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ORIGINAL PAPER

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YIELD OF SOYBEAN (*Glycine max* (L.) Merr.) IN THE HABITAT CONDITIONS OF PODKARPACKIE VOIVODESHIP

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ABSTRACT

Background. Soybean is a thermophilic plant and is sensitive to unfavourable environmental factors. Therefore, the yield obtained varies depending on the growth location and study years. Habitat conditions in the south-eastern part of Poland are conducive to soybean cultivation, however, in other regions of the country satisfactory production can be limited by unfavourable weather conditions. The aim of the work was to evaluate the yield of soybean, cultivars Merlin and Lissabon, at three locations in the Podkarpackie Voivodeship. It was found that the number of pods per plant was the most flexible and the number of seeds per pod was inflexible. Both varieties reacted in the same way to the factors studied.
Material and methods. Field experiments with the soybean cultivars Merlin and Lissabon were set up in the years 2016-2018. Experiments were carried out in three experimental stations in the Podkarpackie Voivodeship. Cultivars Merlin and Lissabon (Saatbau Poland Ltd.) give high and stable seed yield in the study region. Weather conditions are given according to the records of the Meteorological Station PAAC in Boguchwała (hot and dry) and the Meteorological Stations ESCA Przecław (warm and wet) and EDCA Nowy Lubliniec (warm and dry). Soil sample analysis was carried out at the laboratory of the District Chemical-Agricultural Station in Rzeszów.
Results. The cultivar Merlin, in comparison to the cultivar Lissabon, was characterized by a significantly higher plant density before harvest and crude fat content in the seeds, and by a significantly lower number of pods per plant and 1000 seed weight. The average soybean yield at ESCA Przecław, PAAC Boguchwała and EDCA Nowy Lubliniec was 4.18, 3.85 and 2.93 $Mg \cdot ha^{-1}$, respectively. In 2018, the highest protein content in grain and protein yield were obtained. In 2017, the highest amount of crude fat in seeds was found, but the fat yield was the lowest.
Conclusion. The quantity and quality of soybean seed yields were diversified according to the location of the experiment. Also, changing weather conditions in the study years had a significant effect on the studied characteristics and parameters. However, no significant differences were observed in seed yield between the cultivars (Merlin and Lissabon) depending on the study years. It is important to recommend varieties for a given region.

Key words: chemical composition of seeds, cultivar, environment, habitat, yield, yield components

INTRODUCTION

Soybean is one of the most important cultivated plants in the world. Its largest producers are the United States of America, Brazil, and Argentina (Meade *et al.*, 2016). The European Union, on the

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other hand, imports soybean as a component for the fodder industry. In Poland the demand for plant protein is high and national imports amount to circa two million tons of post-extraction soybean meal per year (Woźniak and Twardowski, 2018). In recent years in the European Union, including Poland, interest in soybean production has increased. This is the result of financial support for the production of legumes. Also, studies on the choice of the best cultivars to grow and the optimization of their agricultural engineering have been intensified. Research to date indicates that an increase in the acreage of soybean in Poland is possible. The yields obtained, however, varies according to many factors (Jarecki and Bobrecka-Jamro, 2019). As a result, a cultivar is usually recommended for a specific region (Jandong *et al*., 2019). Samarakoon and Yapa (2019) found that improved agricultural engineering solutions can lead to an improvement in soybean yield quantity and quality. Depending on the applied inorganic and/or organic fertilizers they obtained significant difference in both quantity and quality of seed yield. Oya *et al.* (2004) and Battisti and Sentelhas (2015) demonstrated that soybean yield is significantly limited by drought stress, although the obtained decrease depended on the cultivar. The selection of suitable soybean cultivars for specific environmental conditions makes it possible to offer the best genotypes for existing agricultural practice (Tyagi *et al*., 2011; Ngalamu *et al*., 2013). Alghamdi (2004) concluded that the interaction between the genotype and the environment plays an important role in the success of all breeding programmes. In the study conducted by Rao *et al*. (2002), the average soybean yield varied between 2.0 $Mg \cdot ha^{-1}$ and 3.0 $Mg \cdot ha^{-1}$ depending on the cultivation location and the study year. However, some varieties have been found to have a stable yield in different environments and years. Tukamuhabwa *et al*. (2002) reported that the yield loss due to seed shedding ranged from 0 to 186 $kg \cdot ha^{-1}$ depending on the genotype, experiment location, season and harvest date. Djanaguiraman *et al*. (2013) demonstrated that high temperature during the day (39/20°C) or at night (30/29°C) decreased pod numbers per plant and mass of 1000 seeds. In this kind of situation the selection of tolerant cultivars is of particular importance for growth.

