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Rating of Spring Wheat Varieties (*Triticum aestivum* L.) According to Their Suitability for Organic Agriculture

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Abstract: The selection of a proper variety is one of the main factors influencing the quantity and quality of cereal grain yield in organic agriculture. The aim of the study was to determine the suitability of 13 varieties of spring wheat for cultivation in organic farming according to their competitive potential against weeds, susceptibility to fungal diseases and grain yield. Due to the large share of cereals in organic farms both in Poland and in Europe, the research results could be applied by organic farming system farmers and advisors. High-yielding varieties in the organic system were: KWS Torridon, Kandela, Arabella, Zadra and Waluta. The KWS Torridon and Kandela varieties were resistant to fungal pathogens infestation, while Brawura, Izera, Korynta and Ostka Smolicka showed the highest infestation rate. Ethos variety yields were the lowest due to its low plant density, with a high weed infestation rate. The wheat yields proved to be significantly correlated with plant density and the thousand grain weight, but no significant negative effects of weed infestation and pathogen infestation were found. A synthesis of the three-year results showed that the varieties most useful for organic farming were: Arabella, KWS Torridon, Kandela, Katoda, Waluta and Zadra.

Keywords: spring wheat; organic agriculture; variety; weed infestation; fungal pathogens; grain yield

1. Introduction

Wheat is the basic consumer cereal grown in Poland and Europe [1,2]. In Europe, the cultivation area of spring form of wheat is lower than its winter form [2], which is mainly a result of the latter's lower yield [3]. Spring wheat is more popular among polish organic farmers than winter wheat as it is less susceptible to frost damage and have a lower pressure from yield-reducing factors (pathogens, pests and weeds) [4–6]. Spring wheat grains are smaller than winter wheat grains, but they contain more proteins and therefore their flours are generally of high baking value [7,8].

One of the most important factors affecting yield, yield quality and food safety in organic farming is the selection of varieties. The choice of cereal varieties suited to the specific conditions of organic agriculture requires a different approach to that used in the conventional, high input system [6,9,10]. This is because in organic production there are fewer opportunities to compensate for yield decreases caused by diseases, low nutrients levels and weeds [11]. More than 95% of organic production in Europe is based on crop varieties that were bred for the conventional high-input sector [12]. The lack of information on the performance of modern cereal varieties under organic conditions is a limitation for this type of production [13]. So far, research in Europe and North America has focused on the adaptation of commercial wheat cultivars to organic production to identify suitable cultivars and to better understand important traits in organic production [14]. Carr et al. [15] observed that some modern cultivars had high yields, protein content and volume weight also when grown under organic farming conditions. Cereal varieties that are useful for organic farming should have appropriate agricultural characteristics, i.e., high ability to compete with weeds, resistance to fungal pathogens, high ability to uptake nutrients [6,16,17]. The grain produced should be of appropriate quality for health safety and have sensory qualities desired by consumers of cereal products (bread, pasta, groats) [8,18].

Review of world literature indicates that the competitiveness of cereal varieties against weeds depends on crop density and the morphological features of individual varieties, such as growth rate, length of stem, number of tillers, leaf surface area and angle of leaf attachment as well as their allelopathic properties [19–23]. Based on these parameters groups of cereal varieties (wheat, rye, oat, triticale) that are better and worse competitors against weeds in organic agriculture have been established in Poland [5,24–26] and Latvia [16,17].

The most common wheat pathogens in organic farming are: *Puccinia recondita* Dietel and Holw., *Puccinia striiformis* Schwein., *Drechslera tritici-repentis* (Died.) Shoem. and *Septoria* sp. Due to the ban on the treatment of seeds with chemical plant protection products in organic farming, there is a higher risk of infestation by, e.g., *Tilletia caries* (stinking smut of wheat). Diseases of cereals caused by fungal pathogens may significantly reduce grain yields and make worse quality parameters [6,27]. The degree of cereal infestation by pathogens depends on weather conditions during the growing season [28], sensitivity of varieties to pathogens, crop rotation and nitrogen fertilization level [11]. Breeding resistant varieties and seeking new effective sources of resistance among wheat genotypes are the main way to protect organic cereals from the powdery mildew of cereals and grasses [29]. The recognition of the varietal response to pathogens is a precondition for obtaining satisfactory yields with favorable quality parameters [27]. The aim of the study was to select and evaluate spring wheat varieties that are most suitable for cultivation in organic farming due to their competitive potential against weeds, susceptibility to fungal diseases and grain yield. The research results could be applied by farmers, advisors and food processors that carry out crop production and processing in the organic agriculture sector.

