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RELATIVE SILIQUES POSITION IN A CROP LAYER AS AN INDICATOR OF YIELD AND QUALITY IN WINTER RAPE

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In a two growing seasons (2010-11 and 2011-12) field experiment carried out in temperate climate of Central Europe, the green area index, features of siliques and chemical composition of the seeds of two heterosis cultivars of winter rape, cultivated in three locations: Głubczyce, Pawłowice, and Prusy were compared. It was observed that siliques localization in the specified crop layer significantly affected fruits productivity. The longest siliques were formed in the middle part of the main shoot and lateral shoots. Biosocial localization of the siliques in the middle part of the shoot was responsible for highest seeds weight (0.145 g on the main shoot, and 0.118 g on the lateral shoot). Productive predominance of rape fruits from this layer was a result of high seeds number in the siliques. The lowest mass of a single rape seed was obtained from the siliques located in the bottom infructescence layer. Biosocial localization of rape siliques did not affect significantly fatty acids profile of rapeseed oil, which depended on cultivar features, and to a low degree on vegetation years. The growing seasons only significantly changed the ratio of *n-6* to *n-3*, which for two seasons 2010-11 and 2011-12 was 1:1.97 and 1:2.16, respectively.
Keywords: Chemical composition, cultivar, fatty acids, silique, seeds.

INTRODUCTION

Brasica napus L. var. *oleifera* (subvar. *biennis* or *annua*) is now a leader species in the cultivation of oil plants. In Europe, in warmer and cooler zones of temperate climate, the winter form is cultivated as it gives a higher yield compared with the spring form (Peltonen-Sainio and Jauhiainen, 2008; Waalen *et al.*, 2013). In Canada, spring oilseed rape (canola), which is highly valued for its good quality of oil, is cultivated (Daun, 2004). Attempt of canola cultivation are also made in southwestern Australia, a region with low rainfall and a short vegetation season (Gunasekera *et al.*, 2006). Data from FAOSTAT (2014) indicates that the oilseed rape area is progressively increasing throughout the world, and – at the same time – its yields are increasing. All these factors have contributed to elevating oilseed rape to third place after soybean and palm oil, while in the recent past it was the fourth oil plant ranked after the sunflower. At present, the high nutritive value of extra virgin rapeseed oil of '00' varieties, and thus rapeseed oil is called "the olive of the north" (Rosiak, 2012). The global world average yield of rapeseed doubled from 1970 to 2009, increasing from circa 800 to 1900 kg ha^{-1}, with an increase rate of circa 27 kg ha^{-1} yr^{-1} for the whole period (Rondanini *et al.*, 2012). Winter oil rape has multiple productive functions such as edible oil, feed or biomass for other uses as a bioenergy source or various renewable materials (Nemecek *et al*., 2015).

Diepenbrock, (2000) remarked that the number of siliques per plant primarily affected the seed yield. However, the number of siliques is significantly determined by the number of branches, number of buds, and the number of pods set on a plant. Wang *et al*. (2011) found that the number of siliques per plant, and the number of seeds per silique constitute the most variable components of yield, and their numbers are conditioned upon the amount of assimilates provided for ripening siliques. Furthermore, the authors of these studies stated that the numbers of emerging and ripening seeds in a silique can depend significantly upon the structure of layers in the crop and the timing of their formation on a shoot. In their studies on the effect of foliage on the number of siliques formed, Bennett *et al.* (2011) found that the numbers of siliques and the number of seeds per silique decreased with increased amount of foliage. Studies by Wang *et al.* (2011) found that the number of seeds per silique differed depending on their position on the shoot. On the main shoot, the number of seeds per silique is higher, and their numbers drop in line with the distance from the main shoot. Studies conducted by Zając *et al.* (2011) showed that on a rapeseed plant the number of siliques set on the main shoot is higher, and – additionally – they form more seeds. For this reason, the siliques were divided into five categories of siliques, differing in their mass and the numbers of seeds set. In these studies, it was found that the siliques situated in the middle parts of shoots, both of the main and lateral shoot had more seeds, and – consequently

– the masses of these fruits were greater. Similar observations were made by Sieling *et al.* (1997), and by Wang *et al.* (2011). Chay and Thurling (1989), based on the analysis of 112 breeding lines, noticed increased in the silique length in spring oilseed rape in the range < 65 to > 84 (mm), which led to the increase in the mass of a single seed, as well as to the greater yield of seeds per plant from 11.3 to 17.0 (g plants^{-1}). The opposite was found by Zając *et al.* (2011) when they used the analysis of five classes of siliques with 13 to 31 seeds per silique, and found that the increase in the number of seeds per silique resulted, on the one hand, in the decrease in the mass of a single seed from 6.38 to 4.93 mg, while, on the other hand, the increased number in a single fruit elevated the pod harvest from 0.47 to 0.67 g g^{-1}. In summary, the authors pointed out that "the pod mass of winter oilseed rape is strongly linearly correlated with seed biomass". Weymann *et al.* (2015) showed high vulnerability in winter oilseed rape yield: "in Germany about 40% of seed yield variability could be explained by weather conditions during specific growth phases. The most important phenological phases thereby were: onset of pods and seeds (BBCH 50–65) and seed development (BBCH 71–79)". In available publications, there was no information on the development of fruits and seeds of winter oilseed rape in various parts of the plant layer, therefore in this study a greater number of silique characteristics was taken into account, which was not previously discussed. For this reason, the evaluation of seeds was reduced to (i) estimating the mass of a single seed, (ii) finding the total number of seeds in a single silique, (iii) or calculating per 1 cm of length of seed-containing part of the silique. The principal idea of such proceeding focused on a single plant, not on the crop stand, was to attempt a more precise reflection on the developmental status of seeds depending on the biosocial position of the fruit, also taking into account the position of the fruit in the crop stand, and the shoot category – main shoot vs. lateral branches, being made constantly.

