J. Agr. Sci. Tech. (2017) Vol. 19: 1253-1266

Physicochemical Properties and Milling Characteristics of Spring Wheat from Different Farming Systems

D. Dziki[1*], G. Cacak-Pietrzak[2], U. Gawlik-Dziki[3], M. Świeca[3], A. Miś[4], R. Różyło[5], and K. Jończyk[6]

ABSTRACT

The aim of this study was to investigate the effect of the origin of wheat grown by different farming systems on the physicochemical properties and milling characteristics of grain. Four varieties of spring wheat from two growing years and cropped under Organic (OR), Integrated (IN) and Conventional (CO) management systems were included in this investigation. Grain from IN farming was characterized by the highest values for grain weight and diameter, and the lowest values for grain hardness and average particle size. The values for these parameters obtained for wheat from OR and CO farming systems were similar. Grinding energy indices showed that grain from the IN farming system was characterized by the lowest grinding energy requirements, whereas the energy requirement for size reduction of grain from OR and CO cropping was similar. Moreover, IN farming caused an increase in the milling efficiency index and the amount of phenolic acids in flour. The data showed that the studied farming systems influenced the results of grinding and milling by modifying the physicochemical properties of wheat grain during plant growth.

Keywords: Grinding energy indices, Kernel hardness index, Organic wheat, Phenolic acids.

INTRODUCTION

Wheat plays an important part in human nutrition, because of the large scale of consumption. Wheat is a source of nutrition for 35% of the world population, and currently ranks first among cultivated plants in terms of cultivation area and production (Polat *et al.*, 2016). Wheat products supply human diet with carbohydrates and protein, and are also a useful source of antioxidant compounds. The quality of wheat grain is influenced by genetic factors (varietal) as well as growth location, and agricultural measures, but also conditions of harvest, transport, and postharvest storage of grain (Weightman *et al.*, 2008; Marzec *et al.*, 2011; Mohammadi *et al.*, 2013).

Wheat is also an important crop in organic farming (Mäder *et al.*, 2007). Organic agriculture is of particular interest concerning healthy and ecologically-friendly

[1] Department of Thermal Engineering, University of Life Sciences, Doświadczalna 44, 20-280 Lublin, Poland.
[2] Division of Cereal Technology, Faculty of Food Sciences, Warsaw University of Life Sciences, Nowoursynowska 159C, 02-786 Warsaw, Poland.
[3] Department of Biochemistry and Food Chemistry, University of Life Sciences, Skromna 8, 20-704 Lublin, Poland.
[4] Institute of Agrophysics, Polish Academy of Sciences, Doświadczalna 4, 20-290 Lublin, Poland.
[5] Department of Equipment Operation and Maintenance in the Food Industry, Doświadczalna 44, 20-280 Lublin, Poland.
[6] Department of Systems and Economics of Crop Production, Institute of Soil Science and Plant Cultivation, Czartoryskich 8, 24-100 Puławy, Poland.
[*]Corresponding author, e-mail: dariusz.dziki@up.lublin.pl

produced food, because inputs of chemicals are not allowed. With the increasing consumer pressure to reduce the use of pesticides, fertilizers, veterinary medicines, and growth promoters in food production systems, the demand for organic foods continues to rise. Organic wheat is commonly consumed as whole and sprouted grain, unlike conventional wheat, and might therefore be a good source of biologically active compounds in healthy food (Hussain *et al.*, 2012). It is also used for white bread production (Osman *et al.*, 2012).

Many studies have focused on the differences in nutritional values between organic and conventional cereals (Lairon, 2010; Zuchowski *et al.*, 2011; Mazzoncini *et al.*, 2015). Compared with conventional products, organic products generally have a lower content of macronutrients, especially proteins, but also a higher concentration of secondary metabolites (Zuchowski *et al.*, 2011). Phenolic acids are the main antioxidants in cereal grains which seem to have the greatest potential to be beneficial to our health (Gawlik-Dziki *et al.*, 2012).

Despite the increasing implementation of organic farming systems, in most European countries, they continue to occupy only a small proportion of the utilizable agricultural area. Moreover, within mainstream agricultural science and farm management, there is considerably greater interest in what are called integrated farming systems. These systems can be conceptualized as a “third way” for agriculture which is both economically and environmentally beneficial (Morris and Winter, 1999). An integrated farming system harmoniously combines technical and biological progress in cultivation, fertilization and plant protection. In integrated agriculture farming treatments are used in moderate amounts, they help only the overall actions of the farmer and agricultural practices. The aim of this management system is to achieve stable performance and suitable agricultural incomes in the long term (Zimny, 2007.)

There are few studies on the interaction between the cropping system and the wheat products in terms of physicochemical properties and milling processes. Thus, the aim of this study was to investigate the effect of the origin of wheat grown using three different management systems on the physicochemical properties and grinding characteristics of wheat grain.

MATERIALS AND METHODS

Wheat samples came from a long-term field experiment comparing the influence on crops of different production methods. Varieties of four common spring wheat (Bombona, Tybalt, Parabola, Vinjett) were grown at Osiny Experimental Station, belonging to the Institute of Soil Science and Plant Cultivation (State Research Institute) located in Puławy (Lublin province, Poland) on a gray–brown podsolic soil, under Organic (OR), Integrated (IN) and Conventional (CO) management systems. The field experiment was conducted in 2011 and 2012 growing seasons. The cultivars were chosen according to a number of traits useful in different farming systems, such as a higher resistance to fungal pathogens, a greater length of culm, and an earlier time of grain ripening. Plants were cultivated on 1 ha experimental fields; one field for each production system.

The experimental filed is located on luvisols composed of loamy sand (dominated part), characterizing with slightly acidic pH (pH in KCl: 5.8), average phosphorous content (43.6 mg P kg^{-1} of soil), low content of potassium (63.1 mg K kg^{-1} of soil) and 1.6% of humus.

Individual cultivars were grown on 0.1 ha sections of the fields. Selected details of the agricultural practices are presented in Table 1. Average monthly temperature (°C) and sum of rainfall (mm) during the growing seasons of spring wheat (2011, 2012) are presented in Table 2. In all systems of production and for all varieties used, the

Table 1. Selected elements of agricultural practice for spring wheat in three crop production systems.

Specification	Crop production system		
	Organic	Integrated	Conventional
Crop rotation	P-Sw-Rc- Rc-Ww[a]	P-Sw–L-Ww	Rz-Ww-Sw
Seed dressing	-	+	+
Fertilization (kg/ha)	-	N-90, P-40, K-60	N-120, P-40, K-60
Herbicides	-	1x	1x
Fungicides	-	1x	2x
Insecticide	-	1x	1x
The growth regulator	-	1x	1x

[a] P: Potato; Sw: Spring wheat; Ww: Winter wheat; Rz: Winter rape; Rc: Red clover with grass, L: Legumes.

