Journal of Applied Botany and Food Quality 84, 183 - 191 (2011)

[1]Institute of Crop Production, University of Agriculture, Krakow, Poland
[2]Department of Agrotechnology and Agricultural Ecology, University of Agriculture, Krakow, Poland

Comparison of morphological traits, productivity and canopy architecture of winter oilseed rape (*Brassica napus* L.) and white mustard (*Sinapis alba* L.)

T. Zając[1], A. Oleksy[1], A. Stokłosa[2], A. Klimek-Kopyra[1]

(Received March 22, 2011)

Summary

In the years 2006-2008, comparative studies of productivity and plant architecture of open pollinated winter oilseed rape cv. NK Petrol and white mustard cv. Nakielska were undertaken. Morphological traits, including the stem architecture and display of the siliques of both species, were studied. The contribution of the fruiting part of the plant as well as the number of branches with siliques is higher in winter oilseed rape plants, compared to white mustard. The total number of siliques on lateral branches of oilseed rape is also significantly higher than for white mustard. For both species, lateral branches make a greater contribution to the yield of each single plant, but for white mustard this contribution is not as evident as for oilseed rape. Plants of winter rape have about 25% more siliques per stem unit in comparison to white mustard. Winter oilseed rape siliques contain on average 18.5 seeds. The mass of winter oilseed rape seeds per silique is strongly linearly correlated with seed biomass ($R^2 = 0.95$). However, the length of siliques in these species is poorly correlated with seed mass. The yield of winter oilseed rape is several times higher than that of white mustard; that of a single oilseed rape or white mustard plant is 13.8 g or 2.0 g, respectively. In a single plant of oilseed rape, larger yield is associated with the number of siliques on the lateral branches and further the total yield of a single oilseed rape plant with a predominance of very large, large and medium silique categories based on size. These silique categories constitute 67.7% of the fruits and account for 80.1% of the plant yield. For white mustard small, medium and large siliques predominate, comprising 76.7% of fruits, and account for 78.7% of the total yield.

Introduction

Under Polish climatic conditions, winter oilseed rape is a leading oil crop, due to its high yield potential and appropriate oil quality (Rathke et al., 2006; Jankowski and Budzyński, 2007; Zaller et al., 2008). Additionally, breeding success for this crop over the last 30 year period has led to its increased economic importance in Poland and in Europe. New winter oilseed rape cultivars, both hybrid and open pollinated, produce more lateral branches and siliques, and in turn have greater productive potential (Zaller et al., 2008). The yields of winter oilseed rape are also strongly influenced by agricultural practices and growing habitat (Sieling and Christen, 1997; Zaller et al., 2008). Significantly, few authors (Bilsborrow et al., 1993; Sieling and Christen, 1997) have considered the number of seeds per unit area as the most reliable forecast of oilseed rape canopy yielding.

Furthermore, because a large part of the oilseed rape crop sown in Poland freezes each year, a new alternative spring oil crop with appropriate qualitative and quantitative traits is badly needed. Another cruciferous crop plant, white mustard, is considered to be the best candidate due to its resistance to frost and yield stability (Abou El-Nasr et al., 2006). The productivity of both winter rape and white mustard depends on many factors, such as plant density, number of siliques per single plant, and the mass of 1000 seeds (Sieling and Christen, 1997).

Presently, the seeds of white mustard are used for growing stubble intercrops (Dorsainvil et al., 2005; Zając, 2006), but in the recent years white mustard has also become an important source of erucic acid, a substance in much demand by industry (Gunstone, 1996; Taylor, 2010). Mutants of white mustard that contain increased levels of erucic acid in the seed oil, make this species a promising source of this ingredient in the future. On the other hand, breeding lines of white mustard with reduced content of glucosinolates in seeds and erucic acid in the seed oil have been established making white mustard a potential replacement crop for winter rape (Roy and Saha, 2006).

Past analyses of the yield components of winter rape and white mustard were general, most probably because of the laborious measurements involved and the tendency of winter oilseed rape siliques to break during processing. Our research focuses on the comparable analysis of productivity and plant architecture of open pollinated winter rape cultivars and a traditional cultivar of white mustard based on morphological traits of siliques and their placement on branches. Correlations between plant qualities and silique qualities were also analyzed.

Material and methods

In the years 2006-2008, plants of winter oilseed rape cv. NK Petrol, Syngenta® and white mustard cv. Nakielska were collected from productive fields for 40 km along road no 7. located in communities of southern Poland, namely: Słomniki; Miechów; Książ Wielki and Wodzisław. Each year plants of both species from at least 10 different fields were collected. The fields chosen had to meet certain criteria: a flat area of more than 1 ha, regular shape, and high-input technology. A dose of 160 kg and 80 kg on average N fertilization for winter oilseed rape and white mustard, respectively, was required. Phosphorus-potassium fertilization was applied according to the content of available forms of both nutrients in the soil humus layer. Ten plants from 5 locations along the diagonal of each field were collected (2 plants per location).

For each plant, the following biometric measurements were performed: plant height (main stem), number and length of lateral branches, including sections with and without siliques. The number of siliques was counted on both the main stem and each of the lateral branches. Moreover, siliques were collected from the lower (I), middle (II) and upper parts (III) of the main stem. From the second and fourth lateral branch (counted from the bottom), 2 siliques were collected: one from the lower-middle part (IV) and one from the middle-upper part (V). Each silique was placed separately in a paper bag and air-dried. For each air-dried silique, the length of the pedicel, the length of the pod, number of seeds, the mass of the silique and the mass of seeds per silique, were measured. The mass of silique coats and silique harvest index (SHI), representing the contribution of seeds to the fruit mass, were calculated.

The data were analyzed with descriptive statistical methods and presented as a mean with standard error (±SE) or with standard deviation (±SD). Normality of distribution was tested using Shapiro-Wilk test. Significant differences between means were assessed using *t*-Student test ($p < 0.05$). For selected pairs of traits characterized by high determination coefficient (R^2), regression equations were calculated. All staistical analyses were performed using Statistica 9.0 software (StatSoft, 2009).

