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ASSESSMENT OF THE USEFULNESS OF NEW WINTER WHEAT VARIETIES *(Triticum aestivum* L.*)* FOR CULTIVATION IN ORGANIC FARMING

Summary

The objective of the research was to establish the ranking of the usefulness of winter wheat varieties (Triticum aestivum L.) for cultivation in organic farming, taking into account their competitive ability against weeds, leaf infestation by fungal pathogens and yielding. The study was conducted in the period 2014-2016 in 3 locations in Poland: Experimental Stations of The Institute of Soil Science and Plant Cultivation – State Research Institute in Osiny (Lublin province) and Chwałowice (Masovian province) and private organic farm in Chomentowo (Podlasie province). Twelve winter wheat varieties were sown in a randomized complete block design with four replications. Weed density and their dry matter as well as biometric features of wheat varieties influenced the competitive ability against weeds, such as the height, number of tillers, wheat plant density and dry matter of wheat were assessed at a dough stage. Leaves were scored for infestation rate with fungal pathogens at milky-dough stage. Grain yield and thousand grain weight were estimated after wheat harvest. The results showed that different morphological features and canopy parameters influenced the competitive abilities of the winter wheat varieties tested. A set of varieties with the largest competitive ability and the highest yield: *Julius, Skagen, Sailor, Jantarka, Smuga was established as the most suitable for organic agriculture*. *Muszelka, Banderola, Bamberka and KWS Ozon were characterized by the smallest competitive abilities against weeds. Arkadia, Ostroga and spelt Rokosz were the lowest yielders. For Arkadia variety leaf infestation by pathogens was a factor that limited the yield.*
Key words*: competitiveness, morphological features, winter wheat, selection of varieties, weed infestation, organic farming*

OCENA PRZYDATNOŚCI NOWYCH ODMIAN PSZENICY OZIMEJ *(Triticum aestivum* L.*)* DO UPRAWY W ROLNICTWIE EKOLOGICZNYM

Streszczenie

Celem badań była ocena przydatności odmian pszenicy ozimej (Triticum aestivum L.*) do uprawy w systemie ekologicznym biorąc pod uwagę ich zdolności konkurencyjne w stosunku do chwastów, podatność na choroby grzybowe i plonowanie. Badania przeprowadzono w latach 2014-2016 w trzech lokalizacjach w Polsce: w Rolniczym Zakładzie Doświadczalnym Instytutu Uprawy Nawożenia i Gleboznawstwa – Państwowego Instytutu Badawczego w Osinach (woj. lubelskie) i Chwałowicach (woj. mazowieckie) oraz w indywidualnym gospodarstwie ekologicznym w Chomentowie (woj. podlaskie). Dwanaście odmian pszenicy ozimej wysiewano w układzie całkowitej randomizacji w 4 powtórzeniach. Liczebność chwastów i ich sucha masa, jak również cechy biometryczne odmian pszenicy ozimej wpływające na konkurencyjność w stosunku do chwastów: wysokość, rozkrzewienie, obsada roślin i sucha masa części nadziemnych łanu były oceniane w fazie dojrzałości. Plon ziarna i masa tysiąca nasion były określane po zbiorze pszenicy. Wyniki wykazały, że różne cechy morfologiczne i parametry łanu wpływały na zdolności konkurencyjne testowanych odmian pszenicy ozimej w stosunku do chwastów. Wyróżniono grupę odmian o największej konkurencyjności i plonach: Julius, Skagen, Sailor, Jantarka, Smuga, najbardziej przydatne dla rolnictwa ekologicznego. Odmiany Muszelka, Banderola, Bamberka i KWS Ozon cechowały się najmniejszymi zdolnościami konkurencyjnymi w stosunku do chwastów. Odmiany Arkadia, Ostroga i orkisz Rokosz plonowały na najniższym poziomie. Przyczyną niskich plonów odmiany Arkadia było porażenie liści przez patogeny grzybowe.*
Słowa kluczowe*: konkurencyjność, cechy morfologiczne, pszenica ozima, dobór odmian, zachwaszczenie, rolnictwo ekologiczne*

1. Introduction

Weeds are often recognized as the most serious threat to organic crop production [6]. The fear of ineffective weed control is often perceived by farmers as one of the major obstacles to conversion from conventional to organic farming [1]. Weed management in an organic system aims to create a balance between cultivated crops and weeds using different agricultural practices, such as crop rotation, choice of species and varieties, soil tillage, organic fertilization, date and density of sowing as well as direct mechanical, biological, and physical methods of weed control [3, 9]. One of the cultural method of weed regulation includes the use of crop varieties that possess traits conferring a higher competitive ability against weeds. Usually, these traits are related to faster seedling emergence and canopy establishment, higher growth rates in early stages, the height and tillering, leaf length and width as well as light interception [8, 22, 28].

It should be pointed out that not all traits that give crops a competitive advantage against weeds may usefully be exploited in cropping systems. Plant height is often negatively correlated with crop productivity and can also increase crop sensitivity to lodging, which may lead to severe yield losses [1]. According to Lemerle et al. [15, 16] 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 of modern wheats without compromising their yielding ability, morphological traits that enhance early crop vigour and light interception

without affecting harvest index may need to be incorporated from carefully selected germplasm [25].

