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Chapter 9

The Suitability of Different Winter and Spring Wheat Varieties for Cultivation in Organic Farming

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Additional information is available at the end of the chapter

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1. Introduction

Nowadays, an interest in organic farming is increasing in many countries [1]. In this specific farming system use of synthetic fertilizers and chemical plant protection measures is forbidden. The limitation of pests, diseases and weeds is provided by agricultural practices which create a beneficial condition of canopy and soil, such as crop rotation, fine and careful tillage, organic fertilization, date and density of sowing as well as mechanical, biological and physical methods of plant protection. An appropriate variety choice is a crucial component of agricultural practices. Selection of cereal varieties suited to organic agriculture requires a different approach to that used in the conventional high input system [2-4].

Organic farming gives a reference to varieties of cereals which are characterized by winter hardiness, high competitive ability against weeds (growth rate, length of stem, tillering rate, surface and angle of leaf attachment), tolerance to fungal diseases, ability to uptake of nutrients as well as resistance to nutrients deficiency stress [5-14]. Moreover the ability of symbiosis with mycorrhizal fungi can be important as it supports uptake of water and mineral nutrients from the soil and improves wholesomeness of plants [4]. Preliminary research indicates organic farming system has low influence on physical and chemical characteristics of grain, with the exception of the total protein content [15].

Some authors suggest that old varieties of cereals were characterized by greater competitiveness against weeds because of longer stems, more prolific tillering and larger leaf area, which increase shading and decrease weed infestation [2, 16, 17]. In breeding process, the stem has become shorter and other features connected with high yields were promoted, according to chemical plant protection [18]. Because of the lower competitiveness of modern varieties against weeds, there can be a problem with selection the varieties to organic and other less intensive crop production systems.

Christensen's study [7] showed no significant correlation between yield and competitive ability of cereal varieties against weeds, which means that both of these features should be considered by breeders in selecting varieties for organic farming system. Promising might be the selection for genotypes with high early nitrogen uptake efficiency amongst those already recognised as having good coverage and shading ability [4].

The aim of the research was to compare the yields of several winter and spring wheat varieties cultivated in organic and conventional crop production systems to identify the causes of yield differentiation in these systems.

2. Material and methods

The study was conducted in 2008-2010 at the Experimental Station of Institute of Soil Science and Plant Cultivation – State Research Institute in Puławy, Poland (N:51°28', E:22°04) in an experiment, in which different crop production systems have been compared since 1994. The experiment was located on a Luvisol, a loamy sand and on a sandy loam. The characteristics of agricultural practices used in each system were presented in Table 1.

The area of each crop rotation field was 1 ha. Within the field of winter and spring wheat, the experiment with different varieties was established in completely randomized blocks. Five modern varieties of common wheat (*Triticum aestivum ssp. vulgare*): Kobra Plus, Bogatka, Smuga, Tonacja, Ostka Strzelecka and old variety of spelt wheat (*Triticum aestivum ssp. spelta*)-Schwabenkorn were cultivated. Nine spring wheat varieties: Bombona, Vinjett, Parabola, Tybalt, Nawra, Raweta, Bryza, Żura, Zadra were tested in organic system. In conventional system 4 varieties of winter wheat: Kobra Plus, Bogatka, Rywalka, Legenda and 4 varieties of spring wheat: Bombona, Parabola, Tybalt and Vinjett were cultivated. The varieties of common wheat were sown at a rate of 220 kg grains · ha^{-1}, spelt wheat - 200 kg of spikelets· ha^{-1}, spring wheat – 190 kg grains · ha^{-1}. In conventional system spring wheat was cultivated in pure stand whereas in organic system it was sown with undersown crop (common clover – 10 kg ha^{-1}+Dutch clover 3 kg ha^{-1}+meadow fescue 10 kg ha^{-1}+perennial ryegrass 10 kg ha^{-1}). According to organic agriculture rules, mineral nitrogen fertilizers and chemicals were not used. In winter wheat canopy weeds were controlled in mechanical way, using a weeder, two or three times in spring, at tillering stage, whereas in spring wheat mechanical weed control was not applied due to undersown plants. In conventional farming system chemical plant protection was applied (Table 1).

High differences in weather conditions were observed during the research period (Table 2). The growing season of 2007/2008 was characterized by favourable weather conditions for growth and development of winter wheat and spring wheat. Precipitation slightly higher than average was well distributed. Suitable thermic and moisture conditions reflected in the development of dense wheat canopies of large ability to compete with weeds. The spring of

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	Farming system	
	Organic	**Conventional**
Crop rotation	potato spring wheat ± undersown crop clover and grasses (1 year) clover and grasses (2 year) winter wheat ± catch crop	winter rape winter wheat spring wheat
Seed dressing	-	+
Organic fertilization	compost (30 t·ha^{-1}) under potatoe + catch crop	winter rape straw, winter wheat straw
Mineral fertilization (kg·ha^{-1})	based on soil testing, allowed P and K fertilizers in form of natural rock were used: 150 kg of potassium sulphate (75 kg K_2O), phosphate rock powder 150 kg (42 kg P_2O_5)	winter wheat: NPK (140+60+80) spring wheat: NPK (70+60+45)
Fungicide	-	winter wheat: 2 – 3 x spring wheat: 1 x
Growth regulators	-	winter wheat: 2 x spring wheat: 1 x
Weed control	winter wheat: harrowing 2-3 x spring wheat: none (undersown clovers + grasess)	winter wheat: herbicide 2-3 x spring wheat: harrowing 1x + herbicide 1x

Table 1. Major elements of the agricultural practices of winter wheat and spring wheat cultivated in organic and conventional farming systems

2009 was delayed, which limited the effectiveness of harrowing. Threefold harrowing of winter wheat caused damage to plants. Late spring, lack of precipitation and night frosts until mid-May disturbed the phases of tillering, stem elongation and earing. As a result, the density of wheat canopies was low, which created favorable conditions for weeds. The weather conditions in the autumn of 2009 were suitable for growth and development of winter wheat. Snow mould and frost till the end of April of 2010 had adverse effects on development of winter wheat. Sparse wheat canopies competed worse with weeds. Growing season was characterized by an unfavorable distribution of temperature and precipitation: dry April and heavy rains in May (110 mm). High temperature and drought in June and July negatively affected yields of spring wheat (Table 2).

Grain yield and components of its structure were estimated in 25m^2 plots in 8 replications. Stem and leaves were scored for infestation rate with fungal pathogens at mik-dough stage (BBCH 77-83). Forty individuals in 4 replications for each variety were taken for plant pathology analysis purposes. Percentage of the disease-damaged leaf blade surface was determined in accordance with the recommendations of the EPPO [19]. A 4-step infestation scale was used to calculate the stem base infection index.

The number of weeds and their dry matter were assessed at dough stage of wheat (BBCH 85-87), on an area of 0.5 m^2, in four replications for each variety. Moreover, the biometric

Months	Temperature (°C)				Precipitation (mm)			
	2007/2008	2008/2009	2009/2010	1951-2006	2007/2008	2008/2009	2009/2010	1951-2006
IX	13.1	12.5	14.8	13.2	86	61	22	49
X	7.8	9.9	6.8	8.2	7	42	77	44
XI	1.4	5.1	5.3	2.7	36	20	42	39
XII	-0.7	1.3	-1.7	-1.4	6	35	42	37
I	1.0	-2.6	-8.3	-3.4	46	23	22	31
II	2.9	-0.7	-1.7	-2.4	11	29	29	29
III	3.9	2.2	3.0	1.7	39	61	13	30
IV	9.5	11.0	9.3	7.9	43	2	17	40
V	13.5	13.7	14.3	13.5	83	63	110	57
VI	18.2	16.6	18.3	16.8	42	96	48	70
VII	18.8	20.1	22.1	18.5	94	69	43	85
VIII	18.6	18.4	20.3	17.3	72	98	119	75

Table 2. Mean daily temperature of air (°C) and monthly sum of precipitation (mm) in Osiny in 2007-2010 compared to the longtime average (1951-2006)

analysis of wheat plants and plant canopy, such as plant height, overall tillering, number of plants and dry matter of wheat per unit area (1 m) were done.

Total protein of grain was determined based on the content of nitrogen measured by Kjeldahl Nitrogen Determination Method x 5.83.

The results were analysed statistically. Analysis of variation for the completely randomized model was applied and the significance of differences between means was verified by Tukey test at α=0.05. Pearsons' correlations between grain yield of winter and spring wheat varieties in organic system and yield limiting factors as well as morphological features and canopy parameters were performed. Cluster analysis using Furthest Neighbour method was done in order to divide varieties into groups with similar characteristics. Calculations were performed using Statgraphic Plus version 2.1.

3. Results and discussion

3.1. Estimation of winter wheat varieties suitability for cultivation in organic farming

Yields of winter wheat cultivated in organic farming system were strongly differentiated in years. An average for all varieties reached from 2.1 t ha^{-1} in 2010 (unfavorable weather conditions) to 5.4 t ha^{-1} in 2008 (good weather conditions) (Table 3, 4).

No clear information about yields of winter wheat varieties cultivated in organic farming was achieved. Among the varieties that are in the Registry, Smuga gave the highest yields. That variety yielded so high in the growing season of 2009/2010 thanks to its good winter survival

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and high plant density (table 4). Varieties that yielded the lowest were: Ostka Strzelecka and spelt Schwabenkorn – 3.2 t ha^{-1} (Table 3).

