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JOURNAL OF PLANT PROTECTION RESEARCH Vol. 55, No. 3 (2015)

DOI: 10.1515/jppr-2015-0036

Differences between organically grown varieties of spring wheat, in response to weed competition and yield

Beata Feledyn-Szewczyk, Krzysztof Jończyk*

Institute of Soil Science and Plant Cultivation-State Research Institute, Department of Systems and Economics of Crop Production, Czartoryskich 8, 24-100 Puławy, Poland

Received: February 17, 2015
Accepted: June 9, 2015

Abstract: When growing wheat, one of the non-chemical methods of weed regulation is to choose wheat varieties which have a high ability to compete with weeds. The first aim of the research was the estimation of the relationships between the morphological features and canopy parameters of six spring wheat varieties. The second aim was the estimation of the varieties' competitive ability against weeds. The third aim was the estimation of the grain yield of the six varieties. The experiment was carried out in the 2011–2013 time period, on fields which had been organically managed since 1994. Different features affected the weed infestation levels of the spring wheat varieties. For Bombona, negative correlations between the number of weeds and the height, dry matter of wheat, and wheat density, were proved. For Brawura, Hewilla, and Żura, the height, number of tillers, and dry matter of wheat were the main factors influencing weed abundance. A strong negative correlation between the number of weeds and the dry matter of wheat was found for Parabola. Cluster analysis indicated that Bombona and Brawura were the most competitive against weeds, while Monsun and Parabola were characterized as being the least competitive against weeds. Weed number significantly affected the grain yield of spring wheat (r = –0.418). The grain yield was positively correlated with the number of tillers (r = 0.459) and ears (r = 0.355), and the height (r = 0.534) and wheat dry matter (r = 0.411). Bombona and Brawura were the lowest yielding varieties (3.03 and 3.20 t · ha^{-1}, respectively), whereas the highest yield was achieved by Żura (3.82 t · ha^{-1}, on average).

Key words: competitive ability, organic agriculture, spring wheat varieties, weeds, yield

Introduction

Sustainable agriculture tends to reduce the herbicide input and tends to combine the herbicides with other non-chemical methods to minimalise the negative effects on food and the environment. Strongly competitive wheat crops that have a high tolerance to weed pressure and maintain high yields in the presence of weeds, are a low-cost option for weed management in organic agriculture and can reduce the dependence on herbicides in low-input systems (Lemerle *et al.* 2006). The lack of information on the relative performance of cereal crops and their modern varieties, under organic conditions, is a limitation for farmers (Tamm *et al.* 2009).

Cereal varieties for organic agriculture should be characterised with efficient nutrient uptake and use, and weed competition (Wolfe *et al.* 2008). Morphological traits associated with wheat competitiveness are tiller number, height, and early vigour, but not one set of characteristics makes wheat plants competitive in all situations (Christensen 1995; Seavers and Wright 1999; Lemerle *et al.* 2006; Watson *et al.* 2006). The competitive ability of wheat could be improved by choosing from available varieties or by breeding for competitiveness. It was reported that taller older varieties were more tolerant against weeds by maintaining a yield level in weedy environments (Cosser *et al.* 1997; Lemerle *et al.* 2001; Didon 2002; Bertholdsson 2005).

The selection of varieties suited to organic agriculture requires a different approach to that used in a conventional high input system (Hoad *et al.* 2008; Wolfe *et al.* 2008). In a study of a large number of German variety trials under high-input, low-input, and organic growing conditions, substantial differences in the ranking of the varieties were found (Wolfe *et al.* 2008). In a Danish study of genotype-environment interactions for grain yield of 72 spring barley varieties under conventional and organic farming systems, the choice of variety was found to be as important a factor for grain yield as other factors in the management (Østergård *et al.* 2006).

The objective of the study was to identify the varietal traits that confer competitiveness and yielding of spring wheat under herbicide-free conditions.

