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EFFECT OF THE PRP FERTILIZERS AND MICROBIOLOGICAL INOCULATION AND COINOCULATION IN THE YELLOW LUPINE (*Lupinus luteus* L.) CULTIVATION

Summary

In the years 2014-2015 in Złotniki, on the fields of the Experimental-Didactic Station Gorzyń, belonging to the University of Life Sciences in Poznan, research was carried out aimed at checking the effects of using PRP fertilizers, nitragine and Bacillus subtilis inoculation in the cultivation of yellow lupine of traditional variety 'Mister'. It was shown that the use of the majority of fertilization and inoculation variants contributed to the yield reduction, the highest after the application of PRP EBV along with the B. subtilis seed inoculation. Among the tested combinations, the most beneficial effect on the elements of the yield structure was played by seed inoculation with nitragine, which significantly increased the mass of a thousand seeds, the number and mass of seeds in the plant, and not significantly fresh mass of the aboveground part and root.
***Key words**: yellow lupine, PRP SOL, PRP EBV, nitragine, Bacillus subtilis, coinoculation, seed yield*

EFEKTY STOSOWANIA NAWOZÓW PRP ORAZ INOKULACJI I KOINOKULACJI MIKROBIOLOGICZNYCH W UPRAWIE ŁUBINU ŻÓŁTEGO (*Lupinus luteus* L.)

Streszczenie

W latach 2014-2015 w Złotnikach, na polach Zakładu Doświadczalno-Dydaktycznego Gorzyń, należącego do Uniwersytetu Przyrodniczego w Poznaniu, przeprowadzono badania, których celem było sprawdzenie efektów stosowania PRP, szczepionek mikrobiologicznych i inokulacji Bacillus subtilis w uprawie łubinu żółtego odmiany tradycyjnej 'Mister'. Wykazano, że stosowanie większości badanych wariantów nawożenia i szczepienia przyczyniło się do obniżki plonu, największej po aplikacji PRP EBV w postaci oprysku nalistnego wraz z inokulacją nasion przed siewem. Spośród badanych kombinacji najkorzystniejszy wpływ na elementy struktury plonu odegrało szczepienie nasion nitraginą, które istotnie zwiększyło masę tysiąca nasion, liczbę i masę nasion na roślinie oraz nieistotnie świeżą masę części nadziemnej i korzenia.
***Słowa kluczowe**: łubin żółty, PRP SOL, PRP EBV, nitragina, Bacillus subtilis, koinokulacja, plon nasion*

1. Introduction

Bean plants are a valuable source of protein [26], which can replace costly imported transgenic soy protein imported from abroad. In agricultural practice, there is an increase in interest in the cultivation of legumes, and a tendency to increase the area of their cultivation, although it still carries some risk due to the high sensitivity of this group of plants to unfavorable environmental conditions and yield failure. Legumes have long been valued for their high protein content, long root system, able to absorb nitrogen and as plants leaving a good position for succeeding plants [19]. It is important to restore the bean plants for cultivation and provide farmers with new solutions to increase yield potential, tolerance to cold, drought and diseases. In the cultivation of this group of plants, an important element is nitrogen, which can be supplied not only in the form of fertilization, but also through the use of a inoculants containing live strains of nitrogen fixing bacteria that bind atmospheric nitrogen [4]. Available on the market nitragine intended for specific species of fabaceae plants, introduces live cultures of root nodules bacteria into the soil, thanks to which plants produce root nodules, and the atmospheric nitrogen bound by bacteria is transferred to the plant. Another solution supporting the growth of *Fabaceae* consists in the use of plant co-inoculation with a mixture of many supporting bacteria strains [9]. There are also modern preparations available on the market, which according to their producers are supposed to provide a higher yield of arable crop. More and more often, farmers want to follow the principles of integrated crop production and to limit the use of synthetic fertilizers and they apply such practices. Such solutions include fertilizers form PRP (Procedes Roland Pigeon from France) Technologies Polska, such as PRP SOL and PRP EBV registered also for the use in organic farming. According to the producer, the mineral components of PRP SOL modify the soil environment, stimulate microflora, which in turn improves soil fertility and has a beneficial effect on the development of the root system of the plant. In turn, PRP EBV used in the form of a spray for plants is designed to stimulate physiological processes and increase resistance to various stress factors. Leguminous crops are characterized by high yield variability, as many factors affect the yield and seed value, including foliar fertilization [3, 12]. Hence there is a sense of searching for and checking new, effective methods of fertilizing plants that allow increasing the yield potential of yellow lupine.

The aim of the study was to assess the effects of using different fertilization variants of PRP SOL and PRP EBV, and inoculating yellow lupine seeds with nitragine and *Bacillus subtilis.*

2. Materials and methods

Field experiments with yellow lupine, the traditional "Mister" variety were carried out in 2014-2015 at the Department of Agronomy of the University of Life Sciences in Poznań, on the fields of the Experimental and Educational

