***Pak. J. Bot.*, 54(5): 1893-1902, 2022.** **DOI: http://dx.doi.org/10.30848/PJB2022-5(7)**

ARABINOXYLANS OF HARD WHEAT CULTIVARS IN RELATION TO CROP YEAR AND ENVIRONMENTAL CONDITIONS

SALMAN KHURSHID[1], SAQIB ARIF[1*], QURRAT-UL-AIN AKBAR[1], SHAHID YOUSAF[1], HAFIZA MEHWISH IQBAL[1], SABA IQBAL[1] AND ABID HASNAIN[2]

[1]Food Quality and Safety Research Institute, Southern-zone Agricultural Research Centre, Pakistan Agricultural Research Council, Karachi University Campus, Karachi-75270, Pakistan
[2]Department of Food Science and Technology, University of Karachi, Karachi – 75270, Pakistan
**Corresponding author's email: saqiawan@yahoo.com*

Abstract

Eight hard wheat varieties grown at different locations over three cropping years were studied for arabinoxylan (AX) contents, in terms of total arabinoxylans (TAX), water extractable arabinoxylans (EAX) and water unextractable arabinoxylans (UAX). The levels of TAX, EAX and UAX were found to range between 46.3 to 77.8; 8.8 to 9.0; and 39.9 to 67.7 mg/g, respectively. The percent EAX in TAX and EAX/UAX ratios were found to be independent of the amount of AX. The EAX levels showed a similar pattern to TAX in all varieties. The influence of variety, location, and crop year on the AX contents was also studied. Variety was the main source of variation that influenced the AX content and percent EAX in TAX and EAX/UAX ratio. Location and Variety × Location interactions, were both found to significantly (p<0.001) influence the AX content. Variety × crop year interaction also showed a significant (p<0.001) impact on the percent EAX in TAX and EAX/UAX ratio. The impact of weather conditions on AX levels across the crop year and near the harvest period also showed significant relationships. The AX content across crop year was significantly and positively correlated with average minimum temperature (r=0.68-0.72) and average relative humidity (r=0.64-0.68). Compared to this, the AX level showed a significant negative relationship with maximum temperature (r=0.67) during the period approaching harvest.

Key words: Arabinoxylans, Wheat, Variety, Growing conditions, Non-starch polysaccharides.

Introduction

Arabinoxylans (AX) are one of the most common non-starch polysaccharides known for their impact on product quality. They are largely present in cell walls of wheat and other cereals (Kaczmarek *et al.*, 2016). Compared to wheat flour, most of the arabinoxylans are present in wheat bran (Lempereur *et al.*, 1997). It is providing structural support to the plants by hydroxyl-cinnamate cross-linking (Carpita & Gibeaut, 1993). They are known to affect the dough rheology (Biliaderis & Rattan, 1995), and increase the dough viscosity and development time (Arif *et al.*, 2018; Buksa *et al.*, 2010). The ability of arabinoxylans to bind or squeeze more water speeds up starch retrogradation - possibly due to an increase in molecular mobility of starch (Biliaderis & Rattan, 1995).

Arabinoxylans can be classified as water extractable arabinoxylans (EAX) and unextractable arabinoxylans (UAX) on the basis of their water extractability. The degree of arabinose substitution, xylan polymerization, ferulic acid cross-linking and linkage with other components of the cell wall (Kiszonas *et al.*, 2013; Sinha *et al.*, 2011) are the main factors determinig the extent of water extractability of AX. Each of the AX fraction exerts different impacts on dough rheology and finished product quality (Arif *et al.*, 2018). TAX and UAX largely related with ash content and thus have been considered a flour refinement indicator (Ramseyer *et al.*, 2011). The negative impact of UAX on dough structure and bread quality is due to its interference by hindering the starch and gluten hydration. (Courtin & Delcour, 2002). On other side, EAX contribute to improve viscosity of batters, and quality of flours for baking applications (Molina *et al.*, 2021; Guttieri *et al.*, 2008).

The importance of arabinoxylans in assessment of quality parameters therefore required investigations of AX levels in wheat cultivars in relation to quality characteristics considering genotypes and environmental conditions. Limited studies have already investigated the effect of environmental conditions on AX level in different wheat varieties. The influence of genotype was reported on TAX, EAX in flour and EAX in bran (Gebruers *et al.*, 2010; Kaur *et al.*, 2021). Variation in EAX content has also been affected by genetic makeup of wheat (Dornez *et al.*, 2008). Compared to this, the AX level seems to be highly affected by environmental conditions (Li *et al.*, 2009; Finnie *et al.*, 2006). Crop year also correlated with variation in EAX and TAX (Dornez *et al.*, 2008). The percent EAX in TAX was similar in both winter and spring wheat classes (Li *et al.*, 2009). In five durum wheat cultivars, the ratio of genotype x environment ratios was 4.9 for EAX and 4.4 for TAX (Lempereur *et al.*, 1997). Another study suggested the environment as a main factor influencing AX content as compared to genotype (Li *et al.*, 2009). The agronomic practices can also be an important factor that may cause a variation in AX levels. Even a one month delay in harvest can increase EAX levels in grain (Dornez *et al.*, 2008).

The present study was undertaken to investigate the impact of genotype, environmental conditions, and crop year, on the TAX, EAX and UAX in wheat. Percent EAX in TAX and EAX/UAX (extractability ratio) were also determined as they act independently of the TAX content. To understand the interplay of these factors, eight wheat varieties were studied over consecutive three year cultivation at three different locations.

Materials and Methods

Samples description: Pakistani wheat cultivars (Anmol, TD 1, Mehran, Moomal, Abadgar, Imdad, TJ 83 and SKD 1) were obtained from WRI, Sakrand. These varieties were cultivated in Nawabshah (L-1), Tandojam (L-2) and Dadu (L-3) for three crop years. An RCBD was followed in triplicate for each experiment. All varieties were grown in a uniform plot size (15ft × 6ft) under irrigated conditions. They were planted in November and harvested in May each following year. Standard and uniform agronomic practices were applied for all the cultivars. Before thrashing, wheat was sun dried for about a week. The agronomic and morphological performances of different wheat cultivars are given in (Table 1). Weather conditions of wheat cultivation are given in (Table 2). Location details, and the soil characteristics are provided in (Table 3).

Table 1. Average agronomic and morphological performance of wheat cultivars grown for three years across three locations.

