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ORIGINAL PAPER

ELEMENTAL COMPOSITION AND NUTRITIONAL CHARACTERISTICS OF SPELT FLOURS AND WHOLEMEALS*

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Abstract

Spelt (*Triticum spelta*) is an ancient wheat that has become a popular raw material for bakery products in the last decade owing to its unique nutritional value. In this study, the elemental and nutritional characteristics were investigated in flours and wholemeals from eleven genetic resources of spelt. Hulled and cleaned spelt grains were analysed for thousand-grain weight (TGW), grain length, and grain width characteristics. Spelt flours and wholemeals were prepared in two laboratory mills and characterised for multi-element composition, protein, total arabinoxylan (TOT-AX) and water-extractable arabinoxylan content (WE-AX). A total of twelve elements belonging to macro- (K, P, Mg, S, Ca) and micro- (Na, Fe, Mn, Zn, Mo, Cu, Cr) elements were determined. The highest coefficient of variation was found for Zn, Na and Cu in flour and for Cr, Na and WE-AX in wholemeal. Proteins ranged from 13.3-21.1%, TOT-AX from 11.4-37.3%, and WE-AX from 4.3-8.0%. Highly significant differences between spelt genetic resources were found for WE-AX, S, Na and TKW and between fractions for all macroelements, Fe, Mn, Zn, Cu, TOT-AX and WE-AX. A very strong positive Pearson correlation (>0.80) between flour and wholemeal was found for P, Zn, WE-AX and four pairs of compositional traits (P-Cu, Zn-P, Zn-Cu, protein-S). The study showed that spelt wholemeal is a higher source of minerals (K, P, Mg, Fe, Mn, Zn) and dietary fibre (total arabinoxylans) compared to spelt flour.

Keywords: *Triticum spelta*, spelt wheat, elements, protein, ICP-MS, fraction, arabinoxylan

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INTRODUCTION

Spelt (*Triticum spelta*) is an ancient hulled wheat species that is attracting new interest owing to its nutritional benefits and the increasing demand for whole grain products in diets (Magistrali et al. 2020). In recent years, interest in spelt cultivation has increased, especially in Germany, Austria, Switzerland and the United States because it is a low-input crop suitable for pesticide-free cultivation in organic production systems (Lacko-Bartošová et al. 2010, Wang et al 2021). Due to the increasing importance of dietary diversification and consumption of locally grown foods, many major retailers now offer spelt products grown according to organic and sustainable farming standards (Escarnot et al. 2015). The disadvantages of spelt cultivation include its susceptibility to lodging and the fact that it is not adapted to mechanical harvesting, as its production requires an additional step of grain hulling (Dolijanović et al. 2022).

Compared to wheat, spelt plants are much taller and have a long, loose spike with a brittle rachis and firm glumes (Zanetti et al. 2001). The glumes are a noticeable resistance of the grain to external factors and a natural protective barrier against diseases, pests, heavy metals or pesticide residues (Sobczyk et al. 2017). Spelt causes significant difficulties in harvesting and processing the grain due to the hulled caryopses. Before starting the technological process, the spelt grains must be freed from the glumes using husking devices, hullers or adequately adjusted shellers (Belcar et al. 2020). Milling of cereal grains is probably the oldest manufacturing process in the world and many specific techniques are used in the food industry, such as dry or wet milling with stones and rollers (Cappelli et al. 2020).

From the nutritional perspective, spelt is often considered a healthier grain compared to modern wheat varieties (Bodroža Solarov, Filipčev 2020). According to studies, spelt grains have higher protein and lipid content, more favourable fatty acid profile, different resistant starch, and higher mineral (Mg, P, Fe, Cu, Zn) and antioxidant content than modern wheat varieties (Escarnot et al. 2010, Polonskiy et al. 2020, Tóth et al. 2022). Wheat and cereals, including spelt, are the most important sources of dietary fiber in the human diet, so the development of high-fiber cereal genotypes has received considerable attention in the last decade (Tremmel-Bede et al. 2020). The main components of dietary fibre are arabinoxylan (AX) and β-glucan, which account for 70% and 20%, respectively, of the total cell-wall polysaccharides in the starchy endosperm (Tremmel-Bede et al. 2017). AX and β-glucan occur in both soluble and insoluble forms, which may differ in their health benefits, while AX also affects processing properties such as breadmaking (Rakszegi et al. 2014).

The aim of the present study was to investigate the elemental and nutritional differences in the grains and two different processed fractions (flour, wholemeal) from different genetic resources of spelt.