Expression of competitive advantage is strongly influenced by environmental conditions [15]. Higher crop competitive ability can also be the result of allelopathic activity [2, 21]. Selection of weed-suppressive genotypes has mainly been considered as a way of reducing herbicide rates in integrated cropping systems; however, it is clear that this approach may be even more important for organic systems [1]. The aim of this study was to determine the influence of morphological features and canopy parameters on weed infestation and grain yield of winter wheat varieties and indicate the varieties which are the most useful for organic agriculture.

2. Material and methods

2.1. Site characteristics and experimental design

The study was conducted in the period 2014–2016, on fields managed organically in 3 locations: Experimental Stations of The Institute of Soil Science and Plant Cultivation – State Research Institute in Osiny (Lublin province) and Chwałowice (Masovian province) and private organic farm in Chomentowo (Podlasie province), Poland (Table 1).

One-factor experiment was established with different varieties, arranged in a randomized complete block design with four replications. Twelve winter new wheat varieties from Polish National List of Agricultural Plant Varieties were tested: Arkadia, Bamberka, Banderola, Jantarka, Julius, KWS Ozon, Muszelka, Ostroga, Sailor, Skagen, Smuga and spelt Rokosz. Pre-sowing treatments were performed in accordance with good agricultural practice and sowing was at the optimum time for the region. Sowing rates were the same for each variety – 500 grains · m^{-2}. The row spacing was 12 cm and the planting depth 3.5 cm. According to organic agriculture ruling, mineral fertilizers and other agrochemicals were not used. The harrowing of wheat canopy was done twice in the period from the 4-leaves phase to the tillering stage.

2.2. Sampling and estimation of traits

The number of weeds and their dry matter production were assessed at the dough stage for winter wheat (BBCH 85–87), using the weight-counting method, on an area of 0.5×1 m, in four replications for each variety. Weeds were cut at soil level, sorted by hand and assigned to species. From the same area the parameters of plant canopy, such as number of plants and their dry matter were evaluated. Dry matter production of weeds and wheat was determined after drying at 40°C for 7 days. The results were calculated on the area of 1 m^2. The biometric analysis of oat plants: plant height and overall tillering were estimated for 30 plants. Three upper leaves of 30 wheat plants for each combination were scored for infestation rate with fungal pathogens (% of infected leaf area) at milky-dough stage (BBCH 77-83). Grain yield was estimated in 25m^2 plots in 4 replications after harvesting using a special small harvester, calculated as t · ha^{-1} at 15% moisture content.

2.3. Statistical analysis

Analysis of variation for the completely randomized model was applied and the significance of differences between means was verified by Tukey's test at α =0.05. Pearsons's correlations between the yield of wheat varieties, weed infestation and fungal diseases were performed. Calculations were performed using Statgraphic Plus version 2.1.

3. Results

It was found that the level of weed infestation of winter wheat grown in the organic system differed depending on the location of the experiment and the year of research. The number of weeds in winter wheat, on average for 3 years of the study, was similar in Osiny and Chomentowo (78-86 pcs.· m^{-2}) and almost twice as high in Chwałowice (144 pcs.· m^{-2}) (Table 2). On the other hand, weed infestation measured as dry matter of weeds was the lowest in winter wheat cultivated in Chomentowo (44 g · m^{-2}) and over twice as high in Osiny and Chwałowice (106-108 g · m^{-2}) (Table 3). The weed infestation level observed in Chomentowo (9-70 g · m^{-2}) in none of the years of the study had a significant effect on winter wheat yield. In Osiny and Chwałowice, in two of the three years of the study, the weight of weeds did not exceed 80 g · m^{-2}, and in one year of the study it was higher than 200 g · m^{-2}, which significantly influenced the yield of winter wheat (Table 3).

The varieties with the highest number and weight of weeds were: Muszelka, as well as Banderola, Bamberka and KWS Ozon (Table 4). Muszelka and KWS Ozon were at the same time characterized by the lowest height, which did not favour their competitiveness against weeds (Table 5). KWS Ozon was also a variety with a low plant density and weight of aboveground parts (Table 6).

Table. 1. Habitat conditions of research
Tab. 1. Warunki siedliskowe prowadzenia badań

Item	Location of organic farms		
	Osiny (Lublin province)	Chwałowice (Masovian province)	Chomentowo (Podlasie province)
Complex of agricultural suitability of soils	very good rye (complex 4)	good wheat (complex 2)	very good rye (complex 4)
Soil type	Luvisol soil	Brown soil	Leached brown soil
Soil textural group	heavy loam on clay	loamy silt	silt formations on light silt
Parameters of the soil:			
– humus content (%)	1.4	1.7	1.6
– P_2O_5 (mg · 100 g^{-1} of soil)	8.6	23.0	6.4
– K_2O	10.0	22.0	4.3
– Mg	9.1	13.1	13.6
– pH in KCl	5.9	6.2	6.6
Forecrop	clover with grasses	potato	clover with grasses