Variety	Agronomic and morphological parameters									
	Days to heading	Flag leaf area (cm^2)	Days to maturity	Grain filling period (days)	Grain yield (kg/ha)	Biological yield (kg/ha)	Harvest index	Plant height (cm)	Spike length (cm)	Grains per spike
TD 1	82	19.8	134	75	4380	8866	49.3	87	10.6	53
Imdad	83	19.9	133	77	4486	8998	49.8	91	11.4	55
Mehran	87	22.4	135	78	4291	8886	48.4	89	11.8	54
Abadgar	89	21.2	137	78	4461	9311	47.9	91	11.4	57
Moomal	81	21.3	134	72	4263	8786	48.5	93	11.6	53
Anmol	87	21.4	136	82	4105	8847	46.5	90	10.8	54
SKD 1	86	22.8	137	80	4477	9072	49.3	95	11.3	54
TJ 83	87	22.6	139	78	3744	8967	41.3	81	11.5	57

Table 2. Weather conditions during wheat cultivation.

	Temperature °C																	
	Average minimum									Average maximum								
	Dadu			Tandojam			Nawabshah			Dadu				Tandojam			Nawabshah	
Nov	◑	◔	◔	◕	◕	◕	◑	◔	◔	◔	◔	◔	◔	◔	◔	◔	◔	◔
Dec	◔	○	◔	◔	◔	◑	◔	○	◔	○	○	○	○	◔	◔	○	◔	◔
Jan	○	○	○	◔	◔	◔	○	○	○	○	○	○	◔	◔	○	◔	◔	○
Feb	◑	◔	○	◑	◑	◔	◑	◔	○	◔	○	◔	◔	◔	◔	◔	◔	◔
Mar	◑	◑	◑	◕	◑	◕	◑	◑	◑	◑	○	◔	◔	◔	◔	◔	◔	◔
Apr	◕	◕	◕	◕	●	●	◕	◕	◑	◕	○	◔	◔	◔	◔	◔	◔	◔
May	●	●	●	●	●	●	●	●	●	●	○	◔	◔	◔	◔	◔	◔	◔
Crop year	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3

	Relative humidity (%)																	
	At 1200 UTC									At 000 UTC								
	Dadu			Tandojam			Nawabshah			Dadu				Tandojam			Nawabshah	
Nov	◑	◔	◔	◔	◔	◔	◔	◔	◔	◕	◕	◕	◑	◑	◑	◕	◕	◕
Dec	◑	◑	◑	◔	○	◑	◑	◔	◑	◕	◕	◕	◕	◑	◕	◕	◕	◕
Jan	◔	◑	◕	◔	◔	◔	◔	◔	◔	◕	◕	◕	◑	◑	◑	◕	◕	◕
Feb	◑	◑	◔	◔	◔	○	◔	◔	◔	◕	◕	◑	◑	◕	◑	◕	◕	◕
Mar	◔	◔	◔	○	◔	○	◔	◔	○	◕	◕	◑	◑	◕	◑	◑	◕	◕
Apr	○	○	◔	○	◔	○	◔	○	○	◑	◑	◑	◑	◕	◕	◑	◑	◑
May	◔	◔	◔	◔	◔	◔	○	○	○	◑	◑	◑	◕	◕	◕	◑	◑	◑
Crop year	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3

	Precipitation (mm)								
	Dadu			Tandojam			Nawabshah		
Nov	○	○	○	○	○	○	○	○	○
Dec	◑	○	●	○	◔	○	◔	○	◑
Jan	○	○	○	○	○	○	○	○	○
Feb	○	○	○	○	○	○	○	○	○
Mar	○	◑	○	◔	◔	○	○	◔	○
Apr	○	○	○	○	○	○	○	○	○
May	○	○	○	○	○	○	○	○	○
Crop year	1	2	3	1	2	3	1	2	3

Avg. min.	○ 2.4-6.4	◔ 7.8-12.5	◑ 12.7-17.7	◕ 18-22.7	● 23.1-28
Avg. Max.	○ 20.3-25.3	◔ 26-29.7	◑ 31.5-34.7	◕ 36-40.9	● 41.7-46.4
RH% (1200 UTC)	○ 19-31	◔ 32-42	◑ 46-54	◕ 56-68	● 80
RH% (000 UTC)	○ 57-63	◔ 64-70	◑ 71-75	◕ 80-83	● 85-91
Precipitation (mm)	○ 0-23	◔ 31-37	◑ 48.4-69	◕ NA	● 121

Table 3. Details of growing location and soil properties.

Location coordinates	**Experimental locations**		
	L-1	**L-2**	**L-3**
Latitude	26.27°	25.46°	26.77°
Longitude	68.43°	68.56°	67.80°
Soil properties			
Sand proportion in soil (%)	21.92	25.9	42.75
Silt proportion in soil (%)	49.43	43.5	21.02
Clay proportion in soil (%)	28.65	30.6	36.23
EC (dS/m)	0.64	0.39	1.12
pH	8.0	8.3	8.4
Lime content (%)	12.7	11.6	13.4
Organic matter (%)	0.78	0.84	0.66

Wheat grain analyses: Grains of each sample were homogenized and divided using a mechanical divider to obtain a representative laboratory sample. A precision electronic divider was used for further mixing of laboratory samples and subdivided into working samples. Thereafter, the samples were cleaned by using appropriate sieves and hand-picked to remove clay, small particles, and other grains. The grains of all the wheat varieties were sound as shown by high test weights (77.3-79 Kg/hL) and had lower moisture content (9.8-10.3%). A standard one liter bucket procedure was used for determination of test weight of wheat grains (Dexter & Tipples, 1987). Moisture content of each grain sample was evaluated by using moisture tester, appropriately calibrated with standard air oven method.

Milling of wheat grains into whole-meal flour: Wheat samples were ground into whole meal flours using a sample grinding mill (UDY corp., USA) equipped with a 0.5 mm screen. The feeding rate of grain to the mill was around 70 g/min. Flour yield (98-99%) was recorded, and compared with the quantity of grain fed to the mill.

Estimation of arabinoxylans: A modified method based on colorimetry was used for determining total arabinoxylans (TAX) and water-extractable arabinoxylans (EAX) contents in samples as reported by Finnie *et al.*, (2006). Water unextractable arabinoxylans (UAX) was calculated by subtracting EAX from TAX. The percentage of EAX in TAX, and the ratio of EAX to UAX were also calculated.

Statistical analysis

The AX contents in each laboratory sample were determined in three replicates. A three-way analysis of variance for a CFD (variety, location and crop year) was applied to analyze the sources of variation in TAX, EAX and UAX levels of hard wheat. Mean separation was performed by Duncan's Multiple Range Test. Pearson's correlation coefficients (*r*) were evaluated between arabinoxylan contents and weather conditions. The variance ratio was evaluated to determine genotypic contribution in AX levels. Statistical analysis was performed through the software (SPSS 21v).