Grain yield in conventional farming system was, on average of 4 varieties, 45% higher than in organic farming system (Table 3, 5). The difference between those two farming systems was: 30% in 2008, 49% in 2009 and 61% in disaster-year 2010. Yield differences between organic and conventional farming systems were 37% for a cv. Kobra and 45% for a cv. Bogatka. Research conducted in 2005-2007 on varieties: Roma, Kobra, Zyta, Sukces revealed that average yield differences between organic and conventional farming system were 19%. The old varieties of common wheat: Ostka Kazimierska, Kujawianka Więcławicka, Wysokolitewka Sztywnosłoma were not very useful for cultivation in organic system because of low grain yield [20]. Number of ears per 1 m^2 in organic system was lower than in conventional one, despite the same sowing rate, by 14% in 2008 to 47% in 2010, due to lower density of wheat in organic farming system after the severe winter. Also, the differences between grain weight between two farming system were observed (15% for Kobra and Bogatka cultivars on average) (table 3, 5).

Cultivar	The yield of grain ($t \cdot ha^{-1}$)				Number of ears ($pcs \cdot m^{-2}$)				1000 grains weight (g)			
	2008	2009	2010	**mean**	2008	2009	2010	**mean**	2008	2009	2010	**mean**
Kobra Plus	6.18	2.92	2.39	**3.83**	569	323	268	**387**	46.8	32.0	38.0	**38.9**
Bogatka	6.21	2.33	2.36	**3.63**	479	278	242	**333**	50.9	38.9	44.3	**44.7**
Smuga	5.82	3.91	3.04	**4.26**	576	392	320	**429**	47.2	36.4	38.6	**40.7**
Tonacja	5.56	3.53	1.80	**3.63**	488	444	151	**361**	40.1	37.2	39.6	**38.9**
Ostka Strzelecka	4.94	3.48	1.09	**3.17**	457	423	165	**348**	38.0	33.1	34.0	**35.0**
Spelt*	3.80	3.96	1.94	**3.23**	562	444	251	**419**	76.1	76.6	76.0	**76.2**
Mean	**5.42**	**3.36**	**2.10**	**3.63**	**522**	**384**	**233**	**380**	without spelt			
									44.6	**35.5**	**38.9**	**39.6**
HSD (α=0.05)	0.33	0.28	0.31		51	51	66		2.1	2.9	2.0	

* glume grains and the 1000 spikelets weights

Table 3. The grain yield of winter wheat and the elements of yield in organic system

cultivar	% loss of plants during the winter
Kobra Plus	33
Bogatka	41
Smuga	17
Tonacja	45
Ostka Strzelecka	30
Spelt	35

Table 4. Survival of winter wheat varieties during winter 2009/2010 in organic system

Cultivar	The yield of grain (t·ha-1)				Number of ears (pcs·m-2)				1000 grains weight (g)			
	2008	2009	2010	**mean**	2008	2009	2010	**mean**	2008	2009	2010	**mean**
Kobra Plus	7.41	6.47	4.45	**6.11**	663	483	501	**549**	49.6	44.6	43.5	**45.9**
Bogatka	7.82	6.73	5.36	**6.63**	539	447	419	**468**	56.6	50.1	51.5	**52.7**
Rywalka	8.18	6.41	6.11	**6.90**	614	458	409	**494**	54.1	44.7	48.7	**49.1**
Legenda	7.73	6.81	5.65	**6.73**	607	457	432	**499**	50.7	42.2	49.3	**47.4**
Mean	**7.78**	**6.60**	**5.39**	**6.59**	**606**	**461**	**440**	**502**	**52.9**	**45.4**	**48.3**	**48.8**
HSD (α=0.05)	0.51	ns*	0.31		63	ns	36		1.2	0.9	1.3	

* ns – non significant differences

Table 5. The grain yield of winter wheat grain and the elements of yield in conventional system

According to Seufert et al. [21], crop yields in organic farming are from 5 to 34% lower than those in conventional farming. Those differences depend on plant species, soil type, fertilization, agriculture level and economic development of the country. Tyburski and Rychcik's [22] study showed that winter wheat yield can reach 4.27 t ha^{-1} in an organic farm and 5.63 t ha^{-1} in a conventional one. According to the authors correct crop management in some of organic farms can result in crop yields to be almost as high as in conventional farms.

Weed infestation is one of the most strongly limiting factors to cereals yields in organic farming system. Weed communities differed in years and between tested varieties. The lowest level of weed infestation was observed in 2008 (19-46 g m^{-2}), whereas the biggest dry matter of weeds was noted in 2010 (170-345 g m^{-2}) (Table 6), the latter being connected with sparse canopies after winter (Table 4). Percentage loss of plants during the winter was the highest in Bogatka and Tonacja and the lowest in Smuga (Table 4). The comparison of common wheat and spelt wheat varieties showed the highest abundance of weeds in Tonacja, Kobra Plus and Bogatka (Table 6). Dry matter of weeds was the largest in Bogatka and Kobra Plus canopies. The lowest number of weeds at dough stage was recorded in Ostka Strzelecka and spelt Schwabenkon and the lowest dry matter of weeds in Smuga. In canopies of all varieties a few dicotyledonous species dominated: *Viola arvensis, Stellaria media, Papaver rhoeas, Polygonum convolvulus, Chenopodium album*. Monocotyledonous species were represented mainly by *Apera spica-venti*.

Weed infestation of winter wheat cultivated in conventional system was low (3.0 plants m^{-2}, 2.1 g m^{-2} on average) and did not differ significantly between varieties and years due to the intensive chemical weed control using herbicides (Table 1, 7). That level of weed abundance did not affect yields of winter wheat.

Varieties of common wheat and spelt wheat differed for some morphological features and for canopy structure. Among tested cultivars spelt Schwabenkorn was significantly the tallest (122 cm on average at dough stage) (Figure 1). Differences in height between spelt and common wheat varieties increased with advancing plant age, which influenced the competitive ability against weeds and was reflected in dry matter of weeds (Table 6). The lowest variety in the first stages of growth was Tonacja, while at dough stage Kobra Plus characterized with significantly the smallest stem length (85 cm on average) (Figure 1). In both of these varieties high level of infestation was indicated (Table 6). Among the varieties of common wheat Smuga was the highest in all phases of development and it was the most competitive against weeds.

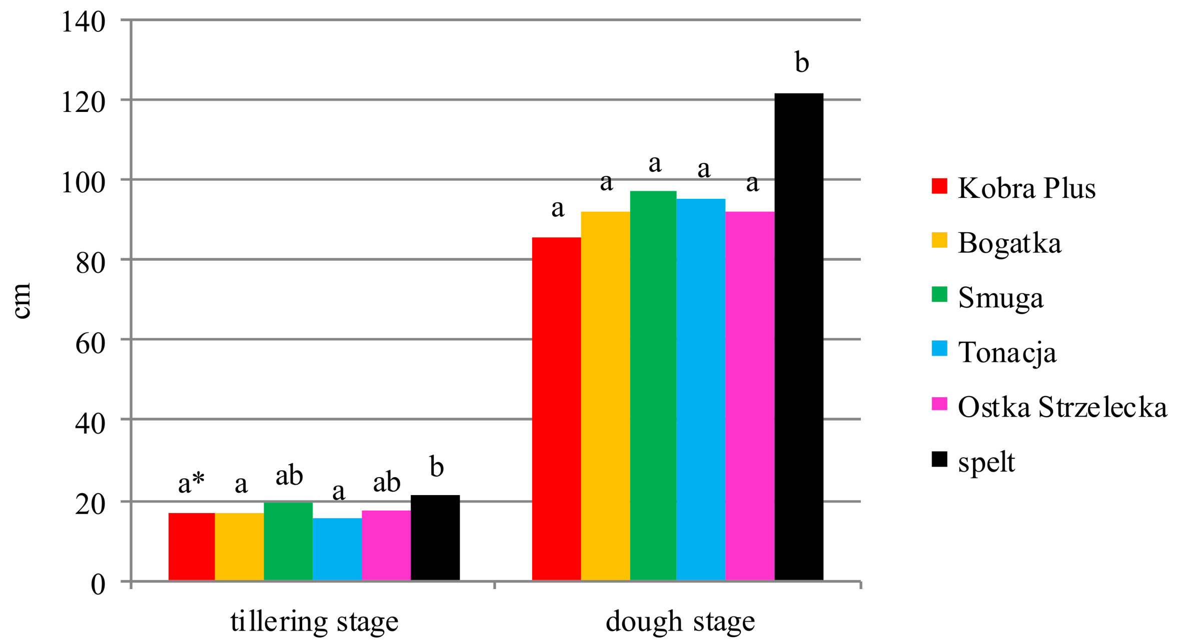
Cultivar (A)	Number of weeds (plants·m^{-2})				Dry matter of weeds (g·m^{-2})			
	Years (B)				Years (B)			
	2008	2009	2010	**mean**	2008	2009	2010	**mean**
Kobra Plus	45.0	147.5	117.5	**103.3**	42.8	188.3	225.7	**152.3**
Bogatka	57.0	87.5	114.0	**86.2**	45.6	184.2	344.5	**191.4**
Smuga	61.0	79.5	101.0	**80.5**	29.7	104.8	169.3	**101.3**
Tonacja	43.0	156.5	132.5	**110.7**	18.3	84.2	293.5	**132.0**
Ostka Strzelecka	64.5	73.0	81.0	**72.8**	42.3	91.0	291.1	**141.5**
Spelt	67.0	91.0	68.5	**75.5**	30.0	114.9	224.0	**123.0**
Mean	**56.3**	**105.8**	**102.4**	**88.2**	**34.8**	**127.9**	**258.0**	**140.2**
HSD (α=0.05) for:	A - 34.9, B - 20.1, interaction AB - 57.8				A - 63.9, B - 36.9, interaction AB - 106.1			