Table 2. Average monthly temperature and sum of rainfall during the growing season of spring wheat (2011, 2012).

Weather parameter	Year	Months					
		III	IV	V	VI	VII	VIII
Temperature (°C)	2011	3.0	10.5	13.8	18.4	18.2	18.6
	2012	4.7	9.6	15.3	17.1	20.8	18.7
	Average 1950/2000	1.9	8.1	13.8	17.1	18.6	17.8
Rainfalls (mm)	2011	11.1	26.6	60.5	54.4	247.8	36.2
	2012	31.3	35.6	39.1	78.0	77.4	81.1
	Average 1950/2000	28.1	42.0	55.0	71.0	78.2	67.3

same seeding density (4.5 million grains ha^{-1}) was applied. Time of sowing and harvesting was the same for all tested cultivars (sowing between 25–30 March, harvesting between 1-10 August).

Each cultivar section contained 12 plots (20 m^2) from which grains were harvested. Samples of grains from all 12 harvest plots were taken and mixed. The obtained mixtures were used for the preparation of grain extracts to create a representative pool for each cultivar.

Physicochemical Characteristics of Grain

The single-kernel characterization system (SKCS 4100, Perten Instruments North America Inc., Reno, USA) was used to determine the kernel Hardness Index (HI), Kernel Weight (KW), Moisture Content (MC), and Kernel Diameter (KD) from the analysis of 300 individual kernels (AACC Method 55–31, 2002). The kernels were also evaluated for Bulk Density (BD) and Vitreousness (KV) (Greffeuille *et al*., 2007), total Protein Content (PC) using the Kjeldahl method with a Kjel-Foss Automatic (N·5.83), and content of total ash (KAC) (ICC Standard no. 104/1, ICC 1990). The analyses were conducted in triplicate.

Impact of Grinding Process

The preliminary cleaned samples of individual wheat varieties (moisture content of 10% wb) were ground using a laboratory hammer mill (POLYMIX-Micro-Hammermill MFC) equipped with a screen with round holes 3.0 mm in diameter. Later, 20-g samples were weighed just before grinding. The mill speed was adjusted to

7,800 rpm for pulverizing. Wheat samples were placed into the mill hopper and the entire sample was released into the grinding mechanism. The mill was equipped with a computer system that allowed the recording and analysis of the grinding energy consumption. The amount of energy consumed during grinding was obtained by using a power transducer (PP71B5, LUMEL, Poland), a data acquisition and a computer system that recorded the data measured by the transducer. The grinding energy was calculated using special computer software. The energy required to run the mill with no load was determined and subtracted from the total energy to obtain the grinding energy. The unloaded grinder current was monitored before grinding and remained constant over all testing. The detailed procedure for measuring stand and procedure was described by Dziki *et al.* (2014). The measurements of grinding energy were replicated ten times. The specific grinding Energy (E_r) was determined as the ratio of the grinding energy to the mass of the material taken for grinding. The sieving test was used to determine the particle size distribution of the pulverized material. Sieving was carried out for 5 minutes, using a laboratory screen (Thyr 2, SASKIA, Germany), and then the material was separated into fractions. On the basis of the particle size distribution, the average particle size (d_p) was calculated (Dziki and Laskowski, 2010). The distribution of the particle size was evaluated three times and the d_p was taken for the calculation of other grinding characteristics. The grinding ability index (E_f) was determined as the ratio of the grinding energy to the surface area of the pulverized material. The surface area of the pulverized material was evaluated according to the procedure described by Jha and Sharma (2010). The Sokołowski's grinding index (Ks) was also calculated. Details of the procedure used in determining these indices can be found in Dziki (2011).

Milling Process

Cleaned wheat kernels from each cultivar were conditioned in two steps. First, water was added to increase the moisture content of the wheat kernel to 13.5% (wb) moisture level 24 hours before milling. Then, kernel moisture was increased to 14% (wb) followed by 30 minutes tempering. The conditioned kernels were then milled using a Buhler MLU 202 Laboratory Mill (Bühler AG, Uzwil, Switzerland). The break flour and the reduction flour were obtained by blending the flours from the breaking and reduction stages, respectively. The total flour was obtained by blending break flour with the reduction flour. The individual flour yields were expressed as the percentage in weight of ground grains. The Content of total Ash in Flour (FAC) was determined (ICC Standard no. 104/1, ICC 1990) and the Index of Milling Efficiency (MEI) was calculated as a ratio of the total flour yield to flour ash content. The experiments were carried out in triplicate.

Extraction of Free and Bound Phenolic Compounds from Flour

Flour samples (1 g) were mixed with 10 mL of 80% chilled ethanol for 20 minutes with continuous shaking at room temperature. The suspension was centrifuged (15 minutes, 300×g), and the supernatant (free phenolic extracts) was collected. The pellet was re-extracted twice with 10 mL of 80% chilled ethanol, centrifuged (15 minutes, 300×g) and all supernatants were combined. The obtained fractions containing free phenolics were concentrated using a vacuum evaporator and then filled up with methanol to a final volume of 10 mL. The free phenolic compounds were then stored at −40°C until further use. After extraction of free phenolics, 20 mL of 2M NaOH was added directly to the pellet and shaken for 90 minutes at 60°C. After alkaline hydrolysis, the solution was acidified to pH 2 with 6M HCl and centrifuged (15 minutes, 3,000×g) to separate cloudy precipitates. The free fatty acids and other lipid contaminants in the clear solution were removed by extraction with hexane (1:1 v/v, five times). The liberated phenolic acids were then extracted six times with ethyl acetate (1:1 v/v). The pooled ethyl acetate extracts (containing bound phenolic acids) were evaporated to dryness, and then bound phenolic compounds were reconstituted in 10 mL of methanol and stored at −40°C until further use (Hung *et al.*, 2011). The experiment was performed in triplicate.

Chemical Analyzes

HPLC analysis of free and bound phenolic acids was estimated according to Gawlik-Dziki *et al.* (2012). A radical scavenging ability assay was performed in triplicate using an improved ABTS decolorization assay (Re *et al.*, 1999).

Antiradical activity was expressed as EC_{50} -Extract Concentration (g mL^{-1}) provided 50% of activity based on a dose-dependent mode of action.

Statistical Analysis

The obtained data were further subjected to a statistical analysis and the consequent evaluations were analyzed for a variance (two-way ANOVA). The statistical differences between the treatment groups were estimated through Tukey's test. The Pearson correlation analysis and the multiple linear regression analysis were also carried out on these data. Statistical tests were evaluated at a significance level of α= 0.05 using Statistica 6.0 software (StatSoft, Inc., Tulsa, USA).