Results and Discussion

Arabinoxylan levels in wheat meal: Tables 4-6. show AX contents in meals of eight wheat varieties grown for three consecutive years at three locations in Sindh province of Pakistan.

Total arabinoxylan (TAX): The TAX levels irrespective of wheat variety, crop year, and location were ranging from 46.3 to 77.8 with an average level of 59.7 mg/g (Table 4). Minimum TAX content was found in variety TJ 83 (48.7 mg/g) while maximum in SKD 1 (68.7 mg/g). Three of the varieties – Imdad, Anmol and Moomal - showed mean TAX above 60 mg/g. Other three varieties – Mehran, TD 1 and Abadghar - showed TAX between 50 and 60 mg/g. TJ 83 was the only variety that fell below the 50 mg/g level. The varieties that were grown in L-2 expressed the maximum TAX values (62.4 mg/g) irrespective of the crop year. The average minimum value of TAX in the varieties grown in L-1 was recorded at 56.3 mg/g. Variation in TAX content in terms of percentage was calculated to range from -22.44 to + 30.32 from the mean value. The coefficient of variance among the varieties was found to range between 9.0 and 16.3 percent in the same year and between the three crop years respectively. Within the variety, there was a lesser variation in five varieties, whereas three varieties - SKD 1, Moomal and Anmol - were found to have more variation across crop years and locations (CV =10-11.8%). The mean CV between the varieties irrespective of location and crop year was found to be 13.2% and within the varieties 6.35%. Other studies carried out elsewhere have also found the TAX in wheat to range between 40 and 78 mg/g (Barron *et al.*, 2007; Saeed *et al.*, 2014; Wang *et al.*, 2006).

Water-extractable arabinoxylan (EAX): Table 5. shows the EAX contents in different wheat varieties. The results reflect similar pattern as TAX contents found to have highly significant correlation with each other. The EAX was found to range between 6.8 to 9.0 mg/g ($\bar{x}$= 7.87 mg/g) irrespective of variety, year and location. Average maximum and minimum EAX levels of 8.3 and 7.4 mg/g were found in L-1 and L-2, respectively. Average maximum EAX contents ranged between 8.8 and 9.0mg/g in varieties Moomal, Imdad, SKD 1 and Anmol,. Whereas varieties TD 1, Abadghar and Mehran showed values between 6.8 to 7.6 mg/g and the variety TJ 83 showed the lowest level (5.9 mg/g). The variation within the variety irrespective of location and crop year were found to be minimum in Imdad and Mehran (3 and 4%) and maximum in Anmol and Moomal with values of 13.4 and 12.7 percent, respectively. The mean CV between the varieties and within the varieties was found to be 15.6 and 7.29 percent, respectively. The EAX level ranging from 4.75 to 9.19 mg/g in the twenty five wheat cultivars grown in USA under different conditions (Li *et al.*, 2009). Another investigations recorded EAX in spring wheat in a range between 6.9 and 12.1 g/Kg (Saeed *et al.*, 2011).

Water unextractable arabinoxylan (UAX): The analysis of samples showed that UAX constitutes major portion of TAX. UAX fraction was approximately 7 times higher than EAX which is inline with the findings of (Finnie *et al.*, 2006). Both AX components exhibited a highly significant correlation (r=0.899**). Average maximum and minimum levels, irrespective of variety, crop year or location, were found to be 67.5 and 39.9 mg/g (Table 6). Like TAX, the maximum quantities of UAX were found in varieties grown in L-2 followed by L-3. Three varieties showed UAX levels less than 50.0 mg/g. The CV values between the varieties and within the varieties ranged from 8.6 to 16.1% ($\bar{x}$=13.56%) and 2.2 to 11.5% ($\bar{x}$=6.39%), respectively.

Percent EAX in TAX and EAX/UAX ratio: Figure 1 summarizes the statistics of percent EAX in TAX and EAX/UAX across the locations and crop years. The percent EAX in TAX was not dependent on TAX as it was weakly related with the quantity of TAX in wheat. The EAX fraction in AX ranged from 12.1 to 13.8%. The EAX as a component of TAX was upto 30% in wheat (Faurot *et al.*, 1995). Higher molecular EAX component in TAX contributed to the desired dough processing properties for bread making quality attributes of wheat (Goesaert *et al.*, 2005; Courtin & Delcour, 2002). EAX/UAX ratio (also termed as extractability ratio of AX narrowly ranged from 0.14 to 0.17. It remained almost same across three locations and crop years. The EAX/UAX did not affected by AX levels as the ratio was weakly related with TAX (r=0.39) and UAX (r=0.33). Other workers have also recorded that the EAX/UAX was independent of TAX level (Ciccoritti *et al.*, 2011; Lempereur *et al.*, 1997).

Effects of variety, location and year on AX levels of wheat: The ANOVA model explained total variations of 58-96% in AX contents, %EAX in TAX and EAX/UAX in wheat due to effect of Variety (V), Location (L), harvest Year (hY) and their interactions (Table 7). TAX, EAX and UAX varied significantly (p<0.001) by variety and location. The magnitude of variation in terms of *F-value* for variety was 2-folds and ~1.4-folds greater than location for TAX & UAX and EAX respectively. Some workers reported climatic conditions as the main variance factor for EAX (Li *et al.*, 2009). Others have recorded the genotype as the primary source of variation (Dornez *et al.*, 2008; Finnie *et al.*, 2006). In the present study, TAX, EAX and UAX contents varied insignificantly by the crop year. The effects of V × L and V × hY were significant for TAX, EAX and UAX. A previous investigation (Dornez *et al.*, 2008) also reported the insignificant effect of crop year, but a significant influence of genotype × crop year for TAX. The present results are in line with the findings of the study. However, a significant variation was observed in rye by some other workers on account of the crop year for EAX (Hansen *et al.*, 2003). Different results for variation due to crop year can be attributed to the possible adoption of various agronomic practices during different harvest years, however it requires further studies. Climate condition's interaction with agricultural inputs and soil characteristics deliberate the variations in AX levels (Gebruers *et al.*, 2010). Crop year is an important factor to entail the variations in their genotype lines. Significant variations were identified in TAX and UAX due to L × hY interaction, while it was found to be insignificant for EAX. The TAX, EAX and UAX varied significantly due to interacting effects of V × L × hY but EAX variation was found at a lower significant level i.e. at p<0.01. Although significant but the influence of V × L × hY component was found lower than the individual effects of variety and location.