Results

In the growing season 2005/6, winter conditions for oilseed rape were difficult, because of the long period of temperatures below freezing (Tab. 1). On the other hand, snowfalls occuring during this time provided insulation for over-wintering oilseed rape plants. Weather conditions at the beginning of March were cool; initation of leaves and the beginning of intensive growth was noted only at the beginning of April. Two other growing seasons, notably 2006/7, were characterized by warm winters and rainy Julys. Such weather variability and differences in growing seasons is typical in Poland and is directly related to the over-wintering and yielding quality of oilseed rape. The months in which generative development of oilseed rape was noted were much warmer, compared to a multiyear period. A large amount of precipitation that occurred in September 2007 resulted in the third year of the experiment being too wet. July 2008 was also very wet, resulting in difficulties in oilseed rape harvesting and seed drying. Weather conditions for the growth and development of white mustard were good, except that it was too wet in August 2007, when combine harvest was conducted.

Although this difference was not statistically significant, white mustard developed taller plants compared to those of oilseed rape, which may be species and cultivar specific (Tab. 2). The number of fertile branches was comparable for both species and ranged between 4-7. At the same time, the number of siliques per plant was about 70% greater for winter oilseed rape. This may be the result of a significantly higher density of siliques per branch unit for oilseed rape, but the lateral branches in oilseed rape were also almost two times longer and had two times more siliques than white mustard (Tab. 2). Location of the siliques on plants was also species specific. Winter oilseed rape plants developed two times more siliques on lateral branches in contrast to the main stem, whereas for white mustard the ratio of siliques on lateral branches and on the main stem was approximately 1:1. These parameters influenced the total yield from a single plant and the number of seeds per plant. For oilseed rape in comparison to white mustard, these were 7 and 6 times higher, respectively (Tab. 2). Comparison of single oilseed rape plant productivity reflects the importance of lateral branches in overall productivity. Breeding should be oriented toward decreasing plant height, as that will result in higher penetration of photosynthetically active radiation (PAR) to the siliques located on lateral branches. When the main stem dominates over lateral branches as for white mustard, increased shadowing and decrease of seed biomass in siliques growing on lower branches is noted.

The relationship between main stem and lateral branches for winter oilseed rape and white mustard plants is presented in a more detailed manner in Fig. 1. The average number of siliques per 10 cm of branch length was greater for mustard, in comparison to oilseed rape (Fig. 1a). Moreover, the density of siliques on the main stem of mustard was significantly greater than on lateral branches. All lateral branches of mustard were characterized by a similar number of siliques per 10 cm, average range 4-8 (Fig. 1a). Winter oilseed rape had similar density of siliques for both, main stem and lateral branches (Fig. 1a). Both species developed the largest total number of siliques on the main stem (Fig. 1b). Differences between the two species were observed for lateral branches, as the total number of siliques showed a decreasing trend for upper branches of oilseed rape, whereas trend was reversed for white mustard – the total number of siliques was greater for upper branches (Fig. 1b). These trends may result from the decreasing length of upper branches in oilseed rape and increasing length of upper branches in white mustard plants (Fig. 1c and 1d). Main stem and lateral branches (I - III) of winter oilseed rape had quite long segments without siliques (Fig. 1d). This species' life strategy aimed at localizing siliques in parts where light penetration was greater, promoting better seed development. In white mustard the lowest three (I - III) segments of lateral branches without siliques were significantly shorter compared to oilseed rape (Fig. 1d), and as a result those siliques had worse conditions for seed development, because of increased shading.

Tab. 1: Weather course during winter oilseed rape (A) and white mustard (B) vegetation.

Years	Months												A	B
	01	02	03	04	05	06	07	08	09	10	11	12	09-07	04-08
	Air temperature [°C]												Average	
2005	-	-	-	-	-	-	-	16.8	14.8	8.7	1.9	-0.9	-	-
2006	-7.5	-3.1	0.1	9.2	13.2	17.7	22.2	17.7	15.2	11.3	6.0	3.1	6.9	16.0
2007	3.22	0.69	6.37	10.36	15.82	18.13	19.57	19.41	13.13	8.35	1.13	-1.05	10.0	16.7
2008	2.0	3.3	4.6	8.6	14.1	18.5	19.1	18.2	-	-	-	-	8.3	15.7
1977-2007	-2.35	-1.08	3.07	8.12	13.74	16.50	18.19	17.90	13.35	8.83	2.94	-0.77	7.3	14.9
	Rainfall [mm]												Σ	
2005	-	-	-	-	-	-	-	101.5	32.3	7.7	30.1	87.7	-	-
2006	28.4	34.0	59.6	36.3	59.6	62.0	28.0	92.6	18.3	18.2	43.2	22.0	465.7	278.5
2007	84.82	35.44	46.54	15.20	56.48	58.81	71.74	124.90	212.80	78.00	49.10	22.60	470.7	327.1
2008	24.7	9.1	71.5	35.1	27.5	25.9	142.1	45.2	-	-	-	-	698.4	275.8
1977-2007	30.36	28.91	35.39	50.19	65.26	80.04	74.88	78.52	64.46	47.24	40.87	41.05	558.6	348.9

Tab: 2: Comparison of morphological traits and the elements of seed yield of winter oilseed rape and white mustard.

Morphological traits	Winter oilseed rape	White mustard	LSD $_{0.05}$
Plant height before harvesting (cm)	119.0 ± 13.5*	133.4 ± 29.3	r.n.
Height of the lowest productive branch [cm]	91.7 ± 11.8	78.1 ± 23.1	r.n.
No of fertile branches	4.9 ± 1.5	4.6 ± 1.9	r.n.
No of siliques per plant	134.1 ± 28.6	79.4 ± 36.2	25.96
No of siliques on main stem	42.0 ± 17.0	36.1 ± 11.2	r.n.
No of siliques on lateral branches	92.1 ± 24.1	43.3 ± 26.7	20.14
Mean length lateral branches [cm]	48.3 ± 17.1	27.7 ± 9.5	10.81
Mean length branches without siliques [cm]	32.5 ± 8.9	13.0 ± 6.2	6.03
Mean length branches with siliques [cm]	28.6 ± 7.0	16.0 ± 3.7	4.37
No of siliques per 10 cm length branches	9.9 ± 3.6	7.5 ± 2.5	2.43
Single plant yield (g)	13.8 ± 3.0	2.0 ± 0.9	1.70
Mean seed weight mass on main stem	4.3 ± 1.7	0.9 ± 0.3	0.97
Mean seed weight mass on lateral branches	9.5 ± 2.5	1.1 ± 0.7	1.41
No of seeds per plant	2485.0 ± 530.9	385.8 ± 175.9	307.95
No of seeds on main stem	778.4 ± 314.2	175.6 ± 54.4	175.05
No of seeds on other branches	1706.6 ± 446.2	210.2 ± 129.5	255.58