Table 6. Number and dry mater of weeds in winter wheat cultivated in organic system as determined at dough stage

Cultivar (A)	Number of weeds (plants·m^{-2})				Weeds dry matter (g·m^{-2})			
	Years (B)				Years (B)			
	2008	2009	2010	**mean**	2008	2009	2010	**mean**
Kobra Plus	3.0	5.0	1.0	**3.0**	1.2	3.8	0.8	**1.9**
Bogatka	2.5	4.5	0	**2.3**	3.9	1.2	0	**1.7**
Rywalka	4.5	4.0	6.0	**4.8**	10.0	2.1	0.6	**4.2**
Legenda	1.0	3.5	1.0	**1.8**	0.4	0.6	0.1	**0.4**
Mean	**2.8**	**4.3**	**2.0**	**3.0**	**3.9**	**1.9**	**0.4**	**2.1**
HSD (α=0.05) for:	A - ns*, B - ns, interaction AB - ns				A – ns, B - ns, interaction AB - ns			

* ns – non significant differences

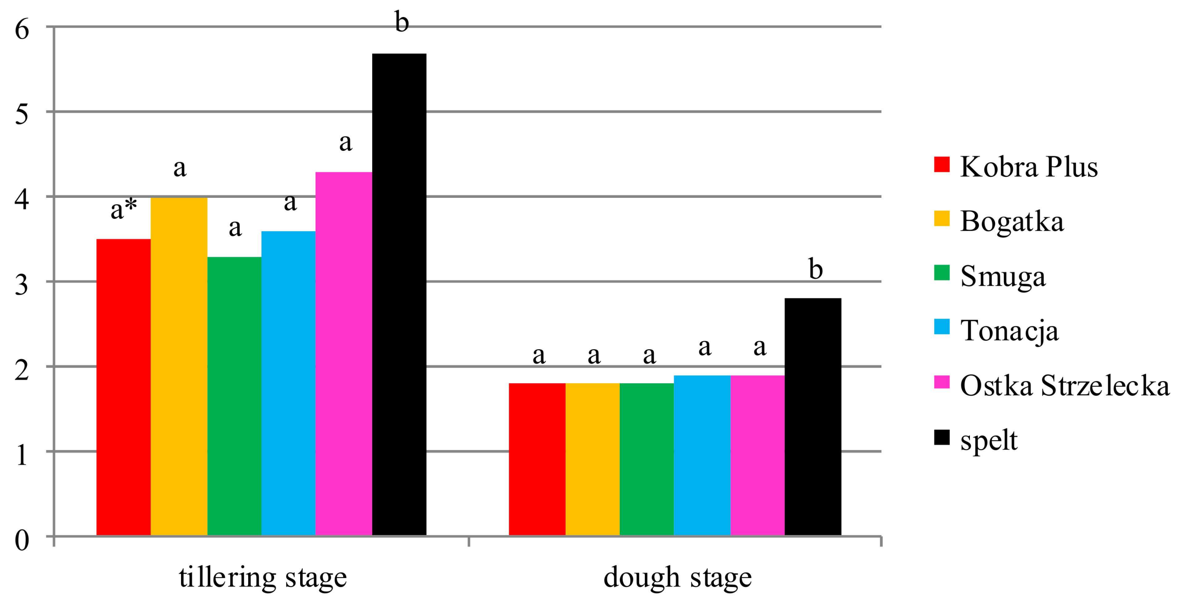
Table 7. Number and dry mater of weeds in winter wheat cultivated in conventional system as determined at dough stage



* data marked with the same letters do not differ significantly at α=0.05

Figure 1. Height of winter wheat varieties cultivated in organic system (mean from 2008-2010)

Spelt Schwabenkorn was characterized by significantly the most profuse overall tillering (Figure 2). There were no differences in tillering of modern varieties of winter wheat.



* data marked with the same letters do not differ significantly at α=0.05

Figure 2. Tillering of winter wheat varieties cultivated in organic system (mean from 2008-2010)

The highest density of plants was noted in a Smuga throughout the growing season and the lowest in spelt Schwabenkorn (Table 8). Plant density was the highest in the best weather conditions of 2008 and lowest in 2010, which was caused by poor winter survival of wheat (table 1, 4, 8). In 2010 weed infestation was determined more by plant density than by morphological features of varieties. The largest biomass was produced by Smuga (Table 8) which could be the reason for its big competitiveness against weeds (Table 6). Bogatka and Kobra Plus canopies were characterized by the lowest biomass.

Cultivar (A)	Density of wheat plants (plants·m^{-2})				Dry matter of wheat (g·m^{-2})			
	Years (B)				Years (B)			
	2008	2009	2010	**mean**	2008	2009	2010	**mean**
Kobra Plus	271	214	116	**200**	684	713	657	**685**
Bogatka	238	223	102	**188**	738	610	651	**666**
Smuga	291	242	156	**230**	817	860	848	**842**
Tonacja	246	219	115	**193**	715	809	590	**705**
Ostka Strzelecka	253	239	122	**205**	707	893	536	**712**
Spelt	234	192	123	**183**	746	976	680	**801**
Mean	**256**	**222**	**122**	**200**	**735**	**810**	**660**	**735**
HSD (α=0.05) for:	A – 42.1, B – 24.2, interaction AB – ns*				A – 137.6, B – 79.2, interaction AB – 228.0			

* ns – non significant differences

Table 8. Selected features of canopy of winter wheat varieties cultivated in organic system

Competitiveness against weeds is one of the criteria of variety selection for the organic farming system [7, 13]. The varieties with a rapid growth rate at the initial growth stages, the biggest height, tillering, the most horizontal (planophile) set of leaves to the soil surface, combined with a low susceptibility to the disease, which prolongs the duration of the foliage, have the highest competitive abilities [2, 8]. These features affects the ability of shading the soil surface, and thus photosynthetically active radiation penetrates into the canopy, which directly influences the growth of weeds. Some authors suggest that the height of the plants is the main reason for the differences in competitiveness against weeds [17, 23, 24], but others believe that this factor has a marginal significance [25, 26]. Recent research on wheat and barley varieties showed that the differences between plant density influence the competitive ability more than do plant height and light penetration in the canopy [27]. Furthermore, some authors suggest that differences between varieties arise from their different allelopathic properties [10, 16]. Moreover, weed infestation suppressing ability of varieties vary because of their combined allelopathic and competitive abilities [28]. Those authors indicates that both the allelopathic potential and the competitiveness connected with morphological characteristics of variety are quantitative factors of complex inheritance which are also dependent on environmental conditions.

The relationship between weed infestation and grain yield of winter wheat varieties was analyzed (Figure 3-5). In 2008 the dry matter of weeds was low, less than 50 g m^{-2} and it probably had no significant effect on grain yield of wheat cultivars. Due to favorable weather conditions of that year grain yields were high, from 3.8 t ha^{-1} of hulled grain of spelt to 6.2 t ha^{-1} in Bogatka and Kobra Plus. At low weed pressure, Kobra Plus and Bogatka gave the highest yield, but when the weed infestation was high, 180 g m^{-2} and more, as in 2009 and 2010, the grain yield was low (Figure 4-5). At the weed infestation of 100-110 g m^{-2} spelt Schwabenkorn and Smuga gave high yields, about 4 t ha^{-1} (Figure 4). In 2010, due to poor winter survival of varieties and unsuitable weather conditions, the yields of all varieties were low (Figure 5). Analysis showed that with the increase in dry weight of weeds grain yields decreased. The highest grain yields and the lowest infestation was found in Smuga, whereas Ostka Strzelecka and Tonacja were the lowest yielding variety with the highest weed weight (280-290 g m^{-2}) (Figure 5).