Variety and V × L showed a significant impact on percent EAX in TAX and EAX/UAX ratios. It showed an insignificant variation due to Location, V × hY and V × L × hY. In contrast to these results, more significant influence of environmental conditions on quantity of EAX in TAX than genotypic effect was observed for winter and spring wheats (Li *et al.*, 2009). Effect of individual sources was much higher than the effect of interactions on AX levels. Variance ratios of variety-to-location (σ^2 V/ σ^2 L) were 1.7, 4.6 and 1.9 for UAX, EAX and TAX, respectively. The variance ratio of 4.9 for EAX and 4.4 for TAX was recorded (Lempereur *et al.*, 1997). Genotypic variance ratios (σ2 V / σ2 V + σ2 l + σ2 V x L) were 0.66, 0.82 and 0.63 for TAX, EAX and UAX, respectively. Variation in AX levels due to variety and location are shown in Fig. 2. The Figure indicates that variety is the major variance contributor to EAX, TAX and UAX contents. Percent EAX in TAX and EAX/UAX ratio showed approx ~ 97% variations due to the varietal effect.

Varietal differences: Duncan's test was performed to figure out the average separation of AX contents among different varieties and locations (Fig. 3). The variety TJ 83 was significantly different in terms of TAX, EAX and UAX contents amongst all other varieties. The higher AX levels were found in SKD 1 followed by Anmol and Imdad with insignificant (p>0.05) difference amongst each other. Variation in EAX fractions due to the genotype effect was reported previously (Li *et al.*, 2009; Saulnier *et al.*, 2007). The variability due to variety in TAX have also been recorded in durum wheat varieties (Ciccoritti *et al.*, 2011; Lempereur *et al.*, 1997). The variability of EAX levels was lower in common wheat as compared to durum wheat (Turner *et al.*, 2008). Variety influences the UAX contents in wheat (Ramseyer *et al.*, 2011).

Table 4. Total arabinoxylan levels (mg/g) in Pakistani wheat varieties.

Growing location	Crop year	Wheat variety								Statistics for 8 varieties	
		TD 1	Imdad	Mehran	Abadgar	Moomal	Anmol	SKD 1	TJ 83	Mean	CV (%)
L-1	CY-1	52.4±0.10aA	63.0±0.12aB	53.9±0.10aA	57.5±0.10aC	56.6±1.19aC	57.8±0.07aC	62.7±0.09aB	47.8±0.17aD	56.5	9.0
	CY-2	52.9±0.07aA	61.8±1.55aB	53.0±0.53aA	56.0±1.01aC	59.3±1.29aB	58.5±0.01aC	61.9±0.03aB	46.3±0.52aD	56.2	9.5
	CY 3	52.8±0.12aA	64.0±0.32aB	53.5±0.03aA	56.7±0.07aC	57.9±0.03aC	56.9±1.33aC	61.1±1.22aB	47.2±0.07aD	56.3	9.2
L-2	CY-1	54.5±0.01bA	67.0±0.16bB	58.4±0.07bC	61.7±0.22bD	66.4±0.24bB	67.3±1.58bB	77.8±3.28bE	50.8±0.10bF	63.0	13.5
	CY-2	56.1±1.36bA	68.9±3.38bB	57.6±1.34bA	62.3±1.09bC	72.4±5.38cD	75.5±4.45cD	74.2±0.06cD	51.6±0.09bE	64.8	14.1
	CY 3	55.4±0.07bA	65.1±0.16cB	59.4±0.12bC	60.0±0.24bC	69.5±0.07cD	71.4±0.10dD	70.5±3.13cD	49.8±0.71bE	62.6	12.5
L-3	CY-1	52.7±0.15aA	65.0±0.21cB	53.4±0.21aA	56.6±0.12aC	58.0±0.14aC	67.5±0.54bB	77.6±0.56bD	47.4±0.31aE	59.8	16.3
	CY-2	52.4±0.22aA	68.7±0.83bB	57.7±0.91bC	57.3±0.28aC	66.6±0.39bB	57.9±0.20aC	70.4±0.82cB	48.0±0.29aD	59.9	13.3
	CY 3	55.1±0.21bA	63.3±0.49aB	53.7±0.35aA	60.3±0.39bC	72.1±0.80cD	75.2±0.41cE	62.2±0.42aB	49.4±0.62bF	61.4	14.5
Statistics for total data for 3 years across 3 locations	Mean	53.8	65.2	55.6	58.7	64.3	65.3	68.7	48.7		
	CV (%)	2.7	3.9	4.6	4.1	10.0	11.8	10.0	3.7		

Mean ± SE (n=3)

Different capital alphabets within same rows and small alphabets within same columns are significantly different at $p<0.05$

Table 5. Water extractable arabinoxylan levels (mg/g) in Pakistani wheat varieties.

Growing location	Crop year	Wheat variety								Statistics for 8 varieties	
		TD 1	Imdad	Mehran	Abadgar	Moomal	Anmol	SKD 1	TJ 83	Mean	CV (%)
L-1	CY-1	6.3±0.13aA	8.6±0.04aB	7.1±0.21aC	7.8±0.22abD	7.3±0.90aC	7.6±0.04aD	7.8±0.23aD	5.6±0.22aE	7.3	12.8
	CY-2	6.6±0.28aA	8.6±0.40aB	7.2±0.20aC	7.3±0.67aC	7.8±0.24bD	7.8±0.17aD	8.2±0.05aB	6.6±0.23bA	7.5	9.3
	CY 3	6.7±0.09aA	8.7±0.20aB	7.1±0.05aC	7.2±0.05aC	7.±0.09abC	7.7±0.53aBC	8.4±0.53aB	6.2±0.05bA	7.4	12.1
L-2	CY-1	6.±0.40aA	9.3±0.05aB	7.5±0.07bC	7.8±0.05bC	9.5±0.17cB	9.2±0.30bB	10.2±0.82bB	5.7±0.05aD	8.3	17.8
	CY-2	7.5±0.23bA	9.0±0.51aB	7.6±0.21bA	8.1±0.27bC	9.8±1.30cBD	10.6±0.72cD	9.3±0.04cB	6.3±0.10bE	8.6	17.2
	CY 3	7.5±0.04bA	9.4±0.43aB	7.6±0.20bA	7.7±0.29bA	9.6±0.05cB	9.4±0.04bB	8.7±0.13dC	5.7±0.23aD	8.2	16.9
L-3	CY-1	6.7±0.23aA	9.3±0.30aB	6.±0.13aA	7.5±0.17aC	7.7±0.21bC	9.3±0.23bB	10.1±0.74b	6.1±0.18bD	7.9	18.1
	CY-2	6.2±0.10aA	9.2±0.52aB	7.5±0.14abC	7.7±0.19bC	9.6±0.20cB	7.7±0.12aC	8.6±0.25dB	5.7±0.17aD	7.8	17.2
	CY 3	7.3±0.25bA	8.±0.17aB	7.3±0.19abA	7.7±0.20abA	9.6±0.23cC	10.4±0.56cC	8.4±0.14aB	5.8±0.19aD	8.1	19.0
Statistics for total data for 3 years across 3 locations	Mean	6.8	9.0	7.3	7.6	8.8	8.9	8.8	5.9		
	CV (%)	6.8	3.0	4.0	3.7	12.7	13.4	9.2	5.5		