RESULTS AND DISCUSSION

Physicochemical Properties

Wheat kernel properties from different farming systems are presented in Table 3. The Protein Content (PC) changed in the range from 12.1% (cv. Parabola, OR farming system) to 15.5% (cv. Bombona, CO farming system). Grain from the OR farming system was generally characterized by a lower *PC* when compared to grain from IN and CO farming systems. The same tendency was found for grain harvested in both 2011 and 2012. The *KAC* changed from 1.74 to 2.10% (cv. Vinjett, from IN and CO farming system, respectively). The lowest level of *KAC* was obtained for wheat from OR farming in all cultivars, except cv. Vinjett. These results agree with those obtained by Marzec *et al.* (2011) and Zuchowski *et al.* (2011). However, Kihlberg *et al.* (2004) found that conventional wheat had lower protein and ash contents than organic variant, but they did not demonstrate the elements of agricultural practice for wheat in crop production systems. The bulk density changed from 703 (cv. Vinjett, CO farming) to 771 kg m^{-3} (cv. Bombona, IN farming). There was no clear effect of farming system on *BD* or *KV*. Generally, kernels obtained from OR farming were characterized by the lowest values of *BD* and *KV*. Marzec *et al.* (2011) found that grain from the CO system was more glassy than from the OR system. In our study, we also found this trend. Vitreousness is generally attributed to the degree of compactness of the endosperm. Environmental conditions during growth and maturation (water and nitrogen availability, temperature, etc.) play a major role in the development of vitreousness (Greffeuille *et al.*, 2007; Knapowski *et al.*, 2015). The year of farming had either no or little influence on *BD* or *KV*, whereas grain harvested in 2011 was usually characterized by slightly higher values for *PC*.

The choice of farming system had a significant influence on *HI*, *KW* and *KD*. The highest values for *KW* and *KD* and the lowest *HI* were obtained for grain from the IN farming system. This trend was observed for all cultivars and for both years of observation. However, the values of these

Table 3. The average values of protein and ash content, and physical properties of wheat kernel.[a]

Cultivar	Year	Farming	PC [a], (% wb)	KAC [b] (% wb)	BD [c] (kg m^{-3})	HI [d]	KW [e] (mg)	KD [f] (mm)	KV [g] (%)
Bombona	2011	OR [h]	12.7±0.07^{g}	1.81±0.015^{abcd}	734±4.^{defg}	72.0±16.15^{e**}	33.0±7.01^{a}	2.77±0.271^{a}	80±2^{ij}
		IN [i]	13.5±0.05^{j}	1.87±0.035^{defg}	771±5^{l}	65.8±14.52^{d}	39.8±7.41^{d}	3.01±0.268^{c}	73±1^{g}
		CO [j]	15.5±0.04^{o}	2.08±0.050^{k}	761±3^{jkl}	71.5±16.33^{e}	33.1±8.64^{a}	2.75±0.310^{a}	93±2^{k}
	2012	OR	12.5±0.05^{ef}	1.82±0.031^{abcd}	739±4^{efgh}	68.0±12.15^{e*}	31.0±6.21^{a}	2.77±0.271^{a}	78±3^{ghij}
		IN	13.3±0.06^{hi}	1.83±0.026^{abcde}	767±4^{kl}	61.8±13.35^{d}	36.8±6.33^{d}	3.01±0.268^{c}	74±1^{gh}
		CO	14.9±0.05^{n}	2.05±0.038^{jk}	750±5^{hij}	70.3±14.23^{e}	32.1±7.12^{a}	2.75±0.310^{a}	92±2^{k}
Tybalt	2011	OR	12.7±0.08^{g}	1.80±0.015^{abcd}	718±5^{bc}	57.2±14.97^{bc}	40.9±7.17^{d}	2.88±0.283^{ab}	63±2^{ef}
		IN	12.5±0.07^{ef}	1.82±0.016^{abcd}	724±5^{cd}	47.8±15.21^{a}	44.7±8.08^{e}	3.03±0.298^{c}	80±3^{ij}
		CO	13.7±0.03^{k}	1.85±0.010^{cdefg}	730±5^{cdef}	52.9±16.43^{b}	36.4±10.96^{bc}	2.74±0.341^{a}	74±2^{ghi}
	2012	OR	12.6±0.06^{fg}	1.78±0.015^{abc}	717±4^{bc}	58.4±15.28^{bc}	39.6±6.28^{d}	2.73±0.256^{ab}	66±2^{f}
		IN	12.4±0.05^{de}	1.81±0.026^{abcd}	728±6^{cde}	45.3±16.87^{a}	43.2±6.74^{e}	3.11±0.241^{c}	81±1^{j}
		CO	13.6±0.04^{jk}	1.83±0.015^{abcde}	740±2^{efgh}	50.9±14.53^{b}	35.22±9.28^{bc}	2.74±0.253^{a}	79±3^{hij}
Parabola	2011	OR	12.1±0.04^{ab}	1.88±0.020^{defgh}	752±2^{hij}	67.6±16.62^{de}	41.2±8.75^{d}	2.93±0.322^{b}	66±2^{f}
		IN	13.3±0.06^{hi}	1.91±0.025^{fgh}	735±3^{defg}	59.2±15.71^{c}	50.4±8.67^{f}	3.21±0.348^{c}	56±2^{cd}
		CO	14.5±0.04^{m}	1.95±0.015^{hi}	760±3^{jkl}	69.4±16.18^{de}	37.4±10.25^{bd}	2.81±0.343^{ab}	95±3^{k}
	2012	OR	12.0±0.04^{a}	1.84±0.015^{bcdef}	746±2^{ghi}	65.2±13.32^{de}	41.7±6.87^{d}	2.89±0.311^{b}	60±2^{def}
		IN	13.1±0.07^{h}	1.90±0.026^{efgh}	743±2^{fghi}	56.1±14.22^{cb}	50.0±7.21^{f}	3.26±0.296^{c}	59±2de
		CO	14.3±0.06^{l}	1.93±0.031^{gh}	755±3^{ijk}	67.4±15.97^{de}	36.9±9.71^{bd}	2.78±0.301^{ab}	92±3^{k}
Vinjett	2011	OR	12.3±0.05^{cd}	1.85±0.025^{cdefg}	703±8^{a}	57.3±15.52^{bc}	33.7±7.92^{a}	2.78±0.292^{a}	46±2^{ab}
		IN	13.4±0.07^{ij}	1.74±0.021^{a}	750±5^{hij}	53.3±16.33^{b}	38.4±6.67^{bd}	2.89±0.239^{ab}	45±1^{ab}
		CO	14.9±0.04^{n}	2.10±0.200^{jk}	728±3^{cde}	67.1±16.39^{de}	34.2±10.53^{ab}	2.75±0.334^{a}	51±2^{bc}
	2012	OR	12.2±0.07^{bc}	1.81±0.013^{abcd}	707±7^{ab}	55.1±14.54^{bc}	34.6±7.90^{a}	2.83±0.302^{a}	45±2^{a}
		IN	13.2±0.05^{h}	1.76±0.021^{ab}	742±5^{fghi}	52.5±15.87^{b}	39.2±7.54^{bd}	2.91±0.245^{ab}	46±2^{ab}
		CO	14.6±0.05^{m}	2.02±0.026^{ij}	727±5^{cdce}	65.3±15.98^{de}	34.9±6.53^{ab}	2.72±0.254^{a}	49±2^{ab}
Means of farming system		OR	12.4±0.27	1.82±0.03	727±18	62.6±6.32	37.0±4.31	2.82±0.071	63±12
		IN	13.1±0.41	1.83±0.06	745±17	55.2±6.93	42.8±5.21	3.05±0.132	64±15
		CO	14.5±0.63	1.98±0.10	744±14	64.4±7.97	35.0±1.85	2.76±0.028	78±19
Means of years	2011		13.4±1.07	1.90±0.11	738.8±20	61.8±8.14	38.6±5.23	2.92±0.15	68.5±17
	2012		13.2±0.96	1.89±0.09	738.4±16	59.7±7.86	37.9±5.26	2.87±0.17	68.4±16