MATERIAL AND METHODS

Genetic resources of spelt (*Triticum spelta*) were grown in Hungary and selected for this study based on their different quality characteristics for bread production (Tóth et al. 2022). As shown in Table 1, a set of eleven genetic resources included two breeding lines (BA7423, TSP06-10), three varieties (MV-Martongold, MV-Vitalgold, Weihenstepan), and six genebank accessions (MVGB139, MVBG142, MVGB144, MVGB308, MVGB529, MVGB557) with different morphological characteristics in terms of spyke type (awn/awnless) and colour of spike (red/white/grey). Plants were grown in 2018, in small plots at the Agricultural Institute of the Centre for Agricultural Research in Martonvásár, Hungary (47°03′N, 18°08′E; 115 m a.s.l.). Plots were 4 m × 1.2 m and contained six rows spaced 20 cm apart. Each genetic resource of spelt was sown in two replicates. An established field management system for spelt cultivation was used in the field, where oil-radish had been grown previously (Tóth et al. 2022). Threshing of the harvested spelt grains was done with a Wintersteiger LD350 (Wintersteiger AB, Arnstadt, Germany), while a Haldrup DC-20 (Haldrup GmbH, Ilshofen, Germany) was used for cleaning. The share of spelt glumes ranged from 21.2% to 47.1% (Table 1).

The thousand-grain weight (TGW), grain length (R-Length) and grain width (R-Width) were determined using the Marvin system (MarviTech GmbH, Germany). Spelt samples were conditioned to a moisture content of 15.5% and milled to flour fraction using a Chopin CD1 Laboratory Mill (Chopin Technologies, France). The flour yields ranged from 51.0% to 63.4% (Table 1). Wholemeal or wholegrain flour fractions were produced using a Perten 3100 laboratory mill (PerkinElmer, Waltham, Massachusetts, US).

Multielement analysis (Na, Mg, P, S, K, Ca, Cr, Mn, Fe, Cu, Zn, Mo) was performed using inductively coupled plasma mass spectrometry (ICP-MS). Prior to determination using a 7900 ICP-MS (Agilent, USA), microwave digestion was performed in an Ethos UP High-Performance System (Milestone, Italy) and each sample was diluted. The calibration curve was prepared using the IV-STOCK-50 standard solution and individual standard solutions of P and S (Inorganic Ventures, USA) were added separately to the mixture. The accuracy of the results was checked using two certified reference materials NIST SRM 1573a Tomato leaves and NIST SRM 1547 Peach leaves (Gaithersburg, MD, USA). All results are quoted on a dry weight basis and are expressed as g kg^{-1} for macroelements or mg kg^{-1} for microelements. Protein content (%) of flour and wholemeal was measured using an Elementar Rapid N III Analyzer (Elementar Analysensysteme GmbH, Germany) according to method ICC 167 (1995). Total arabinoxylan (TOT-AX) and water-extractable arabinoxylan content (WE-AX) were measured colorimetrically according to the method first described by Douglas (1981). Statistics included mean, minimum (Min), maximum (Max), standard deviation (SD),

Table 1

List of the spelt genetic resources (*Triticum spelta*) and their grain characteristics

Sample name	Status	Spike type	Colour of spike	Share of glumes (%)	TGW (g)	R-length (mm)	R-width (mm)	Flour yield (%)
BA7423	breeding line	awnless	red	22.7	33.1	6.9	2.8	64.7
MV-Martongold	variety	awnless	red	34.5	41.6	7.3	3.2	55.7
MV-Vitalgold	variety	awnless	red	37.8	42.6	7.9	3.2	63.3
TSP06-10	breeding line	awnless	red	36.1	38.8	7.4	3.1	57.9
MVGB139	accession	awnless	white	34.3	32.6	7.1	2.8	51.0
MVGB142	accession	awnless	grey	47.1	23.2	6.2	2.6	56.5
MVGB144	accession	awnless	white	30.6	32.8	6.5	3.1	61.1
MVGB308	accession	awnless	white	21.2	40.8	6.5	3.4	63.4
MVGB529	accession	awn	white	36.0	29.9	6.9	2.7	55.6
Weihenstephan	variety	awnless	white	32.9	29.6	6.4	2.9	60.3
MVGB557	accession	awnless	white	35.6	29.6	6.7	2.9	61.6
Mean ± SD				33.5±6.7	34.0±5.9	6.9±0.5	3.0±0.2	59.2±4.0
Min - Max				21.2-47.1	23.2-42.6	6.2-7.9	2.6-3.4	51.0-63.4
CV (%)				20.1	17.2	7.0	7.9	6.8

TGW – thousand-grain weight, R-length – grain length, R-width – grain width, SD – standard deviation, CV – coefficient of variation and coefficient of variation (CV). Least significant differences and correlations were calculated using the Microsoft Excel programme.