MATERIAL AND METHODS

In the years 2016–2018, field experiments with soybean cultivars Merlin and Lissabon were set up. They were carried out in three locations of the Podkarpackie Voivodeship: Experimental Station for Cultivar Assessment in Przecław (ESCA Przecław) – 21°47' E; 50°19' N, Experimental Department of Cultivar Assessment in Nowy Lubliniec (EDCA Nowy Lubliniec) – 23°09' E; 50°29' N, and Podkarpackie Agricultural Advisory Centre in Boguchwała (PAAC Boguchwała) – 21°93' E; 49°99' N. In Nowy Lubliniec, the study was carried out as Post-registered Cultivar Experimentation. In Przecław and Boguchwała the experiments were carried out as part of the multiannual programme 2016-2020 by the Ministry of Agriculture and Rural Development entitled 'Increasing the use of domestic fodder protein for the production of high-quality animal products in the conditions of sustainable development'.

The above were two-factor experiments carried out in four repetitions. Cultivars Merlin and Lissabon (Saatbau Poland Ltd.) give high and stable seed yield. Humidity and thermal conditions were given according to the records of the Meteorological Station PAAC in Boguchwała and the Meteorological Stations ESCA Przecław and EDCA Nowy Lubliniec. Soil sample analysis was carried out at the accredited laboratory of the District Chemical-Agricultural Station in Rzeszów, according to Polish norms. Diversification of soil conditions in which the experiments were carried out is presented in Table 1.

Soybean cultivation was carried out according to the methodology developed by the Research Centre for Cultivar Testing in Słupia Wielka. A single plot area was 15 m^2, row spacing was 25 cm, and sowing depth was 3.5 cm. Seeds were sown in the amount of 70 $seeds \cdot m^{-2}$. Winter or spring cereals were the forecrop. Sowing of originally pelleted seeds was carried out in the last 10 days of April. Phosphorus and potassium fertilization was applied before sowing and the doses depended on soil richness. Nitrogen was applied before sowing at the dose of 30 $kg \cdot ha^{-1}$. The seeds were inoculated. Soybeans had previously been grown on the experimental fields in all of the locations. Weeds (Afalon Dispersive 450 S.C. – linuron, was used at a dose of 1.5 $dm^3 \cdot ha^{-1}$)

and pests (Mospilan 20SP – acetamiprid, was used at a dose of 0.2 $dm^3 \cdot ha^{-1}$) were controlled with the use of chemical plant protection. Pesticides were used as an aqueous solution in an amount of 250 $dm^3 \cdot ha^{-1}$. Chemical treatment against diseases was not applied. At technical maturity (BBCH 88), plant density was calculated per 1m^2 and 20 plants were randomly collected for biometric measurements. Seed harvest was carried out once at full ripeness (14.09.2016, 11.09.2017, 18.09.2018). Seed yield from the plot was calculated up to an area of 1 ha, taking into account 14% humidity. Fat content in the seeds was determined using the Soxhlet method. Total protein content was evaluated using the Kjeldahl method. Based on seed yield and the contents of the components, biological yields of crude fat and total protein per area were calculated.