Source: *own work / Źródło: opracowanie własne*

Table 2. Number of weeds (pcs. · m^{-2}) in winter wheat varieties tested in various locations in the years 2014-2016
Tab. 2. Liczba chwastów (szt. · m^{-2}) w odmianach pszenicy ozimej testowanych w różnych miejscowościach w latach 2014-2016

Varieties	Locations and years											
	Osiny (Lublin province)				Chwałowice (Masovian province)				Chomentowo (Podlasie province)			
	2014	2015	2016	mean	2014	2015	2016	mean	2014	2015	2016	mean
Arkadia	119.0	84.0	47.5	83.5a	223.0	150.5	180.0	184.5 a	93.5	69.0	102.5	88.3aab
Bamberka	109.5	68.5	57.5	78.5a	181.0	107.5	147.0	145.2ab	127.5	91.5	55.0	91.3aab
Banderola	111.0	63.5	78.0	84.2a	166.5	108.0	114.0	129.5ab	187.0	61.5	89.5	112.7 b
Jantarka	106.0	82.0	44.0	77.3a	214.0	139.5	108.0	153.8ab	107.0	54.0	81.5	80.8ab
Julius	101.0	71.5	47.5	73.3a	173.0	113.5	92.0	126.2 b	95.5	62.0	72.0	76.5a
KWS Ozon	117.5	84.0	64.5	88.7a	200.5	110.5	132.0	147.7ab	106.0	52.5	76.5	78.3a
Muszelka	109.0	67.0	72.5	82.8a	228.5	120.0	122.0	156.8ab	201.5	68.5	82.0	117.3b
Ostroga	100.0	66.5	38.0	68.2a	160.5	123.0	113.0	132.2ab	112.5	60.5	74.0	82.3aab
Rokosz	95.0	71.0	38.0	68.0a	199.5	132.5	134.0	155.3ab	107.0	57.5	73.5	79.3a
Sailor	126.5	64.0	39.0	76.5a	148.0	94.0	113.0	118.3 b	94.5	66.0	65.0	75.2a
Skagen	114.0	87.0	39.5	80.2a	127.5	117.0	158.0	134.2ab	107.5	68.0	60.5	78.7a
Smuga	116.0	69.5	38.5	74.7a	148.5	106.0	177.0	143.8ab	103.0	62.0	45.5	70.2a
Mean	110.4c	73.2b	50.4a	78.0A	180.9b	118.5a	132.5ab	144.0B	120.2b	64.4a	73.1a	85.9A

Source: *own work / Źródło: opracowanie własne*

Table 3. Dry matter of weeds (g · m^{-2}) in winter wheat varieties tested in various locations in the years 2014-2016
Tab. 3. Sucha masa chwastów (g · m^{-2}) w odmianach pszenicy ozimej testowanych w różnych miejscowościach w latach 2014-2016

Varieties	Locations and years											
	Osiny (Lublin province)				Chwałowice (Masovian province)				Chomentowo (Podlasie province)			
	2014	2015	2016	mean	2014	2015	2016	mean	2014	2015	2016	mean
Arkadia	236.5	29.3	37.3	101.0ab	31.2	113.2	243.8	129.4ab	31.2	15.0	102.9	49.7ab
Bamberka	332.3	38.4	81.6	150.8b	34.3	63.5	246.7	114.8ab	78.3	19.1	69.0	55.5
Banderola	311.6	15.8	53.1	126.8ab	18.1	84.4	252.8	118.4ab	75.9	10.2	109.7	65.3ab
Jantarka	233.7	34.1	16.5	94.8ab	28.4	71.3	189.3	96.3ab	53.3	9.1	73.9	45.4ab
Julius	265.9	33.4	13.4	104.2ab	17.3	54.5	145.9	72.5a	33.5	5.5	49.8	29.6a
KWS Ozon	336.2	22.5	14.0	124.2ab	25.8	77.9	247.9	117.2ab	66.4	14.3	58.5	46.4ab
Muszelka	239.9	26.0	33.1	99.7ab	25.3	64.0	363.3	150.9b	86.7	5.0	158.0	83.2b
Ostroga	273.6	25.2	18.6	105.8ab	15.7	77.4	182.0	91.7ab	56.8	8.3	50.1	38.4ab
Rokosz	186.5	17.0	8.7	70.7a	51.5	69.6	197.4	106.2ab	33.0	1.9	52.8	29.2a
Sailor	292.2	29.8	17.6	113.2ab	33.2	72.8	183.5	96.5ab	47.3	3.7	41.2	30.7a
Skagen	228.1	27.5	10.8	88.8a	10.3	79.7	228.0	106.0ab	23.9	5.9	39.7	23.2a
Smuga	243.2	30.9	16.7	96.9ab	16.2	51.7	233.1	100.3ab	32.1	6.1	39.5	25.9a
Mean	265.0b	27.5ba	26.8ba	106.4b	25.6a	73.3b	226.2c	108.4b	51.5b	8.7a	70.4b	43.5a