RESULTS AND DISCUSSION

This study describes the elemental composition and nutritional traits of spelt flour and wholemeal from the perspective of the genetic resources of the Hungarian breeding programme in relation to their quality characteristics for bread production. In addition to the physical properties of grain size, a total of fifteen parameters (protein, TOT-AX, WE-AX, K, P, Mg, S, Ca, Na, Fe, Mn, Zn, Mo, Cu, Cr) were determined in the spelt flour and wholemeal samples. The grain characteristics of the spelt genetic resources studied are summarised in Table 1. The share of glumes varied considerably among the genetic resources, ranging from 21.2-47.1%, which is comparable to previous reports (Konvalina et al. 2010, Lacko-Bartošová et al. 2010). Grain size parameters included thousand-grain weight (23.2-42.6 g), grain length (6.2-7.9 mm), and grain width (2.6-3.4 mm). Mean thousand-grain weight was 34.0 g, which is slightly less than previous reports (Konvalina et al. 2010, Xie et al. 2015, Hury et al. 2020, Ratajczak et al. 2020). Mean grain length was 6.9 mm and width was 3.0 mm, which is comparable to the results of Oručević Žuljević et al. (2016) for three spelt varieties. In grain size characteristics, the highest coefficients of variation were found for the share of glumes (21.1%) and thousand-grain weight (17.2%). The yield of the flour fraction after milling spelt grains varied from 51.0% to 63.4%, while the wholemeal fraction contained all the milled spelt grains.

The multi-element composition of spelt flour and wholemeal is shown in Table 2. A total of 12 elements were determined in 22 spelt samples, which can be divided into two groups: macroelements (>0.2 g kg^{-1}) K, P, Mg, S and Ca, and microelements (>0.02 mg kg^{-1}) Na, Fe, Mn, Zn, Mo, Cu and Cr (Table 2). The order of these elements in the analysed spelt flour by abundance was: S > K > P > Mg > Ca > Na > Fe > Zn > Mn >Mo > Cu > Cr, and in spelt wholemeal: K > P > S > Mg > Ca > Fe > Mn > Na > Zn >Cu > Mo > Cr. The highest coefficient of variation for macroelements was obtained for P content in flour and wholemeal and was 16.5% and 15.8%, respectively. Among microelements, the highest coefficient of variation was found for Cr in wholemeal (21.1%), followed by Na and Zn in flour (20.3%). Spelt wholemeal contained significantly higher levels of macroelements K, P and Mg, and microelements Fe, Mn and Zn when compared to spelt flour. Żuk-Gołaszewska (2022) reported lower contents of K, Mg Mn and Mo in spelt flours from north-eastern Poland, while Kraska et al. (2013) found higher K and lower Cu and Zn contents in spelt grains.

The nutritional characteristics, i.e. protein content, total arabinoxylan content and water-extractable arabinoxylan content, for spelt flour and

Table 2

Multi-element composition and summary statistics comparing spelt flour and wholemeal

