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ORIGINAL PAPER

NUTRITIONAL PROPERTIES OF ORGANIC SPELT WHEATS IN DIFFERENT GROWTH STAGES AND THE RESULTING FLOURS*

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Abstract

The content of selected nutrients was determined in immature grain (IG) and mature grain (MG) of seven organically grown spelt cultivars, as well as in the resulting flours (F). A common wheat cultivar was used as a reference. The examined spelt grain and flours were more abundant in protein than common wheat, but they contained a similar amount of exogenous and endogenous amino acids to common wheat. The protein profile of spelt IG was characterized by a higher concentration of essential amino acids in comparison with MG and F. Spelt cultivars also contained more ash, nitrogen, phosphorus, magnesium, calcium, copper, iron, and zinc. With the exception of selenium, the content of all minerals was higher in IG and MG than in F samples, but significant differences were noted only in the content of ash and potassium, which was higher in IG samples. Both IG and MG were more abundant in micronutrients than F samples. IG and MG samples contained more lipids and unsaturated oleic acid than common wheat products. Common wheat grain had higher tocopherol and vitamin levels, although spelt cultivars varied considerably in this respect, and tocopherol and vitamin concentrations were both significantly lower and comparable with the values noted in common wheat. The study demonstrated that organically grown IG of both common wheat and spelt wheat is a source of wheat products with high nutritional value.

Keywords: spelt wheat, common wheat, nutritional value, macronutrients and micronutrients.

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INTRODUCTION

The nutritional value of wheats can be attributed to the interactions between wheat metabolites and other food components. The unique nourishing value of spelt-based products has led to the rediscovery of this ancient species as a source of healthy food. Products made from spelt wheat are considered as functional foods that make a valuable contribution to a balanced and varied diet (Podolska et al. 2020). As of 2017, the value of the global market of functional foods was estimated at USD 299.32 billion, and it is projected to reach USD 441.56 billion by the end of 2022 (Statista 2019). Functional foods contain biologically active compounds that promote health benefits as well as physical and mental wellbeing. Plant-based components with functional properties include proteins, amino acids, macronutrients, micronutrients, fatty acids, tocopherols, and vitamins (Lafiandra et al. 2014, Shewry, Hey 2015). In comparison with common wheat grain, spelt grain is more abundant in protein and mineral elements and is characterized by higher digestibility, as well as higher nutritional and biological value (Abdel-Aal et al. 1995, Tyburski, Żuk-Gołaszewska 1995). Cereal grains abound in valuable bioactive compounds, including tocopherols that are commonly found in oilseeds (Becker 2013). These compounds exhibit vitamin E activity and therefore they are essential in the human diet. The composition of bioactive compounds in cereals depends on the production technology, including fertilizer type (Antonkiewicz et al. 2019). The concentrations of bio-based nutrients, i.e. phosphorus and magnesium, are significantly higher in non-organically than organically grown wheat varieties (Koivistoinen et al. 1974). However, very high concentrations of mineral elements were found in the grain of organically grown ancient wheat genotypes (Hussain et al. 2010). The nutritional value of wheat grain is influenced by grain maturity and the degree of processing. Wheat grain is usually consumed in the form of:

(i) whole grain products composed of premature and mature grain, whose nutritional value can be attributed to the presence of three grain layers: bran (e.g. fiber, omega-3 fatty acids, vitamins, mineral elements), endosperm (mostly starch), and embryo/germ (e.g. protein, E and B group vitamins, mineral elements);
(ii) baked products made from wheat flour or meal, whose nutritional value is determined by baking materials (wholemeal flour);
(iii) milled grain products made mostly from starchy endosperm,
(iv) beverages made directly from grain or from starch by fermentation.

In the conventional milling process, the bran and germ portions are mostly removed because their composition can affect baking quality and consumer acceptability. However, bran and germ are important sources of biologically active compounds and can be used to (bio)fortify the human diet (Żuk-Gołaszewska et al. 2016). The demand for spelt-based products, such as bread, biscuits, groats, flakes, grain coffee and alcoholic beverages, continues to increase. Spelt bread has a pleasant aroma and a long shelf-life (Mikos, Podolska 2012). The health-promoting properties of immature spelt grain harvested in the late milk to the soft dough stage are increasingly recognized in the grain processing industry. For example, freekeh is a cereal food made of green durum wheat (*Triticum turgidum* var. *durum*) that has been consumed in the Middle East for centuries. Immature grain contains unripe endosperm, and starch is synthesized and accumulated in the endosperm by harvest. In terms of nutrition, immature grain contains all essential nutrients, but it is not yet filled with starch. Immediately after harvest, grain is dried and dehulled (Tyburski, Żuk-Gołaszewska 1995, Musselman, Mouslem 2001, Al-Mahasneh, Rababah 2007). Immature grain has a higher content of total reducing sugars and sucrose than mature grain, which contributes to its pleasant, sweet taste (Yang et al. 2012).

A well-balanced diet contributes to overall health and well-being, which is why new research is being done to expand our knowledge about the functional properties and nutritional value of spelt-based foods. The aim of this study was to determine the nutritional value of organic winter spelt grain in different stages of growth and the nutritional value of the resulting flours relative to a common wheat cultivar. The content of protein, amino acids, ash, minerals, fatty acids, tocopherols, and B vitamins was analyzed in immature grain, mature grain and the resulting flours to determine similarities in the nutritional value of organically grown common wheat and spelt wheat grain.

MATERIALS AND METHODS

Materials

The experimental material consisted of immature and mature grain of winter spelt grown in an organic farm in north-eastern Poland. Seven winter spelt cultivars were investigated: Schwabenspeltz (Shz), Schwabenkorn (Shn), Frankenkorn (Fra), Ceralio (Cer), Holstenkorn (Hol), Ostro (Ost), and Oberkulmer Rothkorn (ObR). A winter cultivar of common wheat, Korweta (Kor), was the reference (Żuk-Gołaszewska et al. 2018). Immature grain (IG) and mature grain (MG) of winter spelt and common wheat, and the resulting flours (F) were analyzed. Flour (refined) was produced by grinding grain in a Brabender Quadrumat Junior (Germany) laboratory mill. The moisture content of grain and flour samples was adjusted to 13%.

