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THE DEPENDENCE OF SEED YIELD AND ITS COMPONENTS ON ENVIRONMENTAL FACTORS IN SELECTED LEGUMES

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Summary

Ten cultivars of narrow-leafed lupin and twelve of field pea, differentiated in terms of morphological structure and phenological phases, were studied. Field experiments were conducted in 2011 at Radzików and Wiatrowo in a randomized complete block design.

The aim of this study was to find relationships between seed yield and its components, and meteorological conditions (during the flowering and maturation phases). Weather conditions were characterized using the Sielianinow factor. Highly significant (α=0.01) differences were detected between cultivars in terms of all analyzed traits. The Wricke (1962) ecovalence W_i showed that the most stable lupin cultivars were Kalif and Bojar, similarly Tarchalska and Ezop among pea cultivars. Differences between the high and dwarf cultivars of lupin and pea were found. The length of the maturation phase in pea was negatively correlated with the Sielianinow factor, while in lupin it was positively correlated. Taking into account the differences between cultivars in terms of the discussed traits increases the value of the determination factor in all considered traits, which suggests the need to focus attention on cultivars.

Keywords and phrases: legumes intercropping, seed yield analysis, Sielianinow factor, weather conditions, yield stability

Classification AMS 2010: 62J99, 62P10

1. Introduction

The production capacity of legumes is very large, but the plants use only 20–30% of their biological potential, which in practice is used to a level of only 50–60% (Prusiński and Borowska, 2002). Legumes are characterized by greater variability of seed yield from year to year than other types of species. Variable and insufficiently high yields of legumes, resulting from their high sensitivity to weather conditions and susceptibility to infection, are among the main reasons for the limited interest in their cultivation.

An important aspect of the assessment of cultivars in agricultural production is yield stability. It is assumed that a cultivar is defined as stable with respect to a quantitative trait (for example seed yield) if the average value of this trait is not subject to fluctuation in different environments. In an agricultural sense, a cultivar is defined as stable if its yield varies (among different environments) proportionally to the average response of all cultivars. A stable cultivar displays unchanged performance regardless of any variation of the environmental conditions (Becker and Léon, 1988; Mądry and Rajfura, 2003).

Climate changes, which cause the frequent occurrence of long periods of drought in the spring and summer months, increase the risk associated with legume cultivation. The availability of water for plants, mainly determined by the amount of rainfall or irrigation use, is one of the most important yield elements (Podleśny and Gendarz, 2008). Water scarcity has an especially negative effect in the early stages of plant growth and during the formation of the generative organs. Deficiency of moisture during flowering has a beneficial effect on the protein content of the seeds. However, it can strongly reduce yields. High temperature, especially during budding, flowering and pod formation, limits the formation of pods and seeds by legumes. It causes drying out, drooping flower buds and flowers even before conception, and later pods (Święcicki and Święcicki, 1981). With higher soil moisture and a reduced period of daylight, plants produce many flowers, but only 7–12% of these form pods. However, in conditions of lower soil moisture and longer days, the plants develop fewer flowers but 17–24% of these form pods, hence the final yield of seeds is higher (Prusiński and Borowska, 2002).

The main aim of this study was to find a relationship between seed yield (SY) and the components of its structure for narrow-leafed lupin and field pea (number of pods per plant (PN), number of seeds per pod (SPP) and thousand-seed weight (TGW)), and weather conditions (air temperature and the quantity and distribution of rainfall) at various stages of plant growth and development, in the flowering phase (from the beginning to the end of the flowering phase) and in the maturation phase (from the end of flowering to the end of the technical maturity phase). Determination of the impact of weather conditions on the length of the analyzed phases involves the identification of yield components showing the least dependence on unfavorable environmental conditions.

2. Material and methods

Plant material

The experimental plant material consisted of ten traditional and unbranched cultivars of narrow-leafed lupin (*Lupinus angustifolius* L.) and also twelve cultivars of field pea (*Pisum sativum* L.) with anthocyanin flowers – blue, violet or pink (used for forage) and white flowers (edible usage). Cultivars of both species were differentiated in terms of morphological structure and phenological phases, and originate from different breeding companies in Poland.

Field data

Field experiments with cultivars of narrow-leafed lupin and field pea were conducted in 2011 in two locations: at Radzików (Mazowsze region) and at Wiatrowo (Wielkopolska region). The field experiments were carried out in a randomized complete block design in four replications. The size of each of the plots was 10 m^2. From the center of each plot, within each replication, the plants from one linear meter were measured, giving values for yield component characteristics. During the vegetation season, detailed observations of plant growth and development were made. Dates of phenological phases were noted, and susceptibility to diseases and lodging were assessed. Harvesting was carried out with a plot combine after the plants reached technical full maturity in late July and early August 2011. Yield components and other related characteristics, namely number of plants/m^2, number of pods/m^2, number of seeds/m^2, thousand-seed weight (g), seed yield (g/plot) and seed moisture (%), were measured after harvesting.