** mean (± SD)

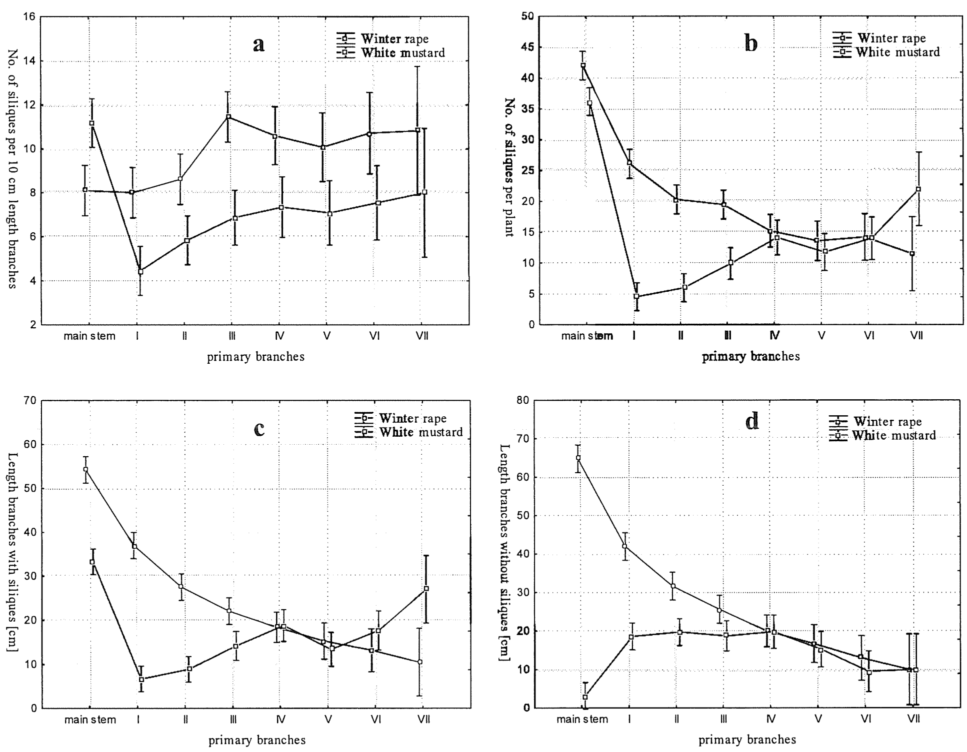

Fig. 1: Number of siliques per 10 cm of branch (a), number of siliques per plant (b), length (cm) of lateral branches with silique (c) length (cm) of lateral branches without siliques (d) depending on placement of branch on winter oilseed rape or white mustard plant. Values are means ± SE.

Comparison of siliques between the species tested clearly shows a domination of winter oilseed rape over white mustard (Tab. 3). Oilseed rape siliques developed significantly longer pedicels, a species specific trait. Oilseed rape pods were three times longer and had almost three times greater weight of silique with seeds. The weight of seeds per oilseed rape silique was four times higher than for white mustard (Tab. 3). On average, the number of seeds per oilseed rape silique was 18.5 and four times greater mass of seeds per silique than found in white mustard. A comparison of seed contribution to silique weight, calculated as silique harvest index (SHI), clearly shows the predominance of oilseed rape over white mustard, because of a greater contribution of oilseed rape

Tab. 3: Comparison of morphological traits of siliques of winter oilseed rape and white mustard.

Morphological traits	Winter oilseed rape	White mustard	LSD $_{0.05}$
Pedicel length (mm)	23.4 ± 3.2*	12.2 ± 2.6	0.84
Pod length (mm)	55.7 ± 7.5	15.0 ± 2.1	1.31
Silique lenght (mm)	79.1 ± 9.1	27.3 ± 3.9	1.77
Silique weight mass with seeds (mg)	170.8 ± 34.9	63.3 ± 12.5	6.48
Weight mass of seeds per silique (mg)	103.5 ± 29.5	25.7 ± 6.5	5.05
Weight mass of coats (mg)	67.3 ± 10.2	37.6 ± 7.2	2.50
No. of seeds per silique (pieces)	18.5 ± 5.9	4.9 ± 1.3	1.02
1000 seed weight mass (g)	5.7 ± 0.8	5.4 ± 0.8	0.24
Silique harvest index (HI)	0.58 ± 0.07	0.40 ± 0.05	0.018

** mean (± SD)

Tab. 4: Characteristics of morphological traits of winter oilseed rape siliques depending on the localization on the main stem or lateral branches.

Traits	Main stem				Lateral branches			LSD $_{0.05}$
	siliques			mean	siliques		mean	
	I*	II	III		IV	V		
Pedicel length (mm)	18.1 ± 6.5**	18.3 ± 5.1	18.2 ± 5.2	18.2 ± 5.5	21.7 ± 5.0	21.9 ± 5.7	21.8 ± 5.3	2.45
Pod length (mm)	61.7 ± 9.0	62.8 ± 12.8	55.6 ± 7.3	60.1 ± 10.1	57.9 ± 9.0	54.5 ± 8.4	56.3 ± 8.8	n.s.
Siliques lenght (mm)	79.8 ± 13.1	81.1 ± 13.3	73.8 ± 8.5	78.3 ± 11.9	79.6 ± 11.6	76.4 ± 11.7	78.0 ± 11.6	n.s.
Silique weight mass with seeds (mg)	198.2 ± 45.4	211.8 ± 46.8	175.4 ± 36.5	195.3 ± 44.2	170.3 ± 50.5	155.4 ± 39.2	163.1 ± 45.6	20.67
Weight mass of seeds per silique (mg)	113.7 ± 33.2	128.3 ± 30.5	102.3 ± 33.6	114.8 ± 33.0	101.3 ± 36.9	92.6 ± 31.9	97.1 ± 34.5	15.59
Weight mass of coats (mg)	84.5 ± 19.5	83.4 ± 17.8	73.1 ± 14.1	80.5 ± 17.5	69.0 ± 16.9	62.8 ± 12.3	66.0 ± 15.0	7.26
No. of seeds per silique	20.3 ± 5.4	22.6 ± 4.9	17.8 ± 6.8	20.2 ± 5.9	18.7 ± 5.8	17.1 ± 6.5	17.9 ± 6.2	n.s.
1000 seed weight mass (g)	5.65 ± 1.21	5.72 ± 0.77	6.00 ± 1.01	5.78 ± 0.99	5.40 ± 0.89	5.57 ± 1.17	5.48 ± 1.03	n.s.
Silique harvest index (HI)	0.57 ± 0.08	0.60 ± 0.03	0.57 ± 0.10	0.58 ± 0.07	0.58 ± 0.08	0.58 ± 0.08	0.58 ± 0.08	n.s.