Immature grain was harvested between the medium milk stage (Z75) and the late milk stage (Z78), when solid components can be clearly seen in the liquid endosperm of squeezed grain (Zadoks et al. 1974). Immature grain was harvested at a stage when squeezed grain did not produce milky exudate. Grain can be easily separated from the glumes in this growth stage. After harvesting, grain was immediately dried (multi-purpose dryer with forced air circulation; Binder GmbH, FED720, Germany) in four stages: (1) grain was gradually heated to a temp. of 50-75°C (rapid heating causes undesirable browning of grain) for approximately 1 h; (2) temp. was increased to 130°C and maintained for 2-3 h; (3) in the last drying stage, temp. was lowered to 60-40°C for 1 h; (4) grain was cooled by controlling the temperature inside the heater. In the last drying stage, grain was cooled for approximately 1 h until the achievement of the desired moisture content (12-13%) to prevent spoilage during storage (Bornebusch 1994). Dried grain was ground using a laboratory mill.

Determination of protein, amino acid, ash, and mineral elements

Nitrogen content was determined by the Kjeldahl method, and a conversion factor of 5.7 was applied to determine protein content (%). The content of 18 amino acids in wheat proteins was determined using a high-performance amino acid analyzer equipped with a 20-cm column (Beckman, model 6300, USA). After hydrolysis, the samples were transferred to measuring flasks according to the procedure described by Dixon-Phillips (1983). Tryptophan was determined colorimetrically based on the method proposed by Opienska-Blauth et al. (1963). Ash content (%) was determined in a gravimetric analysis and expressed on a dry weight basis. In the mineral analysis, ground samples were wet-mineralized in concentrated sulfuric acid with hydrogen peroxide as the oxidant. The content of mineral elements was determined according to Polish Industry Standards (PN-EN ISO 6869, 2002).

Determination of fatty acid and B vitamin content

Fatty acid composition was determined by a modified chromatographic separation method described by Żegarska et al. (1991). Chromatographic separation was carried out using a Varian CP-3800 chromatograph with a flame-ionization detector and a capillary column with a length of 5 m and an internal diameter of 0.25 mm. The liquid phase was Cp-Sil 88, and film thickness was 0.25 μm. Detector temp. was 250°C, injector temperature was 200°C, and column temp. was 50°C to 200°C. The carrier gas was helium with a flow rate of 1.2 ml min^{-1}. The injector had a split ratio of 50:1. The content of α-, β-, γ- and δ-tocopherol was determined according to the method proposed by McMurray and Blanchflower (1979). The concentrations of B_1, B_2, B_3 and B_6 vitamins were determined in mature grain according to the method described by Prodanov et al. (1997).

Statistical analysis

The results were analyzed using descriptive statistics and two-way ANOVA (cultivars, type of wheat product). Mean values were compared in the Tukey's HSD test at a significance level of p<0.01.

RESULTS AND DISCUSSION

Spelt has a high nutritional value, and it contains all chemical constituents that are essential in the human diet, including proteins, mineral elements, lipids, and vitamins (Bojňanská, Frančáková 2002). In the present study, the protein content of immature (IG) and mature common wheat grain (MG) and the resulting flours (F) was determined at 9.7%, 10.6%, and 9.6%, respectively (Table 1). The average protein content of spelt cultivars was higher at 23-25%, and no significant differences were noted between the compared wheat products. The differences in the protein content of spelt cultivars and the common wheat reference cultivar (cv. Korweta) are presented in Figure 1. In comparison with common wheat, the greatest differences

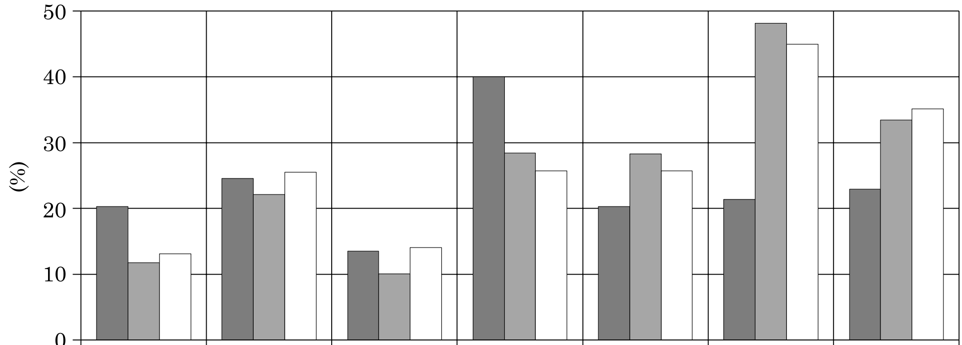
Table 1

The protein content (%) of spelt cultivars and the common wheat reference

Wheat products	Spelt cultivars							Average for spelt	Common wheat (Kor)
	Cer	Shn	Fra	Hol	Shz	Ost	ObR		
IG	11.7	12.1	11.0	13.6	11.7	11.8	11.9	12.0[a]	9.7[b]
MG	11.8	12.9	11.6	13.6	13.5	15.6	14.1	13.3[a]	10.6[b]
F	10.8	12.0	10.9	12.0	12.0	13.9	12.9	12.1[a]	9.6[b]

[a, b, c] homogenous groups in Tukey's HSD test at $p<0.01$

Symbols: IG – immature grain, MG – mature grain, F – flour, common wheat cultivar: Kor – Korweta, spelt wheat cultivars: Shz – Schwabenspeltz, Shn – Schwabenkorn, Fra – Frankenkorn, Cer – Ceralio, Hol – Holstenkorn, Ost – Ostro, and ObR – Oberkulmer Rothkorn.