Mean ± SE (n=3)

Different capital alphabets within same rows and small alphabets within same columns are significantly different at $p<0.05$

Table 6. Water unextractable arabinoxylan levels (mg/g) in Pakistani wheat varieties.

Growing location	Crop year	Wheat variety								Statistics for 8 varieties	
		TD 1	Imdad	Mehran	Abadgar	Moomal	Anmol	SKD 1	TJ 83	Mean	CV (%)
L-1	CY-1	46.1±0.13aA	54.2±0.10aB	47.0±0.13aA	49.9±0.20aC	49.6±0.49aC	50.3±0.09aC	54.9±0.15aB	42.3±0.35aD	49.4	8.6
	CY-2	46.3±0.20aA	53.4±1.23aB	46.1±0.42aA	48.9±0.52aC	51.5±1.53aD	50.9±0.19aD	53.7±0.17aB	39.9±0.10bE	48.9	9.5
	CY 3	46.4±0.10aA	55.3±0.43bB	46.5±0.05aA	49.5±0.07aC	50.6±0.09aC	49.3±1.20aC	52.6±0.99aD	41.3±0.09aE	48.7	8.9
L-2	CY-1	47.7±0.40aA	57.6±0.19cB	50.9±0.07bC	53.8±0.20bD	56.7±0.32bB	58.3±1.33bB	67.3±2.60bE	45.2±0.13cF	54.6	13.0
	CY-2	48.5±1.23bA	59.8±3.01dB	50.3±1.50bC	54.4±0.93bD	62.6±4.13cE	64.9±3.80cF	64.9±0.09cF	45.2±0.11cG	56.4	13.7
	CY 3	48.1±0.12abA	55.9±0.35bB	51.2±0.33bC	52.3±0.38bC	59.9±0.06dD	61.7±0.10dE	61.9±3.30cE	44.1±0.70cF	54.5	11.8
L-3	CY-1	46.2±0.23aA	55.7±0.29bB	46.6±0.12aA	49.3±0.09aC	50.5±0.35aC	58.1±0.55bD	67.5±0.27bE	41.3±0.27aF	52.0	16.1
	CY-2	46.3±0.24aA	59.5±0.83dB	50.3±0.96bC	49.7±0.20aC	57.3±0.49bB	50.2±0.13aC	61.7±0.77cB	42.6±0.45aD	52.3	13.0
	CY 3	48.0±0.44aA	54.5±0.38aB	46.7±0.28aA	52.8±0.30bB	62.6±0.63cC	64.9±0.23cC	54.0±0.26aB	43.5±0.69aD	53.5	13.9
Statistics for total data for 3 years across 3 locations	Mean	47.0	56.2	48.4	51.1	55.5	56.4	59.9	42.8		
	CV (%)	2.2	4.1	4.8	4.2	9.6	11.5	10.2	4.5		

Mean ± SE (n=3)

Different capital alphabets within same rows and small alphabets within same columns are significantly different at p<0.05

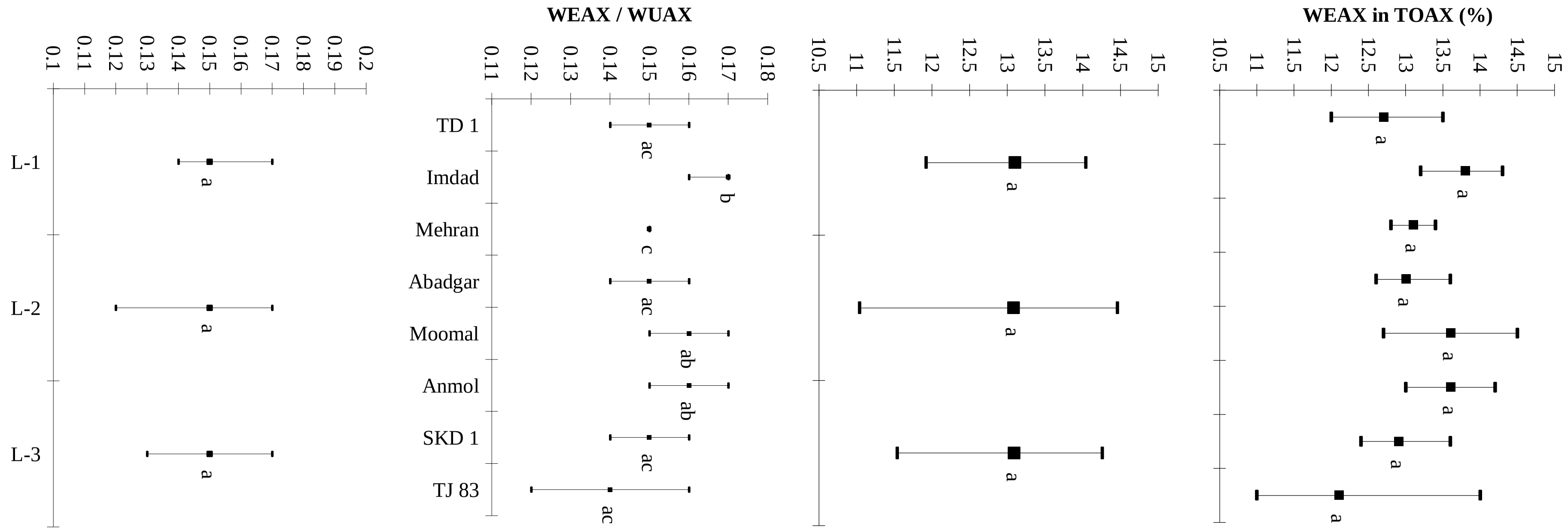

Fig. 1. Minimum, mean and maximum values of % EAX in TAX and EAX/UAX ratio.

