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ENVIRONMENTAL FACTORS INFLUENCE MILLING AND PHYSICAL PROPERTIES AND FLOUR SIZE DISTRIBUTION OF ORGANIC SPELT WHEAT

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Abstract

Spelt grain harvested at four organic farms in Poland were assessed for physical and milling properties and flour size distribution. The spelt grain was diversified in relation to the majority of tested milling quality parameters. The environmental conditions had a significant impact on thousand kernel weight, vitreousness, PSI, kernel ash content, specific energy of milling and the particle size distribution of flour. The values of specific energy of milling, coefficient of grinding efficiency, rupture force and rupture energy in the spelt from the organic farms were significantly lower than common wheat. The highest spelt flour yield was obtained of kernels cultivated on ecological farm with semi-coherent and very dry soil was similar to that of common wheat; the milling yield of the spelt originating from other farms was by 9.5% to 12.7% less than from the wheat one. The greatest differences in PSD between the tested flours were detected for the values over 40 μm. The content of this fraction was determined in the range of app. 1% to almost 4.5%; the flour from common wheat contained app. 2.8% of this fraction.

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Introduction

Recently organic agriculture became one of the most rapidly developing branch of agriculture in the world. The reason is growing demand for organic food. Between 2004–2013 acreage of land under organic cultivation in Europe has been increased from 890 000 to 1 845 000 ha (WILLER, SCHAACK 2015). Along the increase of organic cereal acreage the area of spelt cultivation also increases because this kind of cereal is grown mostly in organic farms.

Due to the fact that spelt is cultivated not only in Europe but worldwide, it has become necessary to determine the impact of spelt reaction to environmental factors. WILSON et al. (2008) emphasized that the environmental conditions have an impact on the quality characteristics and technological parameters of grain. Only limited possibility influencing grain quality by fertilization and pesticide application is permissible in organic production, so, besides genetic features, environmental conditions (type of soil, climate) influence the quality of grain. The assessment of the milling quality of grain is important and, in the case of spelt, it has been studied only to a limited extent. Only few studies investigated physical and mechanical properties of spelt wheat (MARKOWSKI et al. 2013, ŚWIECA et al. 2014). Knowledge of mechanical properties and milling grain spelled leads to the optimization of the design process and equipment intended for such purposes, as well as the harvest and distribution of grain. Milling is the basic process in cereal processing. The physical properties of kernels have a significant impact on the effectiveness of milling. The main factors that influence the properties of kernels during milling are hardness and vitreousness (GREFFEUILLE et al. 2007a,b). The hard wheat varieties produce higher yield of flour since the endosperm is more effectively separated from bran (POSNER 2003b). The hardness of kernels significantly influences energy consumption during grinding. The milling of hard wheat is more energy-consuming as opposed to soft wheat (DZIKI et al. 2012). Furthermore, kernel hardness has an impact on the size distribution of middlings and flour. The milling of wheat with soft endosperm produces more small particles than the processing of kernels with hard endosperm (DEVAUX et al. 1998, GREFFEUILLE et al. 2007b). Depending on the degree of grinding of raw material, the course of such processes as mixing, pelleting, dough preparation and baking is different. The quality of final products is also different (PARK et al. 2006). The quality of milling (including flour yield, ash content and flour color) is associated with the morphological parameters of kernels if the milling is performed in comparable conditions (ZHANG et al. 2005). The same varieties of spelt, though they have the same genotype, have to adapt to different regions and therefore react dissimilarly to the environment. Therefore, the cultivation conditions, apart from genetic potential, have an impact on the quality of grain.

The aim of the study was to investigate some physical and milling properties and flour size distribution of organic spelt grain from different environmental conditions of cultivation. Spelt was compared with common wheat. This study may help elucidate some unique characteristics of spelt grain and flour for future uses in the food industry.

Materials and Methods

Samples

The samples of spelt (*Triticum spelta* L.) Schwabenkorn cultivar (SG1 – SG4) originated from a field trial carried out in 2010 on 4 certified organic farms in Poland, differing in the type of soil and its humidity, were assessed. The grain of common wheat Korweta cultivar (CW) from organic farm was the reference (Tab. 1). This common wheat cultivar is known as healthy and well yielding wheat in the ecological cultivation.

The samples of spelt grain, 10 kg each, were hulled in a laboratory device (LD 180 ST 4, WINTERSTEIGER). The moisture content (MC) of spelt and common wheat was determined (ICC Standard Method No. 110/1).