[a] Protein Content, [b] Kernel Ash Content, [c] Bulk Density, [d] Hardness Index, [e] Kernel Weight, [f] Kernel Diameter, [g] Kernel Vitreousness, [h] Organic, [i] Integrated, [j] Conventional; * The values designated by different letters in each column are significantly different (α= 0.05).

parameters obtained for wheat from OR and CO farming systems were similar (Table 3).

The results showed positive and significant correlations between *HI* and *KAC* (r= 0.596) and confirmed our previous observations (Dziki *et al.*, 2014). Also, significant and positive correlations were found between *HI* and *PC* (r= 0.44) (Table 7). Generally, it has been proved that wheat hardness is mainly regulated by a protein called friabilin. This surface protein complex is present in larger amounts in soft wheat cultivars compared to hard ones (Hrušková and Švec, 2009).

Impact Grinding Results

The results showed that the choice of farming system had a significant influence on particle size distribution of impact ground wheat, whereas the year of farming had either no or little effect on grinding pattern (Table 4). The lowest mass fraction of coarse (> 1.0 mm) and the highest mass fraction of small particles (< 0.2 mm) was observed after grinding kernels from the IN

Table 4. Particle size distribution (%) of the ground wheat samples. Results are shown as average value±standard deviation.

Cultivar	Farming system	Year	Range of class (mm) > 1.0	0.8-1.0	0.63-0.80	0.4-0.63	0.315-0.4	0.2-0.315	< 0.2
Bombona	OR ^{a}	2011	34.0±0.27^{f*}	17.9±0.21^{c}	15.6±0.11^{e}	12.8±0.15^{b}	4.9±0.12^{a}	6.9±0.09^{ef}	7.9±0.18^{a}
	IN ^{b}		32.3±0.18^{de}	15.0±0.17^{a}	16.5±0.21^{f}	14.6±0.13^{d}	4.9±0.02^{a}	5.8±0.11^{b}	10.9±0.21^{e}
	CO ^{c}		32.8±0.33^{e}	17.1±0.08^{b}	15.2±0.05^{d}	14.6±0.11^{d}	5.0±0.07^{a}	6.6±0.15^{e}	8.7±0.23^{b}
	OR	2012	33.7±0.23^{f}	18.1±0.18^{c}	15.2±0.12^{e}	12.9±0.25^{b}	5.0±0.14^{a}	7.0±0.05^{ef}	8.1±0.12^{a}
	IN		32.6±0.21^{de}	14.8±0.25^{a}	16.2±0.09^{f}	14.8±0.24^{d}	5.1±0.08^{a}	5.9±0.08^{b}	10.6±0.16^{e}
	CO		33.0±0.30^{e}	16.9±0.14^{b}	14.9±0.15^{d}	14.5±0.18^{d}	5.1±0.09^{a}	6.7±0.11^{e}	8.9±0.25^{b}
Tybalt	OR	2011	29.8±0.08^{b}	15.0±0.15^{a}	15.6±0.14^{de}	16.2±0.06^{f}	5.4±0.15^{b}	6.7±0.07^{e}	11.3±0.07^{f}
	IN		27.3±0.29^{a}	19.3±0.13^{e}	14.1±0.16^{b}	14.7±0.17^{d}	5.7±0.09^{c}	6.3±0.16^{d}	12.6±0.15^{h}
	CO		29.8±0.17^{b}	17.5±0.22^{c}	13.3±0.11^{a}	15.0±0.25^{e}	5.5±0.08^{b}	6.8±0.17^{e}	12.1±0.25^{g}
	OR	2012	29.7±0.28^{b}	15.0±0.17^{a}	15.5±0.24^{de}	16.0±0.12^{f}	5.7±0.10^{b}	6.5±0.07^{e}	11.6±0.21^{f}
	IN		26.9±0.33^{a}	19.2±0.19^{e}	14.2±0.22^{b}	14.8±0.21^{d}	5.6±0.13^{c}	6.4±0.19^{d}	12.9±0.18^{h}
	CO		29.5±0.25^{b}	17.7±0.12^{c}	13.1±0.18^{a}	15.2±0.23^{e}	5.4±0.05^{b}	6.7±0.21^{e}	12.4±0.20^{g}
Parabola	OR	2011	34.7±0.35^{g}	14.8±0.07^{a}	16.2±0.22^{f}	12.7±0.21^{b}	5.4±0.12^{b}	5.8±0.09^{b}	10.4±0.13^{d}
	IN		32.2±0.22^{d}	18.3±0.12^{d}	13.2±0.23^{a}	13.0±0.14^{b}	5.5±0.16^{b}	5.5±0.11^{a}	12.3±0.09^{g}
	CO		35.1±0.18^{h}	18.3±0.16^{d}	13.8±0.04^{b}	12.2±0.08^{a}	4.9±0.08^{a}	5.3±0.12^{a}	10.4±0.12^{de}
	OR	2012	34.1±0.28^{g}	14.9±0.09^{a}	16.3±0.12^{f}	12.9±0.23^{b}	5.3±0.09^{b}	5.7±0.11^{b}	10.8±0.14^{d}
	IN		31.9±0.17^{d}	18.4±0.11^{d}	13.2±0.31^{a}	13.1±0.17^{b}	5.3±0.17^{b}	5.6±0.08^{a}	12.5±0.12^{g}
	CO		34.8±0.31^{h}	18.1±0.12^{d}	13.6±0.08^{b}	12.4±0.11^{a}	5.1±0.14^{a}	5.3±0.21^{a}	10.7±0.17^{de}
Vinjett	OR	2011	30.9±0.31^{c}	17.2±0.23^{b}	14.9±0.11^{c}	15.3±0.16^{e}	5.3±0.07^{b}	6.1±0.11^{cd}	10.3±0.16^{d}
	IN		30.7±0.47^{c}	14.9±0.07^{a}	16.2±0.17^{f}	14.3±0.13^{c}	5.3±0.15^{b}	7.1±0.08^{f}	11.5±0.17^{f}
	CO		33.9±0.25^{g}	18.3±0.09^{d}	14.8±0.10^{c}	12.3±0.19^{a}	5.0±0.11^{a}	6.0±0.16^{c}	9.8±0.24^{c}
	OR	2012	31.0±0.23^{c}	17.5±0.08^{b}	14.7±0.15^{c}	15.5±0.06^{e}	5.1±0.10^{b}	5.9±0.07^{cd}	10.3±0.12^{d}
	IN		30.3±0.30^{c}	14.6±0.11^{a}	16.3±0.11^{f}	14.6±0.15^{c}	5.5±0.08^{b}	7.0±0.11^{f}	11.7±0.15^{f}
	CO		33.2±0.26^{f}	18.5±0.19^{d}	14.8±0.11^{c}	12.5±0.17^{a}	5.1±0.15^{a}	6.1±0.10^{c}	9.9±0.12^{c}
Means of Farming System		OR	32.2±2.09	16.3±1.49	15.5±0.57	14.3±1.59	5.3±0.26	6.3±0.51	10.1±1.37
		IN	30.5±2.26	16.8±2.16	15.0±1.45	14.2±0.75	5.4±0.27	6.2±0.61	11.9±0.84
		CO	32.8±2.09	17.8±0.60	14.2±0.82	13.6±1.34	5.1±0.21	6.2±0.62	10.4±1.35
Means of Years		2011	32.0±2.33	17.0±1.62	15.0±1.14	14.0±1.32	5.2±0.28	6.2±0.58	10.7±1.42
		2012	31.7±2.31	17.1±1.68	14.8±1.12	14.1±1.26	5.3±0.23	6.4±0.52	10.9±1.45