Materials and Methods

Site characteristics and experimental design

The study was conducted from 2011 to 2013 in the Experimental Station of the Institute of Soil Science and Plant Cultivation – State Research Institute at Osiny, Poland.

*Corresponding address:
bszewczyk@iung.pulawy.pl

Osiny is in the south-eastern part of Poland (N: 51°28′, E: 22°04′). The study was conducted on fields which had been organic since 1994. The experiment was on Luvisol (IUSS Working Group WRB 2006), which had a texture of loamy sand characterised by a slightly acid reaction (pH_{KCl} 5.6). The average phosphorus content was 43.6 mg P · kg^{-1}. The potassium level was low (63.1 mg K · kg^{-1}), and the humus content was 1.6%. The annual total precipitation was 586 mm, with a mean air temperature of 7.5°C (data from the 1950–2010 time period, Agrometeorological Station, Puławy). In the period between sowing and harvest, i.e. April–July, the amount of precipitation reached 252 mm. The mean air temperature was 14,2°C.

Spring wheat was cultivated in a 5-field crop rotation: potato, spring wheat with undersown clover and grass, first year and second year clover and grass, winter wheat and catch crop. Within a one hectare field of spring wheat, a one-factor experiment with different varieties was established, in completely randomised blocks. There were four replications for each variety. The six modern spring wheat varieties used in the study are included in the Common Catalogue of Varieties of Agricultural Plant Species (European Union 2010). The varieties differed in their morphological features. The six varieties which were compared were: Bombona, Brawura, Hewilla, Monsun, Parabola, and Żura. The sowing rates were the same for each variety: 4,5 mln · ha^{-1} of grains. Pre-sowing treatments were performed in accordance with good agricultural practice. Sowing was done at the optimum time for the region (the first decade of April). According to organic agriculture rules, synthetic mineral fertilisers and other agrochemicals were not used. Undersown clover and grass were the factors used for increasing the competitiveness of the spring wheat against weeds.

Sampling and analysis

Weed infestation was evaluated at the dough stage of spring wheat. The botanical-gravimetric method was used (BBCH 85-87) (Zadoks 1974). According to this method, species composition, number of weeds, and their dry matter, were assessed in a 1 × 0.5 m framed area. This area was determined at random, in four replications for each variety.

Selected morphological features and canopy parameters were analysed during the dough stage of spring wheat. The height and number of tillers were measured for 30 wheat plants, in four replications for each variety. Wheat plant density, ear density, and total above ground biomass of wheat were determined from the same area where there were weeds. The results of the weed and crop parameters were calculated as the mean per 1 m^2. The dry matter of the wheat and weeds was determined after drying at 40°C per 7 days. The grain yield of spring wheat varieties was evaluated in four replications, after harvest, at 15% moisture content.

Statistical analysis

One-factor analysis of variation for a completely randomised model was used, where the varieties were the treatments of experiment. The significance of differences between means was verified by LSD test at p = 0.05. To estimate how the features of spring wheat varieties influence the parameters of infestation, Pearson's correlation coefficients between number of weeds and their dry matter, the morphological features, and canopy parameters for the tested varieties, were assessed. Cluster analysis using the furthest neighbour method was done to divide the samples into groups with similar characteristics. Calculations were performed using Statgraphic Plus version 2.1 (Statgraphics 1996).

Results

The number of weeds in the spring wheat canopies did not differ significantly between varieties, but differences were found in the dry matter of weeds (Table 1). Monsun and Parabola were the most weedy varieties (59 and 55 g · m^{-2} of weed dry matter, on average) and Bombona and Brawura were the most competitive against weeds (30 and 34 g · m^{-2}).

There were no significant differences between varieties as far as the composition of weed species was concerned. The number of species in weed communities in the 2011–2013 time period, ranged from 28 in Hewilla to 35 in the Monsun canopy. As for the infestation of all the varieties, short-lived species dominated (88% of total weed number). These weeds were mainly dicotyledonous, such as *Chenopodium album* L., *Stellaria media* (L.) Vill. and *Viola arvensis* Murray. Perennial species (12% of the total weed number) were predominated by *Plantago major* L.