Table 1

Location, certificate number and type of soil organic farms

Samples	Located organic farms	No of certificate	Type of soil
SG1	located at 53°17'N, 19°14'E	AgroBioTest Pl – Eko-07-90013/09	heavy soil with average humidity
SG2	53°01'31.41''N, 17°43'46.56''E	AgroBioTest Pl – Eko-07-05843	semi-coherent soil with average humidity
SG3	53°23'57''N, 19°34'37''E	AgroBioTest Pl – Eko-07-00005	semi-coherent soil and very dry
SG4	53°21'54''N, 19°06'24''E	AgroBioTest Pl – Eko-07-90011/09	very heavy and humid
CW	53°21'54''N, 19°06'24''E	AgroBioTest Pl – Eko-07-90011/09	very heavy and humid

Physical properties

Thousand kernel weight (TKW) was measured for each sample with the use of an electronic kernel counter (Kernel Counter LN S 50A, UNITRA CEMI, Poland) and an electronic scale WPE 120 (Radwag, d = 2 mg, Poland). The kernels were also evaluated for bulk density (BD) (AACC Method 55–31, 2002).

The kernel vitreousness (KV) was evaluated by cross-sections of kernels and expressed as the percentage of vitreous kernels in the sample of 50 elements. The partially vitreous kernels were classified as semi-vitreous kernels and their number in the sample was multiplied by 0.5. The particle size index (PSI) was determined after the AACC Method 55–30: 2002. Total ash content in grain (KAC) and in flour (FAC) were also determined in accordance with ICC Standard Method No. 104/1. The index FA/WA (flour ash/wheat ash) was used to evaluate the differences in the milling of tested spelt grain (POSNER 2009). The kernels of each sample were classified into five fractions based on the thickness: 2.0 – 2.25; 2.25 – 2.5; 2.5 – 2.75; 2.75 – 3.0; 3.0 – 3.5 mm by using the sieves of the following sizes: 2.0, 2.25, 2.5, 2.75, 3.0 and 3.5 mm and by shaking for 5 minutes.

Mechanical tests

Quasi-static compression tests on a single wheat kernel were performed. Thirty kernels were randomly selected from every sample. Each kernel was crushed between parallel plates of Texture Analyzer TA.XT Plus (Stable Micro Systems) with a constant velocity of 0.05 mm $\cdot$ s^{-1} until the distance between plates was fixed at 0.5 mm. The kernel was placed on the lower plate of the testing machine and crushed. For each test load-deformation data was recorded with the computed system. The mechanical behavior of wheat kernels was expressed in terms of deformation, force (F), and energy required to reach the point of total rupture (W) of a single kernel during the quasi-static compression test. The mean value of kernel displacements (l) up to the rupture point for each kernel was calculated.

Test milling

Moisture content of spelt and common wheat was determined and the grain was then re-moisturized to 14.5 ± 0.2% moisture with the addition of distilled water. The restoration of moisture was performed in a tightly-closed container for 48 hours. The samples of grain (100 g) from each farm were weighed on a WLC 2/A1 electronic scale (Radwag, d = 10 mg, Poland) and then milled using Quadrumat Junior mill (Brabender) equipped with a cylinder sifter with a 70GG sieve (PE 236 μm) and flour yield was determined. Six samples of each material were milled.

Milling energy determination

The mill was connected to the power source through the system measuring the consumption of electrical energy. The milling time (t_m) was measured with a stop watch with accuracy of ± 0.1 s. The power of idle running (P_i) of the mill was also determined (the average value of power consumed before the measurements and immediately after the milling of the last sample of each material). The energy necessary for putting the elements of the mill into motion (E_i – energy of idle running) was calculated by multiplying the active power of idle running and the time of milling ($E_i = P_i \cdot t_m$). The work of milling was determined assuming that the total energy consumed (E_c) by the mill equaled the sum of grinding energy and the energy needed for putting the elements of the mill into motion. The specific energy of milling E_m (kJ · kg^{-1}) was calculated with the following formula:

$$E_m = (E_c - E_i) : m \quad (1)$$

where:
m – the weight of grain (kg).

The coefficient of grinding efficiency K_0 (kJ · kg^{-1} flour) was also calculated after GREFFEUILLE et al. (2007b):

$$K_0 = (E_c - E_i) : m_{Fl} \quad (2)$$

where:
m_{Fl} – the mass of the obtained flour (kg).