[a] Organic; [b] Integrated, [c] Conventional. [*] The values designated by different letters in each column are significantly different (α= 0.05).

farming system. In most cases, significantly different mass fractions of these particles were obtained for grain from OR and CO management systems. This tendency was found in both years of farming. The particle size and the particle size distribution are significant from the technological point of view. It has been proved that the amount of finely ground particles mainly depends on kernel hardness. Soft wheat kernels are characterized by a lower degree of adhesion between starch granules and protein matrix and thus a higher mass fraction of fine particles is produced (Haddad *et al.*, 1999). This method is commonly used for evaluation of wheat hardness on the basis of the mass fractions of small particles. In our study, *HI* was also significantly and negatively correlated (r= −0.835) with the mass fraction of fine particles (< 0.2 mm) (Figure 1-A). In addition, we found a stronger and positive correlation (r= 0.906)

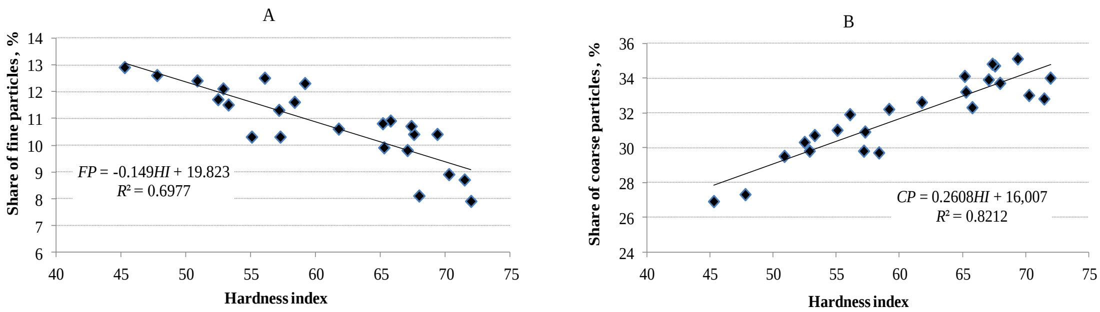

Figure 1. Relationship between grain hardness and the mass fraction of fine (A) and coarse particles (B). FP: Share of Fine Particles; CP: Share of Coarse Particles, HI: Hardness Index.

between *HI* and the mass fraction of the coarse particles (> 1.0 mm) (Figure 1-B). This indicated that not only the mass fraction of small particles but also the mass fraction of coarse particles could be an indirect indicator of wheat hardness. The results of multiple regression showed that *HI* can be expressed according to the followed equation with an estimation error of ±2.46:

$HI = 2.18CP – 2.29FP + 15.79$; $R^2 = 0.911$ (1)

Where, *CP* and *FP* are the mass fraction of coarse and fine particles, respectively.

The d_p ranged from 727 μm for Tybalt (IN farming) to 791 μm for Bombona (OR farming) cultivated in 2011 and 2012, respectively. The lowest values of d_p were always found for ground wheat obtained from the IN farming system, whereas values for this parameter for ground wheat from CO and OR were in most cases significantly higher (Table 5). The year of farming had no significant influence on d_p. The results showed significant and positive correlations between d_p and *HI* (r= 0.912) and between d_p and *KAC* (r= 0.596) (Table 7). Wheat kernels with higher ash content usually have a higher bran to endosperm ratio. Bran is more resistant to grinding than endosperm, thus, a greater ratio of bran to endosperm can result in an increase in d_p value.

The results of grinding energy requirements (Table 5) showed that E_r ranged from 34.5 (cv. Tybalt, IN farming) to 41.3 kJ kg^{-1} (cv. Bombona, OR farming). Also, the lowest and the highest values of E_f and K_s were obtained for these cultivars, i.e. from 5.4 to 7.1 kJ m^{-2} and from 58.0 to 78.6 kJ kg^{-1} mm$^{0.5}$, respectively. The farming system had a significant influence on wheat kernel grinding energy indices, whereas the year of farming had a negligible effect on these parameters All grinding energy indices showed that grain from the IN farming system was characterized by the lowest grinding energy requirements, whereas the energy requirements for size reduction of grain from OR and CO cropping were similar and usually significantly higher than IN farming (Table 5). This is caused by the harder endosperm of kernels from these farming systems. The correlation coefficients between *HI* and E_r, E_f and K_s were 0.863, 0.907 and 0.891, respectively. In addition, E_r was significantly and positively correlated with d_p (r= 0.845) (Table 7). Moreover, the grinding energy requirements depend on grinding method and especially on the degree of fineness (Dziki, 2008).