In order to assess the impact of weather conditions on seed yield, the hydrothermal Sielianinow factor k (Skowera and Puła, 2004) was used. It is the ratio of total rainfall to mean daily sum of air temperature during the considered period of time: $k=P/0.1\Sigma t$, where P is the sum of rainfall in mm, and Σt is the sum of daily mean air temperatures > 0°C. It is known as the factor of collateral of water or contractual balance of moisture (Radomski, 1977). The Sielianinow factor is used as an indicator of drought intensity in an agro-climatological sense. Each period for which the Sielianinow factor is smaller than 1.0 is treated as drought. Meteorological data came from the Institute of Plant Breeding and Acclimatization in Radzików and Poznan Plant Breeders Ltd. Tulce (Wiatrowo Plant Breeding Branch).

Methods

The results of the trials were analyzed statistically using the analysis of variance under a linear model for randomized complete block design, so eliminating some influence of soil variability (Elandt 1964) and the significance of differences among cultivars was tested using the Fisher F-test. Differences among pairs of cultivars were tested using Student's t-test by application of the least significant difference (LSD) at the significance level α=0.01. The LSD% values (LSD/x)100%, where x is the average value of the analyzed traits, was calculated for an assessment of precision of the individual field experiments. In order to explain the reason for the relatively low precision of individual experiments, the residua (rest, errors) were calculated. The Wricke (1962) ecovalence W_i allowed to assess of the share of each cultivar in the creation of a genotype by environment interaction. The ecovalence for i-th genotype was calculated according to the formula:

$$W_i = \sum(\bar{x}_{ij} - \bar{x}_{i.} - \bar{x}_{.j} - \bar{x}_{..})^2$$

where:

$\bar{x}_{ij}$ − average value of analyzed trait of genotype *i* in environment *j*,

$\bar{x}_{i.}$ − average value of analyzed trait for genotype *i*,

$\bar{x}_{.j}$ − average value of analyzed trait for environment *j*,

$\bar{x}_{..}$ − overall mean.

Analysis of correlation between seed yield and its components and correlation between the length of the flowering and maturation phases with the Sielianinow factor was performed using the EXCEL 2010 program. Multiple regression was applied in order to identify relationships between seed yield and its components and the Sielianinow factor in the flowering (x_1) and maturation (x_2) phases, using the GENSTAT package.

3. Results and discussion

The meteorological conditions during April–July, from sowing to harvesting of the narrow-leafed lupin and pea, in Tables 1 and 2 are presented. It was noted that the weather conditions modified emergence, plant growth, and the development and yield of legumes. Low temperatures during germination and emergence enabled the correct vernalization process. A critical factor for plant development was lack of water during budding, flowering and pod formation. The average values of the Sielianinow factor in the flowering phase in individual experiments ranged from 0.43 to 1.0, which reflects the dry period (Table 3). Drought during this period caused drying out and falling of flower buds, flowers and pods. The results of the research confirmed those of Pokorny (1973), who explains the negative effect of low sum of rainfall on seed yield. According to Święcicki and Święcicki (1981) legumes are sensitive to long-term soil and atmospheric drought, and produce significantly lower yields in dry years. Drought during pod filling substantially reduced yields of other legumes (Turk et al., 1980).

Table 1. Meteorological conditions during the vegetation season in Radzików

Month	10-day period	Sum of rainfall [mm]	Sum of temperature [°C]
April	I	13.8	91.1
	II	22.8	82.4
	III	4.2	144.6
May	I	18.8	97.1
	II	16.8	159.9
	III	2.0	199.2
June	I	20.6	207.1
	II	26.6	179.2
	III	5.6	182.1
July	I	112.4	168.0
	II	55.0	202.9
	III	124.8	194.0

Table 2. Meteorological conditions during the vegetation season in Wiatrowo

Month	10-day period	Sum of rainfall [mm]	Sum of temperature [°C]
April	I	4.0	93.5
	II	0.0	89.3
	III	1.8	128.0
May	I	3.3	81.3
	II	19.6	128.5
	III	2.0	166.5
June	I	7.7	173.8
	II	19.3	149.8
	III	26.7	161.3
July	I	37.0	145.3
	II	77.1	170.0
	III	61.4	147.5