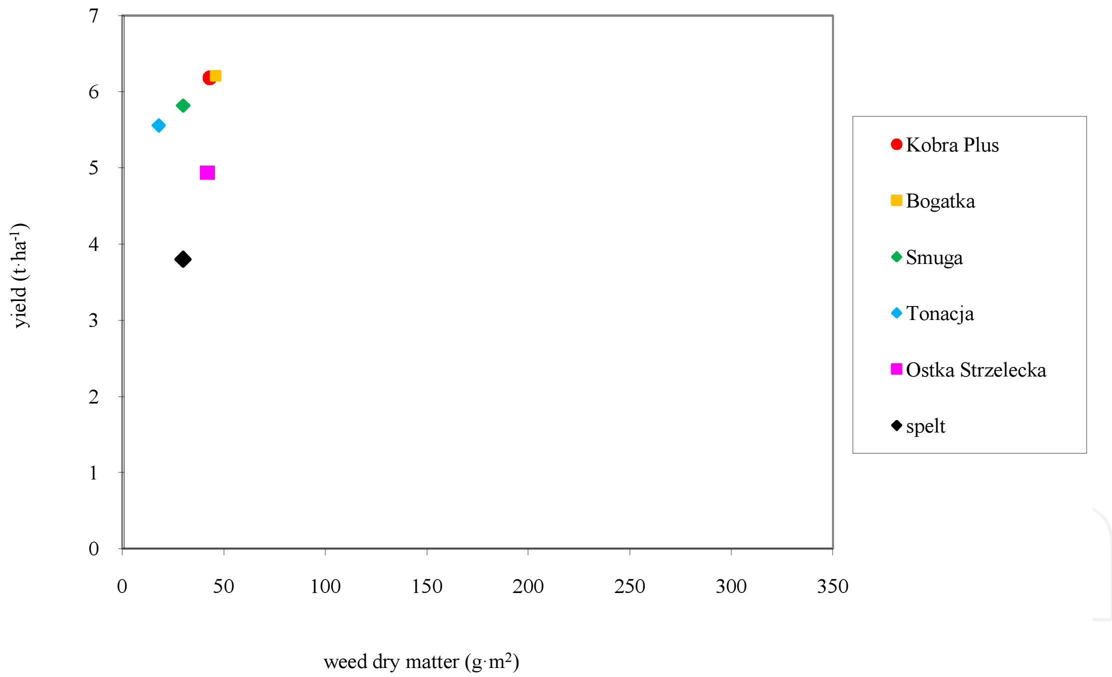


Figure 3. The dependence between weed dry matter and grain yield of winter wheat varieties cultivated in organic system at dough stage in 2008

The infection by pathogens can be as well as weed infestation the yield limiting factors in organic farming [6]. The similar effect can be produced by restricted nitrogen supply of plants [12]. The results showed that stem base disease incidence was relatively low in winter wheat varieties (approximately 10%) (Table 9). Comparison of sanitary conditions of winter wheat growth under conventional vs. organic system indicate that crop rotation applied in organic

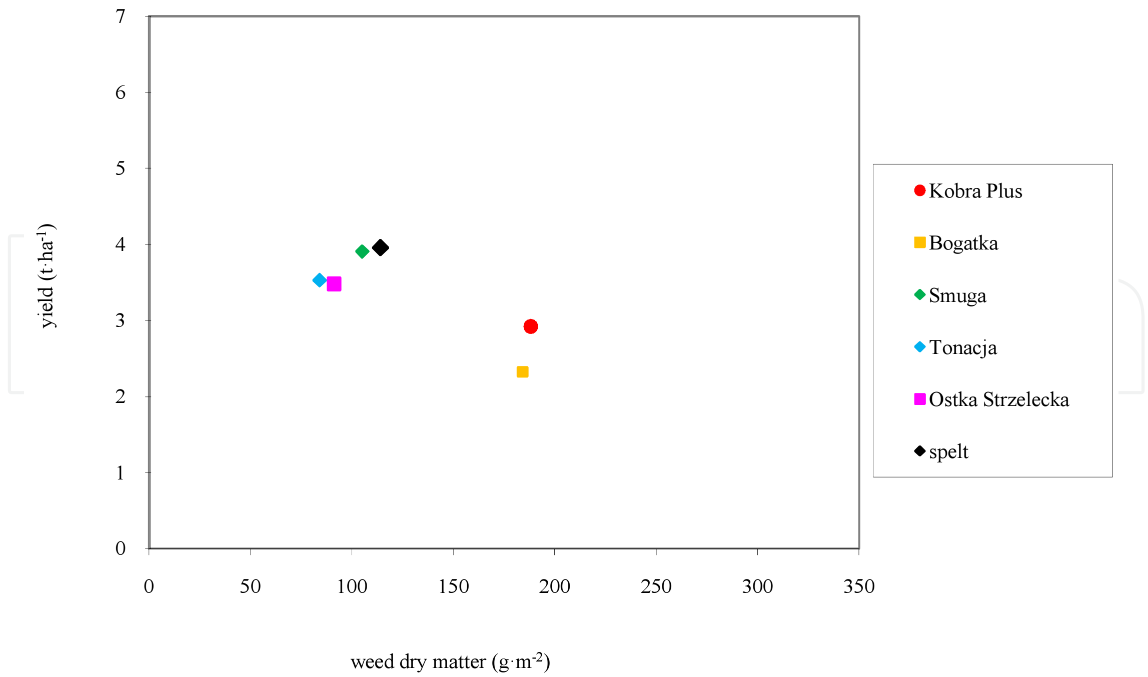


Figure 4. The dependence between weed dry matter and grain yield of winter wheat varieties cultivated in organic system in dough stage in 2009

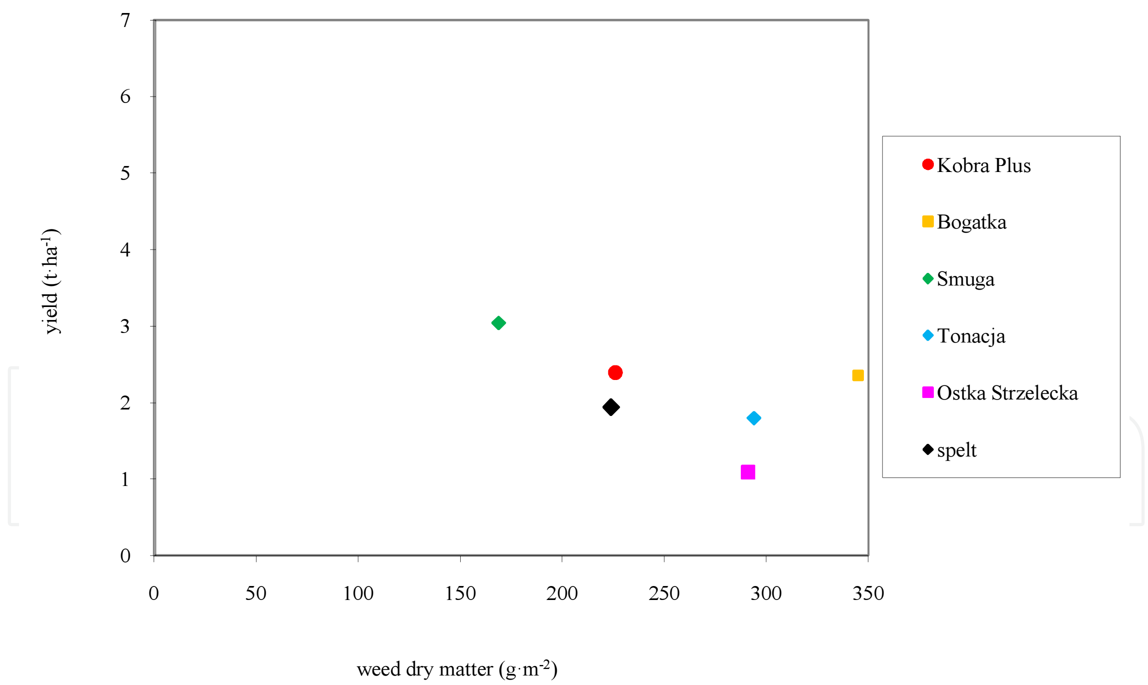


Figure 5. The dependence between weed dry matter and grain yield of winter wheat varieties cultivated in organic system at dough stage in 2010

farming system effectively limited stem base disease development. Incidence of stem base disease observed at milk-dough stage of winter wheat was twice lower in organic than in conventional farming system, although in conventional system with simplified crop rotation fungicides were used. On the other hand, incidence of leaf diseases was approximately four times higher in organic farming system than in conventional one (Table 9).

The rate of infection by fungal stem base and leaf diseases differed from variety to variety (Table 9). Cvs. Tonacja and Ostka Strzelecka had the lowest rate of stem base disease infection. However those varieties (as well as Smuga) had the highest rate of infection by leaf diseases. A pathogen species infecting the common wheat was also different in years. *Puccinia recodita* had the highest rate of infection in 2008, *Septoria spp.* in 2009 and in year 2010 both those pathogens infected common wheat. Cvs. Kobra Plus and Bogatka showed the lowest rate of the leaf disease infestation in organic farming system through the years. However, they were highly infected by stem base diseases (Table 9). Those varieties also revealed a high rate of fungal disease infestation in conventional farming system.

Cultivar	Stem base infection index (%)				Leaves infection index (%)*			
	2008	2009	2010	**mean**	2008	2009	2010	**mean**
organic system								
Kobra Plus	15.1	12.0	10.4	**12.5**	4.6	15.0	31.2	**16.9**
Bogatka	25.1	5.1	10.0	**13.4**	10.8	11.6	29.7	**17.4**
Smuga	18.7	10.0	5.6	**11.4**	21.2	39.7	21.4	**27.4**
Tonacja	15.8	1.1	5.3	**7.4**	21.9	22.3	31.1	**25.1**
Ostka Strzelecka	14.2	1.8	6.3	**7.4**	20.2	30.3	28.8	**26.4**
spelt	11.1	8.2	8.3	**9.2**	18.9	27.3	22.7	**23.0**
mean	**16.7**	**6.4**	**7.7**	**10.2**	**16.3**	**24.4**	**27.5**	**22.7**
conventional system								
Kobra Plus	42.8	2.6	23.7	**23.0**	1.6	10.9	18.9	**10.4**
Bogatka	45.2	3.4	32.2	**26.9**	0.8	11.1	5.2	**5.7**
Rywalka	34.4	0.5	18.6	**17.8**	0.4	5.0	0.5	**2.0**
Legenda	16.4	3.0	20.2	**13.2**	0.3	10.1	0.5	**3.6**
mean	**34.7**	**2.4**	**23.7**	**20.3**	**0.8**	**9.3**	**6.3**	**5.4**

*The area (%) of flag and underflag leaf infested by pathogens

Table 9. The infestation of stem base and leaves of winter wheat by pathogens in milk-dough stage in organic and conventional farming system

Higher leaf infestation by fungal pathogens in organic farming system, as well as nitrogen deficiency during shaping of grains, negatively influenced nitrogen availability and decreased total protein content of the grain (Table 10). Varieties listed in the regional allocation of crops contained an average of 12.6% protein, although protein content in highly fertilized conventional farming was on average 2.1% higher. Differences in the total protein content between varieties were insignificant, both in organic and conventional farming system. Spelt Schwabenkorn was the only exception as it had a clearly higher content of proteins (compared to modern varieties) (Table 10).