The oil content in rape seeds may change under the influence of various factors, both agronomic and agrobiological (Farooq *et al.*, 2017). Bennett *et al.* (2011) and Marjanović-Jeromela *et al.* (2014) found a positive correlation between the seed yield and the amount of oil, indicating the fat content is positively correlated with the number of seeds in a silique, and on their mass. Similar results were reported by Basalma (2008) who obtained a significant increase in fat content along with an increase in the number of seeds in a silique on the main shoot, thus concluding that the selection of oilseed rape varieties should be conducted based on the yield of the main shoot. However, so far no explanation has yet been found on what could be the effect of the biosocial position of siliques in a crop stand upon the quantity and quality of the accumulated fat. In the studies known to date, only the effect of environmental conditions on the profile of fatty acids have been proven, but these studies did not take into account the positioning of the fruits in the layers of the crop stand. Baux *et al.* (2008) claimed that fatty acid composition is affected by environmental conditions, temperature being the main factor. Monitoring the fatty acid profile in low-linolenic varieties from the beginning of seed-filling to full maturity showed that alpha-linolenic acid synthesis occurred mainly between 550 and 850 degree-days after the onset of flowering, that is during the 20 first days of seed filling. According to Ferrie *et al.* (2008): "Fatty acid analysis of the B. *napus* double haploid lines showed that saturated fatty acid proportions ranged from 5.0% to 7.7%. For B. *juncea*, saturate proportions ranged from 5.4% to 9.5%". Deng and Scarth (1998) pointed out that: "The low-C18:3 trait in 'Stellar' demonstrated good stability over locations and under the temperature conditions used in this study. This result provides quality assurance to the producers and processors of low-linolenic cultivars developed from this source of the low-linolenic trait". Badea and Basu (2009) stated: "Overall, there was an important increase in linoleic (C18:2) and alpha-linolenic (C18:3) acids in both types of studied plants when exposed to low temperature. However, what is notable is the time of accumulation of these acids in the tested plants. The tolerant plants showed a very fast accumulation in unsaturated acids, after only a few days compared to the sensitive ones, conferring a more rapid adaptation to cold". So far, it is believed that genetic manipulation and therefore practical plant breeding can deliver rapeseed varieties with different fatty acid profiles of the oil. Simultaneously, there is no research to explain the existence or non-existence of the stability of oil content in winter oilseed rape seeds, especially hybrid ones, currently dominant in the selection. This begs the question whether the biosocial position of pods in the crop has implications for quantitative and qualitative productivity of this most important oil plant. The studies conducted so far have examined the components of winter rape seed yield on quite a high level of generality, probably due to the great effort of measurements and their spontaneous rupturing tendency.

The aim of this study was to compare ten traits of silique of winter oilseed rape hybrid cultivars localized in three locations and in three crop layers (bottom, middle and top). The working hypothesis assumed the existence of an effect of the biosocial position of siliques in the crop stand of oilseed rape upon the quantitative and qualitative properties of seeds.

MATERIALS AND METHODS

***General design*:** During two growing seasons 2010-11 and 2011-12 strict three factorial field experiments were carried out in three southern Polish location: Głubczyce- (17º 50'E 50º 12'N) - Research Centre for Cultivar Testing (COBORU) in Opolskie Voivodeship, Pawlowice- (18º 31'E 50º 28'N) - Research Centre for Cultivar Testing (COBORU) in the Silesian Voivodeship, Prusy- (20º 05'E 50º 07'N) – the Experimental Station of the Agricultural University in

Krakow, Małopolska Voivodeship. The choice of location, lying at a similar north latitude, was to determine the production potential of two hybrid cultivars (F1) of winter oilseed rape 'Adam'- from AG Deutsche Saatveredelung culture and 'Poznaniak' – Strzelce Plant Breeding Ltd. IHAR Group, under southern Poland conditions. In the Głubczyce and Prusy stations, the experiments were conducted on degraded black soil, situated on loess, while in Pawłowice the experimental field was set on Luvisols formed from glacial till. Nutrients needed to make soil fertile: P, K, Mg, and doses of mineral fertilizers were adequate for high productivity. The application of pesticides fully reduced the occurrence of pests and diseases in winter oilseed rape fields. In the 2010-11 and 2011-12 growing seasons, cultivars of winter oilseed rape seeds were sown in quantities of 60 and 50 units per 1 m^2. Space between the rows in Głubczyce and Pawłowice was 30 cm and 28 cm in Prusy. Experiments were carried out in four replicates and the plot size for harvest was 15 m^2. In the four characteristics of the development stages, the green area index (GAI) of the canopy was measured, using a Sunscan Delta-T® device. The number of plants on two linear meters was determined in the phase of green maturity of rape plants (BBCH 69–71). One week prior to the planned harvest, the plants were collected for biometric measurements. The positions of siliques on the mains shoot and lateral shoots were determined. The plants harvested from sample plots were dried for one month. During the biometric measurements, the main shoot and lateral shoots were distinguished, and the three layers of siliques were distinguished within each shoot: lower, middle, and upper. The lower layer of shoot with siliques was situated from 80 to 100 cm distance from the bottom, middle layer – in 101-120 cm, and the top layer – in 121-140 cm. From the central section of each layer, siliques were collected, and the lengths of their elements (peduncle, pod, beak) were measured. Next, the whole silique was weighed, and the number and mass of seeds in the silique were determined. Two following indices were calculated for siliques: number of seeds per 1 cm of the part with seeds, and the silique harvest.

Sampling and analyses of plant material**:** In the seed samples from each crop layer the content of: ash, crude fiber, crude protein, crude fat and nitrogen-free extract was investigated with the near-infrared Foss® samples analyzer. Lipids (saturated, unsaturated) extraction contained in rapeseeds was performed according to Folch *et al*. (1957) method. Then the esterification of fatty acids was carried out using AOAC method (2002). To the obtained 10 mg of fat, 0.5 ml of 0.5 M KOH in methanol was added and then the solution was heated at 85 ºC. Afterwards, 1 ml. of 12% BF3 in methanol was added and heated again at 85 ºC. After cooling it down to room temperature, 1 ml of hexane and 5 ml saturated NaCl solution were added. The TRACE GC Ultra gas chromatograph from Thermo Electron Corporation R with flame ionization detector (FID), was injected with 1 µl Fatty acid separation was made in Supelcowax 10 - 30 m - 0.25 mm - 0.25 µm column, using helium (1 ml min^{-1}) as the gas carrier. Based on peaks, the same acids were classified to various families. The proportions of the groups of acids and individual fatty acids in rapeseed oil were calculated, as well as the ratios between the families of fatty acids *n6:n3*.

Weather course**:** In 2010-11 growing season, during the autumn the vegetation of winter oilseed rape more rain fell in the Prusy, and much less in the western part of the Poland - Glubczyce (Fig. 1). Very low rainfall was recorded in October and February. Strong temperature declines occurred in December, but snow cover present on the field at that time protected juvenile rape plants (rosette stage) from freezing.