Source: *own work / Źródło: opracowanie własne*

Table 4. Characteristics limiting yields and grain yields of winter wheat varieties (mean of 3 years of research and 3 locations)
Tab. 4. Cechy ograniczające plonowanie i plony ziarna odmian pszenicy ozimej średnie 3 z lat badań i 3 lokalizacji)

Varieties	The number of weeds	Dry matter of weeds	Yield	1000 grain weight	Incidence of diseases (% of infected leaf area)
Arkadia	119	93.4	4.97	41.6	63.4
Bamberka	105	107.0	5.41	45.8	29.0
Banderola	109	103.5	5.28	43.7	32.9
Jantarka	104	78.8	5.54	43.8	44.6
Julius	92	68.8	5.49	41.2	31.6
KWS Ozon	105	96.0	5.45	44.3	33.8
Muszelka	119	111.3	5.28	41.7	45.0
Ostroga	94	78.2	5.06	43.2	38.9
Spelt Rokosz	101	69.1	4.67	39.3	47.9
Sailor	90	80.1	5.67	42.5	42.0
Skagen	98	72.6	5.61	41.8	24.0
Smuga	96	74.4	5.47	43.1	52.1
Mean	103	86.1	5.32	42.7	40.4

Source: *own work / Źródło: opracowanie własne*

Julius, Sailor, Ostroga, Smuga, Skagen and spelt Rokosz showed the highest competitive abilities in relation to weeds at all the research locations, mainly due to a relatively high plant density, a large weight of the aboveground parts, significant height and number of tillers, and a more horizontal arrangement of leaves, which affected their ability to shade the soil and inhibit the development of weeds (Table 2-6). Spelt wheat var. Rokosz grew the highest among the tested cultivars (Table 5). Variety Arkadia, in spite of the traits favoring its competitiveness in relation to weeds (large plant density, weight of aboveground parts, and length of the stem) (Tables 5-6), was accompanied by a significant number and weight of weeds (Tables 4). This may have been caused by its small tillering in the initial growth phases (Table 5).

Significant differences in winter wheat yields were found among experimental points in each year. In 2014, wheat yielded the highest in Chwałowice, and in 2016 wheat yield in this location was the lowest. In 2015 and 2016, on average, the highest wheat yields were recorded in Osiny (Table 7).

Among the tested varieties, in 2014 the highest yields were obtained by variety Smuga (mean 6.04 $t \cdot ha^{-1}$), while the lowest yields were achieved by varieties Rokosz and Ostroga (below 5 $t \cdot ha^{-1}$), however their yields significantly differed only from the yields of Smuga (Table 7).

The highest differentiation of yields between winter wheat varieties occurred in 2015. Yields over 6 $t \cdot ha^{-1}$ were obtained for Bamberka, Banderola, Jantarka, Julius, KWS Ozon, Muszelka, Sailor and Skagen, while the lowest for Arkadia, Ostroga and Rokosz. A detailed analysis of the data allowed to separate the varieties, which in two locations: Osiny (Lublin province) and Chwałowice (Masovian province) showed the highest productivity – namely, Muszelka and KWS Ozon. In Chomentowo (Podlasie province), significantly higher yields were obtained by varieties Bamberka, Skagen and Jantarka, but Muszelka and KWS Ozon were in the group of cultivars yielding above average (Table 7). The results indicate that in the conditions of high weed infestation in the experiment in Chwałowice (Tables 1-2), varieties Muszelka and KWS Ozon were able to compete with weeds and produce compact canopy and large grains (Table 7).

In 2016, a higher intensity of weed infestation was noted in comparison with 2015, especially in Chwałowice (Table 2-3). In 2016, the lowest yields of all varieties were recorded. Muszelka, Banderola, Bamberka and Rokosz yielded lower than 4 $t \cdot ha^{-1}$, while the highest yields of winter wheat were obtained for Jantarka and Sailor varieties. The yield analysis of the tested varieties showed a different response, depending on the area of cultivation. Nevertheless, it is possible to single out varieties which, irrespective of the locality, obtained high yields or maintained stable yields (in all locations they were classified as higher yielding varieties). In 2016, these criteria were met by Jantarka, Sailor, Smuga and Arkadia varieties.

To sum up, despite significant differences in winter wheat yields in years, Jantarka, Sailor and Skagen varieties gave much higher yields than spelt Rokosz, Arkadia and Ostroga.

Table 5. Selected morphological traits of the tested winter wheat varieties grown in the organic system in Osiny
Tab. 5. Wybrane cechy morfologiczne badanych odmian pszenicy ozimej uprawianych w systemie ekologicznym w Osinach