Spring wheat varieties differed in some morphological features and canopy structure. Bombona, Brawura, and Hewilla were characterised by the biggest number of tillers per plant, whereas Parabola was characterised by the smallest overall tillering (Table 1). Hewilla and Brawura were the tallest varieties (89 and 88 cm, respectively) and they differed significantly from Monsun and Parabola (77 and 81 cm). Brawura and Bombona were also characterised by the highest plant density and dry matter of above ground parts, whereas Monsun was characterised with the lowest values of these traits. The Bombona and Brawura canopies had the highest number of ears, whereas the Parabola canopy had the lowest number. Generally, the most features enhancing competitiveness against weeds were recorded for Bombona and Brawura which also had the lowest level of weed dry matter. At the same time, Monsun and Parabola were characterised by the highest level of weed infestation which suggests the lowest competitive potential against weeds. The grain yield was significantly the highest for the Żura variety (3.82 t · ha^{-1}, on average) and the lowest for Bombona (3.03 t · ha^{-1}, on average).

The analyses of correlation showed that different features of spring wheat varieties influenced the level of weed infestation (Tables 2–4). For the Bombona variety, there were negative but not statistically significant correlations between the height, dry matter of wheat, wheat density, and number of weeds (r = –0.498, r = –0.474, r = –0.415, respectively) (Table 2). Only a weak correlation between the dry matter of weeds and wheat density

Table 1. Weed infestation, selected morphological features, and canopy parameters of spring wheat varieties in an organic system, at the dough stage (the mean is from the 2011–2013 time period) (N = 72)

Varieties	Parameters[a]							
	NW	DMW	NT	H	WD	WDM	NE	GY
Bombona	74.8 a	30.1 a	1.43 b	83.5 bc	239.3 ab	674.7 a	384.0 b	3.03 a
Brawura	84.8 a	34.4 a	1.45 b	87.5 c	241.7 b	859.9 b	398.5 b	3.20 ab
Hewilla	78.7 a	37.1 ab	1.45 b	89.1 c	226.0 ab	779.7 ab	380.7 ab	3.48 ab
Monsun	92.5 a	59.3 c	1.31 ab	76.8 a	211.0 a	654.3 a	352.7 ab	3.43 ab
Parabola	97.2 a	54.9 bc	1.24 a	80.9 ab	222.3 ab	712.5 ab	329.2 a	3.55 ab
Żura	74.2 a	45.8 abc	1.39 ab	84.1 bc	222.7 ab	710.3 ab	378.2 ab	3.82 b
The mean	83.7	43.6	1.38	83.7	227.2	731.9	370.6	3.42

[a]NW = number of weeds (plants · m^{-2}); DMW = dry matter of weeds (g · m^{-2}); NT = number of tillers per plant; H = height (cm); WD = wheat density (plants · m^{-2}); WDM = wheat dry matter (g · m^{-2}); NE = number of ears (ears · m^{-2}), GY = grain yield (t · ha^{-1})

Table 2. Correlation coefficients (*r*) between weed infestation parameters and morphological features for Bombona and Brawura (N = 12)

	Parameters[a]	Bombona							
		NW	DMW	NT	H	WD	WDM	NE	GY
Brawura	NW	x	0.204	–0.246	–0.498	–0.415	–0.474	–0.095	–0.532
	DMW	0.147	x	0.544	0.362	–0.314	0.071	0.413	0.065
	NT	–0.514	–0.008	x	0.602*	–0.178	0.248	0.169	0.404
	H	–0.507	0.076	0.908*	x	–0.065	0.415	0.109	0.555
	WD	0.358	0.638*	–0.440	–0.445	x	0.008	–0.149	0.364
	WDM	–0.334	0.454	0.420	0.530	0.193	x	0.250	0.270
	NE	–0.088	0.371	0.326	0.496	–0.016	0.810*	x	0.154
	GY	–0.591*	0.208	0.683*	0.653*	–0.329	0.417	0.278	x