	Cer	Shn	Fra	Hol	Shz	Ost	ObR
IG	20.3	24.5	13.5	40.0	20.3	21.3	22.9
MG	11.8	22.1	10.0	28.4	28.2	48.2	33.5
F	13.1	25.5	14.0	25.7	25.7	45.0	35.1

Fig. 1. Surplus protein (%) in immature and mature grain (IG, MG) of spelt cultivars and the resulting flours (F) relative to common wheat cv. Korweta

in protein content were observed in the immature grain of spelt cv. Holstenkorn (40.0% higher) and cv. Schwabenkorn (32.8% higher), and in the mature grain and flour of spelt cv. Ostro (48.2% and 45.0% higher, respectively), and cv. Oberkulmer Rothkorn (33.5% and 35.1% higher, respectively). In the group of the analyzed spelt cultivars, cvs. Ceralio and. Frankenkorn were characterized by similar protein content to common wheat (Table 1).

The quality of dietary proteins should be evaluated in terms of the protein digestibility corrected amino acid score by comparing the content of the first limiting amino acid in the analyzed material and the reference (Livesey 1987). Premature green grain and mature yellow grain of common wheat had similar protein content, but this parameter differed across the spelt cultivars and was highest in mature yellow grain of cv. Ostro (by 15.6%) and cv. Oberkulmer Rothkorn (by 14.1%) (Table 1). Similar results were reported by other authors (Marconi et al. 1999, Abdel-Aal, Hucl 2002, Escarnot et al. 2012). In a study on six spelt cultivars, the protein content was the highest in cv. Spelt I.N.Z. and cv. Schwabenkorn (155 mg g^{-1}), and lowest in cv. Ceralio (98 mg g^{-1}) – Świeca et al. (2014). In all tested wheat products, the total content of exogenous amino acids was somewhat higher in common wheat than in spelt (by 2.6% in IG and MG, and by 2.9% in F) – Table 2. The total content of endogenous amino acids was similar in common wheat and spelt, and the analyzed parameter was only somewhat higher (by 2%) in spelt MG and F.

The relative differences in the amino acid composition of spelt and common wheat are presented in Figure 2. In both wheat species, the dominant exogenous amino acids were leucine (7.6 vs. 7.7 mg 100 g^{-1} protein in common wheat and spelt, respectively), valine (5.1 vs. 5.0 mg 100 g^{-1} protein in common wheat and spelt, respectively), and phenylalanine (4.8 vs. 5.0 mg

Table 2

Total content of exogenous and endogenous amino acids (mg 100 g^{-1}) in immature grain, mature grain and the resulting flours of spelt cultivars and the common wheat reference

Wheat products/ Amino acids	Spelt cultivars							Average for spelt	Common wheat-Kor
	Cer	Shn	Fra	Hol	Shz	Ost	ObR		
Exogenous amino acids									
IG	38.8	38.9	40.5	38.2	38.0	40.0	38.2	38.9	39.9
MG	38.4	39.1	39.7	38.1	37.6	38.3	38.6	38.5	39.5
F	37.4	37.5	37.8	37.8	38.5	36.8	37.7	37.6	38.7
Endogenous amino acids									
IG	67.3	64.8	64.3	65.1	63.9	68.0	65.0	65.5	65.7
MG	65.9	66.5	64.2	66.1	65.4	66.8	65.9	65.8	64.7
F	68.9	68.7	66.9	68.8	69.0	68.1	69.8	68.6	67.9

Symbols: see Table 1.