2. Materials and Methods

2.1. Sites Characteristics, Experimental Design and Agronomic Practices

The experiments were carried out in the years 2014–2016 at organic farms located in three different parts of Poland (Table 1).

In each of the locations a one-factor experiment with different varieties of spring wheat (*Triticum aestivum* L.) was established in a randomized complete block design, with four replicates. The area of each plot of replication for sowing was 30 m^2 (3×10 m) and for harvest was 18 m^2 (2×9 m). Thirteen spring wheat varieties (*Triticum aestivum* L.) included in the Common Catalogue of Varieties of Agricultural Plant Species [30]: Arabella, Brawura, Cytra, Ethos, Izera, KWS Torridon, Kandela, Katoda, Koksa, Korynta, Ostka Smolicka, Waluta, Zadra were cultivated in 3 locations (Table 1). Sowing treatments were performed in accordance with good agricultural practice and sowing was at the optimum time for each region. The sowing rates were the same for each variety—450 grains per 1 m^2. The row spacing was 12 cm and the planting depth 3.5 cm. According to organic farming rules, mineral fertilizers and chemical plant protection products were not used [31]. Spring wheat was cultivated after good forecrops: potato in Osiny and Chwałowice and mixture of clover and grasses in Chomentowo. Compost (30 t ha^{-1}) and natural phosphorus and potassium fertilizers, such as crude potassium salt or kainite, according to crop requirements and soil analysis, were applied under potato. Harvests were undertaken in the first decade of August.

Table 1. The characteristics of habitat conditions of the experiment.

Items	Experimental Organic Farms in Poland		
	Osiny	**Chwałowice**	**Chomentowo**
Province	Lublin	Masovian	Podlasie
Type of organic farms	Experimental Station of the Institute of Soil Science and Plant Cultivation—State Research Institute (IUNG-PIB)	Organic farm of Agricultural Advisory Centre in Radom, cooperating with IUNG-PIB	Individual organic farm cooperating with IUNG-PIB
Soil type	*Luvisol*	*Cambisol*	leached *Cambisol*
Texture	loamy sand	silt loam	silt on sandy loam
pH_{KCl}	5.9	6.2	6.6
Soil abundance:			
humus (%)	1.4	1.7	1.6
P_2O_5 (mg·100 g^{-1} soil)	8.6	23.4	6.4
K_2O (mg·100 g^{-1} soil)	10.0	22.3	4.3
Mg (mg·100 g^{-1} soil)	9.1	13.1	13.6
Forecrop	potato	potato	clover + grasses

2.2. Estimation of Weed Infestation

The number of weeds and their dry matter were analysed at the dough stage of spring wheat (BBCH 85–87) [32] cultivated in the 3 locations, using the weight—counting method, on an area of 0.5 × 1 m in each plot of replication. Weeds were indicated to species according to Rutkowski [33]. Dry matter of weeds was determined after drying at 40 °C for 7 days.

2.3. Estimation of Diseases Infestation

Depending on the location and the year of research, different pathogens of differing severity were recorded. Hence, for statistical analyses, the sum of infections by pathogens was used as the variable characterizing infection by pathogens: *Puccinia recondite* Dietel and Holw. (brown rust), *Puccinia striiformis* Schwein. (yellow rust), *Drechslera tritici-repentis* (Died.) Shoem. (wheat tan spot), *Septoria* sp. (septoriosis) oraz *Blumeria graminis* (DC.) Speer (powdery mildew). The three uppermost leaves were scored for infestation rate with fungal pathogens at the milk-dough stage (BBCH 77–83). For phytopathological analysis, these three leaves were taken from 10 plants in each of the four repetitions. The percentage of leaf-blade surface damaged by individual pathogens was then determined. The method of disease assessment, the recording of the observation results and the scale of leaf infestation were in line with the EPPO recommendations [34].

2.4. Wheat Canopy and Yield Assessment

From the same area that the weeds were taken, wheat plants were removed by hand to assess the density per 1 m^2 and number of productive tillers in dough stage of wheat. Grain yield was evaluated after harvest. Harvest was done using a special small harvester, for the plot area of 18 m^2, which was smaller than sowing area (30 m^2) to avoid border effect. The results were calculated as t·ha^{-1}, at 15% moisture content.

2.5. Statistical Analysis

The assessment of the level and repeatability of yields of varieties and other accompanying traits were discussed on the basis of average values and coefficients of variation. The significance of differences among varieties, experimental points, the year of the research and the significance of interactions among genotypes, years and locations were determined on the basis of an analysis of multiple experiment variance and Tukey's confidence intervals for such parameters: grain yield, plant density, thousand grain weight, number of weeds and their dry matter and plant infestation by diseases (n = 3 years × 3 locations × 4 replicates = 36). The effect of accompanying variables stimulating or limiting the yield level of varieties was investigated using simple correlation coefficients and multiple regression.