Particle size analysis

The particle size distribution (PSD) of flour was obtained with Laser Diffraction Analysis (LDA) with Malvern Mastersizer 2000 (version 5.22, Malvern lnstruments Ltd, Malvern, UK). The result of the measurement was expressed as the mean value from six replications. Average size of particles, as a widely used parameter characterizing the granulometric composition, was calculated as the sum of the products of the volumetric part (φ_i) and the average size of each faction (d_i) with the following formula (VELU et al., 2006):

$$d = \text{SUM}\ (\varphi_i \cdot d_i) \quad (3)$$

Particle sizes $d(0.1)$, $d(0.5)$ and $d(0.9)$ are equivalent to the sieve with mesh sizes correspond to pass of 10%, 50% and 90% (respectively) mass of the material. They were used as indexes of the smallest, average and maximum particle size of flour, respectively.

Statistical analysis of results

Analysis of variance (one-way ANOVA) was performed. The significance of differences between the means was evaluated with Tukey's test. The statistical calculations were performed with STATISTICA® for Windows v. 10 (StatSoft Inc.). The statistical hypotheses were tested at a significance level of $p = 0.05$.

Results and Discussion

Properties of kernels of spelt of Schwabenkorn cultivar are presented in Table 2. No significant difference was calculated for moisture content (MC) determined for spelt and common wheat samples. The values of bulk density (BD) of spelt grain (from 677.1 to 695.6 kg · m^{-3}) from the organic farms were similar, nevertheless, were significantly lower than the BD of common wheat (719.5 kg · m^{-3}).

Table 2

Physical properties of spelt and common wheat grain before milling

Feature	SG1	SG2	SG3	SG4	CW
MC [%]*	11.98 ± 0.23**	11.79 ± 0.25	11.21 ± 0.22	11.56 ± 0.18	11.70 ± 0.22
BD [kg · m^{-3}]	677.1^{a} ± 4.6	684.0^{a} ± 4.2	683.4^{a} ± 2.5	695.6^{b} ± 2.6	719.5^{c} ± 0.5
TKW [g]	36.3^{a} ± 0.6	41.4^{b} ± 0.9	43.9^{c} ± 1.9	43.5^{bc} ± 0.8	36.5^{a} ± 0.7
KAC [%]	2.23^{d} ± 0.03	2.16^{c} ± 0.02	1.98^{a} ± 0.02	2.09^{b} ± 0.01	1.94^{a} ± 0.02
KV [%]	3^{c} ± 1.50	6^{c} ± 1.53	41^{b} ± 5.01	9^{c} ± 3.33	60^{a} ± 5.68
PSI [%]	81.63^{c} ± 7.46	61.08^{b} ± 3.37	53.60^{a} ± 2.14	60.45^{b} ± 1.52	64.75^{b} ± 1.76

* MC – moisture content, BD – bulk density, TKW – thousand kernel weight, KAC – kernel ash content, KV – kernel vitreousness, PSI – particle size index

** The values are expressed as mean ± SD (n=3).

a, b, c, d – values denoted in individual lines with the same letters do not differ significantly for $p \le 0.05$

The thousand kernel weight (TKW) ranged from 36.6 to 43.9 g and depended on the place of cultivation. Such an influence was also proved in the study of ZHANG et al. (2004). WILSON et al. (2008) determined TKW of spelt grain originating from Ohio in a range of 26 to 41 g, whereas for the same varieties cultivated in Europe MARCONI et al. (1999) reported the range from 49 to 55 g. Environment of plant vegetation play an important role in formation of wheat TKW. Occurrence of soil drought at the time of plant growth depress shapeliness: endosperm filling extent deceases what is manifested with kernels wrinkling (GAINES et al. 1997). The highest TKW value was determined for SG3 grain; these kernels also yielded the highest milling efficiency. According to POSNER (2003b), larger wheat kernels are correlated with higher flour yield whereas smaller kernels have a larger pericarp-endosperm ratio and therefore less endosperm is available. This correlation was confirmed in our studies.

According to some authors (GREFFEUILLE et al. 2006, MIŚ et al. 2002, TURNBULL, RAHMAN 2002) the genetic potential and environmental conditions have a major impact on the hardness of kernels. The virtuousness and hardness of kernels are important factors which influence the behavior of grain during milling (GREFFEUILLE et al. 2007a,b). The virtuousness (KV) of spelt grain ranged from 3% to 41% and significantly depended on the environment of cultivation in agreement to the previous studies of GREFFEUILLE et al. (2006). The kernels of spelt had lower virtuousness than the common wheat ones (60%). The hardness of tested kernels expressed with the PSI ranged from 53.6% for SG3 to 81.63% for SG1, so, the kernels of spelt and common wheat were classified as "extra soft". MIŚ and GEODECKI (2000) proved that gradual reduction of hardness occurs as a result of repeated moistening of kernels. According to GLENN and JOHNSTON (1994), the kernels with more vitreous endosperm are usually harder. A similar correlation was observed in our studies.