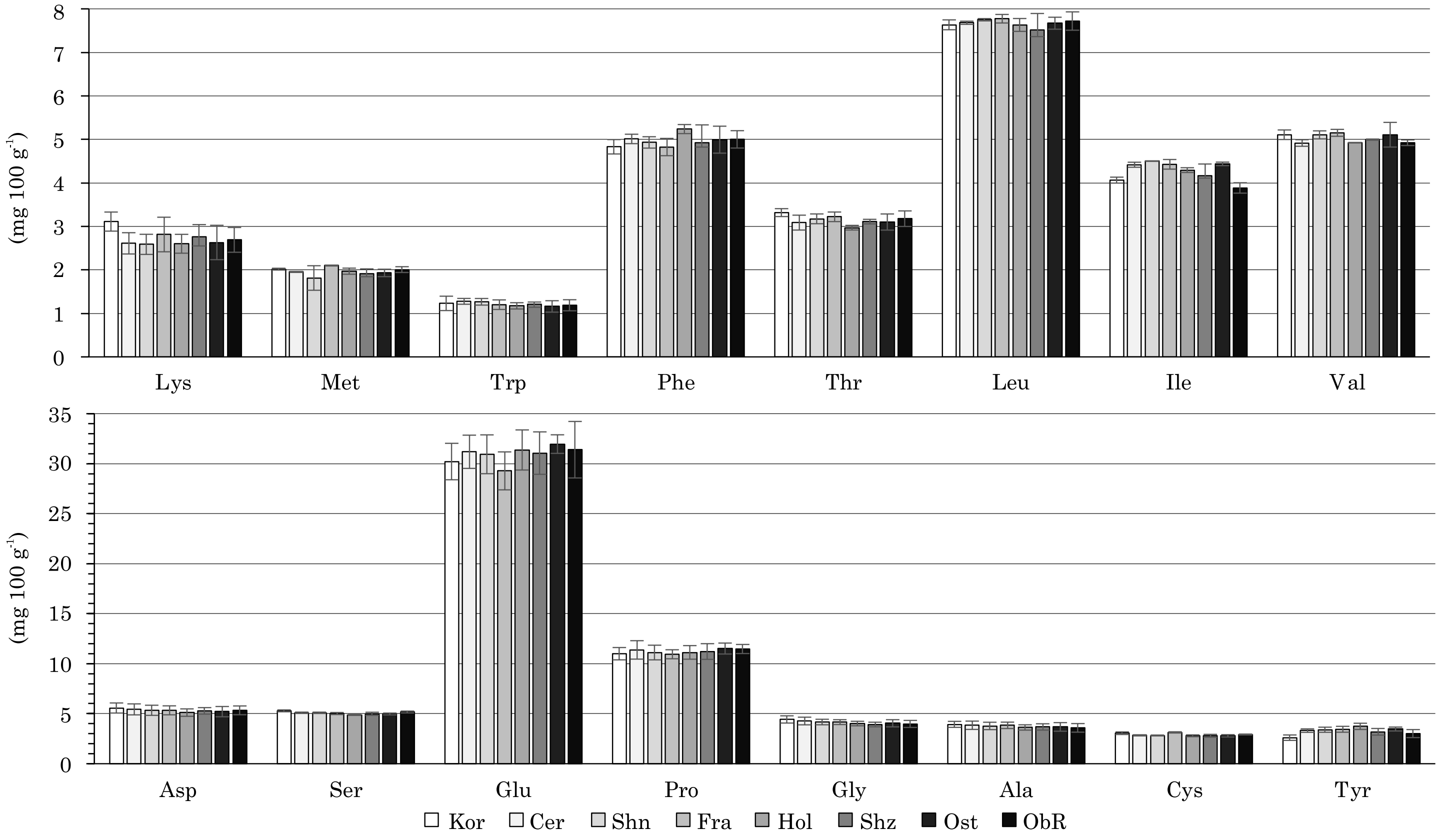


Fig. 2. Relative differences between the average content of exogenous (above) and endogenous (below) amino acids in spelt cultivars and common wheat (mean ± standard deviation). Exogenous amino acids: Lys – mysine, Met – methionine, Trp – tryptophan, Phe – phenylalanine, Thr – threonine, Leu – leucine, Ile – isoleucine, Val – valine; endogenous amino acids: Asp – aspartic acid, Ser – serine, Glu – glutamic acid, Pro – proline, Gly – glycine, Ala – alanine, Cys – cysteine, Tyr – tyrosine

100 g^{-1} protein in common wheat and spelt, respectively), whereas the dominant endogenous amino acids were glucosamine (30.2 vs. 31.0 mg 100 g^{-1} protein in common wheat and spelt, respectively) and proline (11.0 vs. 11.3 mg 100 g^{-1} protein in common wheat and spelt, respectively).

In spelt wheat products, the content of exogenous amino acids decreased in successive stages of grain maturation and processing. In comparison with IG, the content of lysine decreased by 2.5% in MG and 18.3% in F; the content of methionine decreased by 2.6% in MG and 7.2% in F; the content of threonine decreased by 2.1% in MG and 7.0% in F; whereas the content of tryptophan decreased by 4.6% in flour only. As regards endogenous amino acids, a decrease was observed in the concentrations of glycine (2.6% in MG and 12.8% in F), alanine (4.7% in MG and 17.29% in F), and asparagine (14.2% in F only) – Figure 3. However, the content of phenylalanine and endogenous amino acids (glutamine, proline and tyrosine) was lower in immature grain.

These findings suggest that the tested spelt products were significantly more abundant in protein than common wheat products. However, mature grain and, in particular, flour samples were less abundant in essential amino acids such as lysine, methionine and threonine than immature grain, whereas flour samples contained more phenylalanine (Figure 3). In the work of Yang et al. (2012), the content of valine, methionine, isoleucine, threonine, lysine, aspartic acid and alanine was significantly higher in immature than mature grain. In a study by Belitz et al. (1989), cysteine levels were higher in spelt than in common wheat, whereas similar concentrations of lysine and methionine were reported in the tested spelt cultivars and common wheat.

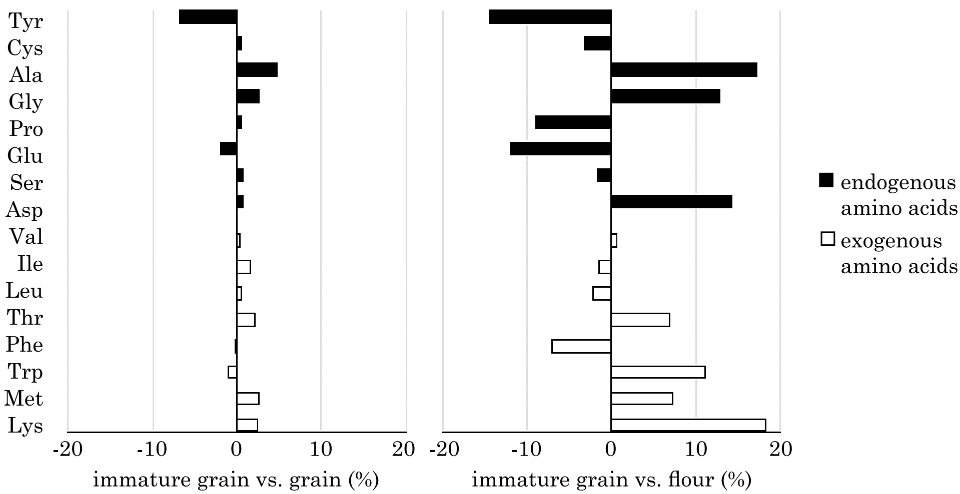


Fig. 3. Differences (%) in the average content of exogenous and endogenous amino acids in immature spelt grain (IG) vs. mature spelt grain (MG) and in immature spelt grain (IG) vs. spelt flour (F); e.g. the content of lysine in IG was 18.3% higher than in F

The analyzed wheat cultivars differed significantly in the content of ash and macronutrients, including nitrogen, phosphorus, potassium, and magnesium (Table 3). Ash content was significantly influenced by the interaction between cultivars and wheat products due to significantly higher ash levels in immature (17.0%) and mature grain (13.0%) of spelt than in common wheat. Ash levels were similar in the compared flours. On average, in comparison with common wheat, spelt cultivars contained more ash (by 12.4%), nitrogen (20.5%), phosphorus (20.5%), magnesium (9.5%) and calcium (8.0%), and less potassium (-2.6%) and sodium (-11.7%). Immature and mature grain samples were more abundant in macronutrients than flour samples, but the only significant difference was noted in ash and potassium levels.