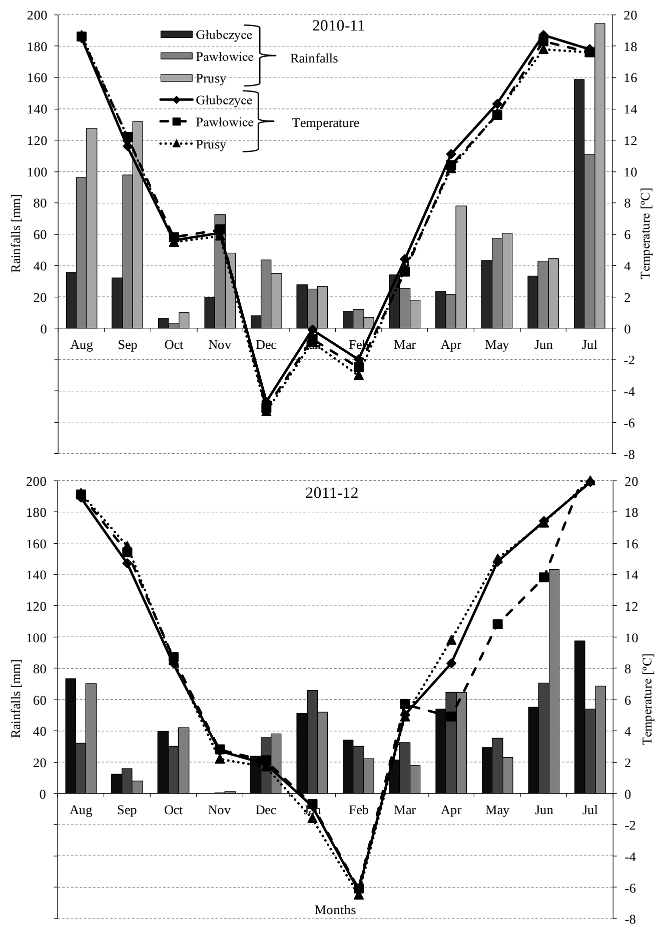

Figure 1. The course of weather conditions in individual months of winter oilseed rape in two growing seasons

Stronger air temperature drops in February were more visible in the eastern part of the country - Prusy. Catastrophically high rainfall recorded in the month of July impeded the harvest of oilseed rape. In the next growing season (2011-12) after sowing the seeds there was fairly dry weather, and November was characteristic as there was no rainfall in that month. Major cooling - frost occurred in the months of January and February, but this time the snow cover protected the oilseed rape plants from freezing. After the resumption of oilseed rape vegetation in the spring in 2012 the condition was slightly cooler in Pawłowice compared to other locations. Furthermore, in Prusy in June there was high rainfall, significantly higher than these reported in two other locations. In the assessment of agroclimate for winter rape grown in Poland, it should be noted that, the annual occurrence of frost period (usually lasting for 2-3 months), is a phenomenon that negatively affects the juvenile plants, if there is a lack of snow cover.

***Statistical analyses*:** The data were statistically analyzed using variance and analysis included in Statistica® package. The significance of differences was determined with the Fisher test (Stanisz, 2006).

RESULTS

The value of green area index (GAI) depended mainly on the field conditions, as revealed in the earlier stages of development (Table 1). In Głubczyce, the oilseed rape field throughout the whole growing season had the largest green area of assimilation. In other locations, the GAI field index of winter rape was significantly lower, which depended mainly on the less favorable habitat conditions for this plant. Significant interactions were found for years, locations, and cultivars (Fig. 2).

Table 1. The changes in the green area index (GAI m^2m^{-2}) of the stands of different cultivars of winter rape in characteristic growth stages depending on the locations and growing seasons

Treatment	Growth stages (BBCH)			
	35-51	**57-61**	**64-68**	**71-73**
Growth season				
2010-11	1.20	2.83	4.70	2.77
2011-12	1.55	3.82	4.92	3.55
LSD $_{P\leq0.05}$	NS	0.845	NS	0.428
Locality				
Głubczyce	2.98	5.30	6.79	3.29
Pawłowice	0.83	3.68	4.48	3.05
Prusy	0.93	2.39	4.25	3.02
LSD $_{P\leq0.05}$	0.432	0.661	0.686	NS
Cultivar				
cv. ‘Adam’	1.32	3.01	4.91	3.18
cv. ‘Poznaniak’	1.26	3.45	4.65	2.98
LSD $_{P\leq0.05}$	NS	NS	NS	NS

NS – not significant; 35-51 stem elongation - inflorescence emergence (“green bud”); 57-61 end of inflorescence emergence – beginning of flowering; 64-68 full flowering; 71-73 (beginning of) development of fruit

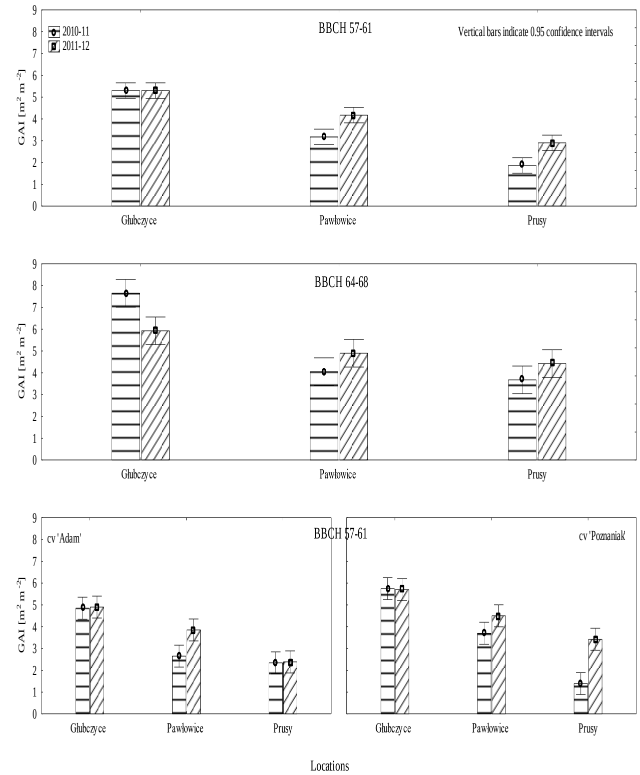

Figure 2. Changes in the GAI in compared growing stages (BBCH) as an effect of interactions between cultivars and locations

In both growing seasons oilseed rape (regardless of cultivar) developed the largest assimilation area in Głubczyce. In Prusy and Pawłowice, the precipitation regime in March and April was more beneficial to oilseed rape but was not reflected in any higher value of GAI.

Direct comparisons between the morphometric features of a single silique of oilseed rape pertaining to the length of silique indicate their diversity depending on the compared features (Tables 2, 3). The lengths of parts of siliques containing seeds, developed on the main or lateral shoot, were significantly different between cultivars and biosocial position in the layer of field (Table 3). Longer siliques were noted in the 2011-12 season, in the ‘Adam’ cultivar (Fig. 3a). In the first vegetation season, significantly longer siliques were found in the middle layer of the crop stand, whereas in the second season they appeared both in the lower and middle layers (Table 2, Fig. 3b). The changes in the lengths of siliques with seeds were observed as the result of the significant interaction occurring between varieties and locations (Fig. 3c). The highest values of that feature were obtained in Pawłowice, whereas the opposite situation appeared in Głubczyce where rape plants developed siliques with lesser lengths of parts containing seeds.