* localization of siliques on the main stem: I - lower, II - middle and III - upper part; localization of siliques on the lateral branches: IV - lower-middle part and V - middle-upper part.
** mean (± SD)

seeds (58%) than those of white mustard (40%). At the same time, the small changeability of the SHI value in both species is worth underlaying (Tab. 3).

Detailed comparison of siliques located on the main stem and lateral branches of oilseed rape shows that fruits developed on lateral branches had longer pedicels (Tab. 4). The weight of siliques with seeds and the weight of seeds per silique were higher in fruits developed on the main stem. This distribution of traits demonstrates the significance of the amount of photosynthetically active radiation reaching siliques. Fig. 2 features the localization of different categories of siliques on main and lateral branches of oilseed rape and white mustard. The two species showed great similarity in localization of different categories of siliques. Siliques of lower mass were localized in both species mostly on lateral branches, whereas those of large and very large categories were found mostly on the main stem (Fig. 2). The scope of comparison between two species was broadened by examining differences of the number of siliques between the five distinguished categories (Tab. 5). For both species siliques of mean seed number were dominant categories, determining the total fruit number in winter oilseed rape in 28.9% and white mustard in 28.7%. Pedicel length was a highly stable trait, independent of the size of the siliques. The number of seeds per silique was weakly correlated with pod length, as for very small pods it was 54.9 mm and for very large pods only 64.7 mm. At the same time, siliques that were slightly different in length differed greatly in their seed mass. The seed yield of very small siliques was 60.1 mg, whereas the yield of very large siliques was 164.2 mg. On the other hand, the productivity of large siliques was accompanied by seed diminution, as the mass of 1000 seeds decreased by about 23% and 15% for oilseed rape and white mustard, respectively (Tab. 5). Changes in canopy management should be undertaken, leading to increasing the mass of seeds procured from large and very large siliques, developed earlier, but localized in the middle part of canopy, where PAR penetration is low. Significantly lower silique harvest index of very small siliques of winter oilseed rape indicates a tendency to produce a smaller number of seeds, which have better

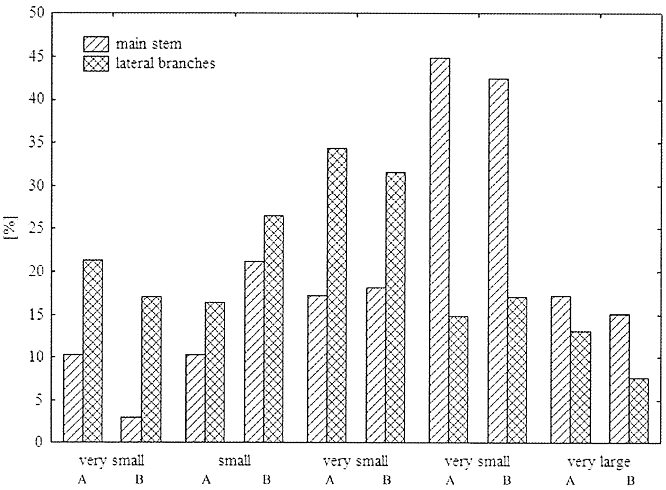

Fig. 2: Biosociological localization of silique categories on the main stem and lateral branches of winter oilseed rape (A) and white mustard (B).

growth conditions and as a result higher biomass (Tab. 5).
Between the seed mass per oilseed rape silique and the total mass of the silique, a linear correlation with a high coefficient of determination R^2 = 0.945 was observed (Fig. 3A). Such strong colinearity of both traits suggests the reliable use of total silique biomass as a predictor of yield. In white mustard (Fig. 3B), the correlation between both of these traits also was high (R^2 = 0.801), despite the different shape of fruits of the genus *Sinapis* and a lower silique harvest index. Between seed mass and seed number per silique, an almost analogical correlation was noted. However, as expected, the length of the silique of either of the two species, oilseed rape or white mustard, was very poorly correlated with seed mass. Reasons for that were given earlier in Tab. 3, 4 and 5.
Correlations between seed mass per silique and seed coat or silique harvest index (SHI) for each species are given in Fig. 4. Between both components of silique biomass, correlations were of temperate strength and of power relation. Silique harvest index of oilseed rape siliques was strongly correlated with single silique mass (R^2 = 0.819). In the case of white mustard, correlation of those traits was weak, most probably because of lower seed number per silique (see Fig. 4B).
In our work, the yield of oilseed rape and white mustard was examined on two levels: that of the single plant and the canopy. Single plant yield of oilseed rape and white mustard was on average 13.8 g and 2.0 g, respectively (see Tab. 2). Siliques developed on branches contributed at a higher level to overall plant yield. All categories of siliques were found on lateral branches in both species, although the most frequent were those of lower seed number and mass. Comparison of silique categories clearly points out that in the case of oilseed rape large, medium and very large siliques contribute most strongly to single plant yield (Tab. 5). These categories contributed 80.1% to the seed yield of winter oilseed rape. For white mustard those categories included small, medium and large

Tab. 5: Characteristics of silique properties depending on number of seeds per silique (silique category) in winter oilseed rape (A) and white mustard (B)