In a study by Cacak-Pietrzak et al. (2013), the ash content was higher in both immature green grain and mature yellow grain of spelt than common wheat. These findings can be attributed to the smaller size and higher seed coat-to-endosperm ratio of spelt grain. In the work of Kohajdova and Karovičová (2009), wholemeal spelt flour produced in an organic farming system differed from commercially produced wheat flours mainly in the content of ash (1.82%), protein (16.5%), minerals (Ca, Fe, Zn), and organic acids. In the present study, immature and mature spelt grain was more abundant in ash than common wheat products.

A micronutrient analysis revealed that common wheat and spelt differed only in the content of copper (34.5%) and zinc (26.8%) – Table 4. Copper levels ranged from 3.24 mg kg^{-1} (Ceralio) to 4.11 mg kg^{-1} (Holstenkorn) in spelt, and reached 2.7 mg kg^{-1} in common wheat. Zinc concentrations ranged from 18 mg kg^{-1} (Ceralio) to 26.5 mg kg^{-1} (Oberkulmer Rothkorn) in spelt, and reached 17.2 mg kg^{-1} in common wheat. Only the zinc content was significantly influenced by the cultivar *x* wheat product interaction, and zinc concentrations in immature grain (34.7%) and flour (25.9%) differed considerably between common wheat and spelt cultivars, whereas smaller differences were noted in mature grain (19.2%). However, the content of micronutrients in IG and MG was similar and significantly higher than in flour (F). Only the concentration of selenium was identical in all wheat products. It should be noted that the absolute differences in micronutrient levels were very high in the compared wheat products. In comparison with flour, the copper content was 3.1- and 2.9-fold higher in immature and mature grain, respectively; the iron content was 3.8- and 3.8-fold higher, respectively; the manganese content was 6.3- and 5.4-fold higher, respectively; the zinc content was 4.5- and 4.3-fold higher, respectively, and the molybdenum content was 1.3- and 1.3-fold higher, respectively.

In a study by Hussain et al. (2010), spelt grain contained more Cu (5.50 mg kg^{-1}), Fe (38.0 mg kg^{-1}), and S (1.360 mg kg^{-1}) than other wheat genotypes, but it was less abundant in Se (0.10 mg kg^{-1}), Zn (39.2 mg kg^{-1}), Ca (327 mg kg^{-1}), Mg (20.0 mg kg^{-1}), Mo (1.75 mg kg^{-1}) and K (4.15 mg kg^{-1}) than other wheats. In our study, only immature spelt grain was characterized by higher levels of N, P, Mg, Cu, Fe, and Zn (Tables 3 and 4).

Table 3

Content of ash and macronutrients in spelt cultivars and the common wheat (Kor) reference

Wheat products/Cultivars	Ash	N	P	K	Mg	Ca	Na
	g 100 g-1						
Mean values for the cultivar x wheat product (CxWP) interaction							
Immature grain							
Kor	1.66	1.53	0.32	0.41	0.12	0.026	0.0090
Cer	1.88	2.07	0.41	0.45	0.14	0.030	0.0076
Shn	1.89	2.03	0.43	0.41	0.14	0.026	0.0073
Frau	1.99	2.06	0.46	0.45	0.14	0.030	0.0070
Hol	2.06	2.04	0.45	0.45	0.14	0.030	0.0080
Shz	1.83	1.97	0.41	0.42	0.14	0.030	0.0073
Ost	1.95	2.11	0.45	0.42	0.14	0.033	0.0073
ObR	1.99	2.28	0.44	0.40	0.15	0.030	0.0073
Mature grain							
Kor	1.61	1.93	0.38	0.40	0.13	0.030	0.0070
Cer	1.76	1.86	0.37	0.38	0.13	0.036	0.0063
Shn	1.79	2.04	0.42	0.38	0.13	0.026	0.0073
Frau	1.88	1.89	0.42	0.39	0.14	0.030	0.0066
Hol	1.82	1.98	0.43	0.40	0.14	0.030	0.0070
Shz	1.71	1.90	0.37	0.35	0.13	0.023	0.0063
Ost	1.78	2.16	0.45	0.36	0.13	0.026	0.0063
ObR	1.99	2.08	0.42	0.38	0.14	0.040	0.0096
Flour							
Kor	0.51	1.42	0.11	0.13	0.02	0.018	0.0058
Cer	0.47	1.54	0.12	0.12	0.01	0.031	0.0058
Shn	0.49	1.81	0.13	0.13	0.02	0.021	0.0048
Frau	0.47	1.69	0.13	0.11	0.02	0.028	0.0045
Hol	0.52	1.70	0.13	0.12	0.02	0.018	0.0031
Shz	0.43	1.62	0.11	0.09	0.02	0.011	0.0048
Ost	0.53	1.98	0.15	0.09	0.02	0.018	0.0061
ObR	0.48	2.02	0.13	0.10	0.02	0.024	0.0051
Mean values for cultivars (C)							
Kor	1.26	1.63	0.270	0.313	0.09	0.025	0.0073
Cer	1.37	1.82	0.300	0.317	0.09	0.032	0.0066
Shn	1.39	1.96	0.327	0.307	0.10	0.024	0.0065
Frau	1.45	1.88	0.337	0.317	0.10	0.029	0.0060
Hol	1.47	1.91	0.337	0.323	0.10	0.026	0.0060
Shz	1.32	1.83	0.297	0.287	0.10	0.021	0.0061
Ost	1.42	2.08	0.350	0.290	0.10	0.026	0.0066
ObR	1.49	2.13	0.330	0.293	0.10	0.031	0.0073
Mean values for wheat products (WP)							
Immature grain	1.91	2.01	0.42	0.43	0.13	0.029	0.0076
Mature grain	1.78	1.98	0.41	0.38	0.13	0.030	0.0071
Flour	0.48	1.72	0.12	0.11	0.02	0.021	0.0051
$HSD_{0.01}$							
Cultivars, C	0.101	0.312	0.051	0.042	0.009	n.s.	n.s.
Wheat products, WP	0.050	0.154	0.025	0.021	0.005	0.008	0.0013
Interaction CxWP	0.211	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

All values are expressed on a dry weight basis, n.s. – non-significant at $p<0.01$.