Table 2. Multifactor analysis of variance for the main principal factors and interactions

Source of Variation	DF	Silique length		Seed mass		Silique harvest		Number seeds		Crude fat	Total	
		M	L	M	L	M	L	M	L		saturates	unsaturates
Years (Y)	1	4.34	1.14	3 205	698.000	77.1	17.5	1.8	25.2	16.1	0.09	0.110
Location (L)	2	0.15	0.11	2 024*	2.804**	69.7**	83.9**	26.2	18.3	32.6**	0.38	0.351
Cultivars (C)	1	2.04**	1.11*	50.000	4.000	41.8*	4.7	71.3*	52.2*	12.1*	6.99**	7.208**
Crop layer (Cl)	2	5.70**	3.99**	3 281**	2 079**	43.5*	19.7	82.2**	68.9**	39.7**	0.11	0.097
L x C	2	0.83*	0.16	422.000	874.000	32.7*	7.5	34.2	53.5**	4.7	1.39**	1.327
L x Cl	4	0.55	0.04	225.000	39.000	3.6	5.7	3.5	1.3	3.5	0.05	0.054
C x Cl	2	0.17	0.08	318.000	41.000	1.6	14.7	32.4	4.3	1.0	0.01	0.005
L x C x Cl	4	0.35	0.10	585.000	44.000	6.9	2.4	9.1	2.8	1.4	0.06	0.064
Y x L	2	0.28	0.16	2 259**	1 826**	5.7	3.9	33.4	15.0	13.7**	0.08	0.107
Y x C	1	1.01*	0.11	1 543	296.000	59.0*	36.1*	100.0**	25.3	51.0**	0.19	0.163
Y x CL	2	0.75*	0.11	758.000	27.000	4.8	13.2	35.5	1.8	3.9	0.33	0.288
Y x L x C	2	0.04	0.08	1 419	337.000	17.1	58.3**	23.5	4.9	1.6	0.06	0.057
Y x L x Cl	4	0.10	0.07	324.000	120.000	12.1	5.5	7.7	3.5	1.4	0.05	0.065
Y x C x Cl	2	0.50	0.26	450.000	156.000	6.8	2.3	14.5	8.4	1.4	0.09	0.111
Y x L x C x Cl	4	0.13	0.04	224.000	101.000	7.4	2.1	3.5	4.9	2.6	0.16	0.165

DF – degree of freedom, M- main shoot, L- lateral shoot; *P<0.05, ** P<0.01, *** P<0.001

Table 3. Comparison of the siliques components length [cm] derived from the main shoot and lateral shoot

Treatments	Main shoot				Lateral shoot			
	Peduncle	Silique (pod with seed)	Beak	Total length	Peduncle	Silique (pod with seed)	Beak	Total length
Locality								
Głubczyce	2.17	6.48	1.30	7.78	2.22	6.08	1.29	7.37
Pawłowice	2.36	6.68	1.38	8.05	2.45	6.27	1.31	7.58
Prusy	2.13	6.66	1.36	8.09	2.14	6.13	1.33	7.45
LSD $_{P\leq0.05}$	0.209	NS	NS	NS	0.169	NS	NS	NS
Cultivar								
cv. 'Adam'	2.07	6.84	1.35	8.19	2.15	6.34	1.29	7.63
cv. 'Poznaniak'	2.37	6.37	1.35	7.75	2.39	5.99	1.33	7.31
LSD $_{P\leq0.05}$	0.142	0.338	NS	0.373	0.115	0.247	NS	0.286
Crop layer								
Lower	2.56	6.71	1.43	8.14	2.56	6.32	1.40	7.71
Middle	2.21	7.24	1.45	8.69	2.34	6.64	1.40	8.04
Upper	1.88	5.87	1.16	7.09	1.92	5.52	1.13	6.65
LSD $_{P\leq0.05}$	0.209	0.497	0.093	0.549	0.169	0.364	0.090	0.421

NS – not significant

The length of peduncle was significantly diverse between locations (Table 3). The significantly longer peduncles of siliques were obtained in the Pawłowice locality. In all locations, the peduncles of siliques from lateral shoots were longer than those from the main shoot. The 'Poznaniak' cultivar had longer peduncles independently of their position in the main shoots vs. lateral shoots. The factor which diversified most the lengths of siliques was situating the siliques in the layers of the rape stand. The siliques which grew in the lower layers of the crop stand (independently of the location of the experiment and the cultivar) had the longest peduncles. It was quite the opposite when it came to the siliques situated in the upper parts of inflorescences. The siliques situated in the middle layer of the stand had the longest productive parts (i.e. the one in which the seeds are deposited). It seems highly probable that the shortening of these parts of fruits developing in the lower layer of the crop stand could result from the deficit of light.

The weight of seeds depended significantly on the locality and biosocial position of siliques in the stand (Tables 2 and 4). Independent of location research, the siliques of oilseed rape showed a reduced weight of seeds in both the lower and upper layer of the crop stand (Table 4). Additionally, significant interaction was found between years and locations (Fig. 4). The significant increase in the weight of seeds was found in the second year of research in the Pawłowice locality whereas the lowest weight was that observed in Głubczyce on the main and lateral shoots. It is worth mentioning that the highest values of GAI occurred in Głubczyce (Table 1).

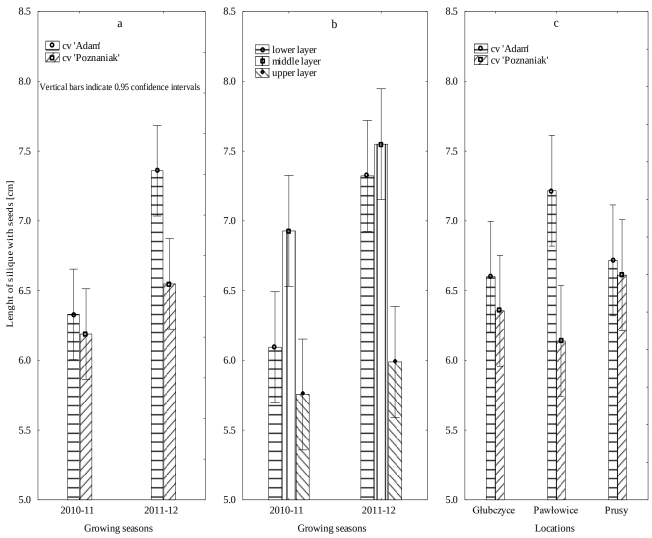

Figure 3. Changes in silique length as an effect of interactions between particular years and the cultivars (a), as well as between years (b) and the crop layers (c)

Such data pattern indicates the possibility of a significant impairment in the development of siliques which occurs when there is an excessive GAI provoking the great shadowing of siliques in the lower layer of the stand. It should be added that the flowering of inflorescences of oilseed rape plants begins from the bottom which means that this layer of siliques develops first. Such a situation probably affected the deteriorated development of oilseed rape siliques in the Głubczyce locality which translated into a lower weight and less oil content in seeds (cf. further parts of this study). The 'Adam' cultivar developed a higher number of seeds in its siliques independently from their position on various categories of shoots (main, lateral), which showed in their lower weight. Similarly, strong effects on the weight of rape siliques were exerted by their situation in the analyzed layers of the crop stand (upper, middle, or lower). Most ripe fruits developed in the middle layer because of their earlier development compared with the upper layer of the stand which developed last because it had a shortened ripening phase. A noticeable lower number of seeds developed in the siliques set on lateral shoots (Table 4).