Table 7. ANOVA of arabinoxylan contents (TAX, EAX and UAX) in meals of different wheat varieties.

Source	TAX	EAX	UAX	% EAX of TAX	EAX/UAX
R^2	0.96	0.89	0.96	0.58	0.59
Corrected Model	44.27***	15.93***	43.20***	2.78***	2.89***
Variety	308.96***	118.16***	295.32***	15.24***	16.32***
Location	221.27***	55.31***	225.99***	0.03	0.06
Year	1.38	0.98	1.26	0.35	0.58
Variety × Location	12.24***	5.83***	11.85***	2.69**	2.79**
Variety × Year	10.45***	2.63**	11.05***	1.04	0.96
Location × Year	5.66***	2.01	5.78***	0.94	1.11
Variety × Location × Year	6.95***	2.31**	7.19***	1.23	1.16

*= p<0.05; **= p<0.01; and ***= p<0.001

UAX = Water-unextractable arabinoxylans; EAX = Water-extractable arabinoxylans; TAX = Total arabinoxylans

Table 8. Correlation between arabinoxylan parameters and weather conditions.

	TAX	EAX	UAX	% EAX in TAX	EAX/UAX ratio
1) Crop year					
Temp max	-0.308	-0.281	-0.306	0.063	0.044
Temp min	**0.711***	**0.684***	**0.7178***	0.042	0.016
Temp mean	0.477	0.465	0.484	0.058	0.03
Precipitation	0.313	0.305	0.309	0.044	0.054
Humidity at 000	-0.269	-0.211	-0.275	0.254	0.218
Humidity at 1200	-0.186	-0.197	-0.186	-0.112	-0.144
Humidity Average	0.653	**0.679***	0.647	0.336	0.28
b) Heading to harvest span					
Temp max	**-0.673***	**-0.671***	**-0.677***	-0.189	-0.145
Temp min	0.426	0.398	0.426	-0.038	0.028
Temp mean	-0.012	-0.034	-0.014	-0.133	-0.055
Precipitation	-0.008	-0.086	0.008	-0.466	-0.463
Humidity at 000	0.077	0.114	0.084	0.245	0.249
Humidity at 1200	0.164	0.182	0.163	0.154	0.1179
Humidity Average	0.172	0.2	0.173	0.225	0.1942

* Significant at $p<0.05$

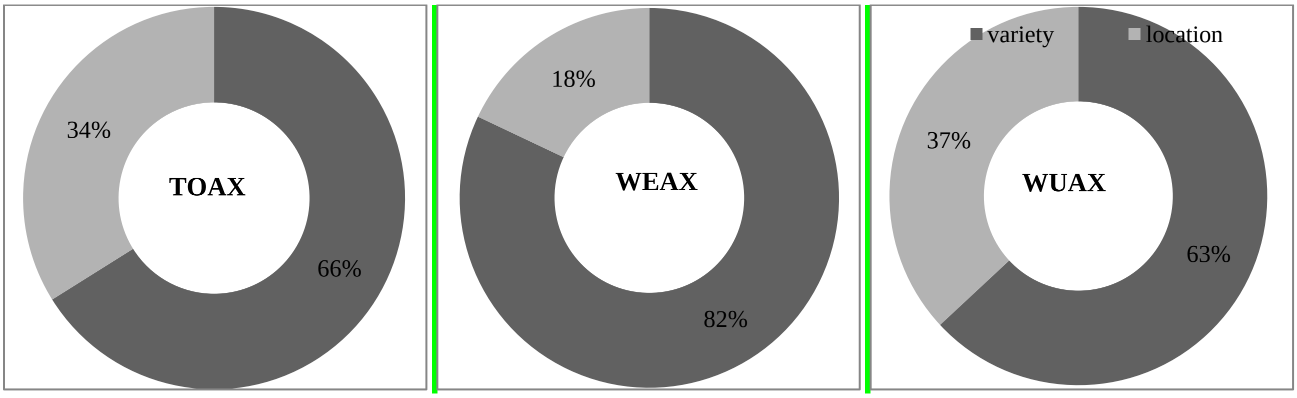

Fig. 2. Effect of variety and location in variation of AX contents in wheat.

Cropping locations: Figure 3 also shows that AX contents are significantly ($p<0.05$) different across the 3 cropping locations. Performance of varieties in terms of AX levels were found better in L-2, followed by L-3 and L-1. The location differences in EAX contents of barley have previously been reported (Mikyska *et al.*, 2002; Holtekjølen *et al.*, 2006). The variation in UAX levels due to environmental conditions had also been recorded for durum wheat (Ciccoritti *et al.*, 2011).

Effects of weather conditions on AX contents of wheat: Table 2. shows that weather in crop producing areas was dry and irrigation was the main source of water. Minimum temperature during crop year was significantly and positively correlated with the AX contents, while the maximum temperature throughout heading-harvest had a negative relationship with AX levels (Table 8). Average temperature recorded during crop year had moderate positive effect on AX level in wheat. EAX negatively correlated with average temperature throughout heading-harvest (Shewry *et al.*, 2010). They found these relationships in winter wheat at near to harvest temperatures range ~10 between 25°C. In present study, the average temperature across heading to harvest had no relationship with any of the AX component. Differences in temperature values, nature of samples and wheat fractions would be the possible reasons of differences in findings of studies.

Average precipitation across heading to harvest had moderately inverse correlation with percent EAX in TAX and EAX/UAX ratio. Earlier report by Li *et al.*, (2009) has also indicated an inverse correlation of rainfall with EAX content and the level of EAX in TAX. Other researchers recorded positive relationship of rainfall with TAX (Ciccoritti *et al.*, 2011; Li *et al.*, 2009) and EAX (Dornez *et al.*, 2008). The quantity of AX fractions showed direct relationship with average RH across crop year. But none of the RH values across heading-harvest influenced the AX levels. This shows that the increased accumulation of AX may be observed in high humidity during early growth period of the crop.