Cultivar	**Years of research and farming systems**		
	2008	2009	**mean**
organic system			
Kobra	11.2	13.6	**12.4**
Bogatka	11.4	13.6	**12.5**
Smuga	11.4	14.1	**12.8**
Tonacja	11.7	13.3	**12.5**
Ostka Strzelecka	11.7	13.9	**12.4**
Spelt	16.8	16.3	**16.6**
mean (without spelt)	**11.5**	**13.7**	**12.6**
conventional system			
Kobra	13.4	15.7	**14.6**
Bogatka	12.9	15.9	**14.4**
Rywalka	13.6	16.2	**14.9**
Legenda	14.0	15.8	**14.9**
mean	**13.5**	**15.9**	**14.7**

Table 10. The content of total protein of the grain (%) of selected winter wheat cultivars in organic and conventional farming system

Analysis of correlation was done to assess the relationships between grain yield of winter wheat in organic system and factors limiting the yield as well as morphological features and canopy parameters. This analysis showed strong, negative correlation between grain yield of winter wheat and weed dry matter at dough stage (r=-0.792) (Table 11). The grain yield was also significantly influenced by number of weeds and leaf infestation by fungal pathogens. There was no correlation between stem base diseases and grain yield of winter wheat in organic system. The tillering and height of common wheat did not have a significant impact on yields, but there was a strong correlation between grain yield and plant density. Weed infestation was significantly influenced by density of wheat, dry matter of wheat and its height. There was no significant correlation between tillering and parameters of weed infestation (Table 11).

Parameters	Grain yield	Stem base diseases	Leaves diseases	Number of weeds	Dry matter of weeds	Tillering	Height	Density of wheat	Dry matter of wheat
Grain yield	x	0.069	-0.477*	-0.463*	-0.792*	-0.205	0.124	0.716*	0.297*
Stem base diseases		x	-0.434	-0.435*	-0.412*	-0.048	0.272*	0.358*	-0.030
Leaves diseases			x	0.223	0.369*	0.195	-0.116	-0.368*	0.129
Number of weeds				x	0.494 *	-0.099	-0.407 *	-0.357 *	-0.123
Dry matter of weeds					x	0.103	-0.242 *	-0.701 *	-0.435 *
Tillering						x	0.597*	-0.366*	0.167
Height							x	0.030	0.188
Density of wheat								x	0.359*
Dry matter of wheat									x

* significant at α=0.05

Table 11. Correlation coefficients (r) between grain yield and factors limited the yield, some morphological features and canopy parameters for all tested varieties cultivated in organic system at dough stage (N=72)

The cluster analysis based on a grain yield, weed and fungal infestation, some morphological features and canopy structure at dough stage allowed to divide varieties into 3 groups with similar characteristics (Table 12).

Cluster	Grain yield (t•ha^{-1})	Leaves infestation index (%)	Number of weeds (pcs•m^{-2})	Dry matter of weeds (g•m^{-2})	Density of wheat stand (pcs•m^{-2})	Dry matter of wheat (g•m^{-2})	Varieties
1	3.69	19.8	100.1	158.5	191.6	683.2	Kobra Plus, Bogatka, Tonacja
2	3.20	24.7	74.2	132.2	193.8	756.5	Spelt Schwabenkorn, Ostka Strzelecka
3	4.26	27.4	80.5	101.3	229.7	841.3	Smuga

Table 12. The results of cluster analysis based on grain yield, factors limiting the yield, some morphological features and canopy parameters for tested varieties grown in organic system

The first cluster was characterized by the highest level of weed infestation (number and dry matter) and the smallest density of wheat plants and dry matter of wheat. This cluster was represented by 3 varieties: Kobra Plus, Bogatka, Tonacja with the lowest competitive ability

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against weeds, average level of grain yield and low leaf infestation by fungal pathogens (Table 12). The second cluster grouped 2 varieties: spelt Schwabenkorn and Ostka Strzelecka, with the lowest grain yield, small wheat density, medium level of infestation by weeds and leaf diseases. Third cluster was represented only by one variety – Smuga, which was characterized by the highest yields and the highest stand density and biomass. These parameters of Smuga's canopy influence its competitiveness against weeds and is reflected in the lowest weed infestation. If not for its highest leaves infestation index, Smuga would have been recommended variety for organic system (Table 12).

The most required features of cereal varieties cultivated in organic system are: winter hardiness, high competitive ability against weeds, tolerance of fungal diseases and ability to take up and effectively use fertilizers from soil [5-14]. Smuga, due to its winter hardiness, competitiveness ability against weeds and high yields seems to be suitable for organic farming system. A little less suitable (considering the same features) are spelt Schwabenkorn and Ostka Strzelecka. Kobra Plus, Bogatka and Tonacja were the highest yielders in years with good weather conditions, with optimal plant density and poorer weed pressure. The grain yield of these varieties was low when there was a high level of weed infestation (180 g m^{-2} and more), as in 2009 and 2010. Kobra Plus and Bogatka was also the less leaf fungal-infested varieties in organic system in the research period 2008-2010.

3.1.1. Summary

1. In organic farming system, among the tested varieties, Smuga gave the highest yields (4.26 t ha^{-1}), while Ostka Strzelecka was the lowest yielder (3.17 t ha^{-1}). Yields of spelt Schwabenkorn were approximately 13% lower than those of modern varieties (glume grain) (3,20 t ha^{-1}). Old varieties of common wheat: Ostka Kazimierska, Kujawianka Więcławicka, Wysokolitewka Sztywnosłoma were not very useful for cultivation in organic system because of low grain yield and high infestation of leaves.

2. Yields of winter wheat cultivated in conventional farming system were on average 45% higher than those produced in organic system. Research conducted in 2005-2007 on varieties: Roma, Kobra, Zyta, Sukces revealed that average yield differences between organic and conventional farming system were 19%. Lower yields in organic system, despite the same sowing rate, were caused by lower number of spikes per m^2 (25% on average) and slightly lower grains weight (15%).

3. Weed communities differed in years and between tested varieties. The lowest level of weed infestation was observed in 2008 (19-46 g m^{-2}), whereas the biggest dry matter of weeds was noted in 2010 (170-345 g m^{-2}), which was related to sparse canopies after winter. The comparison of common wheat and spelt wheat varieties showed the highest level of weed infestation in Kobra Plus, Bogatka and Tonacja canopies. The lowest number of weeds at dough stage was shown by Smuga, Ostka Strzelecka and spelt Schwabenkon. Weed infestation was significantly influenced by wheat plant density, dry matter and plant height.

4. Stem base diseases has a lower importance in organic farming system than have leaf diseases. Kobra Plus and Bogatka showed the highest resistance to leaf fungal diseases.

5. Higher infestation rates by leaf diseases and lower nitrogen supply to the crop under the organic system caused a decrease of total grain protein content compared to that under conventional system. Spelt Schwabenkorn produced grains with the highest protein content.

3.2. Estimation of spring wheat varieties suitability for cultivation in organic farming

In organic farms spring wheat is much more popular than winter wheat. The reason for that is that weed infestation in spring wheat is easier to control than in winter wheat, also fungal diseases in spring wheat are less common. Moreover, it is sown after late-harvested proceeding crops (vegetables, potatoes, fodder crops and intercrops). Spring wheat is also a valuable protective crop for undersown papilionaceous plants and grasses [29].

In organic system the yield of spring wheat, mean for 9 tested varieties, ranged from 4.7 t ha^{-1} in 2008, when the weather was favourable for plant growth, to 2.8 and 3.1 t ha^{-1} in other years (Table 13). The higher yield of spring wheat in 2008 than in the other two years of the study could be caused by higher rainfall in autumn and winter. The sum of rainfall for 6 months of 2007/2008 (X 2007 – III 2008) reached 146 mm, whereas in the subsequent years it reached approximately 220 mm (Table 2). This could cause leaking of mineral nitrogen into the deeper layers of soil resulting in an impaired nitrogen supply to plants. The effects of deficiency became especially manifest in the springtime period of rainfall shortage, when intensity of biological processes slowed down. Such weather conditions prevailed in 2009 and 2010.

Cvs. Nawra and Bryza had the lowest yields while Tybalt, Żura, Zadra and Vinjett were the highest yielders (Table 13). Among those varieties Żura showed the most stable yields (3.31 – 4.86 t ha^{-1}), whereas Tybalt's yields were the most differentiated (6.16 – 2.43 t ha^{-1}). An extremely high plant density as well as grains weight was the main reason of high wheat yields in 2008. Likewise the weed infestation in this year was very low (Table 15).