Table 4

Content of micronutrients in spelt cultivars and the common wheat (Kor) reference

Wheat products/Cultivars	Cu	Fe	Mn	Zn	Se	Mo
	mg kg^{-1}					
Mean values for the cultivar x wheat product (CxWP) interaction						
Immature grain						
Kor	3.61	34.63	20.03	22.53	4.39	1.69
Cer	4.00	37.70	15.76	25.53	4.39	1.62
Shn	4.49	40.00	15.80	29.73	4.54	1.83
Fra	5.56	46.56	16.90	30.23	4.36	1.52
Hol	5.60	44.66	20.93	28.23	4.55	1.77
Shz	4.62	43.16	14.60	30.03	4.41	1.75
Ost	4.57	42.30	15.23	31.76	4.36	1.65
ObR	5.14	51.80	15.60	36.86	4.47	1.78
Mature grain						
Kor	3.23	35.30	15.63	23.83	4.52	1.65
Cer	3.78	36.56	14.83	23.30	4.52	1.58
Shn	4.09	38.60	13.20	27.66	4.68	1.78
Fra	4.45	39.26	14.00	28.26	4.48	1.49
Hol	5.04	33.73	12.66	27.50	4.69	1.73
Shz	4.75	49.43	11.90	27.26	4.54	1.71
Ost	4.75	42.33	13.26	30.26	4.48	1.62
ObR	4.68	61.10	10.90	34.63	4.60	1.74
Flour						
Kor	1.25	15.00	1.94	5.32	4.43	1.25
Cer	1.95	11.95	4.22	5.30	4.43	1.21
Shn	1.37	11.08	2.12	7.49	4.58	1.34
Fra	1.33	9.44	2.15	4.73	4.39	1.16
Hol	1.70	10.80	3.35	7.12	4.59	1.31
Shz	1.19	8.73	1.74	5.54	4.45	1.29
Ost	1.80	12.50	3.22	8.78	4.39	1.23
ObR	1.41	9.71	2.60	7.92	4.51	1.31
Mean values for cultivars (C)						
Kor	2.70	28.3	12.5	17.2	4.45	1.53
Cer	3.24	28.7	11.6	18.0	4.45	1.47
Shn	3.32	29.9	10.4	21.6	4.60	1.65
Fra	3.78	31.8	11.0	21.1	4.41	1.39
Hol	4.11	29.7	12.3	21.0	4.61	1.60
Shz	3.52	33.8	9.4	20.9	4.47	1.58
Ost	3.71	32.4	10.6	23.6	4.41	1.50
ObR	3.74	40.9	9.7	26.5	4.53	1.61
Mean values for wheat products (WP)						
Immature grain	4.71	42.85	16.79	29.36	4.43	1.70
Mature grain	4.34	42.04	14.42	27.84	4.56	1.66
Flour	1.50	11.15	2.67	6.52	4.47	1.26
$HSD_{0.01}$						
Cultivars, C	1.132	n.s.	n.s.	3.266	n.s.	n.s.
Wheat products, WP	0.560	8.532	3.395	1.616	n.s.	0.149
Interaction CxWP	n.s.	n.s.	n.s.	6.774	n.s.	n.s.

All values are expressed on a dry weight basis, n.s. – non-significant at $p<0.01$.

Fatty acids

Fatty acids are accumulated mainly in the germ and the aleurone layer of grain. Wheat grain contains saturated fatty acids, including palmitic ($C_{16:0}$) and stearic ($C_{18:0}$) acids, as well as nutritionally valuable unsaturated fatty acids such as oleic ($C_{18:1}$), linoleic ($C_{18:2}$) and linolenic ($C_{18:3}$) acids. In this study, the total content of lipids and fatty acids differed across the examined wheat species and products (Table 5). The average lipid content was higher in immature grain (IG) (2.18%) than in mature grain (MG) and flour (F) (1.97% and 1.22%, respectively). The total lipid content of the analyzed spelt cultivars ranged from 1.62% in cv. Ceralio to 1.96% in cv. Holstenkorn, whereas common wheat was characterized by the lowest lipid content (1.45%). Common wheat was abundant in palmitic ($C_{16:0}$), linoleic ($C_{18:2}$), and linolenic ($C_{18:3}$) acids, but it was low in oleic acid ($C_{18:1}$). Immature grain (IG) contained less palmitic acid ($C_{16:0}$) than mature grain (MG) and flour (F). The concentration of linoleic acid ($C_{18:2}$) was the lowest (2.4%) in mature grain (MG). Generally, the analyzed spelt cultivars were characterized by a higher content of stearic ($C_{18:0}$) and oleic ($C_{18:1}$) fatty acids in IG and a higher content of oleic ($C_{18:1}$) fatty acid in MG and F.