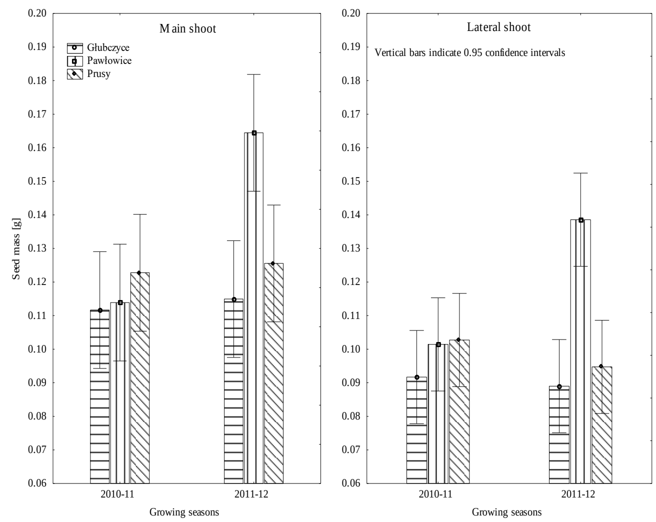

Figure 4. Changes in seed mass as an effect of the interaction between particular growing seasons and locations determined on the main shoot (a) and on the lateral shoot (b)

Table 4. Changes in the total silique mass, seed mass, mass of a single seed, number of seeds per silique, number of seeds from 1 cm of silique and silique harvest derived from the main shoot and lateral branches

Treatments	Main shoot						Lateral shoot					
	mass			number		Silique harvest [%]	mass			number		Silique harvest [%]
	silique [g]	seeds [g]	1 seed [mg]	seeds	from 1 cm of silique		silique [g]	seeds [g]	1 seed [mg]	seeds	from 1 cm of silique	
Locality												
Głubczyce	0.180	0.113	4.51	25.2	3.87	62.5	0.144	0.090	3.98	22.8	3.72	62.0
Pawłowice	0.238	0.139	5.71	24.3	3.59	57.7	0.202	0.120	5.14	23.2	3.64	58.8
Prusy	0.203	0.124	4.57	27.1	4.06	60.3	0.172	0.099	4.75	20.9	3.34	56.8
LSD $_{P\leq0.05}$	0.0345	0.0227	0.495	NS	NS	3.11	0.0272	0.0173	0.384	NS	0.361	3.04
Cultivar												
cv. 'Adam'	0.205	0.127	4.70	26.9	3.92	61.3	0.170	0.103	4.32	23.5	3.65	59.5
cv. 'Poznaniak'	0.209	0.124	5.16	24.1	3.76	59.1	0.175	0.103	4.93	21.1	3.49	58.8
LSD $_{P\leq0.05}$	NS	NS	0.336	2.59	NS	2.11	NS	NS	0.261	1.98	NS	NS
Crop layer												
Lower	0.198	0.116	4.63	25.1	3.71	58.3	0.169	0.099	4.53	22.0	3.41	58.2
Middle	0.234	0.145	5.13	28.3	3.93	62.1	0.193	0.118	4.73	24.9	3.71	60.6
Upper	0.189	0.116	5.04	23.1	3.88	60.1	0.156	0.093	4.61	20.1	3.59	58.8
LSD $_{P\leq0.05}$	0.0345	0.0227	0.495	3.82	NS	3.11	0.0272	0.0173	NS	2.91	NS	NS

NS – not significant

The number of seeds developed in a single silique of winter oilseed rape differed depending on the cultivar and biosocial position in the layer of the stand (Table 4). Additionally, it was shown that the number of seeds in siliques was effected by interaction between years and cultivars determined on the main shoot, and of interaction between varieties and locality determined on the lateral shoot (Fig. 6). In the 2011/2012 vegetation season, the cv. 'Adam' developed significantly more seeds per single silique. The cv. 'Adam' developed less seeds in Głubczyce. It seems that the lower number of seeds wasn't the causative factor in lowering the silique harvest, as presented in Fig. 5.

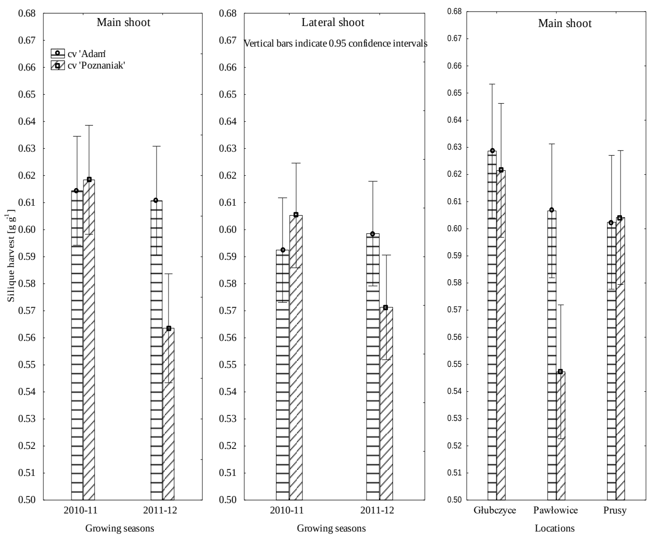

Figure 5. The changes in silique harvest as an effect of the interaction between growing seasons and cultivars in the main and lateral shoot, and of interaction between cultivars and locations in the lateral shoot