In order to classify the varieties according to their traits, Principal Component Analysis (PCA) was used to perform direct ordination [35]. The analyses were performed in the Canoco 4.5 program [36]. Moreover, cluster analysis using the Furthest Neighbour method was done to classify varieties in terms of their similarity for all features together, and a single-factor analysis of variance was used to assess differences among clusters.

3. Results

The analysis of mean values of traits (Table 2) and coefficients of variation (Table 3) enables a determination of the level and stability of the tested variables, i.e., yields, plant density, 1000 grain weight (TGW) as well as infestation by weeds or fungal diseases of the tested varieties. The comparison of averages together with the confidence interval showed that KWS Torridon, Kandela, Arabella, Zadra and Waluta were the highest yielding varieties, while the group of significantly lower yielding varieties was Izera and Ostka Smolicka (Table 2). The yields of varieties over years and experimental locations turned out to be relatively stable. The coefficients of variation for the vast majority of varieties were lower than 30%, with the exception of Ethos (44.6%) and Arabella (30.4%) (Table 4).

The highest plant density was found for Brawura and Waluta, while the lowest was for Ostka Smolicka and Ethos (Table 2). The plant density of Ethos was significantly lower than that of Brawura and Waluta. Coefficients of plant density variation for cultivars ranged from 12.9% to 21.7%, i.e., the variation of this trait over years and localities was small (Table 3).

Table 2. Average grain yields and associated traits for spring wheat varieties from 3 years of research (2014–2016) and 3 experimental locations (n = 36).

Variety	Yield ($t \cdot ha^{-1}$)	Crop Density ($Plants \cdot m^2$)	1000 Grain Weight (TGW) (g)	Number of Weeds ($Plants \cdot m^2$)	Weed Dry Matter ($g \cdot m^{-2}$)	Infestation by Diseases (% Infested Leaves Area)
Arabella	4.05 de [1]	398 abc	35.0 ab	94 a	31.4 a	44.9 abcd
Brawura	3.80 abcde	413 c	34.7 ab	104 a	33.5 a	57.1 cd
Cytra	3.60 abcd	379 abc	34.8 ab	84 a	28.7 a	35.4 abc
Ethos	3.51 abc	353 a	33.6 a	117 a	39.4 a	25.3 a
Izera	3.37 a	388 abc	33.5 a	101 a	34.2 a	56.5 cd
KWS Torridon	4.10 e	383 abc	37.0 cde	97 a	34.0 a	28.8 ab
Kandela	4.10 e	389 abc	35.7 bcde	103 a	34.0 a	34.0 abc
Katoda	3.80 abcde	377 abc	37.6 e	99 a	32.3 a	53.7 cd
Koksa	3.48 abc	369 abc	35.1 abc	96 a	29.2 a	54.3 cd
Korynta	3.70 abcde	362 ab	35.5 abcd	100 a	36.0 a	51.0 bcd
Ostka Smolicka	3.40 ab	359 a	34.6 ab	101 a	34.7 a	61.7 d
Waluta	3.86 bcde	407 bc	37.3 de	91 a	31.2 a	54.3 cd
Zadra	3.95 cde	381 abc	34.4 ab	93 a	34.4 a	46.9 abcd
Mean	3.76	383	35.4	98	33.1	47.2
$HSD_{0.05}$	0.47	47	1.96	34	13.5	24.8

[1] Different letters after the mean values indicate significant differences ($p \leq 0.05$). For significant model effects a post hoc Tukey HSD test was performed to compare mean values.

Table 3. Coefficients of variation for grain yields and associated traits of spring wheat varieties from 3 years of research (2014–2016) and 3 experimental locations (n = 36).

Variety	Yield	Crop Density	1000 Grain Weight (TGW)	Number of Weeds	Weed Dry Matter	Infestation by Diseases
Arabella	30.4%	14.9%	10.9%	45.6%	50.2%	48.2%
Brawura	24.9%	17.0%	10.2%	41.5%	64.1%	51.7%
Cytra	26.7%	12.9%	10.0%	45.2%	65.7%	48.8%
Ethos	44.6%	17.7%	12.5%	40.0%	73.5%	15.8%
Izera	26.6%	21.5%	9.4%	40.7%	83.8%	42.5%
KWS Torridon	29.3%	17.8%	11.2%	45.7%	79.3%	79.0%
Kandela	28.4%	17.7%	12.7%	47.0%	79.6%	64.4%
Katoda	23.7%	19.7%	9.5%	44.6%	92.6%	58.1%
Koksa	27.5%	20.2%	9.1%	57.3%	76.3%	48.1%
Korynta	27.8%	21.7%	8.5%	42.6%	90.4%	56.7%
Ostka Smolicka	28.2%	16.4%	9.0%	50.1%	75.0%	34.3%
Waluta	22.9%	17.5%	10.6%	44.7%	91.5%	53.4%
Zadra	27.9%	15.1%	11.3%	46.8%	83.8%	70.8%
Mean	28.4%	17.7%	10.4%	45.5%	77.4%	51.7%

Table 4. The level of significance of F tests corresponding to sources of variability of the analysis of variance from 3 years of research (2014–2016) and 3 locations for the analyzed traits (n = 36).