The obtained data were statistically processed by the analysis of variance with the FR-ANALWAR-5FR program. Significance of the differences between average values of the characteristics was tested based on Tukey's confidence limits at $P < 0.05$. Due to the lack of interaction between the study factors the results are not given in the tables.

Table 1. Soil conditions (average from the study years)

Parameter		PAAC Boguchwała	ESCA Przecław	EDCA Nowy Lubliniec
Agronomic category of soil		medium	medium	light
Agricultural usefulness soil complex		good wheat	very good wheat	good rye
Soil class		IIIa	II	IVa
Soil pH in 1 M KCl		6.53	6.94	6.35
P_2O_5		18.3	18.7	17.9
K_2O	$mg \cdot 100\ g^{-1}$ soil	22.4	20.6	16.5
Mg		7.6	8.1	6.8

RESULTS AND DISCUSSION

From April to June 2016 moderate precipitation was noted, which was conducive to plant growth and development. July was very humid in all of the locations. In the subsequent two months precipitation was moderate. From April to September, the highest total precipitation was noted at ESCA Przecław. Air temperature in that period did not diversify much between the locations. In April, the average temperature was nearly 10°C, and persistent high temperatures in May made uniform plant emergence possible. July was the warmest month (Table 2). Kania *et al*. (2016), after conducting an economic and production analysis, stated that under more adverse weather conditions rapeseed gives higher yield than soybean. Bury and Nawracała (2004) confirmed that soybean growth, development, and yield to a large extent depends on the weather conditions. The low yields that they obtained was a result, among others, of low precipitation in the study years.

In 2017, total precipitation from April to May was higher at ESCA Przecław and PAAC Boguchwała. In all of the locations precipitation was high in September and at ESCA Przecław it was also high in May. Average temperatures were similar in all the locations. The warmest month in 2017 was August (Table 3).

In 2018, low precipitation occurred in April. In the subsequent months it was diversified depending on the month and location. The highest total precipitation from April to September was noted at EDCA Nowy Lubliniec. Average temperatures in 2018 were high. In July only at ESCA Przecław was a lower temperature (16.8°C) recorded (Table 4).

Table 2. Weather conditions in 2016

Month	Total precipitation, mm			Average temperature, °C		
	PAAC Boguchwała	ESCA Przecław	EDCA Nowy Lubliniec	PAAC Boguchwała	ESCA Przecław	EDCA Nowy Lubliniec
April	59	55	77	9.8	9.8	9.9
May	34	42	63	13.9	14.1	13.6
June	39	24	56	18.7	18.6	18.4
July	103	152	99	19.2	19.0	19.4
August	59	68	38	17.9	17.6	18.3
September	40	45	40	15.4	14.7	15.0
Period of time	334	386	373	15.8	15.6	15.8

Table 3. Weather conditions in 2017

Month	Total precipitation, mm			Average temperature, °C		
	PAAC Boguchwała	ESCA Przecław	EDCA Nowy Lubliniec	PAAC Boguchwała	ESCA Przecław	EDCA Nowy Lubliniec
April	55	78	37	8.2	7.5	7.5
May	86	112	41	13.5	13.7	12.8
June	41	42	45	18.4	18.7	17.9
July	95	44	78	18.7	18.4	18.6
August	95	84	25	19.6	18.6	19.2
September	107	111	129	13.8	14.0	13.8
Period of time	479	471	355	15.4	15.2	15.0

Table 4. Weather conditions in 2018

Month	Total precipitation, mm			Average temperature, °C		
	PAAC Boguchwała	ESCA Przecław	EDCA Nowy Lubliniec	PAAC Boguchwała	ESCA Przecław	EDCA Nowy Lubliniec
April	17.7	16	25	13.8	13.0	13.2
May	80.5	69	53	16.3	16.1	16.0
June	44.6	47	120	18.2	18.4	18.1
July	82.7	108	101	19.3	16.8	20.6
August	54.9	97	38	19.8	20.1	20.1
September	19.4	51	127	15.1	15.2	15.0
Period of time	299.8	388.0	464.0	17.1	16.6	17.2