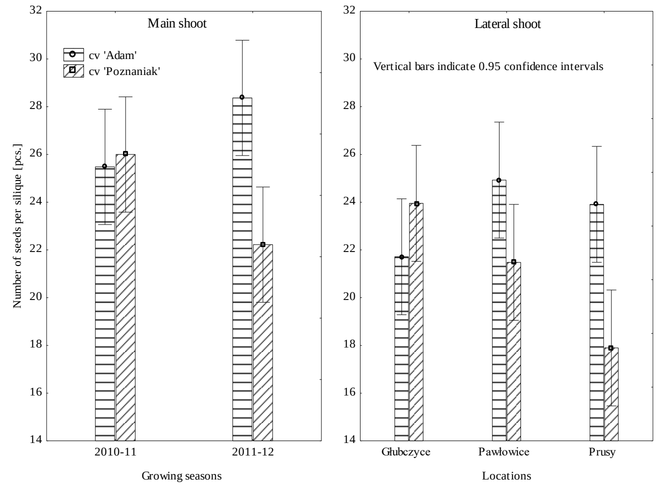

Figure 6. The changes in the number of seeds per silique as an effect of the interaction between growing seasons and cultivars determined on the main shoot, and of interaction between cultivars determined on the lateral shoot

The silique harvest also showed great diversity, depending on the studied experimental factors and their mutual interactions (Tables 2, 4, Fig. 5). In Głubczyce, the siliques of rape plants had a high silique harvest both on the main and lateral shoots. Furthermore, the differences in the silique harvest occurred between the cultivars in particular years of study. A significantly greater silique harvest was obtained in the cv. 'Adam' in the second year of the study (Fig. 5).

The basic chemical composition of the seeds of particular cultivars of winter rape was based on the analysis of the total protein, crude fat, nitrogen-free extract, crude fibre, and ash content. It demonstrated that the main experimental factors had relatively little effect on the concentrations of total protein in seeds (Table 5). The highest amounts of total

Table 5. Comparison of rapeseeds basic chemical composition (% DM) depending on the cultivar, location, the growing season and position of fruits in crop layers

Treatments	Ash	Crude fat	Crude fiber	Total protein	Nitrogen-free extract
Locality					
Głubczyce	6.83	39.30	7.14	26.38	20.35
Pawłowice	7.19	41.77	8.05	26.00	17.00
Prusy	7.44	42.43	8.42	25.67	16.03
LSD $_{P\leq0.05}$	0.447	1.506	0.456	NS	1.017
Cultivar					
cv. 'Adam'	7.50	40.59	8.05	25.89	17.96
cv. 'Poznaniak'	6.80	41.75	7.69	26.14	17.62
LSD $_{P\leq0.05}$	0.304	1.023	0.310	NS	NS
Crop layer					
Botton	7.32	39.07	8.02	26.26	19.33
œMiddle	7.03	42.07	7.88	25.77	17.26
Top	7.10	42.36	7.72	26.03	16.79
LSD $_{P\leq0.05}$	NS	1.506	NS	NS	1.017

NS – not significant

protein were accumulated in seeds of rape cultivated in Głubczyce. At the same time, the seeds from this locality had a lower crude fat content. The crude fat content in the seeds of rape was significantly dependent on the locality, cultivar and the biosocial position of the siliques (Tables 2, 5). The rape seeds from Głubczyce had a lower fat content, and the highest amount of fat occurred in the upper layer, followed by seeds from the middle layer (Table 5). Additionally, the combined effect of years and location, as well as years and cultivars were shown (Fig. 7). In the first vegetation season, the 'Poznaniak' cultivar provided significantly more fat. Significantly more fat was obtained in Pawłowice in the first year of vegetation whereas in the second year of vegetation, significantly more fat was obtained in Prusy.

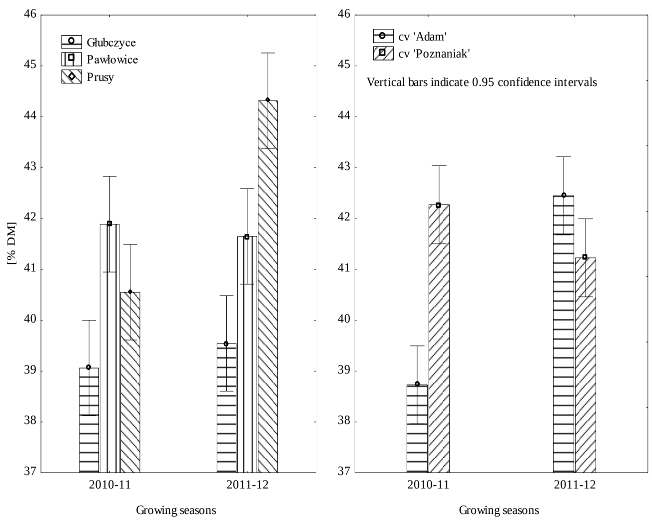

Figure 7. The changes in fat content in rape seeds as the effect of interactions between cultivars and locations with growing seasons.

The proportion of saturated fatty acids in rapeseed oil indicates little changes resulting from the situation of seeds in the selected layers of the rapeseed crop stand (Table 6). The data presented in Table 6 implies that the highest diversities among the profiles of saturated fatty acids in rapeseed oil resulted from the properties of particular cultivars. The 'Poznaniak' cultivars had a significantly higher content of all these acids (Table 6, Fig. 8). A direct comparison of the profiles indicates that the 'Poznaniak' cultivar has better quality fat.

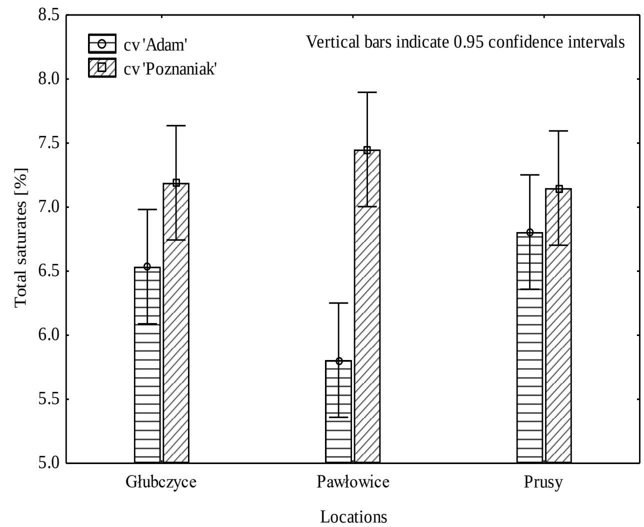

Figure 8. The proportion of saturated acids in rapeseed oil as an effect of the interaction between cultivars and locations.