Varieties	Number of tillers				Height (cm)			
	2014	2015	2016	mean	2014	2015	2016	mean
Arkadia	1.43	1.38	1.40	1.40	94.8	98.4	90.0	94.4
Bamberka	1.39	1.43	1.46	1.43	87.5	90.4	75.2	84.4
Banderola	1.51	1.45	1.45	1.47	88.4	88.4	76.3	84.4
Jantarka	1.43	1.33	1.48	1.41	87.3	98.2	86.6	90.7
Julius	1.45	1.37	1.49	1.44	81.2	86.4	76.5	81.4
KWS Ozon	1.51	1.48	1.53	1.51	79.4	77.6	67.6	74.9
Muszelka	1.46	1.40	1.48	1.45	89.2	78.0	63.2	76.8
Ostroga	1.43	1.53	1.57	1.51	90.8	93.7	79.4	88.0
Rokosz	1.38	1.60	1.58	1.52	113.3	114.6	102.4	110.1
Sailor	1.46	1.47	1.46	1.46	95.9	101.2	89.6	95.6
Skagen	1.43	1.50	1.63	1.52	91.8	89.2	78.6	86.5
Smuga	1.48	1.67	1.46	1.54	98.2	101.4	90.1	96.6
Mean	1.44	1.47	1.50	1.47	91.5	93.1	81.3	88.6

Source: *own work / Źródło: opracowanie własne*

Table 6. Selected parameters of the canopy of the tested winter wheat varieties grown in the organic system in Osiny
Tab. 6. Wybrane parametry łanu badanych odmian pszenicy ozimej uprawianych w systemie ekologicznym w Osinach

Varieties	Plant density (pcs.·m^{-2})				Dry matter of wheat ($g \cdot m^{-2}$)			
	2014	2015	2016	mean	2014	2015	2016	mean
Arkadia	203	286	296	262	949	1373	1405	1242
Bamberka	184	288	230	234	895	1512	1038	1148
Banderola	180	310	207	232	943	1487	1026	1152
Jantarka	182	275	278	245	883	1338	1279	1167
Julius	223	265	287	258	955	1391	1257	1201
KWS Ozon	176	263	263	234	843	1282	1138	1088
Muszelka	205	294	260	253	936	1443	1076	1151
Ostroga	195	258	267	240	932	1308	1349	1197
Rokosz	224	251	286	254	1115	1243	1285	1214
Sailor	199	281	269	250	962	1371	1357	1230
Skagen	219	274	252	248	1144	1292	1308	1248
Smuga	190	269	264	241	993	1325	1336	1218
Mean	198	276	263	246	962	1364	1238	1188

Source: *own work / Źródło: opracowanie własne*

Low yields of Arkadia variety resulted from the highest incidence of infestation by fungal pathogens among all the tested varieties (Table 4). Spelt Rokosz was also characterized by a significant susceptibility to fungal diseases.

An opposite proportional correlation was found between the number and weight of weeds, infestation by fungal diseases and the level of winter wheat yields. A particularly strong negative correlation was obtained between dry matter of weeds and winter wheat grain yield (Table 8).

Taking into account the relationship between weed infestation and winter wheat yield, 3 groups of varieties were distinguished (Fig. 1). The group I consists of the least weed-infested and the highest yielding varieties: Julius, Skagen, Sailor, Jantarka, Smuga, which are the most suitable for organic cultivation. However, in the case of the varieties Jantarka and Smuga, it is necessary to pay attention to their susceptibility to infection by fungal pathogens. The group II of varieties achieves high or medium yields despite a significant weed infestation, i.e. they tolerate well weed infestation, which may also be useful for organic farming: KWS Ozon, Bamberka, Banderola and Muszelka. This group was the least infected by pathogens. The group III, including Arkadia, Ostroga, and spelt Rokosz, was characterized by the lowest yields and low or medium weed infestation. Diseases may be the limiting factor for them. Spelt Rokosz is a highly competitive variety in relation to weeds; hence its low yields may result from its low yielding potential or susceptibility to diseases (Table 4).

Table 7. Winter wheat grain yields (t ha $^{-1}$) in different habitats in the years 2014-2016
Tab. 7. Plony ziarna pszenicy ozimej (t ha $^{-1}$) w różnych środowiskach w latach 2014-2016

Variety	Osiny (Lublin province)				Chwałowice (Masovian province)				Chomentowo (Podlasie province)			
	2014	2015	2016	Mean	2014	2015	2016	Mean	2014	2015	2016	Mean
Arkadia	3.92	6.11	6.70	5.58	7.61	5.52	2.63	5.25	4.04	4.39	3.83	4.09
Bamberka	3.60	7.99	6.05	5.88	8.16	6.25	2.48	5.63	4.86	5.70	3.56	4.71
Banderola	4.31	8.07	5.85	6.08	7.16	6.10	2.38	5.21	5.43	4.78	3.40	4.54
Jantarka	4.54	7.86	7.34	6.58	6.66	5.89	2.44	5.00	5.16	5.31	4.67	5.05
Julius	4.64	7.83	6.60	6.36	8.18	6.58	3.05	5.94	4.57	4.58	3.40	4.18
KWS Ozon	3.27	8.18	6.38	5.94	7.61	6.77	2.85	5.74	5.65	4.94	3.40	4.66
Muszelka	4.43	8.70	5.88	6.34	6.60	6.83	1.93	5.12	5.40	4.96	2.80	4.39
Ostroga	4.62	7.22	6.81	6.22	6.30	5.58	2.71	4.86	3.94	4.75	3.57	4.09
Spelt Rokosz*	3.78	6.35	6.46	5.53	6.88	4.94	2.06	4.63	4.24	3.57	3.72	3.84
Sailor	4.25	7.91	6.85	6.34	7.58	6.60	3.44	5.87	5.63	5.01	3.78	4.81
Skagen	4.71	7.52	6.82	6.35	8.41	6.37	2.33	5.70	4.69	5.63	4.04	4.79
Smuga	5.27	7.62	6.74	6.54	7.27	5.53	2.66	5.15	5.59	4.75	3.78	4.71
Mean	4.28	7.61	6.54	6.14	7.37	6.08	2.58	5.34	4.93	4.86	3.66	4.48
$NIR_{0,05}$	1.26	0.53	0.59		0.10	0.98	0.65	-	0.22	0.23	0.16	-