SINGH et al. (2010) proved that grain of wheat grown in different environmental conditions displayed generally diverse chemical composition. This was also confirmed in this study; the kernel ash content (KAC) in spelt was found in the range of 1.98% – 2.23% and depended on the environment of cultivation. Similar to the studies of CACAK-PIETRZAK and GONDEK (2010) and KRAWCZYK et al. (2008), the kernels of spelt had higher KAC than common wheat (1.94%).

Every grain sample was divides into five fractions (Tab. 3). Kernels of thickness 2.50 – 2.75 mm predominated and their content ranged from 44 (CW) to 55% (SG4).

Rapture force (*F*) and the rupture energy (*W*) differed significantly among samples from various sites of cultivation. The highest value *F* and *W* (58.9 N and 20.8 mJ, respectively) was detected in common wheat and the lowest (26.5 N and 4.7 mJ) was in spelt from SG1 (Tab. 4). The values of rupture force and energy of the spelt Schwabenkorn cv. from the organic farms were significantly lower than common wheat Korweta ones. *F* and *W* obtained for Schwabenkorn cv. were similar to values obtained for spelt wheat cv. Ceralio, Holsternkorn and Oberkulmer Rotkorn (MARKOWSKI et al. 2013). Contrary to the most the common European wheat cultivars, spelt kernels characterized by the lower value of rupture force and the rupture energy (DZIKI et al. 2012).

Table 3

Share of fraction grain of spelt and common wheat (thickness of kernel)

Fraction [mm]	d_k [mm]	Share of fraction [%]				
		SG1	SG2	SG3	SG4	CW
2.00 – 2.25	2.125	9	7	8	4	9
2.25 – 2.50	2.375	22	22	23	18	33
2.50 – 2.75	2.625	45	50	53	55	44
2.75 – 3.00	2.875	14	10	7	11	7
3.00 – 3.50	3.125	10	11	9	11	7

d_k – average size of kernel fraction.

Table 4

The mechanical properties of individual fractions of spelt and common wheat

Feature	SG1	SG2	SG3	SG4	CW
l [mm]*	$0.22^a \pm 0.04$*	$0.30^{ab} \pm 0.06$	$0.37^{ab} \pm 0.04$	$0.36^{ab} \pm 0.06$	$0.48^b \pm 0.06$
F [N]	$26.5^a \pm 3.1$	$26.9^a \pm 3.4$	$52.2^b \pm 6.6$	$39.3^{ab} \pm 5.3$	$58.9^b \pm 6.8$
W [mJ]	$4.7^a \pm 1.5$	$5.6^a \pm 1.5$	$15.3^{ab} \pm 3.3$	$12.5^{ab} \pm 3.9$	$20.8^b \pm 4.7$

* l – kernel displacement up to the rupture point, F – rupture force, W – rupture energy
The values are expressed as averages values ± standard deviation (n = 30).
a, b – values denoted in individual lines with the same letters do not differ significantly for $p \le 0.05$

The values of kernel displacements up to the rupture point (l) changed from 0.22 (SG1) to 0.48 mm (CW) and were significantly lower than those reported for common wheat (DZIKI et al. 2012).

The milling efficiency is the main indicator of milling properties of cereal grain. In this study the highest flour yield (FY) was obtained from SG3 (66%), and was comparable with FY for common wheat (Tab. 5). The kernels of spelt from other farms produced statistically significantly lower flour yield (from 55 to 57%). Similarly, ZHANG et al. (2004) proved that flour yield depended in a higher extent on spelt genotype than on cultivation environment. The milling efficiency of all tested spelt samples was low and lower than the values reported for spelt in other studies (ABDEL-AAL et al. 1997, MARCONI et al. 1999, WILSON et al. 2008). Some authors (ABDEL-AAL et al. 1997, CACAK-PIETRZAK, GONDEK 2010, MARCONI et al. 2002) stated that milling of spelt grain produced lower flour yield than of common wheat what indicated poorer milling parameters of spelt than common wheat. The ash content of flour is an important indicator of milling value. Grain with low ash content, in particular in the endosperm, is a desirable raw material for cereal and milling industry. The flour ash content (FAC) in the tested flours ranged from 0.44 (SG3) to 0.57% (CW). The lowest ash content was determined for the flour the spelt grain of the highest flour yield.