Milling Results and Antioxidant Activity of Flour

Milling results are presented in Table 6. The Break Flour Yield (BFY) ranged from 14.8% (cv. Bombona, CO farming) to 20.8% (cv. Vinjett, OR farming). The lowest Reduction Flour Yield (RFY) was obtained for Vinjet (OR farming) and the highest for

Table 5. Indices characterizing the impact grinding process of wheat grain. Results are shown as average value±standard deviation.

Cultivar	Farming	Year	d_p [a] (mm)	E_r [b] (kJ kg^{-1})	E_f [c] (kJ m^{-2})	K_s [d] (kJ kg^{-1} mm$^{0.5}$)
Bombona	OR [e]	2011	789±5.2^{e*}	41.3±1.5^{d}	7.1±0.11^{e}	78.8±2.17^{f}
	IN [f]		760±3.1^{c}	36.9±1.7^{b}	6.1±0.33^{c}	64.7±1.78^{c}
	CO [g]		775±4.3^{d}	41.1±0.9^{cd}	6.9±0.27^{de}	76.9±2.06^{f}
	OR	2012	791±4.2^{e}	40.9±2.8^{d}	7.0±0.19^{e}	77.2±2.33^{f}
	IN		759±6.1^{c}	36.2±2.2^{b}	5.9±0.26^{c}	63.9±1.88^{c}
	CO		777±5.0^{d}	40.9±1.7^{cd}	6.8±0.30^{de}	76.3±2.11^{f}
Tybalt	OR	2011	734±3.8^{a}	35.2±1.3^{a}	5.6±0.18^{ab}	61.0±0.85^{b}
	IN		727±5.6^{a}	34.5±0.9^{a}	5.4±0.21^{a}	58.0±2.87^{a}
	CO		736±5.8^{ab}	36.2±1.4^{b}	5.8±0.23^{bc}	64.5±1.34^{c}
	OR	2012	731±4.7^{a}	35.5±1.1^{a}	5.5±0.18^{ab}	61.1±0.85^{b}
	IN		728±4.2^{a}	34.6±0.8^{a}	5.5±0.21^{a}	58.2±2.87^{a}
	CO		734±3.6^{ab}	36.9±1.4^{b}	5.6±0.23^{bc}	63.9±1.34^{c}
Parabola	OR	2011	775±4.7^{d}	39.1±1.6^{c}	6.6±0.15^{cd}	70.9±2.21^{de}
	IN		759±3.9^{c}	37.2±2.2^{b}	6.1±0.13^{c}	63.1±3.13^{bc}
	CO		787±4.3^{e}	40.0±0.8^{c}	6.8±0.17^{d}	75.4±1.78^{f}
	OR	2012	770±3.9^{d}	38.0±2.6^{c}	6.4±0.22^{cd}	70.0±3.18^{de}
	IN		755±5.6^{c}	35.8±2.2^{b}	5.9±0.18^{c}	62.7±1.98^{bc}
	CO		784±5.3^{d}	39.4±1.9^{c}	6.7±0.13^{d}	75.0±2.04^{f}
Vinjett	OR	2011	756±2.8^{c}	37.2±1.9^{b}	6.1±0.24^{c}	67.6±2.49^{cd}
	IN		741±3.7^{b}	35.2±2.2^{a}	5.7±0.18^{ab}	61.4±2.35^{bc}
	CO		783±5.4^{d}	37.4±1.8^{b}	6.4±0.13^{c}	71.0±3.11^{e}
	OR	2012	753±1.6^{c}	36.4±2.5^{b}	5.9±0.33^{c}	66.1±3.89^{cd}
	IN		742±3.2^{b}	34.3±2.7^{a}	5.6±0.20^{ab}	60.4±2.55^{bc}
	CO		780±4.1^{d}	36.7±2.2^{b}	6.1±0.34^{c}	69.6±4.61^{e}
Means of Farming System		OR	746±13.8	35.6±1.1	5.8±0.27	61.6±2.52
		IN	770±21.6	38.6±2.0	6.4±0.50	71.6±5.21
		CO	762±22.9	38.0±2.3	6.3±0.60	69.1±6.60
Means of Years		2011	760±21,9	37,6±2,29	6,2±0,55	67,8±6,79
		2012	759±21,8	37,1±2,23	6,1±0,53	67,0±6,50

[a] The average particle size; [b] Specific grinding Energy; [c] Grinding ability index; [d] Sokołowski's grinding index; [e] Organic; [b] Integrated, [c] Conventional. [*] The values designated by different letters in each columns are significantly different (α=0.05).

Bombona (CO farming) (54.1 and 59.5%, respectively). The Total Flour extraction (TFY) ranged from 73.5% (cv. Tybalt and Parabola from OR and CO farming system, respectively) to 76.1% (cv. Vinjett, CO farming). There was no clear influence of farming system on the flour extraction rate. However, the farming system had a significant influence on the *FAC*. Flour from grain obtained from IN farming was usually characterized by the lowest content of ash. This tendency was observed for all cultivars. The year of farming had no significant influence on milling results.

The flour extraction rate depends on the milling process and grain properties. Generally, hard wheat kernels grind better during the reduction stage than the soft kernels do, and bran includes little endosperm and the *TFY* is higher (Haddad *et al.*, 1999). However we did not find any significant correlation between *HI* and *TFY*,

Table 6. Milling results and antioxidant activity of flour. Results are shown as average value±standard deviation.