The fatty acid content of cereal grain can be influenced by the interactions between genotype and environmental conditions. In a study by Rachoń et al. (2015), total lipid content was higher in spelt cv. *Schwabenkorn* and lower in common wheat cv. *Tonacja* grown in high-input farming systems, whereas the reverse was noted in grain harvested from a medium-input farming system. In this study, grain samples were obtained from an organic farm, and the total content of fatty acids was higher in spelt cultivars than in common wheat. The greatest difference was noted in the concentration of oleic acid ($C_{18:1}$) which was over 41.7% higher in spelt than in common wheat grain. The remaining fatty acids were determined in lower concentrations in spelt cultivars. Similar results were reported by Escarnot et al. (2012), who found that lipid concentrations were higher in spelt than in common wheat, but the noted differences did not exceed 3%. Spelt and wheat wholemeal flours are generally most abundant in linoleic, palmitic, oleic, and linolenic acids (Grela 1996, Ruibal-Mendieta et al. 2005). The present study demonstrated that the total lipid content was higher in immature grain (IG) than in mature grain (MG) and flours (F), while the oleic acid fraction remained relatively stable in these products (Table 5).

Tocopherols and vitamins

In this study, the content of tocopherols and B vitamins was investigated only in mature grain (MG). Both spelt and common wheat grain were characterized by a desirable composition of tocopherols and B-group vitamins (Table 6, Figure 4). The compared wheat species differed significantly in tocopherol levels. Common wheat contained 3.759 μg g^{-1} of α-tocopherol, 1.937 μg g^{-1} of β-tocopherol, 0.230 μg g^{-1} of γ-tocopherol, and 0.015 μg g^{-1}

Table 5

Content of total lipids (%) and major fatty acids (%) in spelt cultivars and the common wheat (Kor) reference

Wheat products/ Cultivars	**Total lipids**	**Palmitic $C_{16:0}$**	**Stearic $C_{18:0}$**	**Oleic $C_{18:1}$**	**Linoleic $C_{18:2}$**	**Linolenic $C_{18:3}$**
Mean values for the cultivar x wheat product (CxWP) interaction						
Immature grain						
Kor	1.67	18.60	0.32	14.73	62.94	3.42
Cer	2.02	18.25	0.45	23.01	55.42	2.88
Shn	2.18	17.49	0.36	24.31	56.29	1.57
Fra	2.21	17.54	0.50	22.91	56.84	2.22
Hol	2.45	16.31	0.50	22.60	58.27	2.34
Shz	2.33	16.06	0.41	24.07	57.39	2.09
Ost	2.25	17.40	0.47	23.91	55.94	2.29
ObR	2.32	15.68	0.56	26.00	55.72	2.06
Mature grain						
Kor	1.52	22.63	0.67	13.32	61.09	2.31
Cer	1.79	19.87	0.62	19.21	57.60	2.71
Shn	2.09	19.39	0.41	21.04	57.06	2.11
Fra	2.15	16.77	0.50	22.13	58.10	2.51
Hol	2.23	16.15	0.52	21.82	58.92	2.60
Shz	2.02	16.69	0.43	20.84	59.44	2.61
Ost	2.03	18.50	0.31	21.95	57.45	1.81
ObR	1.96	17.07	0.49	22.96	56.98	2.52
Flour						
Kor	1.16	18.36	1.48	12.69	62.80	4.67
Cer	1.07	20.43	1.48	15.29	59.45	3.37
Shn	1.51	18.82	1.39	18.63	58.22	2.96
Fra	1.16	18.33	1.25	18.68	58.48	3.27
Hol	1.22	18.64	1.45	18.64	57.97	3.31
Shz	1.20	19.11	1.19	17.61	58.88	3.22
Ost	1.33	19.62	1.33	19.36	56.90	2.80
ObR	1.16	18.90	1.29	18.14	58.75	2.94
Mean values for cultivars (C)						
Kor	1.45	19.86	0.82	13.58	62.28	3.47
Cer	1.62	19.51	0.85	19.17	57.49	2.99
Shn	1.92	18.56	0.72	21.32	57.19	2.21
Frau	1.84	17.55	0.75	21.24	57.81	2.67
Hol	1.96	17.03	0.82	21.02	58.38	2.75
Shz	1.85	17.28	0.67	20.84	58.57	2.64
Ost	1.87	18.51	0.70	21.74	56.76	2.30
ObR	1.81	17.21	0.78	22.36	57.15	2.50
Mean values for wheat products (WP)						
Immature grain	2.18	17.16	0.44	22.69	57.35	2.36
Mature grain	1.97	18.38	0.49	20.41	58.33	2.40
Flour	1.22	19.02	1.36	17.38	58.93	3.32
$HSD_{0.01}$						
Cultivars, C	0.099	1.708	n.s.	0.760	1.007	0.729
Wheat products, WP	0.049	0.842	0.142	0.375	0.496	0.360
Interaction CxWP	0.206	3.562	n.s.	1.585	2.099	1.521

All values are expressed on a dry weight basis; n.s. – non-significant at $p<0.01$.

Table 6

Tocopherol content (μg g^{-1}) of mature grain in spelt cultivars and the common wheat reference

Wheat cultivars	α-tocopherol	β-tocopherol	γ-tocopherol	δ-tocopherol
Kor	3.759	1.937	0.230	0.015
Cer	2.033	0.739	0.200	0.021
Shn	3.129	0.798	0.324	0.053
Fra	3.552	1.758	0.218	0.032
Hol	4.036	2.461	0.302	0.054
Shz	3.383	1.245	0.177	0.025
Ost	2.549	1.977	0.359	0.058
ObR	2.914	1.628	0.160	0.043
$HSD_{0.01}$	0.345	0.421	0.072	0.007

All values are expressed on a dry weight basis, mean±SD.