*/ spelt wheat, hulled grain

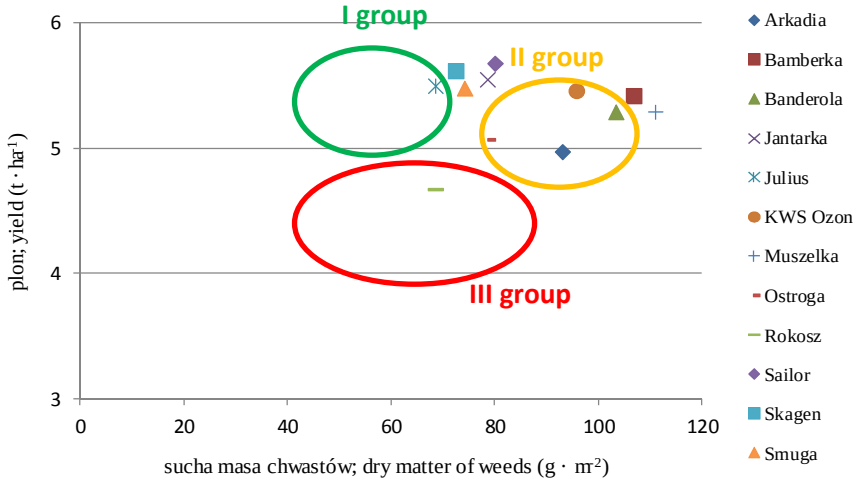
Source: own work / Źródło: opracowanie własne

Table 8. Simple correlation coefficients among the tested characteristics
Tab. 8. Współczynniki korelacji prostej między badanymi cechami

Characteristics	Parameters					
	Yield	Plant density	1000 grain weight	Number of weeds	Dry matter of weeds	Incidence of diseases
Yield		**0.811**	**0.439**	-0.004	**-0.614**	**-0.404**
Plant density	**0.811**		0.058	-0.067	**-0.726**	**-0.389**
1000 grain weight	**0.439**	0.058		**0.206**	-0.121	-0.001

Significant correlation coefficients ($p<0.05$) are indicated in bold

Source: own work / Źródło: opracowanie własne



Source: own work / Źródło: opracowanie własne

Fig. 1. Relationship between weed infestation and yields of winter wheat varieties (mean from 3 years of research and locations)
Rys. 1. Zależność między zachwaszczeniem a plonami odmian pszenicy ozimej (średnia z 3 lat badań i miejscowości)

4. Discussion

The successful weed management is based on an appropriate cropping system design. In Osiny experiment, 5-field crop rotation using crops with different groups (potato-spring wheat - clover and grasses I and II year - winter wheat+catch crop) is realized, which decreases weed population and soil seed bank and protects against weed compensation. In other research locations: Chomentowo and Chwałowice also good forecrops: clover with grasses and potato were sown before winter wheat. Maximum diversification of the cropping system , e.g. alternation between winter and summer crops, grain and root crops, nutrient-depleting and nutrient-building crops disrupt the regeneration niches of different typologies of weeds (annuals, biennials, perennials, obligate seasonal species), thereby preventing the establishment of a specialized flora and promoting that of a multifaceted weed community hosting numerous species each present at a low density [4].

Farmers require precise information about the choice of variety for enhancing crop competitive ability in different environments. Competitive wheat crops should be available as part of reliable and economical weed management strategies [16-17]. The study of winter wheat varieties indicated that dry matter of wheat, plant density, plant height and tillering had an impact on weed number and biomass, which was confirmed by the results of earlier research conducted on spring wheat varieties [10]. Different features determined the competitiveness of winter wheat varieties. For spelt Rokosz, Arkadia and Sailor, the height could be the most important factor. In many studies, plant height has been shown to be a significant or even the only factor for cereal competitiveness [5, 7, 19]. In contrast, other researchers have indicated that plant height is of minor importance [23-26]. In the case of Ostroga, spelt Rokosz, Skagen and Smuga, the number of tillers had also an influence on their competitiveness against weeds. In the case of Julius, Sailor, Arkadia, Skagen, Smuga and spelt Rokosz, density of plant canopy and dry matter of underground parts decided about their high competitive ability. In a study by O'Donovan et al. [20], differences in seedling establishment of wheat and barley varieties tended to influence competitive ability against wild oat (*Avena fatua* L.) more than plant height did. Lemerle et al. [18] also reported that there was no evidence of any relationship between morphological traits and suppression of weeds, which emphasizes the complex nature of competitiveness. According to Lammerts van Bueren et al. [14] traits important for weed suppression are fluid and often dependent on site-specific environmental conditions. In the case of some varieties, a complex of features influence competitive ability but none of them dominates; indeed, other traits such as, e.g., allelopathic effects may be involved [2, 19, 29].