Table 3. Characterization of the weather conditions using the Sielianinow factor

Location	Radzików		Wiatrowo	
Species	Narrow-leafed lupin	Field pea	Narrow-leafed lupin	Field pea
Sielianinow factor				
In the flowering phase	0.75	1.00	0.68	0.43
In the maturation phase	3.06	3.33	2.12	2.46

Despite the significant deficiency of rainfall in the spring and summer months, in July there were heavy rains (292.2 mm in Radzików, 175.5 mm in Wiatrowo), which caused extension of the vegetation season and irregular maturation in legumes. The average values of the Sielianinow factor in the maturation phase in individual experiments ranged from 2.12 to 3.33, values reflecting wet conditions. Plants maturation could occur as a result of physiological maturity. The results are in line with research published by Kotecki (1990).

Studies have shown that in both species there were highly significant (α=0.01) differences among the tested objects in terms of all analyzed traits. The mean values calculated over replicates and locations showed that among narrow-leafed lupin cultivars Boruta and Kadryl had the best yields (2.80 t/ha and 2.81 t/ha respectively), while Sonet and Dalbor had the lowest yields (2.25 t/ha and 2.26 t/ha). Only Boruta and Kadryl had yields above the average for the species *Lupinus angustifolius* L. (2.41 t/ha). Among the field pea cultivars, Gwarek and Hubal had the highest yields (5.01 t/ha and 4.56 t/ha), and Santana and Wenus the lowest (3.53 t/ha and 3.76 t/ha). Besides Gwarek and Hubal, above-average yields for *Pisum sativum* L. were also produced by Sokolik, Wiato, Eureka and Lasso. Based on the LSD% value a difference was observed in the precision of the individual field experiments. A relatively low precision of individual experiments in Wiatrowo was observed (LSD% value 30.5% for narrow-leafed lupin and 35.8% for pea). The ecovalence Wi enabled assessment of the share of each cultivar in the creation of an interaction. Cultivars were divided into stable (showing smaller interaction under changing environmental conditions), less stable and unstable (showing higher interaction) (Becker and Léon, 1988). According to the meaning of the word ecovalence stable genotypes possess a high ecovalence (low values of W_i = high ecovalence) and their W_i are close to 0. Among narrow-leafed lupin the most stable cultivars were Kalif and Bojar, but they yielded slightly below the average for the species. Less stable were Boruta, Sonet, Neptun and Zeus. The Kadryl, Regent, Dalbor and Graf cultivars appeared to be unstable (Fig. 1).

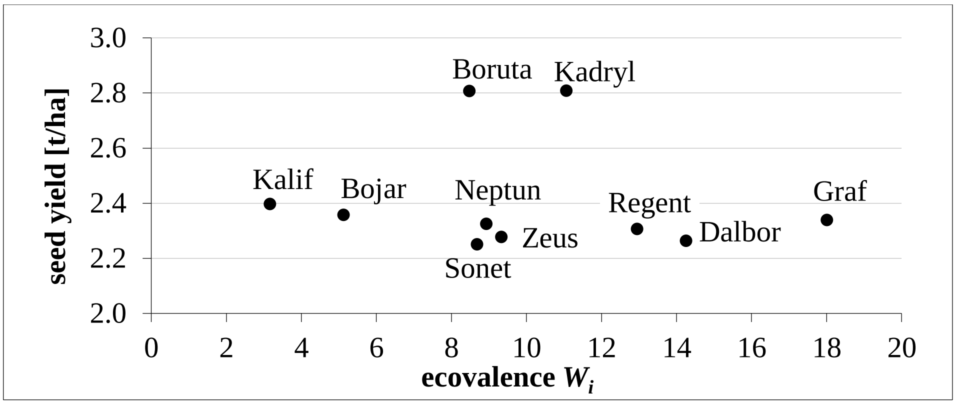

Fig. 1. Seed yield and its stability for different cultivars of narrow-leafed lupin

Among pea cultivars the most stable were Tarchalska and Ezop, which yielded slightly below the average for the species. Wenus, Santana, Eureka and Sokolik were classified as less stable, and Lasso, Hubal, Turnia, Wiato and Gwarek were the most unstable, having a higher interaction with changing environmental conditions (Figure 2). The size of the interaction in each environment was more depended on year conditions than on the field within a location (Drzazga and Krajewski, 2001).

Analysis of the correlation between seed yield and yield components for cultivars of both species showed that the number of pods per plant and thousand-seed weight are positively correlated with yield (Table 4).