[a]as defined under table 1; *significant correlation p-value < 0.05

Table 3. Correlation coefficients (*r*) between weed infestation parameters and morphological features for Hewilla and Monsun (N = 12)

	Parameters[a]	Hewilla							
		NW	DMW	NT	H	WD	WDM	NE	GY
Monsun	NW	x	–0.191	–0.406	–0.548	–0.193	–0.571	–0.491	–0.561
	DMW	0.294	x	0.054	–0.106	–0.534	–0.139	–0.059	–0.161
	NT	–0.330	0.146	x	0.513	0.038	0.656*	0.555	0.771*
	H	–0.269	0.066	0.849*	x	0.256	0.671*	0.734*	0.831*
	WD	–0.460	–0.278	–0.010	–0.010	x	0.370	0.379	0.187
	WDM	–0.416	–0.011	0.502	0.326	0.485	x	0.908*	0.817*
	NE	–0.414	–0.023	0.552	0.713*	0.522	0.714*	x	0.810*
	GY	–0.281	–0.305	0.647*	0.661*	–0.212	0.376	0.338	x

[a]as defined under table 1; *significant correlation p-value < 0.05

Table 4. Correlation coefficients (*r*) between weed infestation parameters and morphological features for Parabola and Żura (N = 12)

	Parameters[a]	Parabola							
		NW	DMW	NT	H	WD	WDM	NE	GY
Żura	NW	x	0.356	–0.283	–0.514	–0.418	–0.631*	–0.328	–0.342
	DMW	–0.029	x	0.046	0.164	0.031	0.208	–0.002	–0.032
	NT	–0.563	0.159	x	0.404	–0.236	0.655*	0.163	0.436
	H	–0.654*	0.096	0.837*	x	0.276	0.652*	0.560	0.649*
	WD	–0.342	0.053	0.199	0.206	x	0.469	0.454	–0.226
	WDM	–0.608*	0.296	0.907*	0.751*	0.297	x	0.614*	0.204
	NE	–0.555	0.392	0.530	0.576	0.456	0.688*	x	0.002
	GY	–0.587*	–0.462	0.407	0.529	0.194	0.369	0.559	x

[a]as defined under table 1; *significant correlation p-value < 0.05

(*r* = –0.314) was established. For Brawura, the weed number was influenced by overall tillering (*r* = –0.514), the height (*r* = –0.507), and the dry matter of wheat (*r* = –0.334). There was no negative correlation between weed dry matter and crop performance.

For the Hewilla variety, the study showed a negative correlation between the number of weeds and the dry matter of wheat, the height, and the number of tillers (*r* = –0.571, *r* = –0.548, *r* = –0.406, respectively) (Table 3). Moreover, a negative correlation between the dry matter of weeds and wheat density was determined (*r* = –0.534). In the Monsun canopy, the number of weeds was affected by all the tested crop parameters, the strongest by wheat plant and ear density, and the dry matter of wheat.

In the case of Parabola, a strong negative correlation between number of weeds and the dry matter of wheat (*r* = –0.631*) was proved (Table 4). Weed abundance was weakly influenced by the other tested parameters of spring wheat. The main factors influencing the weed number in the Żura variety were the height, the dry matter of wheat, and the number of tillers. For all spring wheat varieties, the number of weeds was negatively correlated with the grain yield (Tables 2–4).

The analysis of correlation for all the varieties together showed that height (*r* = –0.453*), the dry matter of wheat (*r* = –0.455*), number of tillers (*r* = –0.389*) and ears (*r* = –0.336*) had the greatest impact on the weed number in spring wheat (Table 5). There was no correlation between the dry matter of weeds and the tested morphological features as well as the canopy parameters of crop. Weed number significantly affected the grain yield of spring wheat (*r* = –0.418*). The yield was positively correlated with the number of tillers (*r* = 0.459*) and ears (*r* = 0.355*), the height (*r* = 0.534*), and the wheat dry matter (*r* = 0.411*).

