solvent retention capacity parameters, only sucrose and lactic acid SRC

Table 4. Pearson Correlation Coefficients of Wire-Cut Cookie Parameters with Flour Quality Parameters and Arabinoxylan Composition for Six Soft Winter Wheats Grown at Two Ohio Locations in 2007

	Pearson correlation coefficient[a] (*r*)			
parameter	diameter	stack height	spread factor	snapping force
flour protein concn	ns	ns	ns	ns
flour ash concn	ns	ns	ns	ns
water SRC	ns	ns	ns	ns
5% w/w Na_2CO_3 SRC	ns	ns	ns	ns
50% w/w sucrose SRC	ns	0.672 *	ns	ns
5% w/w lactic acid SRC	ns	0.620 *	ns	ns
total arabinoxylan concn	ns	0.588 *	ns	ns
Ara/Xyl in total AX	0.615 *	−0.732 **	0.728 **	ns
total AG	ns	ns	ns	ns
AX + AG (total)	ns	0.596 *	ns	ns
water-extractable AX concn	ns	0.735 **	−0.611 *	0.631 *
Ara/Xyl in WE-AX	ns	ns	ns	ns
WE-AG	−0.724 **	ns	−0.647 *	ns
WE-AX+AG	−0.781 **	0.939 ***	−0.937 ***	ns

[a] ns, *, **, and *** indicate nonsignificant and significance at $p < 0.05$, 0.01, and 0.001, respectively.

were correlated with wire-cut cookie geometry. Greater lactic acid and/or sucrose SRC flours were associated with taller cookies.

Total AX concentration also was positively correlated with stack height. The Ara/Xyl ratio of the total AX was positively correlated with cookie diameter, negatively correlated with stack height, and strongly positively correlated with spread factor: more highly substituted AXs were associated with cookies that had greater spread, which is desirable. Water-extractable AX concentration was positively correlated with force with break the cookie and stack height and negatively correlated with spread factor, although the WE-xylose concentration was not itself significantly correlated with force to snap the cookie. The WE-xylose concentration was most tightly correlated with stack height. An important role for arabinogalactan (AG) peptides is implied by the highly significant negative correlation of galactose with cookie diameter. The sum of WE-AX and WE-AG was negatively correlated with diameter, positively correlated with stack height, and thus negatively correlated with spread factor.

Consistent with previous reports (*3*−*5*), sucrose SRC was correlated with water-extractable xylose in these flours (Pearson $r = 0.78$, $p < 0.01$). However, sucrose SRC was not correlated with wire cut cookie diameter, spread factor, or snapping force. One explanation may be that these are relatively high-quality pastry flours with a very narrow range in sucrose SRC values, which limits the range of inference of the sucrose SRC test. In previous studies SRC has demonstrated efficacy in predicting sugar-snap cookie quality in data sets. However, the composition of previous data sets differed from our genotype set. They included samples with much wider ranges of sucrose SRC and cookie diameters as they included both poor and superior quality soft cultivars (*3, 4, 26*).

The correlations of this study support the previous studies of AX (*1*); the increased branching of the AX molecule that occurs with the increase in Ara/Xyl ratio reduces the absorption of water by the flour, reducing the resistance to the dough's outward flow during baking. Sucrose SRC captures some of this effect by simulating the competition for water binding of the AX molecules in a high sugar concentration dough. In the SRC method, a global measure of many compounds affecting water absorption, the increased specificity of the sucrose solvent over simple distilled water may not fully manifest the effects of NSPs. GC quantification of the NSP components more precisely measures wheat flour NSPs than SRC (an inferential measurement), hence, the greater correlation coefficients for direct AX measures, particularly measures such as the Ara/Xyl ratio, that also describe a portion of the structural variation of the NSPs in wheat flour.

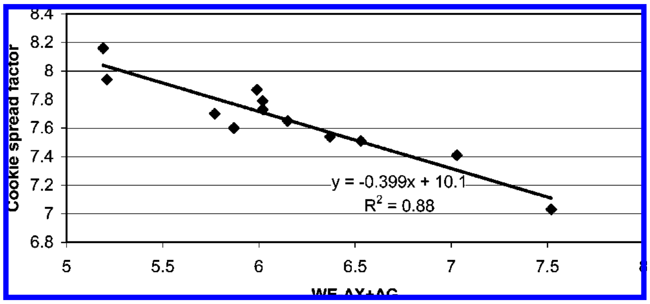

Figure 2. Wire cut cookie spread factor versus water-extractable arabinoxylan + arabinogalactan concentration of six wheat genotypes grown at two Ohio locations in 2007.

Consistent with the results of the correlation analysis in **Table 4**, wire-cut cookie diameter and height both were best predicted by the sum of WE-AX+AG when the R-Square selection method in PROC REG in SAS was used to select among single-variable regression models. Spread factor, the ratio of cookie diameter to height, is commonly reported in flour tests conducted by the U.S. baking industry. It is interpreted as the propensity of dough to spread during baking relative to constraint, and it pertains to critically important packaging issues in the factory. Spread factor also was optimally predicted by WE-AX+AG (**Figure 2**). Remarkably, regression on WE-AX+AG explained 88% of the variation in the spread factor of these cookies. The genotype × environment interaction of the nonstarch polysaccharide fractions may explain some of the genotype × environment interaction variation in cookie geometry that is not fully explained by the solvent retention capacity tests. Although the sucrose SRC is correlated to specific fractions of the nonstarch polysaccharides, the analysis of WE-AX and AG directly more completely predicts the cookie variation.

Peak force in the three-point-bend test, a measure of cookie texture, was strongly correlated with wire-cut cookie spread factor (Pearson $r = -0.736$, $p < 0.01$); wider, thinner cookies required less force to snap. After fitting of the effect of spread factor, the WE-Ara/Xyl ratio was the second most important variable in explaining variation in force to snap the cookie. The multiple regression model including spread factor and WE-Ara/Xyl ratio accounted for 75% of the variation in snapping force.

$$\text{force} = 7610 - \{675 \times [\text{spread factor}]\} + \{569 \times [\text{WE-Ara/Xyl}]\};\ R^2 = 0.73 \quad (1)$$

These data suggest predictive utility for profiles of water-extractable AXs from high-quality soft wheat flours that may lead to improved functional understanding of the role of nonstarch polysaccharides, both AXs and AG peptides, in soft wheat product quality.

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