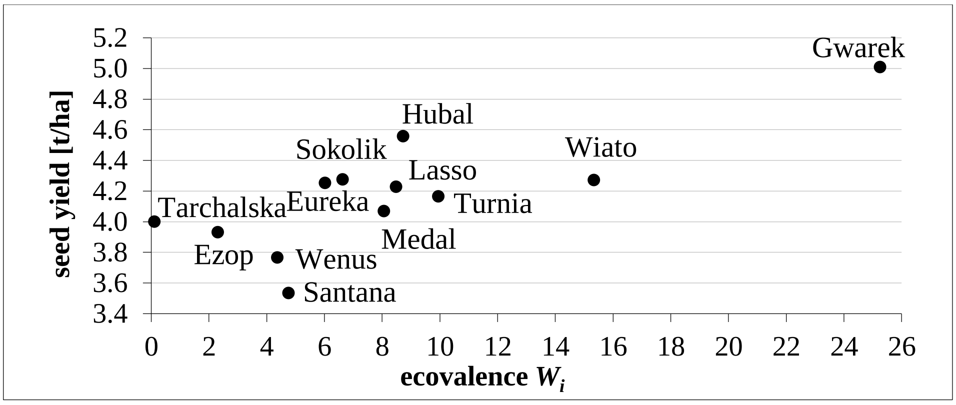

Fig. 2. Seed yield and its stability for different cultivars of field pea

Table 4. Correlation between seed yield and seed yield components in selected cultivars of legumes

	SY for narrow-leafed lupin cultivars		SY for field pea cultivars	
	Graf	Kalif	Lasso	Medal
PN	0.82	0.73	0.95	0.36
SPP	0.37	-0.32	-0.49	0.25
TGW	0.46	0.30	0.06	0.58

SY – seed yield, PN – number of pods per plant, SPP – number of seeds per pod, TGW – thousand-seed weight

These results are in agreement with Acosta-Gallegos and Adams (1991) and Mikič et al. (2013). Correlation between number of seeds per pod and yield was negative or low, which indicates that the trait is genetically determined. Based on correlation analysis between the length of the flowering and maturation phase with the Sielianinow factor, it was found that there were differences between the high and dwarf cultivars of pea. For high cultivars a positive coefficient appeared, and for dwarf cultivars a negative one (Table 5). The length of the maturation phase in pea was negatively correlated with the Sielianinow factor for all studied pea cultivars. The length of the flowering phase in narrow-leafed lupin indicated similar dependences as in pea, while the length of the maturation phase with a hydrothermal factor was positively correlated for all studied narrow-leafed lupin cultivars (Table 6).

Table 5. Correlation of the length of the flowering and maturation phases with the Sielianinow factor of field pea across environments

Cultivar/type	Flowering phase with the Sielianinow factor	Maturation phase with the Sielianinow factor
Lasso/high	0.23	-0.85**
Santana/dwarf	-0.81**	-0.75*
Medal/dwarf	-0.58	-0.89**
Wenus/dwarf	-0.81**	-0.56
Eureka/high	0.50	-0.43
Gwarek/high	0.99**	-0.17
Hubal/high	0.86**	-0.32
Wiato/dwarf	-0.95**	-0.31
Sokolik/high	0.44	-0.46
Turnia/high	0.94**	-0.73
Ezop/high	0.73	-0.56
Tarchalska/dwarf	-0.51	-0.56

* and ** denote significance at 0.05 and 0.01 level

Table 6. Correlation of the length of the flowering and the maturation phases with the Sielianinow factor of narrow-leafed lupin across environments

Cultivars of narrow-leafed lupin	Flowering phase with the Sielianinow factor	Maturation phase with the Sielianinow factor
Dalbor/dwarf	-0.94**	0.96**
Bojar/high	0.66	0.81**
Graf/high	0.69	0.95**
Kalif/high	0.43	0.91**
Neptun/dwarf	-0.35	0.84**
Zeus/high	0.20	0.80**
Boruta/high	0.71	0.96**
Regent/dwarf	-0.91**	0.76*
Sonet/dwarf	-0.74*	0.77*
Kadryl/high	0.31	0.75*

* and ** denote significance at 0.05 and 0.01 level

In order to assess the dependence of seed yield and its components on the Sielianinow factor in the flowering (x_1) and maturation (x_2) phases, multiple regression analysis was applied. Regression analysis across environments under two models was performed. In the simplest, first model the global dependence of yield on the Sielianinow factor in the flowering (x_1) and maturation (x_2) phases for species was studied, while in the second model differences between cultivars were also taken into account. For each model the coefficient of determination (%) was computed. In the case of multiple regression analysis in pea, seed yield was 52.0% explained by the Sielianinow factor for both phases, while taking account of differences between cultivars increased the coefficient of determination to 62.7% (Table 7).