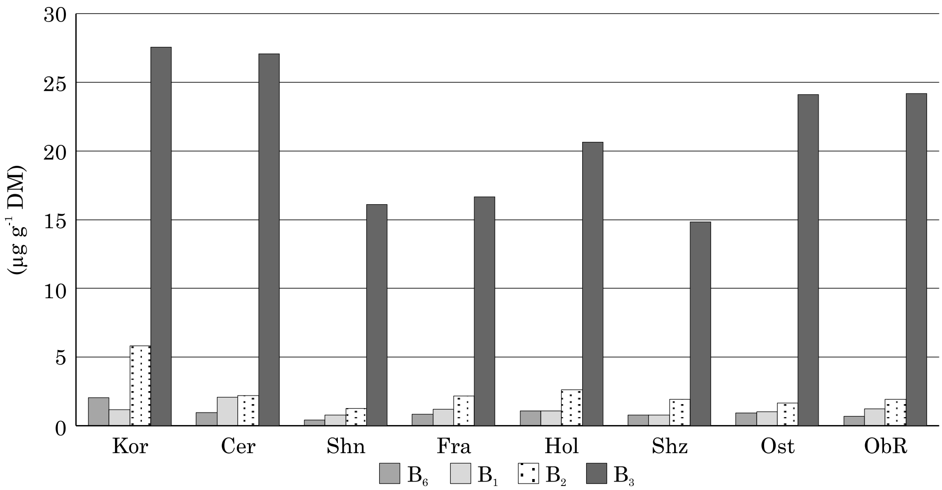


Fig. 4. Content (μg g^{-1}) of B-group vitamins (B_1 – thiamine, B_2 – riboflavin, B_3 – niacin, and B_6 – pyridoxine) in the mature grain of spelt cultivars and common wheat (Kor) on a dry weight basis

of δ-tocopherol. In spelt cultivars, the content of α- and β-tocopherol was 18% and 21% higher, respectively, while the content of γ- and δ-tocopherol was 1.4 and 2.7 times higher, respectively. In the group of the analyzed spelt cultivars, cv. Ceralio was the least abundant in tocopherol. In turn, cv. Holstenkorn was characterized by the highest concentrations of α-tocopherol (4.036 μg g^{-1}) and β-tocopherol (2.461 μg g^{-1}), and it was also rich in γ- and δ-tocopherol (0.302 and 0.054 μg g^{-1}, respectively).

Wheat-based products, in particular whole grain products, are an important source of B group vitamins, including thiamine (B_1), riboflavin (B_2), niacin (B_3), and pyridoxine (B_6), which were investigated in this study. Average thiamine levels were similar in the mature grain of spelt cultivars and common wheat, while the content of riboflavin, niacin, and pyridoxine was significantly higher in common wheat. Spelt cultivars differed in vitamin levels, which were slightly lower or similar to those noted in common wheat. Considerable variation was noted in the content of niacin (μg g^{-1}), which ranged from 14.8 in cv. Schwabenspelz to 24.1 in cv. Ostro, 24.2 in cv. Oberkulmer Rothkorn, and 27.0 μg g^{-1} in cv. Ceralio, and the latter values were comparable with that in common wheat. These results indicate that spelt cultivars differ considerably in the content of tocopherols and vitamins.

In a study by Reboul et al. (2006), the bioavailability of α-tocopherol was determined at 99% in white wheat bread and 53% in wheat germ, whereas the bioavailability of γ-tocopherol reached 8% and 48%, respectively. El-Sayed et al. (2008) observed significant differences in the concentrations of bioactive compounds and antioxidants, including tocopherols, across wheat species and cultivars. On average, whole spelt grain contained 5.5-11.9 μg g^{-1} of α-tocopherol and 2.0-6.6 μg g^{-1} of β-tocopherol (El-Sayed et al. 2008). In the current study, spelt cultivars were far less abundant in α-tocopherol and β-tocopherol. In spelt, α-tocopherol and β-tocopherol concentrations accounted for around 82% and 78% of levels noted in common wheat, respectively. However, γ-tocopherol and δ-tocopherol content was 1.45- and 2.72-fold higher, respectively, in spelt than in common wheat. Whole and ground spelt grain was rich in total lipids and unsaturated fatty acids, but less abundant in tocopherols than common wheat, which suggests that higher lipid levels in spelt are not related to a higher proportion of the germ fraction (Ruibal-Mendieta 2005). Thiamine was the only B-group vitamin whose concentrations were similar in spelt and common wheat grain (1.17 μg g^{-1}), whereas the content of other B-group vitamins, such as riboflavin, niacin and pyridoxine, was significantly lower in spelt than in common wheat. In a study by Shewry and Hey (2015), folate (B_9) levels were higher in durum wheat (0.74 μg g^{-1} DM) and emmer (0.69 μg g^{-1} DM) than in other wheat species, including bread wheat (0.56-0.58 μg g^{-1} DM).

CONCLUSIONS

1. Spelt grain and flour were more abundant in protein than common wheat. In the examined spelt cultivars, the average protein content of immature grain (IG), mature grain (MG) and flour (F) (23%, 26%, and 26%, respectively) was higher than in common wheat.

2. The total content of exogenous and endogenous amino acids was similar in common wheat and spelt cultivars. In comparison with spelt IG, MG and F contained less essential amino acids lysine, methionine and threonine. Spelt F was also less abundant in tryptophan.

3. Average ash content was higher in spelt than in common wheat, and IG was richer in ash than MG and F of both spelt and common wheat. Spelt IG, MG and F were more abundant in P, N and Mg, but the content of P and N was significantly higher in IG and F than in MG. In spelt, micronutrient concentrations (Cu, Fe and Zn) decreased with grain maturation.

4. In comparison with common wheat, spelt cultivars were more abundant in total lipids and unsaturated oleic acid. At the same time, spelt was characterized by a lower content of α- and β-tocopherol and a higher content of γ- and δ tocopherol. The content of thiamine was similar in spelt and common wheat grain, whereas the content of riboflavin, niacin and pyridoxine was significantly higher in common wheat than in spelt grain.

5. A comparison of the concentrations of protein, essential amino acids, mineral elements, tocopherols, and B-group vitamins in spelt and common wheat grain confirmed that spelt cultivars make a varied contribution to the nutritional value of wheat products. The study demonstrated that IG has a much higher nutritional value than MG and F. The study also revealed that immature grain of spelt and common wheat grown in organic farms can significantly enhance the nutritional value of food.

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