During the 3-year period of research, yields of spring wheat cultivated in organic farming system were on average lower by 1.86 t ha^{-1} (34%) than those in conventional farming system (Table 13-14). The difference in yields from organic vs conventional system across the years ranged from 30% in 2008 (high yields) to 36% in 2009 (very low yields). Yield comparison between organic and conventional system showed that Parabola's yield was the most influenced by the farming system (38%) while the yields of the other varieties differed from 32 to 33%.

A lower yields in the organic farming system was caused by lower ear density and inferior grain weight (Table 13-14). Ear density was lower on average by 16% (from 14-15% in cvs. Bombona and Vinjett to 20% in cv. Tybalt). Thousand grain weight of wheat cultivated in organic farming was also lower by 16% than that in conventional farming system. Thousand grain weight of Tybalt was reduced only by 9% while that of Parabola showed decrease by 22% (when in organic vs. conventional farming system).

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Cultivar	The yield of grain (t·ha^{-1})				Number of ears (pcs·m^{-2})				1000 grains weight (g)			
	2008	2009	2010	**mean**	2008	2009	2010	**mean**	2008	2009	2010	**mean**
Bombona	4.29	3.01	3.25	**3.52**	450	433	402	**428**	33.3	37.6	30.8	**33.9**
Bryza	4.13	2.63	2.71	**3.16**	454	363	357	**389**	34.0	38.1	32.1	**34.7**
Nawra	4.36	2.21	2.48	**3.02**	382	339	301	**341**	37.8	35.4	35.5	**36.2**
Parabola	4.31	2.69	3.21	**3.40**	385	341	277	**334**	39.3	41.2	40.9	**40.5**
Raweta	4.65	2.84	3.04	**3.51**	417	383	378	**393**	36.9	36.2	34.0	**35.7**
Tybalt	6.16	2.43	3.60	**4.06**	380	348	307	**345**	43.2	34.2	40.6	**39.3**
Vinjett	4.52	3.01	3.25	**3.59**	505	426	412	**448**	33.9	34.9	31.3	**33.4**
Zadra	4.81	3.05	3.20	**3.69**	422	392	361	**392**	32.8	35.6	31.6	**33.3**
Żura	4.86	3.31	3.40	**3.86**	385	394	360	**380**	38.8	43.3	37.7	**36.9**
mean	**4.68**	**2.80**	**3.13**	**3.54**	**420**	**380**	**351**	**383**	**36.7**	**37.4**	**34.9**	**36.0**
HSD $_{(\alpha=0.05)}$	0.21	0.24	0.29	0.43	43	61	63	54	1.3	1.7	0.9	1.3

Table 13. The yield of spring wheat and the components of yield in organic system

Cultivar	The yield of grain (t·ha^{-1})				Number of ears (pcs·m^{-2})				1000 grains weight (g)			
	2008	2009	2010	**mean**	2008	2009	2010	**mean**	2008	2009	2010	**mean**
Bombona	6.97	4.52	4.37	**5.29**	504	518	471	**498**	46.4	37.5	40.5	**41.5**
Parabola	7.40	4.07	5.06	**5.51**	370	447	398	**405**	56.9	48.2	51.1	**52.1**
Tybalt	7.75	4.37	5.67	**5.93**	512	430	421	**455**	48.9	37.3	43.5	**43.2**
Vinjett	6.71	4.34	4.77	**5.27**	550	507	513	**524**	44.4	33.8	37.2	**38.5**
mean	**7.21**	**4.33**	**4.97**	**5.50**	**484**	**476**	**451**	**470**	**49.1**	**39.2**	**43.1**	**43.8**
HSD $_{(\alpha=0.05)}$	0.52	0.18	0.53	0.64	64	54	61	37	1.6	1.0	1.9	2.1

Table 14. The yield of spring wheat and the components of yield in conventional system

Weed infestation of spring wheat in organic farming was on average 80 plants m^{-1} in 2008 and 2010 while in 2009 it was 115 plants m^{-2} (Table 15). Dry matter of weeds ranged from 7 g m^{-2} in 2008 (very successful wheat cropping) to 57 g m^{-2} in 2009 (worse stand density and uniformity due to unfavorable weather conditions). *Chenopodium album* and *Stellaria media* were the most common weed species throughout the years of the study. In 2010, weeds that are hard to control and more competitive to wheat were common (*Cirsium arvense*, *Anthemis arvensis* and *Galium aparine*).

The competitiveness against weeds of spring wheat sown with the clovers and grasses was depended on morphological features of wheat varieties, plant density and biomass of undersown crop. Whether conditions were also a major factor affecting weed infestation as they affected the emergence rate of wheat and clover-grass mixture and its further development. A dense canopy of the undersown crop in 2008 resulted in a higher competitive abilities of spring wheat which had suppressed the growth of most weeds. On the other hand, a sparse stand of wheat in 2009, despite a good development of the undersown crop, resulted in weaker competitive abilities against weeds. Weed infestation in conventional farming system, where wheat was cultivated in pure sowing and herbicides were applied, was 4 times lower than in organic system (Table 15, 16). Also the dry matter of weeds was 3.5 times lower than that in organic farming. Cv. Vinjett showed statistically the lowest dry matter of weeds, while Parabola was the most weed-infested variety (table 16).

Cultivar (A)	Number of weeds (plants·m^{-2})				Dry matter of weeds (g·m^{-2})			
	Years (B)				Years (B)			
	2008	2009	2010	**mean**	2008	2009	2010	**mean**
Bombona	68.5	82.5	80.5	**77.2**	7.7	36.0	32.3	**25.3**
Bryza	106.5	142.5	92.5	**113.8**	7.5	78.1	57.8	**47.8**
Nawra	66.5	101.5	143.0	**103.7**	9.6	38.0	31.2	**26.3**
Parabola	77.5	84.5	79.0	**80.3**	7.6	79.0	57.8	**48.1**
Raweta	92.5	102.5	70.0	**88.3**	7.4	47.2	30.3	**28.3**
Tybalt	62.5	158.0	95.5	**105.3**	7.8	75.0	50.2	**44.3**
Vinjett	103.5	139.5	57.0	**100.0**	8.3	49.0	35.6	**31.0**
Zadra	58.5	123.5	85.5	**89.2**	2.5	61.0	37.3	**33.6**
Żura	73.0	98.5	77.0	**82.8**	7.4	50.0	60.0	**39.1**
mean	**78.8**	**114.8**	**86.7**	**93.4**	**7.3**	**57.0**	**43.6**	**36.0**
HSD (α=0.05) for:	A - 33.1, B - 14.6, interaction AB - 51.8				A – ns*, B - 14.9, interaction AB - ns			

* ns – non significant differences

Table 15. Number and dry mater of weeds in spring wheat cultivated in organic system at dough stage

Cultivar (A)	Number of weeds (plants·m^{-2})				Dry matter of weeds (g·m^{-2})			
	Years (B)				Years (B)			
	2008	2009	2010	**mean**	2008	2009	2010	**mean**
Bombona	4.0	11.0	29.0	**14.7**	0.3	4.9	17.5	**7.6**
Parabola	12.5	35.0	20.5	**22.7**	2.1	34.9	26.5	**21.2**
Tybalt	13.0	32.5	47.5	**31.0**	1.3	4.4	20.9	**8.9**
Vinjett	8.5	35.5	17.0	**20.3**	1.1	5.4	7.0	**4.5**
Mean	**9.5**	**28.5**	**28.5**	**22.2**	**1.2**	**12.4**	**18.0**	**10.5**
HSD (α=0.05) for:	A – ns*, B – 18.1, interaction AB - ns				A – 16.2, B – 15.1, interaction AB - ns			

* ns – non significant differences

Table 16. Number and dry mater of weeds in spring wheat cultivated in conventional system at dough stage

The differences in weed dry matter in spring wheat cultivated in organic farming were not statistically significant (Table 15). The competitive abilities of winter wheat varieties against weeds differ more than those of spring wheat varieties [2, 3, 30]. Bombona and Raweta were the tallest varieties and they also showed the lowest rate of weed infestation and dry weight of weeds (77 and 88 plants m^{-2}, 25 and 28 g m^{-2} respectively). Cvs. Bombona, Raweta and Vinjett were also characterized by a big density of plants and number of ears per unit area which could have resulted in a limited weed growth. Bryza and Tybalt were the most weed infested varieties (105 and 114 plants m^{-2}, 44 and 48 g m^{-2} respectively). Cv. Parabola also showed a high level of weed dry matter (Table 15). Cvs. Parabola, Tybalt and Nawra were characterized by the lowest number of ears per m^2 (Table 13).

Weed infestation is one of factors that can limit the yield of spring wheat. In 2008 the level of weed infestation was so low (less than 10 g m^{-2}) that it could not have significantly affected the yields of spring wheat (Figure 6). Cv. Tybalt, which was one of the least prone to stem and leaf fungal diseases (Table 17, 18), yielded the highest (6.16 t ha^{-1}), whereas the yield of the other varieties was similar (4.13-4.86 t ha^{-1}). In 2009, lower yields were found in those varieties which were more weed-infested than others (Tybalt, Bryza, Parabola – approximately 80 g of weed dry matter per 1 m^2) (Figure 7). In 2010, weed dry matter did not exceed 60 g m^{-2} and there were no significant differences in yield between varieties which may suggest that this level of weed infestation did not affect the yields (Figure 8). This is confirmed by the research results of Kapeluszny [31] in which the decrease of wheat yield occurred when weed infestation reached 96 plants per m^2 (62 g m^{-2} of dry matter) at dough stage. It is worth noting that cv. Nawra gave the lowest yields in 2009 and 2010 despite a small weed infestation, indicating that other factors could have affected the yields of this variety (Figure 7, 8).