Trait	Species	Silique category				
		very small	small	medium	large	very large
No of seeds per category	A	≤13	14-19	20-25	26-30	≥31
	B	≤3	4	5	6	≥7
Contribution of silique category per plant (%)	A	17.8	14.4	28.9	24.4	14.4
	B	14.0	25.3	28.7	22.7	9.3
Pedicel length (mm)	A	23.9±4.4	23.2±2.6	23.2±2.8	23.4±1.9	23.5±2.1
	B	11.0±1.6	11.9±3.2	12.8±2.1	12.1±2.4	13.9±2.9
Pod length (mm)	A	54.9±10.1	54.5±10.6	57.9±7.7	64.1±7.7	64.7±3.3
	B	12.4±1.4	14.2±1.4	15.5±1.5	16.2±1.7	17.7±1.5
Silique length (mm)	A	78.9±12.6	77.8±12.3	81.1±8.5	87.5±7.2	88.2±2.8
	B	23.5±2.4	26.1±3.9	28.2±2.8	28.4±3.4	31.6±3.7
Silique weight mass with seeds (mg)	A	124.6±33.1	162.3±35.2	199.7±32.3	233.2±38.4	244.1±27.4
	B	43.7±7.8	56.7±6.8	67.9±6.9	71.9±8.7	82.4±5.9
Weight mass of seeds per silique (mg)	A	60.1±20.4	93.9±18.1	126.5±19.6	152.5±24.4	164.2±19.6
	B	15.8±3.8	21.9±3.9	27.7±2.7	30.1±3.5	35.4±3.8
Weight mass of silique coat (mg)	A	64.5±17.6	68.4±20.0	73.2±14.5	80.7±17.3	79.9±9.2
	B	28.0±5.6	34.8±5.6	40.2±6.5	41.7±6.7	46.9±3.9
1000 seed weight mass (g)	A	6.38±1.29	5.93±1.01	5.65±0.75	5.37±0.74	4.93±0.46
	B	5.71±0.96	5.47±0.98	5.54±0.54	5.02±0.58	4.88±0.57
Silique harvest index (HI)	A	0.47±0.10	0.58±0.05	0.63±0.03	0.65±0.04	0.67±0.02
	B	0.36±0.05	0.39±0.06	0.41±0.04	0.42±0.04	0.43±0.03
Share of silique category in plant yield (%)	A	8.77	11.14	30.01	30.61	19.47
	B	8.54	21.47	30.76	26.43	12.80

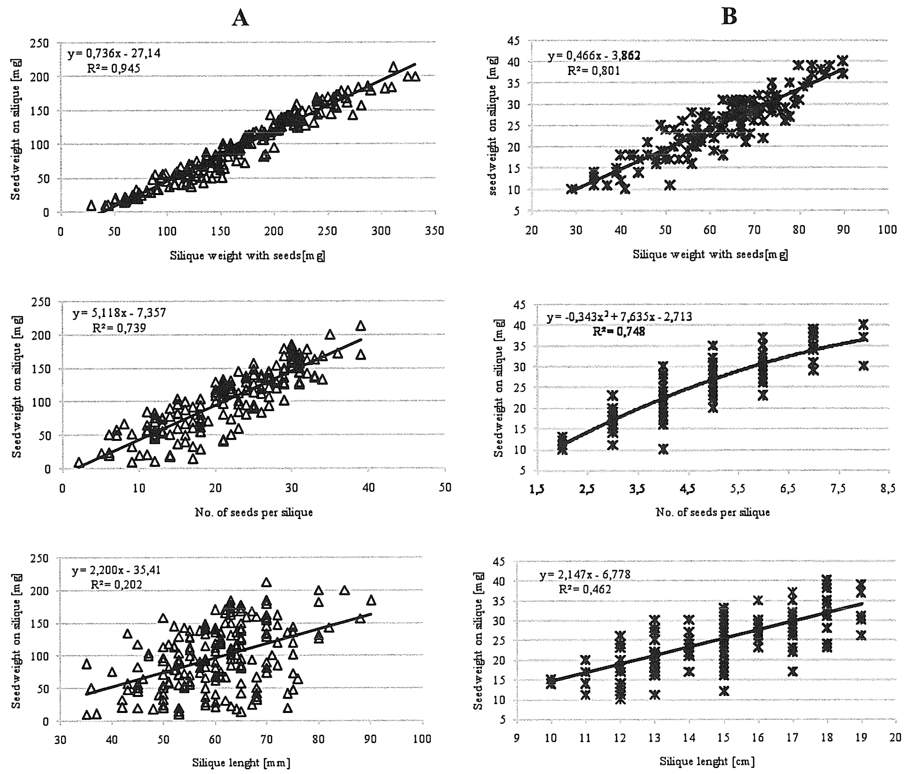

Fig. 3: Relationship between winter oilseed rape silique seed mass (A) and white mustard (B) and a total mass of silique, number of seeds per silique and silique length.

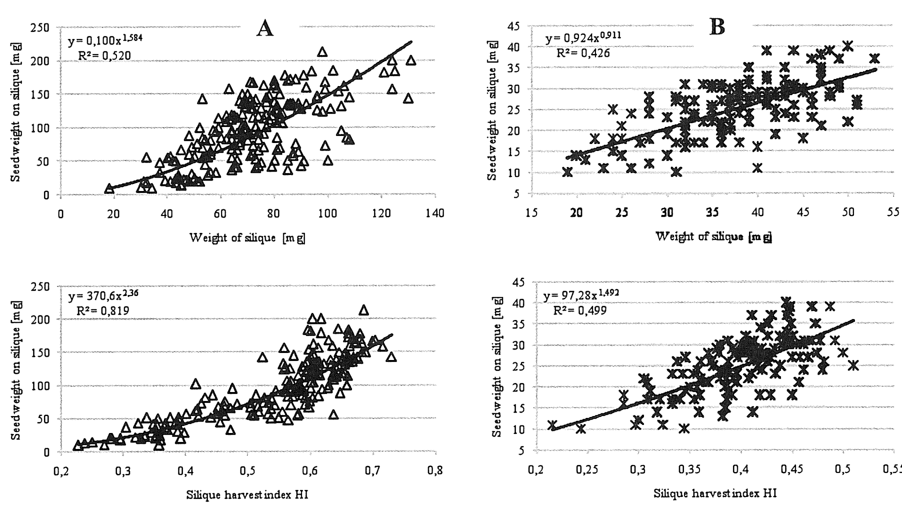

Fig. 4: Relationship between seed mass of winter oilseed rape (A) and white mustard (B) and mass of silique coats and seed ratio per total silique mass.

siliques, that jointly contributed 78.7% to the yield. According to expectations, in both species very small siliques contributed at a much lower level to plant yield. That way of presentation of seed size share in a total yield is a new approach, allowing better understanding of the productive possibilities of a single plant creating a canopy in a temperate climate. Our study also permits a more clear understanding of the value of silique number and size for creating productivity of winter oilseed rape and white mustard.

As the result of production by morphologically different oilseed species, different yield per unit area was noted (Fig. 5). Each year, during the three year period, winter oilseed rape produced several times greater yield in comparison to white mustard. On the other hand, white mustard yield was more stable between years, whereas winter oilseed rape yields differered and were more dependent on weather conditions during the growing period. The lowest oilseed rape seed yield was obtained in the 2007/8 growing season when excessive precipitation in the beginning and in the end of vegetative season occurred.