Sample name	Fraction	Macroelement (g kg^{-1})					Microelement (mg kg^{-1})						
		K	P	Mg	S	Ca	Na	Fe	Mn	Zn	Mo	Cu	Cr
BA7423	flour	1.3	0.9	0.2	2.0	0.2	21.7	9.1	4.1	5.4	2.5	1.3	0.28
MV-Martongold	flour	1.2	1.1	0.3	2.1	0.3	21.1	8.7	5.0	6.4	2.6	1.3	0.30
MV-Vitalgold	flour	1.3	1.3	0.3	2.3	0.2	22.2	9.4	5.0	8.9	2.3	1.3	0.29
TSP06-10	flour	1.3	1.2	0.3	2.3	0.2	23.6	10.0	4.3	8.5	2.2	1.2	0.26
MVGB139	flour	1.7	1.3	0.3	2.1	0.2	22.0	10.1	5.1	7.0	2.3	1.4	0.28
MVGB142	flour	1.7	1.3	0.4	2.2	0.2	28.5	12.6	4.5	9.0	2.4	1.7	0.31
MVGB144	flour	1.4	1.0	0.3	2.0	0.2	22.0	9.1	4.5	5.9	2.3	1.2	0.28
MVGB308	flour	1.5	0.8	0.2	1.8	0.3	23.0	8.9	4.2	5.2	2.3	1.0	0.33
MVGB529	flour	1.4	1.0	0.3	2.2	0.2	19.3	9.2	3.6	5.6	2.3	1.3	0.29
Weihenstephan	flour	1.4	0.9	0.2	2.1	0.2	23.8	12.4	4.5	5.9	2.3	2.0	0.34
MVGB557	flour	1.5	1.0	0.2	2.2	0.2	38.0	10.4	3.8	6.1	2.6	1.5	0.31
Mean ± SD		1.4±0.1	1.1±0.2	0.3±0.0	2.1±0.1	0.2±0.0	24.1±4.9	10.0±1.3	4.4±0.5	6.7±1.4	2.4±0.1	1.4±0.3	0.30±0.02
Min - Max		1.2-1.7	0.8-1.3	0.2-0.4	1.8-2.3	0.2-0.3	19.3-38.0	8.7-12.6	3.6-5.1	5.2-9.0	2.2-2.6	1.0-2.0	0.26-0.34
CV (%)		10.2	16.5	14.6	6.4	15.7	20.3	12.9	10.5	20.3	5.9	19.1	7.6

cont. Table 2

Sample name	Fraction	Macroelement (g kg^{-1})					Microelement (mg kg^{-1})						
		K	P	Mg	S	Ca	Na	Fe	Mn	Zn	Mo	Cu	Cr
BA7423	wholemeal	4.2	3.7	1.4	2.1	0.4	29.1	39.2	33.4	18.8	2.5	2.6	0.28
MV-Martongold	wholemeal	4.1	3.9	1.4	2.3	0.4	24.3	43.9	39.6	21.3	2.7	2.8	0.51
MV-Vitalgold	wholemeal	4.5	4.6	1.5	2.5	0.4	33.5	44.0	37.6	24.3	2.5	3.2	0.31
TSP06-10	wholemeal	5.3	5.3	1.8	2.7	0.4	24.7	56.4	43.0	31.2	2.3	3.6	0.31
MVGB139	wholemeal	4.9	4.4	1.6	2.6	0.3	26.7	48.6	34.5	24.8	2.4	3.0	0.36
MVGB142	wholemeal	4.7	4.5	1.6	2.6	0.4	26.7	51.7	31.1	27.1	2.5	3.2	0.33
MVGB144	wholemeal	3.8	3.3	1.2	2.3	0.4	23.7	37.3	27.1	19.6	2.5	2.5	0.24
MVGB308	wholemeal	3.9	2.9	1.1	2.0	0.4	22.6	35.2	28.4	18.3	2.3	2.3	0.37
MVGB529	wholemeal	4.3	3.9	1.5	2.6	0.4	26.0	43.0	30.1	21.1	2.3	2.8	0.31
Weihenstephan	wholemeal	4.5	3.8	1.4	2.4	0.4	26.0	58.1	34.0	21.2	2.5	2.6	0.39
MVGB557	wholemeal	4.4	3.5	1.3	2.4	0.4	39.3	40.6	31.0	20.4	2.4	2.7	0.26
Mean ± SD		4.4±0.4	4.0±0.6	1.4±0.2	2.4±0.2	0.4±0.0	27.5±4.7	45.3±7.2	33.6±4.6	22.6±3.8	2.5±0.1	2.9±0.3	0.33±0.07
Min - Max		3.8-5.3	2.9-5.3	1.1-1.8	2.0-2.7	0.3-0.4	22.6-39.3	35.2-58.1	27.1-43.0	18.3-31.2	2.3-2.7	2.3-3.6	0.24-0.51
CV (%)		9.6	15.8	13.3	8.7	7.3	17.0	16.0	13.8	16.7	4.6	12.2	21.1

SD – standard deviation, CV – coefficient of variation wholemeal are shown in Table 3. The protein content of spelt flour ranged from 13.3-18.5% and that of spelt wholemeal ranged from 15.0-21.1%. Protein content is an important parameter for grain quality in breeding programmes and is related to gluten content, which allows prediction of industrial quality (Lacko-Bartošová et al. 2020). In general, all spelt wholemeal

Table 3

Nutritional characteristics and summary statistics comparing spelt flour and wholemeal