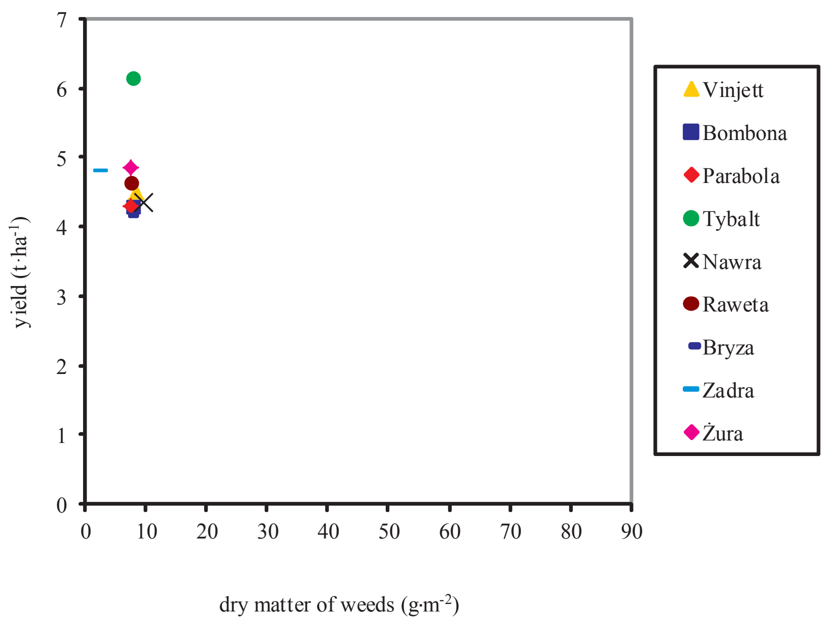

Figure 6. The dependence between weed dry matter and grain yield of spring wheat varieties cultivated in organic system in 2008

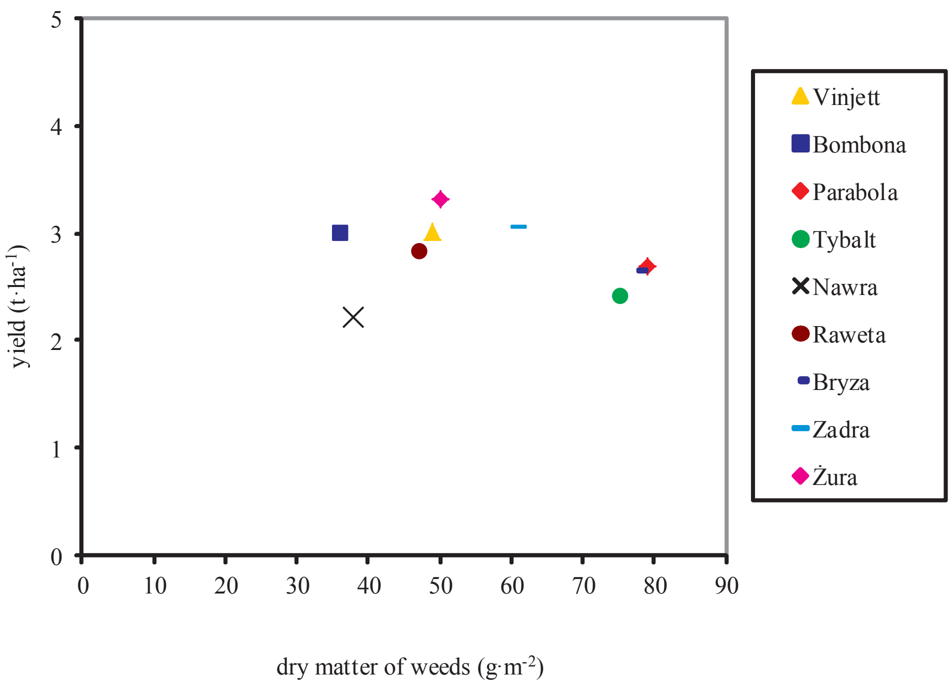

Figure 7. The dependence between weed dry matter and grain yield of spring wheat varieties cultivated in organic system in 2009

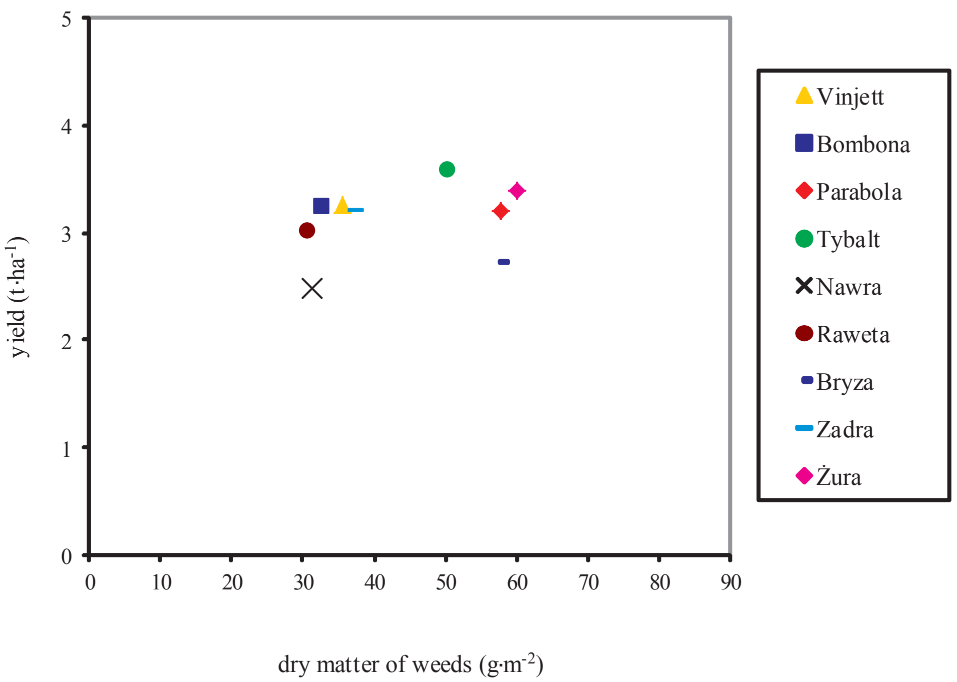

Figure 8. The dependence between weed dry matter and grain yield of spring wheat varieties cultivated in organic system in 2010

Susceptibility to diseases is one of the factors that should be taken into account when evaluating the usefulness of cereal varieties in organic farming. The intensity of stem base diseases in spring wheat was low throughout the research years (Table 17). *Fusarium* spp. pathogens were the most common. According to the literature review, diseases caused by *Fusarium* are not more often in cereals grown in the organic system than in the conventional one (this also applies to mycotoxin content) [32, 33]. Cvs. Tybalt, Nawra and Żura were slightly more resistant to those diseases while Bombona and Parabola were more susceptible.

Cultivar	**Infection index (%)**			**Mean**
	2008	**2009**	**2010**	
Bombona	5.7 ab*	8.6 b	24.8 c	**13.0 b**
Bryza	9.8 b	8.5 b	3.5 ab	**7.3 ab**
Nawra	7.7 ab	4.7 ab	1.5 a	**4.6 a**
Parabola	7.7 ab	3.2 ab	23.4 c	**11.4 b**
Raweta	3.2 a	3.8 ab	13.2 bc	**6.7 a**
Tybalt	3.8 a	2.4 a	6.7 ab	**4.3 a**
Vinjett	4.9 ab	4.1 ab	14.7 bc	**7.9 ab**
Zadra	7.4 ab	8.0 b	9.3 b	**8.2 ab**
Żura	7.4 ab	4.3 ab	4.0 ab	**5.2 a**
mean	**6.4**	**5.3**	**11.2**	**7.6**

* data marked with the same letters do not differ significantly at α=0.05

Table 17. The infestation index (%) of roots and stem base of spring wheat in organic system at milk-dough stage

The damage of flag and underflag leaves by fungal pathogens was different among varieties and years, but in no case it was significant (Table 18). Cv. Tybalt showed the lowest (almost none) damage rate to its flag leaves at milk-dough stage, and its underflag leaves were just a little more damaged in 2009. On the other hand, Cv. Parabola was the most susceptible to fungal damage. With increasing fungal leaf diseases, the thousand grain weight decreased (Table 13). Incidence of fungal diseases in conventional farming system, due to the use of fungicides, was low. The thousand grain weight of conventionally cultivated wheat was higher by 14 to 31% than that of organic farming for cv. Parabola, and from 7 to 12% for cv. Tybalt.