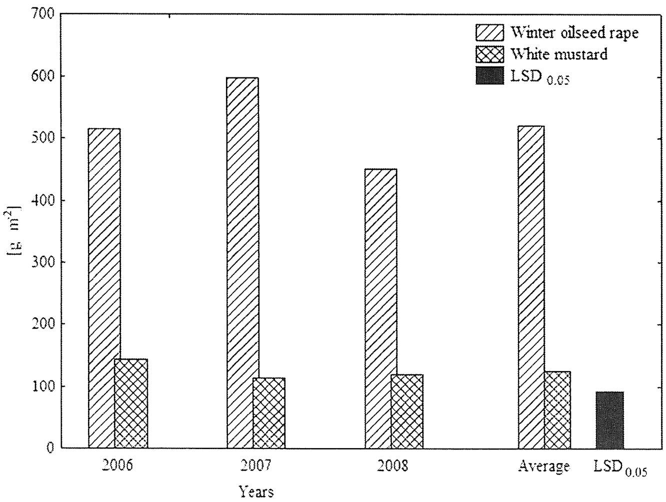

Fig. 5: Seed yield of winter oilseed rape (A) and white mustard (B) in g m^{-2}.

Discussion

Each of the silique traits measured in this study exhibited significantly greater variances between silique size and number of siliques depending on location on the stem in oilseed rape and mustard. The larger number of siliques from primarily lateral branches growing from lower part of rape main stem was noted for rapeseed. Opposite results were observed for mustard. Phenotypic correlations between the size of the silique and stem length reported by KADKOL et al. (1985) in rape were slightly different in the lower part of the main stem. LEBOWITZ (1989) pointed out that many of the silique traits indicated high potential of heritageabilities within species.

In 1979, under controlled greenhouse conditions, DIPENBROCK and GEISLER indicated that the rate of oilseed rape seed development depended on the position of siliques on the plant. In addition, the unit weight of seed mass varied depending on silique position on the main stem. During the seed filling stage, a large part of the biggest seeds comes from main stems, whereas at the end of seed filling stage the largest seeds were located on the lateral branches. At maturity, higher yield was obtained from main stem. These authors proposed a breeding program aimed at reduction of lateral branch length in favor of developing more siliques on the main stem. Our paper has confirmed this earlier report (DIPENBROCK and GEISLER, 1979) and pointed to the main stem as the most productive part of plant.

KHAN et al. (2008) observed highly significant correlation between plant lateral branches and pod length (-0.93), seeds per silique (-0.88) and yield per ha (0.78). Silique length was correlated strongly and significantly with seed yield per ha (0.88). These authors suggested further selection for reduction in the number of oilseed rape lateral branches as useful for yield and yield quality improvement. SANA et al. (2003) pointed out that the number of siliques per plant is determined both by environment conditions and genotype. Those results correspond to results obtained by CHOWDHURY et al. (1987) and SINGH and SINGH (1996) and partly with our results, as we obtained a positive correlation between the weight of seeds per silique with the length of the silique and also with the weight of the silique, both in oilseed rape and mustard. In the categories of large and very large siliques the amount of smaller seeds was greater. It can be assumed that this type of seed distribution in silique categories results from good light penetration into the canopy. DIPENBROCK and GEISLER (1979) and NITSCH (1976) indicated that silique length is the most suitable predictor for yield, because longer siliques had a larger number of seeds.

It is thought (BOELCKE and VIETINGHOFF, 1987; OLLERENSHAW et al., 1999) that oilseed rape plants can compensate for lost buds and siliques through the development of additional lateral branches. Such a phenomenon was noted by LARDON and TRIBOI-BLONDEL (1995), who noted increase in the number of lateral branches and additional siliques as a result of poor over-wintering. Under controlled conditions, loss of flowers from lower parts of lateral branches was tolerated by oilseed rape plants, as they were less productive (DANIELS et al., 1986). For this reason, removal of flowers from the lower parts of stem did not significantly influence plant yield (TOMMEY and EVANS, 1992).

Density of seed sowing is the most important feature of crop management. UZZAMAN (2008) obtained significant diversity of silique number on the main stem depending on the sowing rate. This author indicated that the number of siliques decreases with the increase in sowing density. Other Authors (ALI et al., 1990; MISRA and RANA, 1992; ROY et al., 1993) also confirmed those findings. In addition, increased canopy density leads to a decrease in silique vitality (SIDDIQUI, 1999). KUMAR (1984) noted, that rape cultivation in narrow rows (30 cm) resulted in increased yield per unit area, but decreased number of siliques and weight of seeds. Our results have shown diversity in the number of siliques per plant and the weight of seeds in oilseed rape and mustard at a row spacing of 45 cm. Nevertheless, oilseed rape produced higher yields than mustard. JANKOWSKI and BUDZYŃSKI (2003) obtained negative genotypic correlations (-0.318) between the number of seeds per silique with yield of oilseed rape. KHAN et al (2006) and CHOWDHURY et al. (1987) obtained a positive correlation between the number of siliques with the length of siliques in rape and mustard. Our results indicated an equally positive correlation between the number of seed per silique with their weight in oilseed rape (0.739) and mustard (0.748) and between the weight of seeds per plant with weight of seeds per silique in oilseed rape (0.819) and mustard (0.499). The most effective factor of yield (number of siliques per plant) is determined by plant density per unit area whereas both the number of seeds in each silique and the weight of siliques are modified by crop management techniques. WANG et al. (2007) did not show significant correlation between yield loss and plant height or number of branches per plant, but on the other hand yield was correlated with silique length and relations between silique length and width. The present paper confirmed, that the size of the silique is an important trait in yield moderation, as the total yield of a single oilseed rape plant with a predominance of very large, large and medium silique categories based on size was higher, comparing to smaller siliques.

DHILLON et al. (1990) and MARJANOVIĆ et al. (2008) noted that length of the main stem and lateral branches influenced the yield of oilseed rape. In our studies, such a relationship was also noted, as taller oilseed rape plants (taller main stem) produced a larger number of siliques and, as a result, higher plant yield. The reverse relationship was noted for mustard plants, where the height of plant was not correlated with plant yield.