Sources of Variability	Traits					
	Yield	Crop Density	1000 Grain Weight (TGW)	Number of Weeds	Dry Matter of Weeds	Infestation by Diseases
A: locations	0.000 *	0.000 *	0.000 *	0.000 *	0.000 *	0.000 *
B: years	0.000 *	0.000 *	0.000 *	0.000 *	0.968	
C: varieties	0.000 *	0.004 *	0.000 *	0.670	0.967	0.003 *
AxB	0.000 *	0.000 *	0.000 *	0.000 *	0.000 *	0.022 *
AxC	0.139	0.077	0.022 *	0.882	0.176	0.190
BxC	0.083	0.446	0.101	0.448	0.315	0.105

* significance level $p \leq 0.05$.

The significantly largest 1000 grain weight was found for varieties: KWS Torridon, Waluta and Katoda, while the smallest was for Izera and Ethos (Table 2). The 1000 grain weight of individual varieties proved to be the trait with the lowest variability (8.5%–12.7%) (Table 3).

The low stability of weed infestation of the varieties is shown by the high coefficients of variation for the number of weeds (40–57%), and especially for their dry matter (50–93%), which indicates that the values of these traits differ significantly across years and experimental locations (Table 3). The number of weeds for most varieties was similar (94–104 plants·m^{-2}), while it was lowest for variety Cytra (84 plants·m^{-2}) and highest for Ethos (117 plants·m^{-2}). The dry matter of weeds did not differ significantly for the tested spring wheat varieties in the organic system (29–39 g·m^{-2}).

There was a large variety of infestation of wheat varieties by fungal pathogens (Tables 2 and 3). The varieties most resistant to infestation by pathogens proved to be Ethos, KWS Torridon, Kandela and Cytra, and this group differed considerably from the group of heavily infested varieties, which included Brawura, Izera, Katoda, Koksa, Ostka Smolicka and Waluta.

On the basis of the analysis of yields and yield-limiting factors, it was found that low-yielding varieties included Ethos and Ostka Smolicka, and they also exhibited a low plant density that made them poorly competitive against weeds. High-yielding varieties: KWS Torridon, Kandela, Arabella, Zadra and Waluta exhibited a large plant density per unit area and a large 1000 grain weight. Moreover, the first two of these varieties (KWS Torridon and Kandela) also proved to be resistant to infestation by fungal pathogens.

Table 4 presents the results of the analysis of variance (significance level of *F* test) of multiple experiments for the tested traits. For all variables, the interaction of locations × years was significant, but no significant interaction of varieties with locations and years was found, except for 1000 grain weight, i.e., for most traits the response of varieties was similar in each of the years and locations. Yield, plant density, 1000 grain weight and plant infestation by fungal diseases differed significantly among varieties, while the number of weeds and their dry matter did not differ significantly among them.

Simple correlation coefficients were used to assess the interdependence between the variables (Table 5). Spring wheat yields turned out to be significantly correlated with plant density and TGW, but no significant negative effect of weed and disease infestation on yield levels was found. There was a significant, inversely proportional correlation (r = −0.199) between the plant density and TGW, i.e., a large plant density causes lower values of TGW. The variable depending on the influence of other traits turned out to be the plant density, negatively correlated with the number of weeds (r = −0.233) and their dry matter (r = −0.496), i.e., high plant density reduces weed infestation but promotes the development of fungal diseases (r = 0.607). Both traits characterizing weed infestation turned out to be significantly correlated with each other (r = 0.605).

Table 5. Correlation coefficients (r) among the tested traits (n = 36).

Traits	Traits					
	Yield	**Crop Density**	**1000 Grain Weight (TGW)**	**Number of Weeds**	**Dry Matter of Weeds**	**Infestation by Diseases**
Yield		0.223 *	0.562 *	0.024	−0.092	0.115
Plant density	0.223 *		−0.199 *	−0.233 *	−0.496	0.607 *
TGW	0.562 *	−0.199 *		0.410 *	0.182	−0.023
Number of weeds	0.024	−0.233 *	0.410 *		0.605 *	0.018
Dry matters of weeds	−0.092	−0.496 *	0.182	0.605 *		−0.256 *
Infestation with diseases	0.115	0.607 *	−0,023	0.018	−0.256 *	

* significance level at $p \leq 0.05$.