Average soybean seed yield in the experiment was 3.65 Mg·ha^{-1}. The studied cultivars did not differ significantly in regards to this parameter. However, it ought to be noted that yields were diversified in the study years as the habitat conditions modified soybean yield. On average the highest seed yield was obtained at ESCA Przecław, while it was significantly lower at PAAC Boguchwała, and was the lowest at EDCA Nowy Lubliniec. The obtained difference between ESCA Przecław and EDCA Nowy Lubliniec amounted to 1.25 Mg·ha^{-1}, and the difference between PAAC Boguchwała and EDCA Nowy Lubliniec amounted to 0.92 Mg·ha^{-1}. Seed yield quantity varied between the study years.

In 2017 the average soybean yield was lower by 0.88 Mg·ha^{-1} in comparison to 2018 and by 0.72 Mg·ha^{-1} in comparison to 2016 (Table 5). According to Fried *et al*. (2019) and Narayanan and Fallen (2019), the main environmental factor that limits soybean yield is drought. Therefore, it is important to search for cultivars which are tolerant to abiotic and biotic stress. Śliwa *et al*. (2015) also indicated that habitat conditions determine soybean development and yield. Depending on the study location, they obtained seed yield from 1.55 Mg·ha^{-1} to 2.65 Mg·ha^{-1}. Njoroge *et al*. (2015) and Jandong *et al*. (2019) stated that in field experiments a significant interaction between the cultivar and the environment occurs. This makes it possible to select the best genotypes for actual agricultural practice. Okpara and Ibiam (2000) and Fenta *et al*. (2014) concluded that the high soybean seed yield in the case of some cultivars is indeed a results of adaptation to a given habitat. In our study, the varieties reacted in the same way to the varied locations of the experiment.

Table 5. Seed yield (Mg·ha^{-1})

Factor	2016	2017	2018	Average
		Cultivar		
Merlin	3.63^{b}	3.25^{b}	3.98^{a}	3.62^{a}
Lissabon	4.04^{a}	2.99^{a}	4.01^{a}	3.68^{a}
		Location		
PAAC Boguchwała	4.19^{a}	3.01^{b}	4.36^{a}	3.85^{b}
ESCA Przecław	4.38^{a}	3.62^{a}	4.53^{a}	4.18^{a}
EDCA Nowy Lubliniec	2.94^{b}	2.73^{c}	3.12^{b}	2.93^{c}
		Years		
Average	3.84^{a}	3.12^{b}	4.00^{a}	3.65

Cultivar Merlin was characterized by higher plant density before harvest than cultivar Lissabon. Pod number per plant and mass of 1000 seeds were significantly higher for cultivar Lissabon. Yield components were diversified by the changeable habitat conditions. The highest plant density before the harvest was obtained at EDCA Nowy Lubliniec and was significantly lower at PAAC Boguchwała. Pod number per plant was the highest at ESCA Przecław, significantly lower at PAAC Boguchwała, and the lowest at EDCA Nowy Lubliniec. The highest number of seeds per pod and 1000 seed weight were obtained at ESCA Przecław and PAAC Boguchwała, respectively. Yield components were also diversified within the study years. The highest mass of 1000 seeds was obtained in 2018, in comparison with the earlier years (Table 6). Nwofia *et al*. (2016) demonstrated that from among the factors that determine soybean seed yield the number of pods per plant is the most important. Kobraee and

Shamsi (2011) indicated that during drought stress the seed number per plant played an important role in seed yield modification. Śliwa *et al.* (2015) reported that soybean pods collected in three different locations did not differ significantly regarding seed length, mass, number, or robustness. Thus, habitat conditions did not affect those characteristics.