INAYT-UR-RAHMAN et al. (2009) and AHMAD et al. (2008) indicated that the length of the silique pedicel influences the size of silique. On the contrary, ISLAM et al. (2004) indicated that the length of the pedicel is a feature of the genotype and constant regardless of environmental conditions. In the present paper we have confirmed the results of AHMAD et al. (2008), showing diversification of pedicel length among tested species. Our research has proved, that on the main stem, large siliques had shorter pedicels, in comparison to siliques developed on lateral branches. Moreover, species-dependent differences in this trait were shown. Oilseed rape produced shorter pedicels on the main stem, compared to those of mustard.

According to LEBOWITZ (1989) the average features in *Brassica campestris* (L.) for pedicel, pod, silique length are: 13.4 mm, 40.5 mm and 67.3 mm, respectively. The number of seeds per silique is 6. Both pod and total silique length showed the highest repeatability of measurements and were highly correlated with both seed number and seed weight per silique. The author suggests that these silique-related morphological traits could be used as indirect indices of selection in breeding for improved seed yield in *Brassica campestris* L. In our studies, significant relations between silique length and mass of seeds per oilseed rape silique (0.202*) and mustard (0.462*), mass of oilseed rape seeds and their number (0.739*) and mustard (0.748*) were obtained. At the same time, the assumptions of LEBOWITZ (1989) regarding the importance of indirect breeding were not confirmed, as greater correlation of traits, both for oilseed rape and mustard, was achieved by correlating seed mass per silique with total silique mass. Those results point out indirect selection of tested traits is not always useful for breeders.

In support of our results, KHAN et al. (2003) and ADOMAS and MURAWA (2005) indicated that 1000 seed weight is determined both by genotype and weather conditions. We saw a greater weight per 1000 seeds for oilseed rape both in main branches and lateral ones. KHAN et al. (2003) found a positive correlation between days to flowering and the seed yield. Our results indicated that rainfall during the flowering stage was the most important factor for increasing yield. Low rainfall in May 2008 decreased yield of oilseed rape more significantly than for mustard.

In summary, a breeding program for new mustard mutants should select those plants that are more similar in plant shape to oilseed rape plants. Selection of mustard plants should lead to a decrease in the height of the plant, increase in the number of lateral branches and number of seeds per silique. Oilseed rape could be a model plant for a mustard breeding program.

The results of our studies suggest reasons for the 1000 seed mass differentiation, which depends on silique category and their localization along the stem. Siliques of large and very large categories contained more seeds, but of smaller size, and influenced yield in 50% and 38% for oilseed rape and mustard, respectively. More important in the yield of both species were siliques of medium size.

Our results have confirmed the great yield potential of hybrid varieties, which to a large degree is due to advancements in breeding. A comparison analysis of yield of two leading oilseed species in Malopolska region, showed higher yield of oilseed rape in comparison to white mustard. Process of yield formation was influenced by both their agronomic and biologic traits.

References

ABOU EL-NASR, T.H.S., IBRAHIM, M.M., ABOUD, K.A., 2006: Stability parameters in yield of white mustard (*Brassica alba* L.) in different environments. World J. Agric. Sci. 2, 47-55.

ADOMAS, B., MURAWA, D., 2005: Plant morphology and yielding of spring rape cultivars depending on applied herbicides. Rośliny Oleiste – Oil Crops 26, 369-386 (In Polish with English summary).

ALI, M.H., RAHMAN, A.M.D., ULLAH, M.J., 1990: Effect of plant population and nitrogen on yield and oil content of rapeseed (*Brassica campestris* L.). Indian J.Agric.Sci. 60, 627-630.

AHMAD, H., ISLAM, M., KHAN, I.A., ALI, H., RAHMAN, H., INAMULLAH., 2008: Evaluation of advanced rapeseed line HS-98 for yield attributes and biochemical characters. Pak. J. Bot. 40, 1099-1101.

BILSBORROW, P.E., EVANS, E.J., ZHAO, F.J., 1993: The influence of spring nitrogen on yield, yield components and glucosinate content of autumn-sown oil-seed rape (*Brassica napus*). J. Agric. Sci. Cambr. 120, 219-224.

BOELCKE, B., VIETINGHOFF, G., 1987: Kompensationseffekte an Winterrapspflanzen nach Verlust generativer Organe im Knospenstadium. In: Proceedings of the International Rapeseed Conference, Vol. 7, 630-638.

CHOWDHURY, B.D., THUKRAL, S.K., SINGH, D.P., SING, P., KUMAR, A., 1987: Combining abilities and components of variation in *Brassica campestris* R.S. development. Reporter 4, 125-129.

DANIELS, R.W., SCARISBRICK, D.H., SMITH, L.J., 1986: Oilseed Rape Physiology. Oilseed rape. In: Scarisbrick, D.H., Daniels, R.W. (eds.), 83-126, Collins, London.

DIEPENBROCK, W., GIESLER, G. 1979: Compositional changes in developing pods and seeds of oilseed rape (*Brassica napus* L.) as affected by pod position on the plant. Can. J. Plant Sci. 59, 819-830.

DORSAINVIL, F., DÜRR, C., JUSTES, E., CARRERA, A. 2005: Characterisation and modelling of white mustard (*Sinapis alba* L.) emergence under several sowing conditions. Europ. J. Agron. 23, 146-158.

DHILLON, S.S., LABANA, K.H., BALWANT, S., AHUJA, K.L. 1990: Association analysis in Indian mustard (*Brassica juncea*). J. Res. Pb. Agri. Univ. 27, 385-388.

GUNSTONE, F., 1996: Fatty acid and lipid chemistry.: Blackie Academic & Professional, Glasgow.

ISLAM, M., AHMAD, H., RASHID, A., KHAN, A., RAZZA, A., DERAWADAN, H., 2004: Comparative study of agronomic traits of rapeseed genotypes under Swat conditions. Pak. J. Plant Sci. 10, 31-33.

INAYT-UR-RAHMAN, AHMAD, H., INAMULLAH, SIRAJUDDIN, ISHTIAQ, A., FIDA, M., ABBASI, ISLAM, M., GHAFOOR, S., 2009: Evaluation of rapeseed genotypes for yield and oil quality under rainfed conditions of district Mansehra. Afric. J. Biotech. 8, 6844-6849.

JANKOWSKI, K., BUDZYŃSKI, W., 2003: The role of yield components in the management of yielding of some spring oilseed crops. Rośliny Oleiste – Oilseed Crops XXIV, 443-454 (In Polish).