Spring wheat was infested by different species of pathogens in different years. In 2008, *Puccinia recodita* was the most frequent disease. In that year, cvs. Żura and Zadra were also strongly infected with *Erysiphe graminis.* In 2009, there was no dominant pathogen species. Vinjett and Żura were infected with *Sepptoria* spp. and *Dreschlera tritici-repentis*, Bombona, Bryza and Zadra with *Puccinia recodita* and *Erysiphe graminis* while in Parabola all pathogen species

Cultivar	Flag leaf				Underflag leaf			
	2008	2009	2010	**mean**	2008	2009	2010	**mean**
Bombona	20.3	10.3	11.1	**13.9**	9.3	8.4	8.9	**8.9**
Bryza	14.8	11.8	11.7	**12.8**	8.0	3.6	4.6	**5.4**
Nawra	13.2	7.9	21.2	**14.1**	8.8	3.7	16.2	**9.6**
Parabola	25.2	13.8	27.3	**22.1**	17.4	3.3	7.9	**11.2**
Raweta	14.5	4.0	5.3	**7.9**	8.4	0.3	4.5	**4.4**
Tybalt	1.3	7.5	1.2	**3.3**	0	0.8	1.2	**0.7**
Vinjett	15.7	14.6	8.2	**12.8**	6.6	1.7	7.1	**5.1**
Zadra	16.5	12.1	12.1	**13.6**	7.3	2.6	5.9	**5.3**
Żura	26.5	13.1	15.6	**18.4**	14.1	2.2	10.9	**9.0**
mean	**16.4**	**10.7**	**12.6**	**12.7**	**8.9**	**3.1**	**7.5**	**6.5**

Table 18. The area (%) of flag leaf and underflag leaf infested by pathogens in milk-dough stage in organic system

occurred with similar intensity. *Puccinia recodita* and *Sepptoria* spp were the most common pathogens in 2010 in all varieties.

These small damage of flag and underflag leaves of spring wheat was due to favorable weather conditions. The sum of rainfall in June and July was generally lower than in the long-term average, while the average temperatures were significantly higher than in the long-term average (Table 12). Such pattern of weather conditions is not conductive to fungal diseases.

The analysis of correlation showed negative correlation between grain yield of spring wheat and weed infestation parameters at dough stage (Table 19). This correlation was weaker than that observed for winter wheat (Table 11). There was no significant correlation between grain yield and stem and leaf infestation by fungal pathogens (Table 19). Significant correlations between weed infestation and infection by fungal diseases were determined.

The cluster analysis based on grain yield, fungal infestation, weed abundance at dough stage allowed the division of varieties into 3 groups with similar characteristics (table 20).

The first cluster, represented by Bombona and Parabola, was characterized by the lowest yield, the highest infestation by fungal pathogens and an average level of weed abundance. In the second cluster, there were 6 varieties, characterized by high stand density and high number of ears per unit area, the lowest dry matter of weeds, an average infestation rate by fungal diseases and average yields. Cv. Tybalt was the only variety in the third cluster with the highest values for yield, tolerance of fungal diseases and weed infestation.

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Parameters	Grain yield ($t•ha^{-1}$)	Density of ears ($pcs•m^{-2}$)	Roots and stem base infestation index (%)	Leaves infestation index (%)	Number of weeds ($pcs•m^{-2}$)	Dry matter of weeds ($g•m^{-2}$)
Grain yield ($t•ha^{-1}$)	x	0.379*	-0.108	-0.007	-0.385*	-0.558*
Density of ears ($pcs•m^{-2}$)		x	-0.055	0.062	-0.058	-0.310*
Roots and stem base infestation index (%)			x	0.166	-0.253*	-0.018
Leaves infestation index (%)				x	-0.127	-0.267*
Number of weeds ($pcs•m^{-2}$)					x	0.404*
Dry matter of weeds ($g•m^{-2}$)						x

* significant at α=0.05

Table 19. Correlation coefficients (r) between grain yield and factors limiting the yield for all tested varieties grown in organic system (N=108)

Cluster	Grain yield ($t•ha^{-1}$)	Density of ears ($pcs•m^{-2}$)	Roots and stem base infestation index (%)	Leaves infestation index (%)	Number of weeds ($pcs•m^{-2}$)	Dry matter of weeds ($g•m^{-2}$)	Cultivars
1	3.46	381.0	12.2	27.2	78.8	36.6	Bombona, Parabola
2	3.53	390.3	6.7	19.7	95.8	34.3	Bryza, Nawra, Raweta, Vinjett, Zadra, Żura
3	4.06	345.0	4.3	4.0	105.3	44.3	Tybalt

Table 20. The results of cluster analysis based on grain yield and factors limiting the yield for tested varieties of spring wheat cultivated in organic system

The results obtained in the study does not give a clear assessment of suitability of the tested varieties to organic farming. As judged by the crop yields, cvs. Bryza and Nawra do not seem to be the best choice for the organic farming system (although they were as resistant to fungal diseases as the others). However, cv. Bryza showed lower competitive abilities against weeds that other varieties did. Also cv. Parabola, due to the higher infestation by weeds and diseases as well as because of small weight of grains (as compared to conventional system) is less suitable for organic farming system. On the other hand, cv. Tybalt should be preferred in the organic farming system due to its resistant to fungal leaf and stem diseases. Unfortunately, yields of cv. Tybalt were highly variable over the study years. It can also be assumed (although this was not investigated), that in the 3-year research period, availability of nitrogen and its uptake, besides weeds and disease infestation, had a strong influence on the yields of spring wheat varieties [12].

3.2.1. Summary

1. Among the nine compared varieties, cvs. Tybalt and Żura produced the highest yields, while cvs. Bryza and Nawra yielded the lowest.
2. Crop yields were on average 34% lower in the organic system than in the conventional one. The differences were from 32% (cvs. Tybalt and Vinjett) to 38% (cv. Parabola). Lower yields in organic farming system were caused by lower ear density and thousand grain weight (both showing a reduction of approximately 16%).
3. The weed infestation of spring wheat was strongly limited by undersown crops (clover-grass mixture). The dry matter of weeds averaged 36 g m^{-2} over the research years (from 7 to 57 g m^{-2}). The lowest dry matter of weeds was observed in Bombona, Raweta, Nawra and Vinjett which had a bigger density of canopy.
4. In the 3-year period a minor incidence of stem base and leaf diseases was observed due to an appropriate crop rotation (stem base diseases) and favourable weather conditions in June and July (fungal leaf diseases). Cv. Parabola was more susceptible, while cv. Tybalt was more resistant to those diseases than the other varieties.

4. Conclusions

The yielding of cereals in organic system was lower than in conventional system. In case of winter wheat, the yield was on average 45% smaller in organic system than in conventional one. This low yield of winter wheat in organic system in years of research was mostly connected with unfavorable weather conditions in growing season 2009/2010. Winter wheat cultivars selected for organic farming should be characterized by high winter hardiness, because in this farming system is difficult to compensate for the effects of adverse weather conditions. Cereal canopy with a smaller plant density after winter is more susceptible to weed infestation. Earlier studies conducted on another set of winter wheat varieties (Roma, Kobra, Zyta, Sukces) showed a difference in the yields between organic and conventional systems by 19%. The difference in cereal yields in organic vs. conventional systems are due to lower density of ears, weed infestation, leaves diseases and nutrients deficiency [6, 9, 11, 12, 14, 20].

Tested varieties were differed in their yielding and competitiveness against weeds as well as resistance to fungal diseases. Smuga variety gave the highest yield whereas Ostka Strzelecka and spelt Schwabenkorn the lowest one. In case of spring wheat, 34% less grain yield on average was obtained in organic system than in conventional one. Among compared varieties of spring wheat cultivated in organic system, cvs. Tybalt and Żura, were characterized by the highest yield, while Bryza and Nawra had the smallest yield.

Analysis of correlation showed that grain yield of winter wheat and spring wheat was affected by number and dry matter of weeds. These relations were stronger for winter wheat varieties than for spring wheat varieties. Grain yield of winter wheat was also influenced by leaves infestation by fungal pathogens. There was no correlation between grain yield of winter and spring wheat in organic system and stem base diseases in the research period 2008-2010.

In the organic system weed infestation in cereals is generally greater than in the more intensive crop production systems where herbicides are used [34, 35]. However, the application of agricultural practices according to Good Agricultural Practices, proper crop rotation, delaying sowing time, increasing the amount of seed, maintaining good soil structure, with a high content of organic matter allows to keep the weeds at a level not causing a significant yield decrease [22, 36]. The results show high efficacy of weed control in spring wheat in the organic system by the interaction of 5-year crop rotation, successful undersown clover with grasses and dense canopy of wheat with large ability to compete with weeds. The effectiveness of mixed crops of cereals with legumes in reducing weed confirms the results of other authors [36, 37].

The competitive ability against weeds of winter and spring wheat varieties differed due to canopy parameters and morphological features. The level of weed infestation was influenced by parameters of wheat canopy: density and dry matter of wheat, as well as the height. Among modern varieties there are some with high competitive potential against weeds, for example cv. Smuga, which also has a greater yielding potential than old varieties. The competitive ability of spelt with weeds depends on the variety and habitat conditions [38]. Among spring wheat varieties the greatest suppressive ability against weeds were cvs. Bombona and Raweta.

In organic system stem base diseases were unimportant, contrary to leaves diseases. The dominant pathogens were: *Puccinia recondita* and *Septoria* spp. In case of spring wheat, greater susceptibility to fungal pathogens characterized cv. Parabola, while a smaller – cv. Tybalt. Among winter wheat varieties Kobra and Bogatka were the most resistant to fungal diseases leaves in organic farming conditions.

The old varieties of winter wheat: Ostka Kazimierska, Kujawianka Więcławicka, Wysokolitewka Sztywnosłoma had big potential to weed suppress, but were not very useful for cultivation in organic system, because they yielded 36% lower compare to modern varieties and were also strongly damaged by stem and leaf fungal diseases [20].

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