Sample name	Fraction	Protein (%)	TOT-AX (mg g^{-1})	WE-AX (mg g^{-1})
BA7423	flour	16.37	13.79	4.64
MV-Martongold		15.83	15.10	5.52
MV-Vitalgold		17.09	15.45	5.52
TSP06-10		16.85	15.43	5.18
MVGB139		17.14	16.00	6.56
MVGB142		18.52	15.62	5.87
MVGB144		16.11	14.15	4.80
MVGB308		13.33	14.13	7.99
MVGB529		17.71	13.19	6.89
Weihenstephan		16.10	11.46	5.80
MVGB557		16.89	11.43	5.42
Mean ± SD		16.5±1.3	14.2±1.5	5.8±0.9
Min - Max		13.3-18.5	11.4-16.0	4.6-8.0
CV (%)		7.6	10.8	16.0
BA7423	wholemeal	17.12	31.31	4.28
MV-Martongold		17.76	33.53	5.01
MV-Vitalgold		19.27	30.93	5.25
TSP06-10		18.97	30.03	4.92
MVGB139		14.97	29.87	6.05
MVGB142		21.12	34.76	5.92
MVGB144		18.31	34.88	4.46
MVGB308		15.33	37.26	7.71
MVGB529		20.15	33.87	6.44
Weihenstephan		18.11	35.08	5.61
MVGB557		18.90	32.26	5.26
Mean ± SD		18.2±1.8	33.1±2.3	5.5±0.9
Min - Max		15.0-21.1	29.9-37.3	4.3-7.7
CV (%)		9.8	6.8	16.8

TOT-AX – total arabinoxylan content, WE-AX – water-extractable arabinoxylan content, SD – standard deviation, CV – coefficient of variation samples, with exception of MVGB139, contained slightly higher protein content compared to spelt flours. The total arabinoxylan content in spelt flour ranged from 11.4-16.0% and in spelt wholemeal from 29.9-37.3%, while the water-extractable arabinoxylan content ranged from 4.6-8.0% and 4.3-7.7%, respectively. The total arabinoxylan content (TOT-AX) was significantly higher in spelt wholemeal than in the flour fraction, while no differences were found in the water-extractable arabinoxylan (WE-AX) content. Shewry et al. (2013) found slightly lower contents of WE-AX in five lines of spelt flour and bran (0.30-0.45%), comparable contents of TOT-AX in spelt flour (1.60-2.15%), and significantly higher contents of TOT-AX in spelt bran (11.1-13.9%) compared to our data.

Least Significant Difference (LSD) results in Table 4 show large differences between spelt genetic resources and spelt milling fractions (flour vs. wholemeal). Highly significant differences between the spelt genetic resources studied were found for water-extractable arabinoxylan and very significant differences for S, Na and thousand-grain weight. In addition, significant differences were found for Ca, Zn, Mo and protein content. When spelt milling fractions were compared, highly significant differences were found between flour and wholemeal for all macroelements, Fe, Mn, Zn, Cu, total and water-extractable arabinoxylan content, very significant differences for protein content, and significant for Na and Mo. The matrix of the 15 variables for the 22 spelt samples, i.e. flour vs. wholemeal, was evaluated using Pearson's rank correlation coefficients up to a significance of $p<0.05$ (Table 5). A very strong positive significant correlation (>0.80) between spelt flour and wholemeal was found for P (0.85), Zn (0.87), WE-AX (0.99) and four pairs of compositional traits P-Cu (0.85), Zn-P (0.86), Zn-Cu (0.91) and protein-S (0.83). In addition, strong positive significant correlations (>0.68) were observed for Mg, S, Na, Fe, protein and ten pairs of compositional traits: P-Mg, P-S, Mg-S, Mg-Zn, Mg-Cu, S-Cu, Zn-K, Zn-S, Cr-TOT-AX and protein-Mg. A very high correlation was previously observed for protein with S and P with Cu in spelt under Mediterranean climate (Curzon et al. 2021).