Cluster analysis created three groups of varieties with similar estimations of characteristics (Table 6). The first cluster grouped Bombona and Brawura varieties which were characterised by the highest values of features enhancing the competitiveness: the biggest tillering, wheat dry matter and density, ear number, and at the same time the highest suppressive abilities against weeds, and the lowest grain yield. The highest yielding varieties: Żura and Hewilla belonged to the second cluster. They were additionally characterised by the smallest weed number, and medium weed dry matter level as well as the longest stems and medium values of other morphological and canopy parameters. The third cluster grouped two varieties: Monsun and Parabola with the least competitive ability against weeds, confirmed by the highest weed abundance and dry matter. These two varieties had features that did not promote their competitiveness, such as the smallest tillering, the height, plant and ear density per unit area, dry matter of wheat, while at the same time – yielding at a medium level.

Table 5. Correlation coefficients (*r*) between the number and dry matter of weeds and some morphological features for all the tested varieties of spring wheat at the dough stage (N = 72)

Parameters[a]	NW	DMW	NT	H	WD	WDM	NE	GY
NW	x	0.212	–0.389*	–0.453*	–0.224	–0.455*	–0.336*	–0.418*
DMW		x	0.029	–0.086	–0.203	0.039	0.001	–0.060
NT			x	0.679*	–0.055	0.572*	0.463*	0.459*
H				x	0.115	0.619*	0.584*	0.534*
WD					x	0.291*	0.261*	–0.060
WDM						x	0.683*	0.411*
NE							x	0.355*
GY								x

[a]as defined under table 1
*significant correlation p-value < 0.05

Table 6. The results of cluster analysis based on the parameters of weed infestation, morphological features, and canopy parameters for the tested varieties (N = 72)

Cluster	Parameters[a]								Varieties
	NW	DMW	NT	H	WD	WDM	NE	GY	
1	79.83	32.23	1.44	85.48	250.50	767.30	391.25	3.12	Bombona, Brawura
2	76.42	41.43	1.42	86.57	224.33	745.03	379.42	3.65	Hewilla, Żura
3	94.83	57.14	1.28	78.90	216.67	683.45	340.92	3.49	Monsun, Parabola

[a]as defined under table 1

Discussion

The study showed the medium or weak relationships between the morphological characteristics of spring wheat varieties and weed infestation. Such relationships determine the varieties' competitiveness against weeds, and weed infestation. In most tested varieties, the dry matter of wheat, the height, and the number of tillers influenced the weed density. There was no close association between the dry matter of weeds and the parameters of spring wheat varieties. Lack of a significant correlation between the morphological features or canopy parameters and weed infestation could be related to the different response of these features in the different years. According to Hoad *et al.* (2008), seasonal variations in varietal performance can make it difficult to group variety field traits into consistently good or poor ideotypes. In the case of some varieties, a complex of features influenced the competitive ability, but none of the features dominated significantly, or other features decided about the competitiveness with weeds, for example, early crop vigour and ground cover, leaf area, leaf area angle or allelopathic effects (Bertholdsson 2005; Worthington and Reberg-Horton 2013). Stronger negative correlations between the characteristics of crop and weed infestation were found for winter wheat varieties in the research conducted on the same experimental fields (Feledyn-Szewczyk 2013). Such results correspond with the results of Deveikyte *et al.* (2008).