Using the step-by-step regression method, the functional relationship between the grain yield and accompanying variables was calculated. The obtained regression equation was:

$$Y = -5.150 + 0.004X_1 + 0.203X_2 \qquad R^2 = 62.7\%$$

where: Y—grain yield of winter wheat, X_1—plant density, X_2—TGW, R^2—coefficient of determination.

In order to establich the relationship between spring wheat varieties and the agronomic traits (grain yield, plant density, thousand grain yield (TGW), number and dry matter (DM) of weeds and crop infestation by fungal diseases), the ordination method Principal Component Analysis (PCA) was used (Figure 1).

Along the gradients of the axes of particular traits, wheat varieties most closely associated with a given trait were grouped together (Figure 1). Brawura, Waluta, Arabella, KWS Torridon and Kandela were located near the high yield characteristics (grain yield, wheat density and thousand grain yield). On the opposite site of diagram low yields varieties, such as Ostka Smolicka, Koksa and Korynta, were grouped. Izera was the variety most strongly correlated with fungal diseases axis. Ethos variety was the variety most resistant to pathogens. Ethos variety was correlated also to the number of weeds and dry matter of weeds axes, which indicates its highest level of weed infestation.

The classification of varieties in terms of their similarity for all features together was determined on the basis of cluster analysis (Table 6). Based on the dendrogram (Figure 2), a division of cultivars into four clusters was made. The yield of spring wheat varieties in the 1st cluster proved to be significantly higher than the yield of varieties in the remaining clusters (Table 6). Plant density and TGW did not have a significant effect on variety grouping. Weed infestation and sensitivity of the varieties to fungal diseases turned out to be the factor significantly differentiating the groups of cultivars. The varieties grouped in the 2nd cluster showed the biggest infestation by fungal pathogens. The 3rd cluster included varieties with the least weed infestation but quite large infestation by pathogens. The 4th cluster had only one variety—Ethos, which exhibited the lowest yield due to its small plant density and low TGW, with a simultaneous large weed infestation estimated by the number and weight of weeds. However, a positive feature of this variety in terms of its suitability for organic farming was its resistance to diseases, which was also confirmed by PCA analysis (Figure 1).

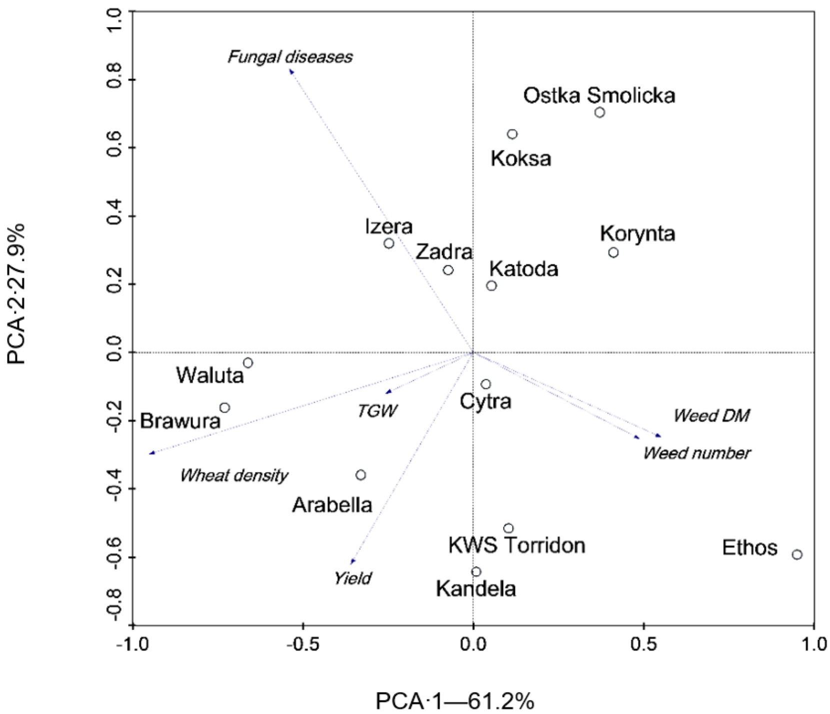

Figure 1. Ordination diagram of agronomic traits and spring wheat varieties in relation to first and second axis of PCA.

Table 6. Value of agricultural traits of spring wheat varieties (n = 36).