Table 5

Milling properties of spelt grain and common wheat

Feature	SG1	SG2	SG3	SG4	CW
FY [%]*	$56.0^{b} \pm 1.5$	$55.0^{b} \pm 1.6$	$66.0^{a} \pm 3.3$	$57.0^{b} \pm 2.1$	$63.0^{a} \pm 1.7$
E_m [kJ · kg^{-1}]	$42.5^{c} \pm 3.5$	$36.6^{ab} \pm 2.5$	$41.6^{bc} \pm 2.7$	$35.5^{a} \pm 3.3$	$55.3^{d} \pm 3.6$
K_0 [kJ · kg^{-1}]	$76.2^{ab} \pm 6.4$	$69.7^{a} \pm 5.8$	$64.1^{a} \pm 5.4$	$62.3^{a} \pm 5.1$	$89.0^{b} \pm 5.2$
FAC [%]	$0.53^{a} \pm 0.02$	$0.50^{ab} \pm 0.04$	$0.44^{b} \pm 0.03$	$0.55^{a} \pm 0.02$	$0.57^{a} \pm 0.04$
FA/WA [–]	0.238^{b}	0.231^{b}	0.222^{a}	0.263^{c}	0.294^{d}

*FY – flour yield, E_m – specific energy of milling, K_0 – coefficient of grinding efficiency, FAC – flour ash content, FA/WA – flour ash/wheat ash.
The values are expressed as averages values ± standard deviation ($n = 6$).
a, b, c, d – values denoted in individual lines with the same letters do not differ significantly for $p \leq 0.05$.

In order to reveal the difference in milliability of the grain, the coefficient FA/WA were determined. The lower value of FA/WA coefficient indicates better milling properties and announces good separation of bran from endosperm (POSNER 1991). In our studies dependence of the environment of spelt cultivation on the milling capacity was proved (Tab. 5). The lowest FA/WA value was detected for the SG3 spelt (0.222); this grain also was classified as a grain with the best milling parameters. The highest milling value was detected for the SG4 grain.

The results of milling energy requirements of spelt grain showed that the specific energy of milling E_m ranged from 35.5 (SG4) to 42.5 kJ kg^{-1} (SG1). Also, for these spelt samples the highest and the lowest values of coefficient of grinding efficiency (K_0) were obtained, i.e. from 62.3 to 76.2 kJ k^{-1}. The analysis of variance of specific energy input for kernel grinding (Er) revealed significant differences between the materials originating from different environments. The milling efficiency coefficient K_0, corresponding to the energy necessary for producing a certain amount of flour, depended to a larger extent on the variety of wheat than on the environment of cultivation. It was found that the grinding of spelt kernels, regardless of the location of growing, required less energy than the grinding of common wheat grain. It resulted mainly from soft texture of spelt wheat grain. Similar observations were reported by ŚWIECA et al. (2014) and WARECHOWSKA et al. (2013). The studies by CACAK-PIETRZAK (2010) indicated that milling of hard and vitreous grain required more the specific energy of milling than the non-vitreous (starchy) grain. In the most extreme cases, the differences in energy consumption of grinding of wheat with hard and soft endosperm reached 100% (PUJOL et al. 2000). According to DZIKI et al. (2012) vitreous kernels are more resistant and require more energy input for grinding, what results from the internal structure of kernel: in vitreous grain, starch granules are deeply seated in the protein matrix, as opposed to non-vitreous grain which has a loose structure of endosperm (starch granules are separated from each other).

The environmental conditions had a significant impact on the particle size distribution of spelt flours. The resultant flours were composed of many fractions (Fig. 1). Four size fractions were identified in each tested samples of flours. Two fractions were predominant in each product: with modal values app. 25 μm and near 100 μm (with the exception of SG3 sample, which structure was mainly composed of two fractions with modal values app. 30 and 70 μm). In each of the tested wheat, these fractions were smaller than 80 μm resulting in high PSI values. The flours of SG1 and SG2 had the highest content of 25 μm fraction (even greater than that of common wheat flour).