Characteristics of cereal varieties suitable for organic farming should be tested on organically managed fields because the genotypes which yielded the highest under weed-free conditions were not necessarily the highest yielding under weedy conditions [13]. Genotypes which suffered smaller yield reductions were more effective in suppressing weed growth. In our study, a group of varieties which yield at high or moderate level despite the high weed infestation (well tolerating weeds) thus being suitable for organic system, were indicated: KWS Ozon, Bamberka, Banderola i Muszelka. Although competitive genotypes were generally taller than non-competitive genotypes, other traits such as large seedling ground cover and flag leaf length were associated with wheat yield under competitive conditions [13].

In our research, in the conditions of moderate infestation, highly competitive varieties (70-80 $g \cdot m^{-2}$) yielded the highest (5,47-5,67 $t \cdot ha^{-1}$), but at weed level 96-111 $g \cdot m^{-2}$ the yield of some varieties was quite high (5,28-5,45 $t \cdot ha^{-1}$). It suggests that observed level of weed infestation did not decrease the yield significantly. In the studies by Hoad et al. [11], some highly competitive cultivars gave only modest yields. Hucl [12] reported yield gains of 7–9% in "competitive" compared to "non-competitive" spring wheat varieties. For winter wheat, the highest grain-producing cultivars included three medium height cultivars [27], but Murphy et al. [19] report no evidence of a causal relationship between ability in weed suppression and grain yield of spring wheat. According to Lemerle et al. [18] competitive ability and yield potential must therefore be treated as separate traits for selection.

The grain yield of wheat in an organic system could be affected not only by weeds, but also by nitrogen status and other nutrient deficiencies as well as, for example, fungal leaf diseases [14]. Varieties for organic farming need efficient nutrient uptake and use and weed competition. These and other characteristics need to be considered in relation to the organic cropping system over the whole rotation. Positive interactions are needed, such as early crop vigour for nutrient uptake, weed competition and disease resistance [28]. Any information about the performance of cereal cultivars in the organic system could also be useful for low-input, integrated and conventional farming in order to achieve the economic and environmental goals [24].

5. Conclusions

1. Winter wheat varieties Julius, Sailor, Smuga, Skagen and spelt Rokosz were distinguished by the highest competitiveness against weeds. Varieties of the largest weed infestation were: Muszelka, Banderola, Bamberka and KWS Ozon.
2. The dry matter of wheat, plant density, the height and tillering had the greatest impact on weed number and biomass.
3. A set of varieties with the largest competitive ability and the highest yield, the most suitable for organic agriculture: Julius, Skagen, Sailor, Jantarka, Smuga was established.
4. In organic farming conditions, the lowest yields were recorded for spelt Rokosz, Arkadia and Ostroga. Low yields of Arkadia variety resulted from being infected by fungal pathogens.

6. References

[1] Barberi P.: Weed management in organic agriculture: Are we addressing the right issues? Weed Res., 2002, 42, 177-193. DOI: 10.1046/j.1365-3180.2002.00277.x.

[2] Bertholdsson N.O.: Early vigour and allelopathy – two useful traits for enhanced barley and wheat competitiveness against weeds. Weed Res., 2005, 45, 94-102. https://doi.org/10.1111/j.1365-3180.2004.00442.x.

[3] Bond W., Grundy A.C.: Non-chemical weed management in organic farming systems. Weed Res., 2001, 41, 383-405. https://doi.org/10.1046/j.1365-3180.2001.00246.x.

[4] Buhler D.D.: Expanding the context of weed management. In: Expanding the Context of Weed Management (ed. DD Buhler), The Haworth Press, New York, USA, 1999, 1-7.

[5] Christensen S.: Weed suppression ability of spring barley varieties. Weed Res., 1995, 35, 241-247. https://doi.org/10.1111/j.1365-3180.1995.tb01786.x.