Table 7. Multiple regression goodness of fit for field pea across environments

Traits explained by the Sielianinow factor in the flowering and maturation phases		SY	PN	SPP	TGW
Coefficient of determination [%]	for species (across all cultivars)	52.0	34.8	0.6	23.5
	allowing for differences between cultivars	62.7	46.4	32.9	64.4

SY – seed yield, PN – number of pods per plant, SPP – number of seeds per pod, TGW – thousand-seed weight

Table 8. Multiple regression goodness of fit for narrow-leafed lupin across environments

Traits explained by the Sielianinow factor in the flowering and maturation phases		SY	PN	SPP	TGW
Coefficient of etermination [%]	for species (across all cultivars)	26.4	24.9	12.1	15.6
	allowing for differences between cultivars	25.9	46.9	66.0	44.3

SY – seed yield, PN – number of pods per plant, SPP – number of seeds per pod, TGW – thousand-seed weight

Table 9. Coefficients of regression for field pea across environments

Traits explained by the Sielianinow factor for the flowering and maturation phase	for species		allowing for differences between cultivars	
	Regression coefficient			
SY	a_1	1.548**	a_1	2.073**
	a_2	0.833**	a_2	1.107**
PN	a_1	2009**	a_1	2707**
	a_2	599**	a_2	834*
SPP	a_1	-0.039	a_1	-0.348*
	a_2	0.124	a_2	0.028
TGW	a_1	-0.049**	a_1	-0.047**
	a_2	0.003	a_2	0.008

SY – seed yield, PN – number of pods per plant, SPP – number of seeds per pod, TGW – thousand-seed weight
* and ** denote significance at 0.05 and 0.01 level

Table 10. Coefficients of regression for narrow-leafed lupin across environments

Traits explained by the Sielianinow factor for the flowering and maturation phase	for species		allowing for differences between cultivars	
	Regression coefficient			
SY	a_1	1.382**	a_1	1.498**
	a_2	0.278**	a_2	0.254*
PN	a_1	1219	a_1	2796**
	a_2	1383**	a_2	1283**
SPP	a_1	-0.163	a_1	-0.248
	a_2	0.239**	a_2	0.247**
TGW	a_1	0.024*	a_1	0.012
	a_2	-0.009**	a_2	-0.009**

SY – seed yield, PN – number of pods per plant, SPP – number of seeds per pod, TGW – thousand-seed weight
* and ** denote significance at 0.05 and 0.01 level

A significant influence of weather on the number of pods per plant and the thousand-seed weight in pea was found under second model. This suggests that thermal and humidity conditions modify the length of the vegetation season and plant growth and development. Good soil moisture stimulates better flowering, stops abortion of flowers and young pods, and favors the accumulation of spare material in seeds. However, weather conditions for both phases had no influence on the number of seeds per pod, which suggests a genetic determinant of this trait. According to Roux (1962) the influence of higher temperature on the number of seeds per pod is small, which agrees with the above conclusion. A slightly weaker association between the Sielianinow factor and seed yield, and yield components was found in narrow-leafed lupin (Table 8). The analyzed traits were less dependent on weather conditions. Seed yield was 26.4 % explained by the Sielianinow factor for both phases, and allowing for differences between the cultivars had no positive influence. The number of pods per plant was 24.9% explained by the hydrothermal factor, while taking account of differences between cultivars increased the coefficient of determination to 46.9%. Weaker dependences were recorded for thousand-seed weight. However, the favorable weather in the generative phase influenced the number of seeds per pod, especially after taking into consideration differences between cultivars. It could be concluded that this trait is genetically determined, which suggests the need to focus attention on cultivars in further studies. Yield components were significantly (at a level of 0.01 or 0.05) explained by conditions at flowering (see a_1) and maturation phase (see a_2) (Tables 9 and 10).

4. Conclusions

Improvement in the moisture conditions to a greater extent affects seed yield and the number of pods per plant in both species, and to a lesser extent the number of seeds per pod and thousand-seed weight. When differences between cultivars are taken into account the value of the coefficient of determination is higher for all analyzed traits, which again suggests that attention should be focused on cultivars in further studies. There is no doubt that thermal conditions, quantity and distribution of rainfall are among the main factors reducing the yield potential of legumes (Łabędzki and Leśny, 2008). It is anticipated that these results, despite their preliminary nature and limited utility, may be validated by future more thorough studies on the same subject.

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