The weakest and most insignificant effect on the profile of unsaturated fatty acids in rapeseed oil was exerted by the

Table 6. Comparison of saturated fatty acid profile (%) of rapeseed oil, depending on the cultivar, location, the growing season and the position of fruits in crop layers

Treatments	$C_{10:0}$	$C_{12:0}$	$C_{14:0}$	$C_{15:0}$	$C_{16:0}$	$C_{17:0}$	$C_{18:0}$	$C_{20:0}$	Total saturates
Locality									
Głubczyce	0.020	0.030	0.089	0.033	4.66	0.049	1.55	0.429	6.86
Pawłowice	0.018	0.027	0.089	0.034	4.35	0.048	1.62	0.441	6.63
Prusy	0.025	0.034	0.093	0.034	4.53	0.044	1.74	0.465	6.96
LSD $_{P\leq0.05}$	NS	NS	NS	NS	0.246	NS	NS	NS	NS
Cultivar									
cv. 'Adam'	0.019	0.023	0.067	0.027	4.09	0.042	1.64	0.457	6.37
cv. 'Poznaniak'	0.023	0.038	0.114	0.040	4.93	0.052	1.63	0.433	7.26
LSD $_{P\leq0.05}$	0.0044	0.0096	0.0253	0.0072	0.201	0.0049	NS	NS	0.253
Crop layer									
Lower	0.022	0.031	0.092	0.036	4.62	0.051	1.59	0.459	6.90
œMiddle	0.021	0.031	0.087	0.033	4.43	0.045	1.64	0.434	6.72
Upper	0.020	0.029	0.092	0.032	4.48	0.045	1.69	0.443	6.83
LSD $_{P\leq0.05}$	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS – not significant

Table 7. Comparison of unsaturated fatty acid profile (%) of rapeseed oil, depending on the cultivar, location, the growing season and the position of fruits in crop layers

Treatments	**$C_{14;1}$**	**$C_{16;1}$ n-9**	**$C_{16;1}$ n-7**	**$C_{17;1}$**	**$C_{18;1}$ n-9**	**$C_{18;1}$ n-7**	**$C_{18;2}$ n-6**	**$C_{18;3}$ n-6**	**$C_{18;3}$ n-3**	**$C_{20;1}$**	**Total unsaturales**	**Ration *n-6:n-3***
Locality												
Głubczyce	0.006	0.061	0.213	0.061	59.32	4.29	18.88	0.003	9.33	0.974	93.1	2.03
Pawłowice	0.004	0.057	0.207	0.060	59.87	4.30	18.99	0.002	8.82	1.057	93.4	2.16
Prusy	0.004	0.055	0.206	0.051	61.11	4.15	17.67	0.003	8.84	0.958	93.0	2.01
LSD $_{P\leq0.05}$	NS	NS	NS	0.0074	NS	NS	1.095	NS	NS	NS	NS	NS
Cultivar												
cv. ‘Adam’	0.003	0.055	0.178	0.056	62.47	3.94	17.40	0.002	8.53	1.000	93.6	2.05
cv. ‘Poznaniak’	0.006	0.060	0.239	0.059	57.73	4.55	19.63	0.003	9.47	0.993	92.7	2.09
LSD $_{P\leq0.05}$	NS	NS	0.0285	NS	1.553	0.506	0.894	NS	0.666	NS	0.25	NS
Crop layer												
Lower	0.006	0.064	0.232	0.057	59.55	4.39	18.71	0.003	9.03	1.058	93.1	2.09
œMiddle	0.004	0.056	0.198	0.059	60.55	4.15	18.44	0.003	8.85	0.979	93.3	2.09
Upper	0.004	0.053	0.196	0.056	60.21	4.20	18.38	0.002	9.12	0.952	93.2	2.03
LSD $_{P\leq0.05}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS – not significant

layers of the stand which proved that a variable situation of seeds in the crop stand did not change the biosynthesis of fatty acids (Table 7). The properties of particular cultivars resulted in significant differences in the content of some unsaturated fatty acids (the seeds of ‘Adam’ cultivar had a higher content of C:18;1). In the oil from this cultivar, the total UFA content was higher. The location of the experiment had a relatively weak effect on the profile of fatty acids in rapeseed oil, and the significant differences were fairly small. In Prusy, the proportion of C:18:2 from the *n-6* family was lower by c. 1%.

DISCUSSION

Among the oilseed plant species belonging to cabbage family, rape is the most important in economic terms in Central Europe because of its high yield potential. The role of basic components of seed yield structure in plants and crop productivity, especially winter rape form, has been known for a long time. Intense cultivation work on the rape caused that high-yielding varieties were formed – first population and recently hybrid ones. For these reasons, the hybrid cultivar was considered in this study. The components of the yield depending on their biosocial localization on the shoot were determined to recognize in a better manner the determination of plant and crop productivity enabling improvement of cultivation technology. It was demonstrated in the study that new hybrid cultivars of winter rape, ‘Adam’ and ‘Poznaniak’, formed similar green area index (GAI). The size of crop green assimilation area mainly depended on location where the study was carried out and climatic conditions in particular vegetation seasons. Mean GAI values (2.65 m^2 m^{-2}) were obtained in southern Poland area (Prusy), while the record results (4.59 m^2 m^{-2}) were found in south-western Poland area (Głubczyce), which means that rape crop in this location was especially well developed and absorbed most of available *photosynthetically* active radiation (PAR). The second year of vegetation, characterized by higher sunlight exposure and temperature, allowed to obtain significantly bigger green leaf assimilation area, which was reflected by significantly higher siliques weight. Similar results were obtained by Hunkova *et al.* (2011), who demonstrated high correlation of integral leaf area (LAD) with the number of siliques per plant (0.7). It was shown in the study conducted by Zając *et al.* (2016) on the rape of ‘Adam’ and ‘Poznaniak’ varieties that the growth and development rate of the seeds was an effect of siliques position on the shoot. In turn, unit weight of seeds was mainly conditioned by fruits arrangement on the shoot. It was found that higher seeds weight in an initial stage of fruits formation was obtained from the siliques formed on lateral shoots. However, in the final phase of vegetation, higher seed yield was obtained from the siliques derived from the main shoot of rape plant. This pattern of results suggested that the emphasis in the production model of plants should be placed on the development of the main shoot, and the productivity of the lateral branches should be reduced. This study partially confirms the conclusions of Batool *et. al.* (2013) concerning the effect of silique position in the main stem on plant productivity. It was demonstrated that siliques position reflected in higher number and weight of seeds derived from these fruits, are observed at the bottom of main stem. Similar results related to winter rape were obtained by Zając *et al.* (2011), who found that length and width of these fruits depend on their localization on specified category of shoots – main and lateral. The authors’ found higher number of siliques formed in the main shoot (middle part) of rape, compared to lateral shoots. High differentiation was demonstrated in the number of siliques depending on shoot localization within the plant. Khan and Khalil (2008) demonstrated that the number of siliques formed on the shoot of rape cultivated in Pakistan was positively correlated with the number of seeds in the silique, length of siliques as well as single plant seeds yield. Fu *et al.* (2015) revealed an existence of positive relationship between the number of seeds from silique and its length. In addition, the authors suggest that long silique has the potential to increase seed weight. It is considered that the number of siliques in rape crop is conditioned by an occurrence of significant genotype-environment interaction (Iqbal *et al.,* 2014; Fu *et al*., 2015). The results of the studies correspond partially to the results of our study, because we proved significant differences between cultivars in siliques productivity. The positive relationship of siliques length to the weight of seeds from siliques, as well as siliques weight to seeds weight from the siliques was obtained in the study of Zając *et al.* (2011) on rape and mustard. The siliques of large and very large classes had higher number of finer seeds in rape and mustard. Moreover, the authors proved that the siliques localized on the main shoot of each compared species are characterized by longer vegetation period, which is related to the seed heads in the bottom part and good lightning. The arrangements made recently by Inayt-ur-Rahman *et al.* (2009) demonstrated that the length of silique peduncle determines the shape of silique, since formation of shorter peduncles positively affects an increase in seeds weight in the silique. The study of Zając *et al.* (2011) confirmed the observations of Ahmad *et al.* (2008) who reported a significant differentiation in the length of peduncles on the main shoot and lateral branches. It was proved that more massive siliques formed on the main shoot of winter rape had shorter peduncles compared to white mustard siliques. Above observations were confirmed in this study, proving that environmentally conditioned length of peduncles differentiates silique productivity. The longest peduncles were formed by less productive cultivar (‘Poznaniak’) in bottom crop layer. Li *et al.* (2014) obtained a significant differentiation in siliques on the shoot depending on sowing density, and the total number of siliques from the plant was increasing with the density increase. Bennett *et al.* (2012) suggest that shoot architecture has a substantial impact on the portioning of reserves between vegetative and reproductive tissues and is an important trait of yield formation. Removal of lateral branches resulted in a stimulation of elongation of the primary inflorescence and an increase in the distance between siliques.