[6] Clark M.S., Ferris H., Klonsky K., Lanini W.T., Van Bruggen A.H.C., Zalom F.G.: Agronomic, economic, and environmental comparison of pest management in conventional and alternative tomato and corn systems in Northern California. Agric. Ecosyst. Environ., 1998, 68, 51-71.
[7] Deveikyte I., Semaškiene R., Leistrumaite A.: The competition between cereals and weeds under the conditions of organic agriculture. Zemdirbyste-Agriculture, 2008, 95, 3-15.
[8] Feledyn-Szewczyk B.: The influence of morphological features of spelt wheat (*Triticum aestivum* ssp. *spelta*) and common wheat (*Triticum aestivum* ssp. *vulgare*) varieties on the competitiveness against weeds in organic farming system. J. Food Agri. Environ., 2013, 11(1), 416-421.
[9] Feledyn-Szewczyk B., Kuś J, Jończyk K., Stalenga J.: The suitability of different winter and spring varieties for cultivation in organic farming. In: Pilipavičius V, editor. Organic agriculture towards sustainability. Rijeka: Intech; 2014, 197-225. https://doi.org/10.5772/58351.
[10] Feledyn-Szewczyk B., Jończyk K.: Weed suppression and yield of thirteen spring wheat (*Triticum aestivum* L.) varieties grown in an organic system. Acta Agrobot., 2017, 70 (3), 1675. DOI: https://doi.org/10.5586/aa.1721.
[11] Hoad S., Topp C., Davies K.: Selection of cereals for weed suppression in organic agriculture: a method based on cultivar sensitivity to weed growth. Euphytica, 2008, 163(3), 355-366. https://doi.org/10.1007/s10681-008-9710-9.
[12] Hucl P.: Response to weed control by four spring wheat genotypes differing in competitive ability. Can J Plant Sci., 1998, 78, 171-173. https://doi.org/10.4141/P97-02.9
[13] Huel D.G., Hucl P.: Genotypic variation for competitive ability in spring wheat. Plant Breed., 1996, 155(5), 325-329. https://doi.org/10.1111/j.1439-0523.1996.tb00927.x.
[14] Lammerts van Bueren E.T., Jones S.S., Tamm L., Murphy K.M., Myers J.R., Leifert C..: The need to breed crop varieties suitable for organic farming, using wheat, tomato and broccoli as examples: a review. NJAS-Wageningen Journal of Life Sciences, 2011, 58, 193-205. https://doi.org/
[15] 10.1016/j.njas.2010.04.001.
[16] Lemerle D., Verbeek B., Cousens R.D., Cooombes N.E.: The potential for selecting wheat varieties strongly competitive against weeds. Weed Res., 1996, 36, 505-513.
[17] Lemerle D., Verbeek B., Orchard B.: Ranking the ability of wheat varieties to compete with *Lolium rigidum*. Weed Res., 2001, 41, 197-209.
[18] Lemerle D., Gill G.S., Murphy C. E., Walker S. R., Cousens R. D., Mokhtari S., Peltzer S. J., Coleman R., Luckett D.J.: Genetic improvement and agronomy for enhanced wheat competitiveness with weeds. Australian Journal of Agricultural Research, 2001, 52(5), 527-548.
[19] Lemerle D., Smith A., Verbeek B., Koetz E., Lockley P., Martin P.: Incremental crop tolerance to weeds: a measure for selecting competitive ability in Australian wheat. Euphytica, 2006, 149, 85-95. https://doi.org/10.1007/s10681-005-9056-5.
[20] Murphy K., Dawson J., Jones S.S.: Relationship among phenotypic growth traits, yield and weed suppression in spring wheat landraces and modern cultivars. Field Crops Res., 2008, 105, 107-115. https://doi.org/10.1016/j.fcr. 2007.08.004.
[21] O'Donovan J.T., Blackshaw R.E., Harker K.N., Clayton G.W., McKenzie R.: Variable plant establishment contributes to differences in competitiveness with wild oat among wheat and barley varieties. Can. J. Plant. Sci., 2005, 85(4), 771-776. https://doi.org/10.4141/P04-190.
[22] Olofdotter M.: Rice – a step toward use of allelopathy. Agron. J., 2001, 93, 3-8.
[23] Rasmussen K., Rasmussen J.: Barley seed vigour and mechanical weed control. Weed Res., 2000, 40 (2), 219-230. https://doi.org/10.1046/j.1365-3180.2000.00184.x.
[24] Satorre E.H., Snaydon R.W.: A comparison of root and shoot competition between spring cereals and *Avena fatua* L. Weed Res., 1992, 32, 45–55. https://doi.org/10.1111/j.1365-3180.1992.tb01861.x.
[25] Tamm I., Tamm Ü., Ingver A.: Spring cereals performance in organic and conventional cultivation. Agronomy Res., 2009, 7(1), 522-527.
[26] Vandeleur R.K., Gill G.S.: The impact of plant breeding on the grain yield and competitive ability of wheat in Australia. Australian J. Agric. Res., 2004, 55(8), 855-861. https://doi.org/10.1071/AR03136.
[27] Wicks G.A., Ramsel R.E., Nordquist P.T., Smith J.W., Challaiah R.E.: Impact of wheat cultivars on establishment and suppression of summer annual weeds. Agron J., 1986, 78, 59-62.
[28] Wicks G.A., Nordquist P.T., Baenziger P.S., Klein R.N., Roger H.H., Watkins J.E.: Winter wheat cultivar characteristics affect annual weed suppression. Weed Technol., 2004, 18(4), 988-998. https://doi.org/10.1614/WT-03-158R1.
[29] Wolfe M.S., Baresel J.P., Desclaux D., Goldringer I., Hoad S., Kovacs G.: Developments in breeding cereals for organic agriculture. Euphytica, 2008,163(3), 323–346. https://doi.org/10.1007/s10681-008-9690-9.
[30] Worthington M., Reberg-Horton C.: Breeding cereal crops for enhanced weed suppression: optimizing allelopathy and competitive ability. J. Chem Ecol., 2013, 39(2), 213-231. https://doi.org/10.1007/s10886-013-0247-6.

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