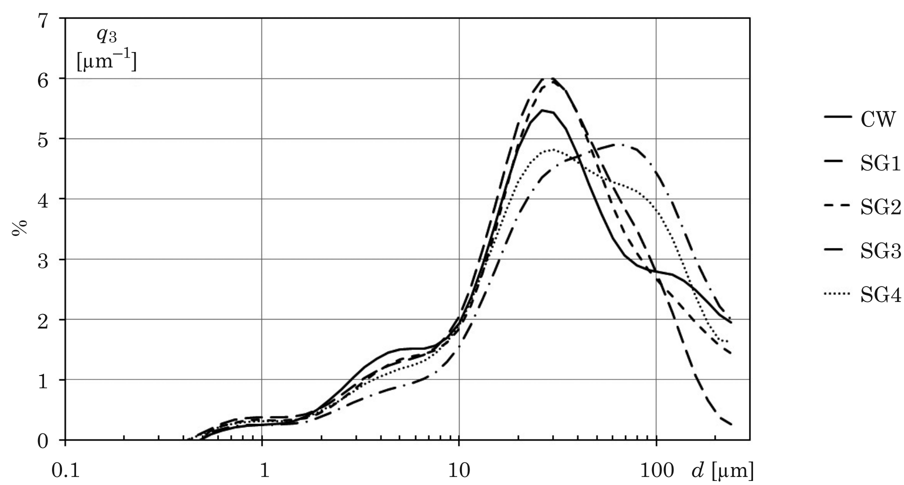

Fig. 1. The particle size distribution of flour

Furthermore, contribution of the largest particles constituting the coarse SG3 and SG4 fraction was greater by approx. 1–2 μm^{-1} than in the case of common wheat. Common wheat had high PSI value (64.75) due to a higher content of 4 μm fraction (higher than any of the tested spelt kernels). An opposite tendency relating to the content of main fractions in comparison with common wheat was observed in the flours obtained from SG4. The content of the 30 μm fraction was smaller by app. 1% and the content of the 80 μm fraction was also significant and higher by app. 1% than in the flour of common wheat. The milling product from SG3 spelt grain, characterized by contribution of 80 μm fraction more approx. 0.5% than 30 μm fraction. Flour obtained from SG4 spelt grain have opposite tendency. It constituted a comparable amount of milling product as the corresponding fraction of common wheat.

The greatest differences between PSD's the tested flours were detected in the section over 40 μm. The lowest content of this fraction was found in SG1 and SG2 material (app. 1% of the total) and the highest was in SG3 and SG4 material (almost 4.5% of the total). The flour from common wheat contained app. 2.8% of the total of this fraction. Similar findings were reported by ABDEL-AAL et al. (1997) who carried out studies on soft spelt.

Specific area of the tested materials assumed the similar values (Tab. 6), excluding SG3. The minimal., median and maximal particle size of flour ($d(0.1)$, $d(0.5)$ and $d(0.9)$ respectively), as well as mean particle size (d) of SG4 and the of common wheat cultivated in the station with comparable soil and climatic conditions assumed the similar values. In the case of SG3 $d(0.1)$ amounted to 7.253 μm, which indicated that this flour contained significantly less fine fractions than other. SG3 assumed the higher values of the traits mentioned above. SG1, SG2 and SG4 assumed the similar values of the parameters of particle size distribution as in the case of common wheat. For all obtained flours fine fraction predominant, $d(0.5)$ was about 60% of the average particle size.

Table 6
The parameters of particle size distribution and specific area of flours of spelt and common wheat

Material	Spec. area [$m^2 \cdot cm^{-3}$]	$d(0.1)$ [μm]	$d(0.5)$ [μm]	$d(0.9)$ [μm]	d [μm]
SG1	0.571	4.666	26.396	86.257	36.000
SG2	0.514	5.082	28.619	112.835	48.363
SG3	0.412	7.253	40.297	137.012	61.929
SG4	0.502	5.353	32.406	123.309	54.088
CW	0.501	4.700	28.055	129.925	51.728

Explanation of the symbols in the paper.

Conclusions

The environmental conditions had a significant impact on thousand kernel weight, vitreousness, PSI, kernel ash content, specific energy of milling and the particle size distribution of flour. The values of specific energy of milling, coefficient of grinding efficiency, rupture force and rupture energy of spelt kernels from the organic farms were significantly lower than of the common wheat ones. The highest spelt flour yield obtained of kernels cultivated on ecological farm with semi-coherent and very dry soil was similar to that of common wheat; the milling yield of the spelt originating from other farms was by 9.5% to 12.7% less than from the wheat one. The greatest differences in PSD between the tested flours were detected for the values over 40 μm. The content of this fraction was determined in the range of app. 1% to almost 4.5%; the flour from common wheat contained app. 2.8% of this fraction.

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