Table 6. Yield components (average from the study years)

Factor	Plant density before harvest (pcs.·m^{-2})	Pod number per plant	Seed number per pod	Mass of 1000 grains (g)
Cultivar				
Merlin	61.4^{a}	18.0^{b}	2.02^{a}	164.2^{b}
Lissabon	56.9^{b}	19.4^{a}	1.91^{a}	176.4^{a}
Location				
PAAC Boguchwała	57.2^{b}	18.9^{b}	1.94^{ab}	186.4^{a}
ESCA Przecław	58.7^{ab}	20.2^{a}	2.07^{a}	167.6^{ab}
EDCA Nowy Lubliniec	61.6^{a}	17.0^{c}	1.89^{b}	156.9^{b}
Years				
2016	62.1^{a}	19.5^{a}	1.99^{ab}	164.1^{b}
2017	56.1^{b}	17.9^{b}	1.87^{b}	166.5^{b}
2018	59.3^{ab}	18.7^{ab}	2.04^{a}	180.3^{a}
Total average	59.2	18.7	1.97	170.3

In the studied cultivars total protein content in seeds and protein yield was on the same statistical level. Crude fat content was higher in the seeds of cultivar Merlin in comparison with cultivar Lissabon. However, there was no difference in fat yield between the varieties. Seeds obtained from the experiment located at PAAC Boguchwała were characterized by high total protein content and low crude fat content. This is due to the dry and hot weather conditions experienced there. Total protein yield and crude fat yield were high at ESCA Przecław and significantly lower at EDCA Nowy Lubliniec. Protein content in seeds and protein yield were the highest in 2018 and significantly lower in 2017. The fat yield was the lowest in 2017, even though fat content in seeds was the highest (Table 7). Jakubus *et al.* (2015) indicated that the method of cultivation determines the chemical composition of soybean seeds and that better effects are obtained by sowing soybean in rotation as compared to those from under monoculture.

Śliwa *et al.* (2015) reported that the chemical composition of soybean seeds varied depending on the experiment location and that higher total protein content and lower crude fiber content were determined in soybean seeds collected in the conditions of south-western Poland. Biel *et al.* (2017) found that the chemical composition of soybean seeds depended first of all on the cultivar and the weather conditions. Gurmu *et al.* (2009) claimed that stable protein and fat contents in soybean seeds depends first of all on the cultivar, and to a lesser extent on other factors (years, agrotechnical treatments). However, in the case of several cultivars, the above mentioned authors demonstrated a lack of stability of the chemical composition of seeds depending on the location and the study years. Mertz-Henning *et al.*

(2018) obtained a negative relation between protein and oil contents and between protein content in the seeds and protein yield. Sinclair *et al.* (2007) indicated that symbiotic binding of atmospheric nitrogen (N_2) decreases with water shortage in the soil. An effect of this is a soybean yield lower and poorer in quality being obtained, especially with cultivars sensitive to water deficit.

Table 7. Chemical composition of seeds, total protein yield and crude fat yield (average from the study years)

Factor	Total protein (%)	Protein yield (kg·ha^{-1})	Crude fat (%)	Fat yield (kg·ha^{-1})
		Cultivar		
Merlin	36.8^{a}	1332.2^{a}	22.4^{a}	810.9^{a}
Lissabon	36.7^{a}	1350.6^{a}	21.1^{b}	776.5^{a}
		Location		
PAAC Boguchwała	37.5^{a}	1443.8^{ab}	20.9^{b}	804.7^{ab}
ESCA Przecław	36.7^{b}	1534.1^{a}	22.1^{a}	923.8^{a}
EDCA Nowy Lubliniec	36.2^{b}	1060.7^{b}	22.3^{a}	653.4^{b}
		Years		
2016	36.2^{b}	1390.1^{b}	21.8^{ab}	837.1^{a}
2017	33.7^{c}	1051.4^{c}	22.7^{a}	708.2^{b}
2018	40.4^{a}	1616.0^{a}	20.9^{b}	836.0^{a}
Total average	**36.8**	**1352.5**	**21.8**	**794.0**