JANKOWSKI, K., BUDZYŃSKI, W., 2007: Response of different breeding forms of winter oilseed rape to date and density of sowing II. Seed yield and yield components. Rośliny Oleiste – Oilseed Crops XXV, 195-208 (In Polish).

KADKOL, G.P., HALLORAN, G.M., MACMILLAN, R.H., 1985: Evaluation of *Brassica* genotypes for resistance to shatter. II. Variation in siliqua strength within and between accessions. Euphytica 34, 915-924.

KHAN, S., FARHATULLAH, KHALIL, I.H., 2008: Phenotypic correlation analysis of elite $F_{3:4}$ *Brassica* populations for quantitative and qualitative traits. ARPN J. Agric. Biol. Sci. 3, 38-42.

KHAN, A., ULLAH, I., MURTAZA, S.B., KHAN, M.Y., 2003: Variability and correlations study in different newly developed sunflower hybrids. Asian J. Plant Sci. 2, 887-890.

KHAN, F.A., ALI, S., SHAKEEL, A., SAEED, A. 2006: Correlation analysis of some quantitative characters in *Brassica napus* L. J. Agric. Res. 44, 133-141.

KUMAR, P., YADAVA, T.P., YADAV, A.K., 1984: Association of seed yield and its components traits in the F_2 generation of Indian mustard. Indian J. Agric. Sci. 54, 604-607.

LARDON, A., TRIBOI-BLONDEL, A.-M., 1995: Cold and freeze stress at flowering - effects on seed yield in winter rapeseed. Field Crops Res. 44, 95-101.

LEBOWITZ, R.T., 1989: Image analysis measurements and repeatability estimates of siliques morphological traits in *Brassica campestris* L. Euphytica 43, 113-116.

MARJANOVIĆ-JEROMELA, A., MARINKOVIĆ, R., MIJAĆ, A., ZDUNIĆ, Z., IVANOVSKA, S., JANKULOVSKA, M., 2008: Correlation and path analysis of quantitative traits in winter rapeseed (*Brassica napus* L.). Agriculturae Conspectus Scientificus 73, 13-18.

MISRA, B.K., RANA, N.S., 1992: Response of yellow sarson (*Brassica napus* var. *glauca*) to row spacing and nitrogen fertilization under late sown condition. Ind. J. Agron. 37, 847-848.

NITSCH, A., 1976: Genetische und Physiologische Untersuchen an Polyenfettsauremutanten von Raps. II. Entwicklung und Polyenfettsauregehalt von reifen Samen. Angew. Bot. 50, 31-42.

OLLERENSHAW, J.H., LYONS, T., BARNES, J., 1999: Impacts of ozone on the growth and yield of field-grown winter oilseed rape. Environ. Pollut. 104, 53-59.

RATHKE, G.W., BEHRENS, T., DIEPENBROCK, W., 2006: Integrated nitrogen management strategies to improve seed field, oil content and nitrogen efficiency of winter oilseed rape (*Brassica napus* L.): a review. Agric. Ecosyst. Environ. 117, 80-108.

ROY, A, SAHA, P.K., 2006: Isolation of low erucic acid-containing genotype of Indian mustard (*Brassica juncea* Czern. and Coss.) through F_1 hybrid anther culture. Afr. J. Biotech. 5, 2092-2096.

ROY, S.K., AKTERUZZAMAN, M., SALAHUDDIN, A.B.M., 1993: Effect of sowing date and seeds rate on growth, harvest index and yield of Indian mustard (*Brassica juncea*). Ind. J. Agric. Sci. 63, 345-350.

SANA, M., ALI, A., MALIK, M.A., SALEEM, M.F., RAFI, Q.M., 2003: Comparative yield potential and oil contents of different canola cultivars (*Brassica napus* L.). Pak. J. Agron. 2, 1-7.

SIDDIQUI, S.A., 1999: Population density and source-sink manipulation effects on rapeseed (*Brassica napus* L.). M.S. Thesis. Dept. of Agron., Bangabandhu Sheikh Mujibur Rahman Agril. Univ., Gazipur, Bangladesh.

SIELING, K., CHRISTEN, O., 1997: Effect of preceding crop combination and N fertilization on field of six oil-seed rape cultivars (*Brassica napus* L.). Europ. J. Agron. 7, 301-306.

SINGH, M., SINGH, G., 1996: Evaluation of yellow sarson germplasm at mid hills of Sikkim. J. Hill Res. 8, 112-114.

STATSOFT INC., 2009: STATISTICA (data analysis software system), version 9.0. www.statsoft.com.

TAYLOR, D.C., FALK, K.C., PALMER, C.D., HAMMERLINDL, J., BABIC, V., MIETKIEWSKA, E., JADHAV, A., MARILLIA, E.F., FRANCIS, T., HOFFMAN, T., GIBLIN, E.M., KATAVIC, V., KELLER, W.A., 2010: *Brassica carinata* – a new molecular farming platform for delivering bio-industrial oil feedstocks: case studies of genetic modifications to improve very long-chain fatty acid and oil content in seeds. Biofuels, Bioprod. Bioref. 4, 538-561.

TOMMEY, A.M., EVANS, E.J., 1992: Analysis of post-flowering compensatory growth in winter oilseed rape (*Brassica napus*). J. Agric. Sci. 118, 301-308.

UZZAMAN, H., 2008: Siliques and seed development in Rapeseed (*Brassica campestris* L.) as affected by different irrigation levels and row sparing. Agricult. Consp. Sci. 73, 221-226.

WANG, R., RIPLEY, V.L., RADKOW, G., 2007: Pod shatter resistance evaluation in cultivars and breeding lines of *Brassica napus*, *B. juncea* and *Sinapsis alba*. Plant Breed. 126, 588-595.

ZAJĄC, T., 2006: Green manure as a source of nutrients in wheat cultivation. Post. Nauk Rol. 321, 9-23 (In Polish).

ZALLER, J.G., MOSER, D., DRAPELA, T., SCHMÖGER, C., FRANK, T., 2008: Effect of within-field and landscape factors on insects damage in winter oilseed rape. Agric. Ecosyst. Environ. 123, 233-238.

Address of the authors

Prof. Tadeusz Zając, Dr. Andrzej Oleksy and Dr. Agnieszka Klimek-Kopyra, Institute of Crop Production, University of Agriculture, Mickiewicza 21, 31-120 Krakow, Poland

Dr. Agnieszka Stokłosa, Department of Agrotechnology and Agricultural Ecology, University of Agriculture, Mickiewicza 21, 31-120 Krakow, Poland