Cluster	Cultivar	Yield ($t \cdot ha^{-1}$)	Crop Density ($Plants \cdot m^2$)	1000 Grain Weight (TGW) (g)	Number of Weeds ($Plants \cdot m^2$)	Weed Dry Matter ($g \cdot m^{-2}$)	Infestation by Fungal Diseases (% Infested Leaves Area)
I	Arabella, KWS Torridon, Kandela, Katoda, Waluta, Zadra	3.98 b [1]	389.3 a	36.2 a	96 a	32.9 b	43.8 ab
II	Brawura, Izera, Korynta Ostka Smolicka	3.57 a	380.6 a	34.6 a	101 ab	34.6 b	56.3 b
III	Cytra, Koksa	3.54 a	374.0 a	35.0 a	90 a	28.9 a	44.9 ab
IV	Ethos	3.51 a	353.5 a	33.6 a	117 b	39.4 c	25.3 a

[1] Different letters indicate that the mean values of parameters differ significantly between clusters. A single-factor analysis of variance was used to assess differences among clusters. For significant model effects a post hoc Tukey HSD test was performed to compare mean values ($p \leq 0.05$).

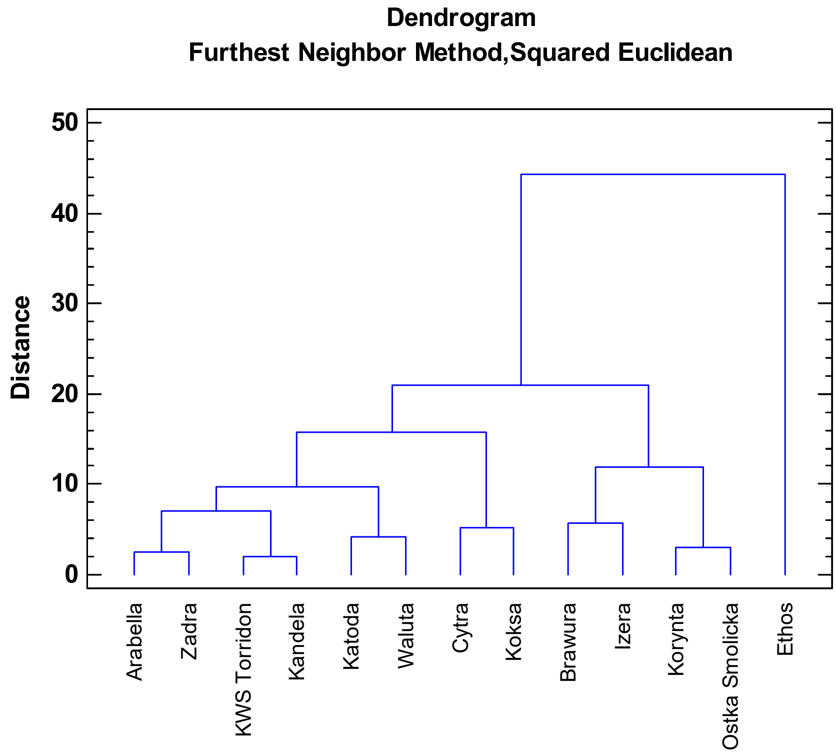

Figure 2. Dendrogram showing the similarity of spring wheat varieties.

The above analyses show that Arabella, Brawura, KWS Torridon, Kandela, Katoda, Waluta and Zadra are among the best varieties for organic farming in terms of agricultural traits (Figure 3). It should be stressed that the yields of tested spring wheat varieties did not greatly depend on weather conditions, as has been shown by the lack of significant interaction of varieties with locations and years, as shown in Table 4.