Cultivar	Farming	Year	BFY [a] (%)	RFY[b] (%)	TFY [c] (%)	FAC [d] (%)	MEI [e]	EC_{50F} [f] (g mL^{-1})	EC_{50B} [g] (g mL^{-1})
Bombona	OR [h]	2011	$15.5\pm0.31^{b*}$	59.1 ± 0.35^{fg}	74.6 ± 0.45^{bc}	0.81 ± 0.02^{bc}	92.1 ± 1.11^{d}	0.28 ± 0.01^{ef}	0.42±0.03cd
	IN [i]		16.4 ± 0.52^{c}	58.6 ± 0.52^{f}	75.0 ± 0.53^{cd}	0.79 ± 0.01^{b}	94.9 ± 1.05^{e}	0.22 ± 0.02^{d}	0.44±0.03cd
	CO [j]		14.8 ± 0.45^{a}	59.5 ± 0.41^{g}	74.3 ± 0.62^{bc}	0.88 ± 0.02^{d}	84.4 ± 2.33^{b}	0.19 ± 0.01^{b}	0.47±0.03e
	OR	2012	16.1 ± 0.42^{b}	58.6 ± 0.23^{fg}	74.7 ± 0.55^{bc}	0.83 ± 0.02^{bc}	90.0 ± 1.82^{d}	0.26 ± 0.02^{e}	0.39±0.04c
	IN		16.6 ± 0.38^{c}	58.2 ± 0.46^{f}	74.8 ± 0.48^{cd}	0.77 ± 0.03^{b}	93.5 ± 1.22^{e}	0.23 ± 0.02^{d}	0.45±0.03d
	CO		15.0 ± 0.45^{a}	59.1 ± 0.41^{g}	74.1 ± 0.62^{bc}	0.85 ± 0.03^{d}	87.2 ± 1.65^{b}	0.18 ± 0.01^{b}	0.53±0.03e
Tybalt	OR	2011	18.4 ± 0.22^{e}	55.1 ± 0.17^{b}	73.5 ± 0.41^{a}	0.82 ± 0.03^{b}	89.6 ± 2.14^{c}	0.52 ± 0.03^{j}	0.27±0.01a
	IN		17.1 ± 0.16^{c}	57.2 ± 0.35^{e}	74.3 ± 0.42^{bc}	0.78 ± 0.01^{ab}	95.3 ± 1.35^{e}	0.35 ± 0.01^{ch}	0.34 ± 0.01^{b}
	CO		17.5 ± 0.33^{cd}	57.4 ± 0.62^{e}	74.9 ± 0.51^{c}	0.80 ± 0.02^{bc}	93.6 ± 1.03^{e}	0.19 ± 0.02^{bc}	0.42 ± 0.02^{cd}
	OR	2012	17.6 ± 0.25^{d}	55.7 ± 0.27^{b}	73.3 ± 0.51^{a}	0.81 ± 0.05^{b}	90.5 ± 1.73^{c}	0.54 ± 0.03^{dk}	0.29 ± 0.01^{a}
	IN		17.4 ± 0.26^{c}	57.0 ± 0.31^{e}	74.4 ± 0.53^{bc}	0.79 ± 0.04^{ab}	94.6 ± 1.51^{e}	0.31 ± 0.02^{g}	0.34 ± 0.03^{b}
	CO		17.8 ± 0.13^{cd}	56.9 ± 0.52^{e}	74.7 ± 0.48^{c}	0.82 ± 0.02^{bc}	91.1 ± 1.1^{e}	0.21 ± 0.02^{cd}	0.41 ± 0.02^{c}
Parabola	OR	2011	17.9 ± 0.42^{de}	55.7 ± 0.42^{bc}	73.6 ± 0.40^{a}	0.97 ± 0.03^{e}	75.9 ± 2.13^{a}	0.35 ± 0.01^{ch}	0.42 ± 0.03^{cd}
	IN		18.4 ± 0.28^{e}	55.8 ± 0.52^{c}	74.2 ± 0.38^{b}	0.90 ± 0.02^{d}	82.4 ± 1.75^{b}	0.29 ± 0.02^{f}	0.39 ± 0.02^{c}
	CO		17.4 ± 0.38^{cd}	56.1 ± 0.35^{cd}	73.5 ± 0.37^{a}	1.02 ± 0.02^{f}	72.1 ± 2.78^{a}	0.19 ± 0.03^{bc}	0.30 ± 0.02^{b}
	OR	2012	18.1 ± 0.37^{de}	55.5 ± 0.35^{bc}	73.6 ± 0.38^{a}	0.99 ± 0.04^{e}	74.1 ± 1.13^{a}	0.40 ± 0.02^{gj}	0.42 ± 0.02^{de}
	IN		18.6 ± 0.18^{e}	55.7 ± 0.41^{c}	74.3 ± 0.39^{b}	0.91 ± 0.02^{d}	81.6 ± 1.21^{b}	0.27 ± 0.02^{f}	0.41 ± 0.03^{cd}
	CO		17.9 ± 0.41^{cd}	55.7 ± 0.55^{cd}	73.6 ± 0.42^{a}	1.00 ± 0.03^{f}	73.6 ± 1.06^{a}	0.21 ± 0.02^{c}	0.28 ± 0.03^{a}
Vinjett	OR	2011	20.8 ± 0.21^{g}	54.1 ± 0.36^{a}	74.9 ± 0.34^{c}	0.83 ± 0.01^{c}	90.2 ± 2.33^{cd}	0.41 ± 0.02^{di}	0.43 ± 0.03^{d}
	IN		18.6 ± 0.25^{e}	56.8 ± 0.48^{d}	75.4 ± 0.44^{de}	0.75 ± 0.02^{a}	100.5 ± 2.01^{f}	0.36 ± 0.02^{ch}	0.28 ± 0.01^{a}
	CO		19.8 ± 0.18^{f}	56.3 ± 0.26^{d}	76.1 ± 0.37^{e}	0.91 ± 0.03^{d}	83.6 ± 2.36^{b}	0.14 ± 0.01^{a}	0.49 ± 0.02^{f}
	OR	2012	20.2 ± 0.21^{g}	54.5 ± 0.36^{a}	74.7 ± 0.34^{c}	0.85 ± 0.01^{c}	87.9 ± 2.33^{cd}	0.39 ± 0.02^{ei}	0.46 ± 0.03^{ef}
	IN		18.5 ± 0.25^{e}	57.0 ± 0.48^{d}	75.5 ± 0.44^{de}	0.78 ± 0.02^{a}	96.8 ± 2.01^{f}	0.33 ± 0.01^{h}	0.30 ± 0.02^{a}
	CO		19.4 ± 0.18^{f}	56.6 ± 0.26^{d}	76.0 ± 0.37^{e}	0.89 ± 0.03^{d}	85.4 ± 2.36^{b}	0.17 ± 0.01^{b}	0.52 ± 0.03^{e}

[a] Break Flour Yield, [b] Reduction Flour Yield, [c] Total Flour Yield, [d] Flour Ash Content, [e] Milling Efficiency Index, [f] Antioxidant activity of Free phenolic acids, [g] Antioxidant activity of Bound phenolic acids, [h] Organic, [i] Integrated, [j] Conventional. [**]The values designated by different letters in each column are significantly different (α= 0.05).

but the range of hardness of the investigated kernels was narrow. On the other hand, *KV* was significantly and negatively correlated with *BFY* (r= −0.81) and positively with *RFY* (r= 0.56) (Table 7). These results confirm the hypothesis suggested by Haddad *et al.* (1999) and Lasme *et al.* (2012) that, as changes in mechanical behavior only concern wheat with similar hardness, there is an apparent relationship between vitreousness and milling behavior.

One of the best direct indicators of wheat milling value is *MEI*, which is defined as the ratio of the total flour yield to the flour ash content, the higher the value of this index the better the milling value of wheat. *MEI* ranged from 72.1 (cv. Parabola, CO farming) to 100.5 (cv. Vinjet, IN farming). Farming system had a significant influence on *MEI*. The highest values of this index were always found for grain from IN farming, whereas values of this index for grain from OR and CO farming systems were significantly lower. Besides, three of the four tested wheat cultivars were characterized by higher *MEI* from OR farming grain than from CO farming (Table 6). Table 7 presents the correlation coefficients between the physicochemical properties of grain, impact grinding, and milling results. The results showed that *MEI* was significantly and negatively correlated with d_p and grinding energy indices. Generally, a higher value of milling efficiency was found for grain with lower grinding energy requirements.