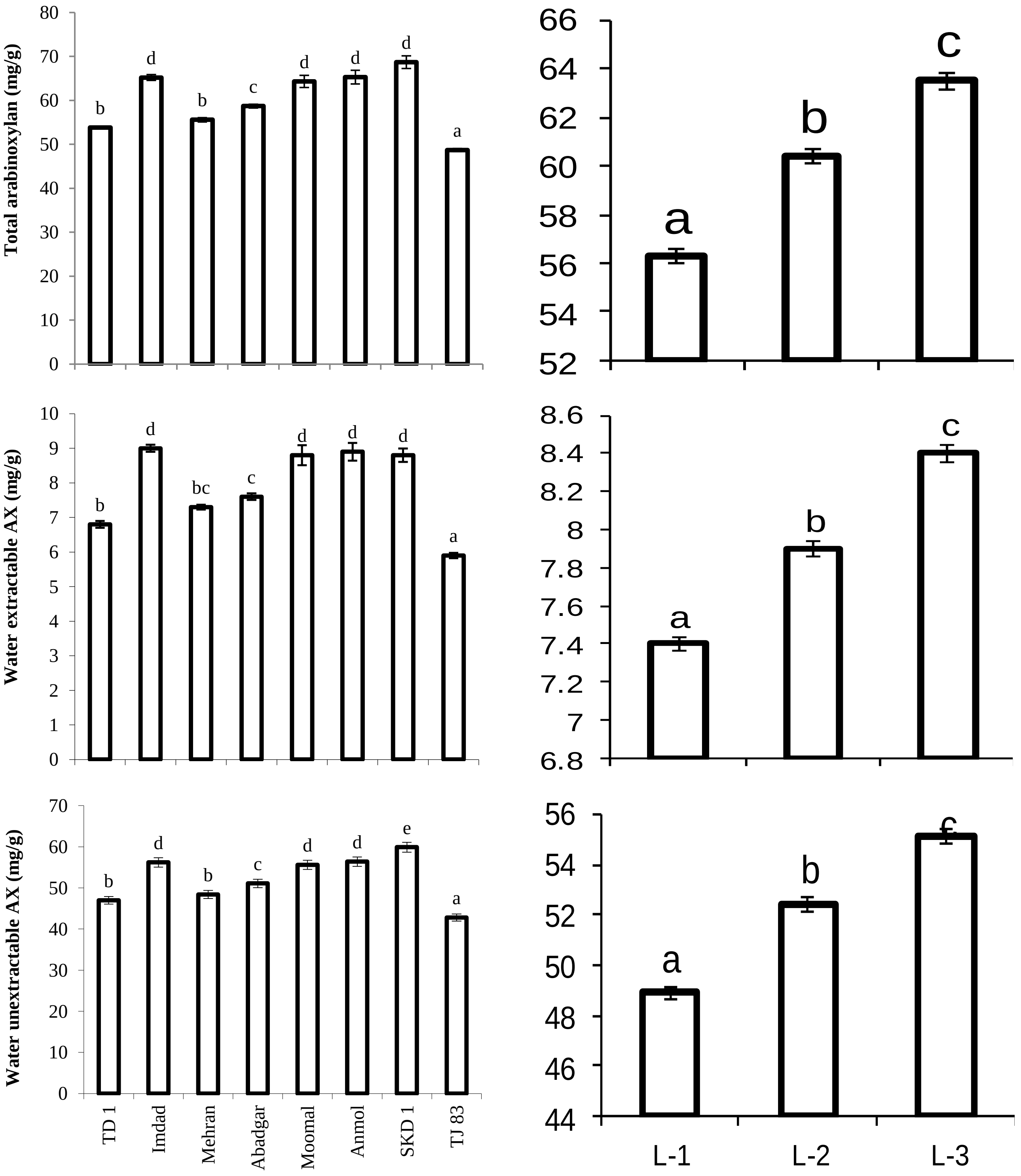

Fig. 3. Varietal and location wise differences in arabinoxylan contents in wheat.

Conclusions

Wheat varieties tested have a wide range of total AX (TAX) levels between 46.3 to 77.8 mg/g. The EAX and UAX were found to range between 5.5 to 10.7 mg/g and 39.9 to 67.5 mg/g respectively. The coefficient of variance (CV) in AX contents between the varieties was found to be almost double to that within the varieties. This clearly indicates that genotype is a main source of variation for AX contents of wheat than location and crop year. The extractability ratio (EAX/UAX) and percent EAX in TAX fluctuated marginally in various varieties and was found to be independent to the amount of AX in wheat meal. Statistically wheat variety, location and their interactions showed a strong influence on AX contents. The varietal differences played a key function to determine the levels of AX in wheat meal and percent EAX in TAX and EAX/UAX ratio. The impact of individual components was much larger than the interaction influence. Crop year was found to be an insignificant source of variation for AX levels.

The weather conditions at the cultivation sites were generally dry with less precipitation. Slightly significant positive influence of minimum temperature and humidity was found in tabulations carried out across the year. While, the maximum temperature and precipitation were found to be correlated negatively with the AX contents across the heading to harvest span of the crop. There is a need to further investigate the environmental influence on AX contents by designing large studies encompassing many types of agro-ecological conditions.

These results may likely add up to the information to increase our understanding of the role of different factors that influence the levels of AX in different wheat varieties. The information on the AX contents, combined with the agronomic response of wheat varieties, may inform the millers and processors about the likely quality of the wheat products. The determination of AX levels can be better utilized for end-use and higher content varieties may gain a premium value in trade. The knowledge of the exact role of genotypic variation in determining AX contents can be instrumental to motivate the breeders to work on the wheat varieties with high AX contents.

References

Arif, S., M. Ahmed, Q. Chaudhry and A. Hasnain. 2018. Effects of water extractable and unextractable pentosans on dough and bread properties of hard wheat cultivars. *LWT - Food Sci. Technol.*, 97: 736-742.

Barron, C., A. Surget and X. Rouau. 2007. Relative amounts of tissues in mature wheat (*Triticum aestivum* L.) grain and their carbohydrate and phenolic acid composition. *J. Cereal Sci.*, 45(1): 88-96.

Biliaderis, C.G. and O. Rattan. 1995. Effect of arabinoxylans on bread-making quality of wheat flours. *Food Chem.*, 53(2): 165-171.

Buksa, K., A. Nowotna, W. Praznik, H. Gambus, R. Ziobro and J. Krawontka. 2010. The role of pentosans and starch in baking of wholemeal rye bread. *Food Res. Int.,* 43(8): 2045-2051.

Carpita, N.C. and D.M. Gibeaut. 1993. Structural models of primary cell walls in flowering plants: Consistency of molecular structure with the physical properties of the walls during growth. *The Plant J.*, 3(1): 1-30.

Ciccoritti, R., G. Scalfati, A. Cammerata and D. Sgrulletta. 2011. Variations in content and extractability of durum wheat (*Triticum durum*) arabinoxylans associated with genetic and environmental factors. *Int. J. Mol. Sci*., 12(7): 4536-4549.