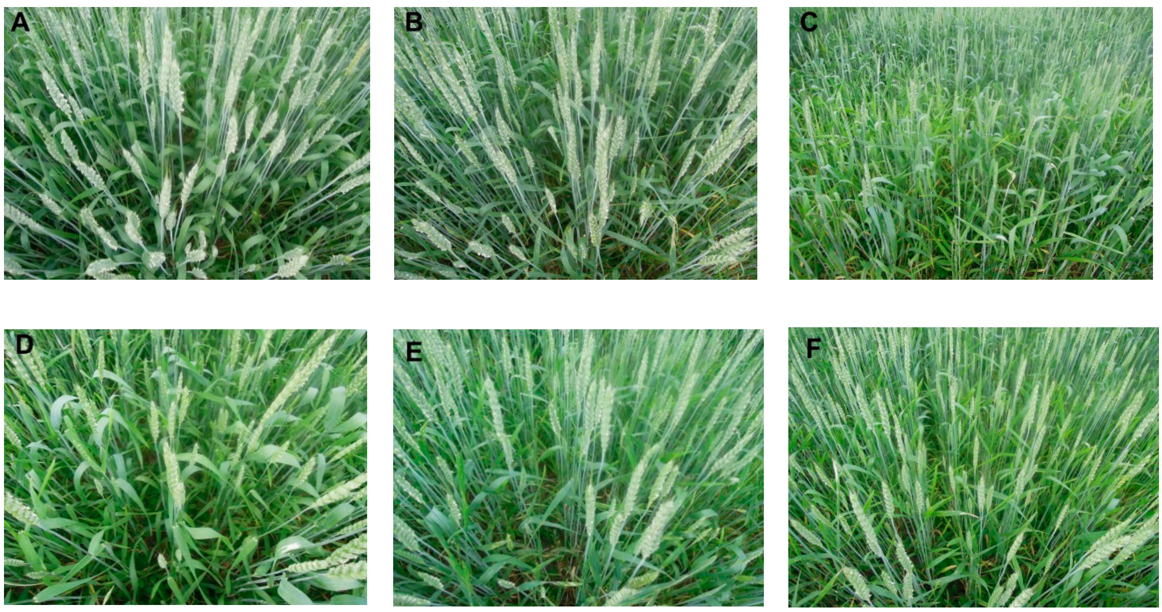

Figure 3. Selected varieties of spring wheat grown under the organic system—flowering phase (BBCH 65–68) in Osiny. (**A**)—Arabella, (**B**)—Brawura, (**C**)—Cytra, (**D**)—Kandela, (**E**)—Katoda, (**F**)—Waluta.

4. Discussion

In the organic farming system, the use of chemicals is forbidden, thus nonchemical methods of weed, disease and pest controls are important to achieve a high yield of good quality [6,37]. For this purpose, different agrotechnical practices are used, such as diversified crop rotation, careful tillage, organic fertilization, sowing date and density of sowing, mechanical measures as well as the selection of proper varieties [9,11,38]. Organic farming gives a preference to varieties of cereals that are characterized by high competitive ability against weeds, tolerance to fungal diseases, ability to uptake nutrients and resistance to nutrients deficiency stress [6,16,17,39].

Weeds are often recognized as the most serious problem in organic farming [37,40]. One of the nonchemical methods of weed regulation is the use of varieties that possess traits conferring a higher competitive ability against weeds [19,22,26]. The results obtained in this study indicate no significant differences in the competition against weeds of the tested spring wheat cultivars. However, in our own prior research on another set of varieties in one location a significant, but weak, correlation ($r = -0.328$, significant at $p < 0.05$) was noted between the number of weeds and wheat grain yield [4]. Moreover, greater differences in weed competitive abilities between cultivars have been observed for winter wheat than for spring wheat [5,6].

The study showed that a spring wheat canopy with a smaller plant density was more susceptible to weed infestation. High plant density limited weed infestation. Our own earlier study conducted on winter wheat varieties showed that the dry matter of wheat, plant density, plant height and tillering had an impact on weed number and biomass [4]. Mason et al. [41] confirmed crop height as the trait most closely associated with positive performance of conventional wheat cultivars under weedy conditions. Duch organic farmers value spring wheat traits that contribute to weed suppression, such as vigorous early growth, tillering capacity, canopy density and plant length and toleration for intensive harrowing [42]. Higher crop competitive ability can also be the result of allelopathic activity [20]. According to Worthington and Reberg-Horton [43], the differences in the weed suppression abilities of particular cultivars are a result of the interaction of their allelopathic and competitive abilities. According to Lemerle et al. [44], the expression of competitive advantage of spring wheat is strongly influenced by environmental conditions. This hypothesis may explain the lack of significant differences between the spring wheat varieties in our own study, due to different soil and habitat conditions in individual localities and the different weather conditions in years and places. Moreover, the results can depend on the term of weed estimation, which in our research was at the end of the growing season.

In an assessment of the suitability of cereal varieties for cultivation in an organic farming system, the yielding potential should also be taken into account. According to Lemerle et al. [44,45], it is possible to select wheat cultivars that possess competitive traits against weeds while maintaining an adequate grain yield potential. To improve the competitive ability against weeds of modern wheats without compromising their yielding ability the morphological traits that enhance early crop vigour and light interception without affecting the harvest index may need to be incorporated from carefully selected germplasm [46].