CONCLUSIONS

This study provides the first overview of the multi-elemental composition and nutritional characteristics of spelt flour and wholemeal of most prospective genetic resources of the Hungarian breeding programme, based on their quality characteristics for bread production. Spelt wholemeal was richer in macroelements K, P and Mg, microelements Fe, Mn and Zn, protein and total arabinoxylan content than spelt flour. Significant differences between spelt genetic resources were found for water-extractable arabinoxylan, S, Na and thousand-grain weight and between milling fractions (flour vs. whole-

Table 4

LSD summary statistics

Parameter	Macroelement					Microelement							TGW	Protein	TOT-AX	WE-AX
	K	P	Mg	S	Ca	Na	Fe	Mn	Zn	Mo	Cu	Cr				
LSD5% $_{\text{genetic resource}}$	0.29	0.34	0.12	0.10	0.02	2.56	4.49	3.12	1.88	0.08	0.30	0.05	4.10	9.10	2.21	0.11
LSD5% $_{\text{fraction}}$	1.33	1.56	0.52	0.43	0.09	11.60	20.31	14.13	8.48	0.34	1.34	0.21	/	41.00	10.00	0.51
Genetic resource	n.s.	n.s.	n.s.	**	*	**	n.s.	n.s.	*	*	n.s.	n.s.	**	*	n.s.	***
Fraction	***	***	***	***	***	*	***	***	***	*	***	n.s.	/	**	***	***

n.s. – not significant; *, **, *** – significant at 0.05, 0.01 and 0.001 probability level, TGW – thousand-grain weight, TOT-AX – total arabinoxylan content, WE-AX – water-extractable arabinoxylan content

Table 5

Correlation between the compositional characteristics of spelt flour and wholemeal

Wholemeal	Flour														
	K	P	Mg	S	Ca	Na	Fe	Mn	Zn	Mo	Cu	Cr	potein	TOT-AX	WE-AX
K	0.24	0.65	0.55	0.64	-0.11	0.18	0.49	0.18	0.69	-0.25	0.30	-0.31	0.56	0.30	-0.15
P	-0.01	0.85	0.73	0.74	-0.15	-0.08	0.29	0.40	0.86	-0.24	0.15	-0.51	0.65	0.55	-0.29
Mg	0.06	0.79	0.73	0.74	-0.11	-0.05	0.31	0.23	0.78	-0.21	0.17	-0.50	0.71	0.49	-0.22
S	0.34	0.77	0.80	0.77	-0.16	0.11	0.40	0.12	0.71	-0.26	0.24	-0.37	0.83	0.32	-0.09
Ca	-0.15	-0.65	-0.51	-0.15	0.61	0.23	0.08	-0.68	-0.41	0.07	0.08	0.59	-0.37	-0.58	0.43
Na	0.04	0.10	-0.05	0.62	-0.09	0.71	0.12	-0.18	0.15	0.54	0.22	-0.01	0.35	-0.37	-0.31
Fe	0.07	0.51	0.42	0.44	-0.25	0.01	0.71	0.28	0.54	-0.23	0.67	0.06	0.45	0.08	-0.15
Mn	-0.47	0.54	0.29	0.49	-0.01	-0.17	-0.05	0.48	0.54	0.01	0.02	-0.42	0.17	0.39	-0.33
Zn	0.18	0.81	0.74	0.64	0.03	0.04	0.38	0.32	0.87	-0.34	0.12	-0.42	0.55	0.56	-0.17
Mo	-0.35	0.21	0.03	-0.09	-0.18	0.00	0.09	0.52	0.05	0.67	0.34	0.12	0.05	0.09	-0.47
Cu	0.02	0.85	0.74	0.77	0.01	0.06	0.26	0.32	0.91	-0.19	0.06	-0.52	0.62	0.56	-0.30
Cr	-0.21	0.10	0.09	-0.23	0.31	-0.30	-0.01	0.52	-0.01	0.23	0.17	0.34	-0.28	0.22	0.29
Protein	-0.10	0.36	0.39	0.67	-0.01	0.26	0.39	-0.26	0.48	0.09	0.32	-0.04	0.69	-0.09	-0.34
TOT-AX	0.13	-0.56	-0.34	-0.62	0.38	-0.01	0.14	-0.27	-0.44	-0.07	0.10	0.75	-0.48	-0.35	0.46
WE-AX	0.55	-0.25	0.07	-0.29	0.62	-0.05	0.08	-0.17	-0.16	-0.36	-0.09	0.55	-0.33	0.00	0.99

r 5% – 0.55, *r* 1% – 0.68, *r* 0.1% – 0.80, shown by light grey, grey and dark grey, respectively, TOT-AX – total arabinoxylan content, WE-AX – water-extractable arabinoxylan content meal) for most nutritional traits studied except for the microelement Cr. The tested genetic resources of spelt show great potential for organic cultivation and use in breeding programmes as genetic resources for the development of healthy foods of the future.

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