Zając *et al.* (2011) pointed that hybrid varieties of rape (*Brassica napus* L.) are characterized by huge yielding potential, which is mainly affected by the breeding progress observed over the last two decades. The process of yield formation in winter rape was determined by its agricultural and biological properties. Sidlauskas and Bernotas (2003) emphasized that highly variable seeds yield of spring rape form was conditioned by genetic, environmental and agro-technical factors, as well as their mutual relationships. It is emphasized that biological yield of winter rape form depends on the length of vegetation season creating the harvest index variable over the years (Zirgoli and Kahrizi, 2015). Also Rathke *et al.* (2005) claim that the harvest index (HI) is the main indirect parameter determining the seeds yield, and this index value is highly differentiated (from 0.28 to 0.50). This quotient feature was not analyzed in the study with respect to the crop, and only the share of seeds in single silique mass was determined. We found that silique harvest is relatively stable, since for the main shoot it is between 57 and 62.5%, and for lateral shoots between 56.8 and 62.0%. Number of seeds formed on 1 cm of the length of fruit part with the seeds was lower in the fruits from bottom part of the crop, but the differences were not statistically significant.

Marjanović-Jeromela *et al.* (2008) observed that the length of main shoot, as well as lateral ones, affected the yield of seeds from rape plant. This was confirmed in the study of Zając *et al.* (2011), since higher number of siliques, and thus higher yield of the seeds from the single plant, was obtained from the main shoot that was the longest. However, the reverse tendency was observed in the compared species. Longer shoots, mainly these of mustard, did not form considerably higher number of siliques, and fruits number per length unit (10 cm) was lower in this species. According to Rad *et al.* (2014), the weight of seeds is considered as an important yield-forming element determined by genotype-environmental interaction. This was confirmed in this study, which proved that habitat conditions significantly affected rape seeds weight. In Głubczyce, rape siliques were characterized by the reduced weight of the whole fruits as well as the seeds evaluated on the level of silique or single seed. Localization in crop layer strongly influenced the weight of rapeseeds. The most robust fruits were developed in the middle layer, probably due to their earlier development compared to the top crop layer, which developed last, which shortened the time of maturation stage. Noticeably lower number of seeds developed in siliques was formed on the lateral shoots. The weight of single rapeseed was higher on the main shoot compared to lateral one. The number of seeds per 1 cm of the length of fruit part with seeds was insignificant; however, the siliques from lateral shoots were characterized by slightly lower number of seeds per specified unit of rape fruit length.

The constant direction in rape cultivation is work to increase oil content in the seeds (Delourne *et al.*, 2006). Guan *et al.* (2012) quote: “Oilseed rape (*Brassica napus*) is the third leading source of vegetable oil for human consumption in the world. Some long-standing cultivated oilseed rape varieties produce oils that contains 55–60% oleic acid (C18:1), 20% linoleic acid (C18:2) and 10% linolenic acid (C18:3), but are very low in erucic acid (C22:1) and glucosinolate”. It was demonstrated in this study that localization of siliques and seeds in a specified crop layer determined basic chemical composition of the seeds. These findings were partially confirmed by Batool *et al.* (2013). Authors proved that oil content from seeds of lowest siliqua position was maximum (48.5%) and decreased constantly to the top, giving the minimum (40%) oil content. This study is contradicted to research by Hua *et al.* (2012) suggesting that an increase in the temperature and lightning of the crop significantly improves fat content in rapeseeds.

Fatty acids profile in rapeseed oil mainly depended on the features of winter rape varieties, while environmental factors (fruit localization in a given layer, agro-climate of location in particular years) have low impact. Hybrid varieties of winter rape compared in this study differed in the share of saturated and unsaturated fatty acids in oil. Higher amount of unsaturated fatty acids in oil was found in 'Adam' cultivar and because of this it is recommended for cultivation, since the number of seeds in both siliques varieties – 'Adam' and 'Poznaniak', was similar.

The level of saturated fatty acids was significantly differentiated by the weather conditions. The level of C16:0 acid in oil was significantly higher, and the level of C18:0 acid slightly lower, in Prusy characterized by high temperatures during vegetation season. Our results are consistent with the study of Joughi *et al.* (2018) whose found that the content of C16:0 and C18:0 in the fatty acids profile is conditioned by the weather. The authors proved that high temperature during rape vegetation contributes for formation of fat with lower amount of C18:0 acid and an increased level of C16:0 and C18:3 acids.

***Conclusions*:** Siliques localization in the specified rape layer had some production consequences. The longest siliques were formed in the middle part, both on main and lateral shoots. Among the compared varieties, longer siliques were formed by 'Adam' cultivar. Productivity of single silique was strongly differentiated by the main factors. Biosocial localization of the siliques in the middle layer of the infructescence caused that these seeds formed the highest seed weight and also the number of seeds in the fruits from this layer was the highest. The lowest weight of single seed was obtained from the bottom layer. Silique harvest was similar, however the most profitable values for this index were observed in Głubczyce. Crude fat content in rapeseeds was the lowest for the seeds derived from siliques bottom layer. Biosocial localization of the siliques did not affect fatty acids profile of rapeseed oil, which was strongly dependent on cultivar features, and poorly on the years of vegetation.

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