Antioxidant activity (EC_{50} value) of flour obtained from different wheat farming systems is presented in Table 6. Generally, the antioxidant activity of wheat flour

Table 7. Pearson's correlation coefficients between the physicochemical properties of wheat and the impact grinding and milling results. ^{a}

	PC	KAC	BD	HI	HV	KT	KV	d_p	E_r	E_f	KS	BFY	RFY	TFY	FAC
KAC	0.80*														
BD	0.43*	0.24													
HI	0.44*	0.60*	0.46*												
HV	-0.34	-0.24	0.01	-0.44*											
KT	-0.34	-0.23	0.16	-0.39	0.87*										
KV	0.35	0.27	0.49*	0.34	-0.19	-0.15									
d_p	0.39	0.60*	0.38	0.91*	-0.43*	-0.31	0.24								
E_r	0.36	0.51*	0.37	0.86*	-0.52*	-0.43*	0.55*	0.85*							
E_f	0.35	0.53*	0.40	0.91*	-0.47*	-0.35	0.43*	0.93*	0.97*						
K_s	0.42*	0.56*	0.31	0.89*	-0.62*	-0.54*	0.44*	0.91*	0.96*	0.97*					
BFY	-0.27	-0.14	-0.59*	-0.40	0.20	0.06	-0.81*	-0.22	-0.53*	-0.43*	-0.39				
RFY	0.41*	0.22	0.55*	0.34	-0.36	-0.13	0.56*	0.25	0.42*	0.37	0.35	-0.87*			
TFY	0.03	-0.08	0.31	0.01	-0.10	0.16	0.00	0.00	-0.14	-0.12	-0.13	-0.11	0.23		
FAC	0.22	0.52*	0.22	0.54*	0.10	-0.06	0.18	0.61*	0.49*	0.55*	0.53*	0.14	-0.36	-0.29	
MEI	-0.19	-0.51*	-0.22	-0.55*	-0.12	0.04	-0.22	-0.60*	-0.50*	-0.55*	-0.53*	-0.09	0.35	0.23	-0.99*

*Statistically significant coefficients (α= 0.05). ^{a} Symbols as defined under previous Tables.

changed within a narrow range from 0.14 to 0.54 g mL^{-1} for free phenolic acids and from 0.27 to 0.53 g mL^{-1} for bound phenolic acids. Considering free phenolics, it may be concluded that the highest activity (the lowest EC_{50} value) was determined for flours obtained from CO farming wheat, whereas the lowest was for flours from the OR farming system. This tendency is clearly visible for Tybalt and Vinjett varieties, while the lowest differences were observed for Bombona. Interesting results were obtained for bound phenolics. In all tested cultivars, except Parabola, the lowest antiradical activity was found for CO farming wheat**.** In recent literature, there is a lack of data concerning the antiradical activity of white wheat flour in terms of farming system. The growing season had little influence on the antioxidant activity of wheat flour. Contrary to our results, Lacko-Bartošová *et al*. (2013) proved that the farming system did not affect white flour or whole grain flour antioxidant capacity. On the other hand, Zuchowski *et al.* (2011) found that organically produced spring and winter wheat had significantly higher concentrations of ferulic and *p*-coumaric acid as well as the total phenolic acid content than conventional wheat.

CONCLUSIONS

In our study, we found that the farming system had a significant influence on both the physicochemical properties of grain and grinding process. In particular, grain from IN farming was characterized by the highest values for *KW* and *KD* and the lowest *HI*. The values of these parameters obtained for wheat from OR and CO farming systems were similar. These changes influenced both the impact grinding and milling results. Wheat hardness, in particular, had a very strong influence on the milling process. The lowest HI values were obtained for grain from the IN farming system, whereas the values of this parameter for CO and OR farming were similar.

The results of the grinding process showed that the lowest d_p was obtained for ground wheat from the IN farming system. This was caused by the fact that ground grain from the IN farming system had the highest mass fraction of fine particles (< 0.2 mm) and the lowest mass fraction of coarse particles (> 1.0 mm). However, the particle size distributions of ground wheat from CO and IN farming were similar. The grinding energy indices showed that grain from the IN farming system was characterized by the lowest grinding energy requirements, whereas the energy requirements for grinding wheat from OR and CO farming systems were similar and significantly higher. There was no clear influence of farming system on flour extraction rate. However, the IN farming system had a significant influence on *FAC* and generally improved wheat milling values, as expressed by higher *MEI* values. In the case of free phenolics, the highest antioxidant activity was obtained for flours from CO farming and the lowest for flour from the OR farming system. However, for bounded phenolics, the lowest antiradical activity was usually found for CO farming wheat**.** Considering the physical properties of kernel and milling results, the IN farming system seems to be the most suitable for spring wheat.

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خواص فیزیکوشیمیایی و ویژگی های آسیاب کردن گندم بهاره در سامانه های زراعی مختلف

د. دزیکی، گ. کاکاک-پیترزاک، ی. گاولیک-دزیکی، م. سویکا، ا. میس، ر. روزیلو، و ک. جونسژیک

چکیده

هدف این پژوهش بررسی اثر مبدا گندم کشت شده در سامانه های زراعی مختلف روی خواص فیزیکوشیمیایی و ویژگی های آسیاب کردن دانه گندم بود. به این منظور، چهار رقم گندم بهاره که در

شرایط کشت ارگانیک (OR)، کشت ادغام شده (IN) و کشت رایج (CO) پرورش یافته بودند در دو فصل رشد بررسی شدند. دانه های سامانه IN بیشترین وزن و قطر دانه و کمترین سفتی (hardness) و میانگین اندازه ذرات را داشتند. مقادیر عددی این صفات در گندم سامانه های OR و CO مشابه هم بودند. نمایه انرژی مورد نیاز برای آسیاب کردن نشان داد که دانه های سامانه IN به گونه ای مشخص کمترین انرژی مورد نیاز برای آسیاب کردن را داشت در حالیکه انرژی مورد نیاز برای کاهش اندازه دانه ها در سامانه OR وCO مشابه هم بود. افزون بر این، سامانه IN موجب افزایش نمایه کارآیی آسیاب کردن و مقدار اسیدهای فنولیک در آرد شد. داده ها نشان داد که سامانه های زراعی مطالعه شده در این پژوهش با تغییر دادن خواص فیزیکو شیمیایی دانه های گندم در طی فصل رشد نتایج خردکردن و آسیاب کردن را تحت تاثیر قرار دادند.