The yield level was similar to in the study of other authors from Europe (UK) who obtained 3.54 t$\cdot$ ha^{-1} of wheat grain in organic system [3]. In addition, other parameters of spring wheat were similar. The current research showed that the observed level of weed infestation in spring wheat cultivars (98 plants$\cdot$m^{-2}, 33 g$\cdot$m^{-2}, on average) did not significantly affect the yield. It suggests a high efficacy of weed control in spring wheat in the organic system. The research of other authors indicates that in the organic system weed infestation in cereals is generally greater than in the more intensive crop production systems where herbicides are used [47,48]. According to the Good Agricultural Practices use of the best management strategies as the proper crop rotation, delayed sowing time to gain time to reduce weed infestation by harrowing, increased seeding rate and maintaining good soil structure with a high content of organic matter allows the weeds to be kept at a level that does not cause a significant yield decrease [49,50]. However, in some conditions these practices can cause the increased weed infestation from the weed soil seed bank [51]. The level of weed infestation in organic systems depends also on weather conditions, as they influence the possibility and effectiveness of the weed management measures [52].

The research of Kuś et al. [6,48] conducted in 2008–2010 showed that, from among nine spring wheat cultivars grown in the organic system, Tybalt yielded the highest, but that it had high yield variability over the years (2.43–6.16 t·ha^{-1}). Only in the year with low weed infestation (62 plants·m^{-2}, 8 g· m^{-2}) was the yield of this variety high, while in the years with higher weed pressure (95–158 plant· m^{-2}, 50–75 g·m^{-2}) the yield was lower with this variety. Another study shows that in the case of spring wheat only weed infestation of more than 60 g·m^{-2} can affect significantly grain yield [5]. This is confirmed by the results of Kapeluszny [53], who observed a significant decline in spring wheat yield under weed infestation of 96 pcs·m^{-2} (62 g·m^{-2} of dry matter) at the dough stage.

Susceptibility to diseases is one of the factors that should be taken into account when evaluating the usefulness of cereal varieties in organic farming. Fernandez et al. [54] identified resistance to leaf spotting diseases as important for the performance of wheat grown under organic management in Saskatchewan. Triticale infestation by pathogens can lead to a 5–20% yield reduction, and in extreme cases even to 60% [28]. According to Kuś et al. [27], the complex influence of such factors as tillage, crop rotation, selection of varieties, sowing of mixtures, and fertilization with organic and natural fertilizers reduces disease pressure and influences the formation of a specific balance between pathogenic factors and saprophytic microflora and pathogen antagonists.

In the present research there was no significant influence of fungal diseases on the yield. The cultivars most resistant to infection by pathogens turned out to be Ethos, KWS Torridon, Kandela and Cytra, and this group differed significantly from the group of more strongly infected cultivars, which included Brawura, Izera, Katoda, Koksa, Ostka Smolicka and Waluta. According to Osman et al. [42], organic farmers generally do not consider diseases as an important constraint in wheat production. This can be partly explained by the high level of resistance in modern varieties whereby the disease pressure remains usually low throughout the season. In addition, lower amounts of used nitrogen fertilizers than in conventional fields and the absence of growth regulators in organic fields can be associated with a reduced severity of powdery mildew, brown rust, Septoria tritici blotch and Fusarium head blight [55].

In a long-term study by Feledyn-Szewczyk et al. [6], the yield of spring wheat in an organic system was lower than in a conventional system by 34%. The difference in cereal yields in organic vs. conventional systems are due to lower density of ears, weed infestation, leaf diseases and nutrients deficiency [13,27,39]. In our results it was found that the low-yielding cultivars, Ethos and Ostka Smolicka, were characterized by a low plant density. The cultivars with high yields: KWS Torridon, Kandela, Arabella, Zadra and Waluta were characterized by a large plant density per unit area and a large thousand grain weight. A correlation analysis showed that grain yield of spring wheat was not affected by either the number and dry matter of weeds or by fungal pathogens.

According to some authors [56], it is mainly genetic conditions, and to a lower extent habitat conditions and the applied agrotechnology determine the achievement of satisfactory yields and that is why it is so important to look for and select suitable varieties for organic farming. It is worth underlining that the information about the performance of wheat varieties in the organic system could be valuable not only for organic farms but also for low-input conventional and integrated farms in order to achieve the goals of sustainable agriculture (a high yield, safe food and a healthy environment) [13].

5. Conclusions

Our results give information about the traits of spring wheat varieties that are desirable for an organic system. We divided the tested varieties into groups with high and low suitability for this specific farming system according to their agricultural features. On the basis of the results of a three-year study, the varieties most useful for cultivation in organic farming were found to be Arabella, KWS Torridon, Kandela, Katoda, Waluta and Zadra. The highest yielding varieties were: KWS Torridon, Kandela, Arabella, Zadra and Waluta. Brawura, Izera, Korynta and Ostka Smolicka showed the biggest infestation by fungal pathogens.

Cytra and Koksa were characterized by the least weed infestation but quite large infestation by pathogens. Ethos variety exhibited the lowest yield due to its small plant density, with a large weed infestation, but a positive feature of this variety was its resistance to diseases.

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