Among the morphological features of cereal varieties, plant height is widely reported as an important trait for increasing crop competitiveness (Balyan *et al.* 1991; Eisele and Köpke 1997). In the study by Huel and Hucl (1996), the most competitive genotypes of spring wheat were generally taller than non-competitive genotypes, but other traits such as large seedling ground cover and flag leaf length were associated with wheat yield under competitive conditions. In the present study, Bombona and Brawura were the most competitive. These two varieties were characterised by the highest rate of tillering, plant, and ear density as well as the largest dry matter of above ground parts. In contrast, most features that seems not to favor the competitive ability against weeds, such as the lowest height, tillering, plant density, and dry matter, were found in Monsun and Parabola. These two varieties were the least competitive against weeds, which was confirmed by the highest weed infestation in the canopy. A similar level of weed dry matter (41.5 g · m^{-2}), and the same dominant species [*Chenopodium album* L., *Viola arvensis* Murray and *Stellaria media* (L.) Vill.] were noted by Sadowski and Tyburski (2003) in spring wheat cultivated on organic farms.

For all the tested spring wheat varieties, the number of weeds negatively affected the grain yield. The yield was positively correlated with number of tillers and ears, the height, and the dry matter of wheat. Our results were in agreement with the study by Leistrumaite *et al*. (2009), which reported that grain yield of spring barley varieties correlated with the number of productive tillers and plant height. It may be suggested that there is no conflict between the features enhancing competitiveness and the yielding of spring wheat varieties. However, in our study, the best competitors Bombona and Brawura, gave the lowest yields. This was similar to the results of Hoad *et al*. (2008), who found that some highly competitive varieties gave modest yields. In the presented research, the highest yielding variety was Żura which had a medium competitive ability. In the study of Tyburski *et al.* (2010), the highest winter wheat variety (Roma) and one of the lowest (Pegassos) had the same yields. Such a finding indicates that there are varieties which are both high yielders and good weed competitors.

Wheat crop tolerance (yield) and weed suppression were broadly correlated in several studies (Challaiah *et al.* 1986; Lemerle *et al.* 1996), although other results (Coleman *et al.* 2001; Lemerle *et al.* 2001) found no wheat genotype that had consistently high tolerance and a high level of weed suppression. The studies by Siddique and Belford (1989) have shown a negative correlation between grain yield potential and the morphological characteristics that provide high competitive ability. The results of Christensen (1995) showed virtually no correlation between yielding ability and weed suppression ability in seven varieties of spring barley. The response of varieties depends on the weed infestation level, as suggested by Hoad *et al.* (2008). In the study of Huel and Hucl (1996), the highest-yielding genotypes under weed-free conditions were not necessarily the highest yielding ones under weedy conditions.

According to Lemerle *et al*. (2006), competitive ability and yield potential must be treated as separate traits for selection. Further studies are needed to determine if genotypes that have both high crop tolerance to weeds and weed suppression can be selected. A good solution might be to select genotypes with a high early nitrogen uptake efficiency, amongst those already recognised as having a good competitive ability (Wolfe *et al.* 2008).

Conclusions

The studies showed the medium or weak relationships between the morphological characteristics of spring wheat varieties which determine their competitiveness against weeds, and weed infestation. Different features affected the level of weed infestation of spring wheat varieties. Generally, in most tested varieties, the dry matter of wheat, the height, and tillering influenced the number of weeds at the dough stage. For all tested spring wheat varieties, the number of weeds was negatively correlated with grain yield. The grain yield was positively correlated with the number of tillers and ears, the height, and dry matter of wheat. Bombona and Brawura were the most competitive against weeds, while Monsun and Parabola were characterised with the least competitiveness against weeds. The highest yielding variety was Żura (3.82 t · ha^{-1}, on average), and the lowest Bombona and Brawura (3.03 and 3.20 t · · ha^{-1}, respectively).

Acknowledgements

The study was supported by the Polish Ministry of Agriculture and Rural Development under the grant for the research on organic crop production [PKre-029-14-

14/13(742)] and the multi-annual program of Institute of Soil Science and Plant Cultivation-State Research Institute, task 2.4. Evaluation of the Opportunities for Sustainable Development of Agriculture on the Different Levels of Management.

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