CONCLUSIONS

1. Cultivars Merlin and Lissabon did not differ significantly in seed, protein, and fat yields. Cultivar Merlin in comparison with cultivar Lissabon was characterized by significantly higher plant density before harvest and crude fat content in seeds and by a significantly lower pod number per plant and mass of 1000 seeds.
2. Depending on the location a significant diversification in seed yield, yield components, seed chemical composition, protein yield, and fat yield was obtained. Average soybean yield at ESCA Przecław was 4.18 Mg·ha^{-1}. A significantly lower yield was obtained at PAAC Boguchwała and EDCA Nowy Lubliniec, by 0.33 Mg·ha^{-1} and 1.25 Mg·ha^{-1}, respectively.
3. Yield quantity and quality depended on the weather conditions. The obtained difference in seed yield between the year 2018 and the years 2017 and 2016 amounted to 0.88 Mg·ha^{-1} and 0.72 Mg·ha^{-1}, respectively. In 2018, the highest protein content in seeds and protein yield were obtained. In 2017, the highest crude fat content in seeds was found, but fat yield was the lowest.

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PLONOWANIE SOI (*Glycine Max* (L.) Merr.,) W WARUNKACH SIEDLISKOWYCH WOJEWÓDZTWA PODKARPACKIEGO

Streszczenie

Soja jest rośliną ciepłolubną oraz wrażliwą na niekorzystne czynniki środowiska. Dlatego uzyskiwane plony są zróżnicowane w zależności od lokalizacji uprawy czy lat badań. Warunki siedliskowe w południowo-wschodniej części Polski sprzyjają uprawie soi, przy czym w innych rejonach kraju też uzyskuje się zadowalające efekty produkcyjne. Celem badań była ocena plonowania soi, odmiany Merlin i Lissabon w trzech lokalizacjach województwa podkarpackiego. Ścisłe doświadczenia polowe z soją odmiany Merlin i Lissabon założono w latach 2016–2018. Eksperymenty przeprowadzono w trzech lokalizacjach województwa podkarpackiego: Stacji Doświadczalnej Oceny Odmian w Przecławiu (SDOO Przecław), Zakładzie Doświadczalnym Oceny Odmian w Nowym Lublińcu (ZDOO Nowy Lubliniec), Podkarpackim Ośrodku Doradztwa Rolniczego w Boguchwale (PODR w Boguchwale). Odmiany Merlin i Lissabon (Saatbau Polska sp. z o.o.) wydają wysoki oraz stabilny plon nasion w rejonie badań. Warunki pogodowe podano według zapisów Stacji Meteorologicznej PODR w Boguchwale oraz Stacji Meteorologicznych SDOO Przecław i ZDOO Nowy Lubliniec. Analizę próbek glebowych wykonano w laboratorium Okręgowej Stacji Chemiczno-Rolniczej w Rzeszowie. Odmiana Merlin w porównaniu z Lissabon charakteryzowała się istotnie większą obsadą roślin przed zbiorem oraz zawartością tłuszczu surowego w nasionach, zaś istotnie mniejszą liczbą strąków na roślinie i MTN. Średni plon soi w SDOO Przecław wyniósł 4,18 $Mg \cdot ha^{-1}$, w PODR Boguchwała 3,85 $Mg \cdot ha^{-1}$ a w ZDOO w Nowym Lublińcu 2,93 $Mg \cdot ha^{-1}$. W 2018 r. uzyskano najwyższą zawartość białka w nasionach oraz plon białka. W 2017 r. oznaczono najwyższą zawartość tłuszczu surowego w nasionach, ale plon tłuszczu był najniższy. Wielkość i jakość plonu nasion soi była zróżnicowana w zależności od lokalizacji doświadczenia. Duży wpływ na badane cechy i parametry wywarły także zmienne warunki pogodowe w latach badań. Odmiany Merlin i Lissabon nie różniły się istotnie plonem nasion, przy czym było to zależne od lat badań.

Słowa kluczowe: komponenty plonu, odmiana, plon, siedlisko, skład chemiczny nasion, środowisko