Courtin, C. and J.A. Delcour. 2002. Arabinoxylans and endoxylanases in wheat flour bread-making. *J. Cereal Sci.*, 35(3): 225-243.

Dexter, J.E. and K.H. Tipples. 1987. Wheat milling at grain research laboratory. *2. Milling*, 180(70): 16: 18-20.

Dornez, E., K. Gebruers, I.J. Joye, B. De Ketelaere, J. Lenartz, C. Massaux, B. Bodson, J.A. Delcour and C.M. Courtin. 2008. Effects of genotype, harvest year and genotype-by-harvest year interactions on arabinoxylan, endoxylanase activity and endoxylanase inhibitor levels in wheat kernels. *J. Cereal Sci.*, 47(2): 180-189.

Faurot, A.L., L. Saulnier, S. Bérot, Y. Popineau, M.D. Petit, X. Rouau and J.F. Thibault. 1995. Large scale isolation of water-soluble and water-insoluble pentosans from wheat flour. *LWT - Food Sci. Technol.*, 28(4): 436-441.

Finnie, S., A. Bettge and C. Morris. 2006. Influence of cultivar and environment on water-soluble and water-insoluble arabinoxylans in soft wheat. *Cereal Chem*., 83(6): 617-623.

Gebruers, K., E. Dornez, Z. Bedõ, M. Rakszegi, A. Frás, D. Boros, C.M. Courtin and J.A. Delcour. 2010. Environment and genotype effects on the content of dietary fiber and its components in wheat in the health grain diversity screen. *J. Agric. Food Chem*., 58(17): 9353-9361.

Goesaert, H., K. Brijs, W. Veraverbeke, C. Courtin, K. Gebruers and J. Delcour. 2005. Wheat flour constituents: How they impact bread quality, and how to impact their functionality. *Trends Food Sci. Tech*., 16(1): 12-30.

Guttieri, M.J., E.J. Souza and C. Sneller. 2008. Nonstarch polysaccharides in wheat flour wire-cut cookie making. *J. Agric. Food Chem*., 56(22): 10927-10932.

Hansen, H.B., C.V. Rasmussen, K.E. Bach Knudsen and Å. Hansen. 2003. Effects of genotype and harvest year on content and composition of dietary fibre in rye (S*ecale cereale*) grain. *J. Sci. Food Agric*., 83(1): 76-85.

Holtekjølen, A., A. Uhlen, E. Bråthen, S. Sahlstrøm and S. Knutsen. 2006. Contents of starch and non-starch polysaccharides in barley varieties of different origin. *Food Chem.*, 94(3): 348-358.

Kaczmarek, R.J., A. Komisarczyk, E. Nebesny and B. Makowski. 2016. The influence of arabinoxylans on the quality of grain industry products. *Eur. Food Res. Technol.*, 242(3): 295-303.

Kaur, A., B. Singh, M.P. Yadav, S. Bhinder and S. Singh. 2021. Isolation of arabinoxylan and cellulose-rich arabinoxylan from wheat bran of different varieties and their functionalities. Food Hydrocolloids. 112: 106287. https://doi.org/10.1016/j.foodhyd.2020.106287.

Kiszonas, A.M., E.P. Fuerst and C.F. Morris. 2013. Wheat arabinoxylan structure provides insight into function. *Cereal Chem.,* 90(4): 387-395.

Lempereur, I., X. Rouau and J. Abecassis. 1997. Genetic and Agronomic variation in arabinoxylan and ferulic acid contents of durum wheat (*Triticum durum* L.) grain and its milling fractions. *J. Cereal Sci.*, 25: 103-110.

Li, S., C.F. Morris and A.D. Bettge. 2009. Genotype and environment variation for arabinoxylans in hard winter and spring wheats of the us pacific northwest. *Cereal Chem*., 86(1): 88-95.

Mikyska, A., J. Prokes, D. Haskova, P. Havlova and M. Polednikova. 2002. Influence of the species and cultivation area on the pentosan and beta-glucan content in barley, malt and wort. *Monatsschr. Brauwiss.,* 55(5/6): 88-97.

Molina, M.T., L. Lamothe, D.Z. Gunes, S.M. Vaz and P. Bouchon. 2021. The Effect of Arabinoxylan and Wheat Bran Incorporation on Dough Rheology and Thermal Processing of Rotary-Moulded Biscuits. *Foods.,* 10(10): 2335. https://doi.org/10.3390/foods10102335.

Ramseyer, D.D., A.D. Bettge and C.F. Morris. 2011. Distribution of total, water-unextractable, and water-extractable arabinoxylans in wheat flour mill streams. *Cereal Chem*., 88(2): 209-216.

Saeed, F., I. Pasha, F.M. Anjum and J.I. Sultan. 2011. Water-extractable arabinoxylan content in milling fractions of spring wheats. *CyTA J. Food*, 9(1): 43-48.

Saeed, F., I. Pasha, F.M. Anjum, J.I. Sultan and M. Arshad. 2014. Arabinoxylan and arabinogalactan content in different spring wheats. *Int. J. Food Prop.,* 17(4): 713-721.

Saulnier, L., P.E. Sado, G. Branlard, G. Charmet and F. Guillon. 2007. Wheat arabinoxylans: Exploiting variation in amount and composition to develop enhanced varieties. *J. Cereal Sci*., 46(3): 261-281.

Shewry, P.R., V. Piironen, A.M. Lampi, M. Edelmann, S. Kariluoto, T. Nurmi, R. Fernandez-Orozco, C. Ravel, G. Charmet and A.A.M. Andersson. 2010. The healthgrain wheat diversity screen: Effects of genotype and environment on phytochemicals and dietary fiber components. *J. Agric. Food Chem*., 58(17): 9291-9298.

Sinha, A.K., V. Kumar, H.P. Makkar, G. De Boeck and K. Becker. 2011. Non-starch polysaccharides and their role in fish nutrition–A review. *Food Chem.*, 127(4): 1409-1426.

Turner, M.A., C.H.N. Soh, N.K. Ganguli and M.J. Sissons. 2008. A survey of water-extractable arabinopolymers in bread and durum wheat and the effect of water-extractable arabinoxylan on durum dough rheology and spaghetti cooking quality. *J. Sci. Food Agric*., 88(14): 2551-2555.

Wang, M., H.D. Sapirstein, A.S. Machet and J.E. Dexter. 2006. Composition and distribution of pentosans in millstreams of different hard spring wheats. *Cereal Chem*., 83(2): 161-168.

(Received for publication 11 January 2021)