Station Gorzyń, branch in Złotniki. The experiments were established in four replications, and the size of the plot was 25.5 m^2. The testing factor included the variant of lupine fertilization and inoculation, with the following levels: control, *Bacillus subtilis* inoculation, nitragine (*Rhizobium*), PRP SOL, PRP EBV, PRP SOL + PRP EBV, PRP SOL + *B. subtilis*, PRP SOL + nitragine, PRP EBV + *B. subtilis*, PRP EBV + *B. subtilis* + nitragine, PRP SOL + *B. subtilis* + nitragine, PRP SOL + PRP EBV + *B. subtilis* + nitragine. The PRP SOL fertilizer was applied at a dose of 200 $kg \cdot ha^{-1}$, and the PRP EBV fertilizer was sprayed in doses: $2l \cdot ha^{-1}$ (BBCH 13-16) and $1.5l \cdot ha^{-1}$ (BBCH 51-55 and BBCH 70-73). Lupine seeds were treated with nitragine, purchased at the Institute of Soil Science and Plant Cultivation in Puławy and *Bacillus subtilis* inoculant produced in the Department of General Microbiology and Environmental at the University of Life Sciences in Poznań, according to the experimental scheme. In the phase of full seed maturity, 20 plants were randomly picked from each plot and the yielding components were determined: the number of pods per plant, the number of seeds per plant and the weight of one thousand seeds. In addition, the height of plants and the mass of aboveground parts and roots were determined. The seed yield, seed moisture content were assessed during the harvest, and then the yield was converted to 15% H_2O.

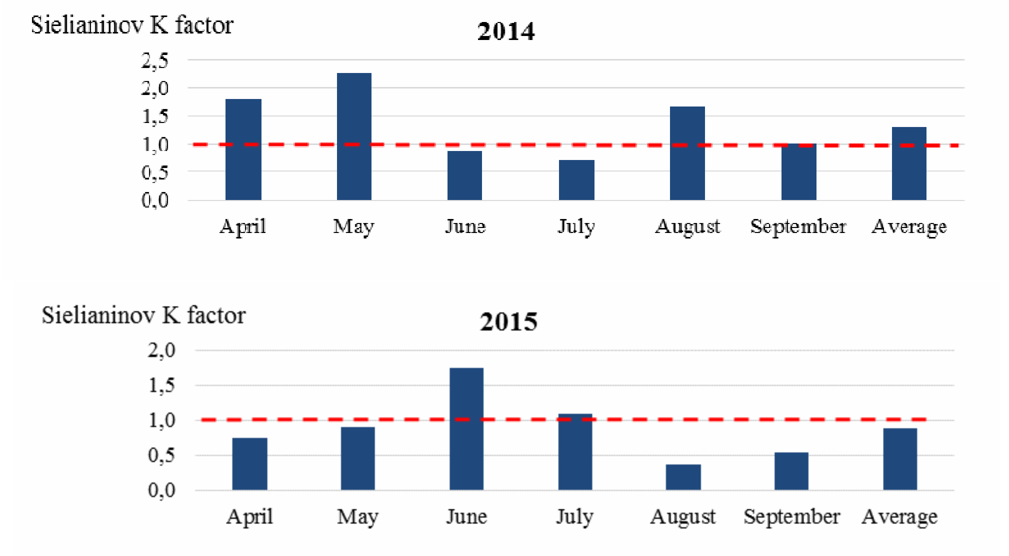
In order to characterize the meteorological conditions during the growth and development of test plants, the hydrothermal coefficients of Sielianinov K [30] were calculated (Fig. 1), according to the formula $K=(P \cdot 10)/(T \cdot L)$, where: P- sum of monthly precipitation, T- average temperature of a given month, L- number of days in a given month [14].

Values of the assessed features were subject to the analysis of variance for univariate experiments, and then a synthesis was made from the years of research. To assess the significance of differences between object-related averages, the Duncan's test was used at the significance level of $p<0.05$. In order to determine the relations between the studied features, the values of linear correlation coefficients were calculated.

3. Results and discussion

The precipitation conditions during the growing season of yellow lupine varied in the years 2014-2015 (Fig. 1). In the growing season of 2014, the greatest fluctuations in rainfall occurred, with the highest water deficit in the whole period of research. In June this year, the Selianinov coefficient reached the value of 0.88, and in July 0.70, which indicates the appearance of a drought, while in May 2014 it reached the value of 2.24, demonstrating very humid conditions. In turn, 2015 was more stable in terms of thermal and water conditions and exceeded June and July rainfall in 2014, while periods of drought appeared in April, August and September.

The average yield of "Mister" yellow lupine seeds was 19.3 $dt \cdot ha^{-1}$ (Table 1) and lower by 2.03% than the average seed yield obtained in 2014-2015 at Experimental Station for Variety Testing, recommending the tested variety for cultivation in the Wielkopolska voivodeship, hence the obtained results can be considered as good. The seed yield was influenced both by the fertilization and inoculation variants used and the weather conditions as well as their relation. Many authors emphasize the low soil requirements of yellow lupine and, at the same time, high in relation to weather conditions which determine the growth and yield of varieties [25]. The even supply of plants with water throughout the growing season, which can definitely increase yields, is particularly important for lupines [6]. Terminal drought is a major limitation for lupin production [16]. In 2015, the yield of seeds was significantly higher by 4.5 $dt \cdot ha^{-1}$ than in the previous year, with a significantly lower weight of one thousand seeds (by 45.4 g). In 2015, very good supply of plants with water occurred in June and July, during the period of setting and filling pods, while in the previous year, there was a drought at the same time, which could reduce yields. The yields of plants growing under good water supply conditions were higher by 20.9% than in 2014, the year characterized by summer drought. In experiments, it was shown that yellow lupine yielded more stably in favorable humidity conditions, and the coefficient of variation for objects and repetitions in 2015 was 8.96%.



where the value >0,5 – drought; 0,5 –1 – medium drought; 1,1–2 – humid; > 2 – very wet

Source: own study / Źródło: badania własne

Fig. 1. Plant supply with water in the growing seasons 2014 and 2015 expressed by Sielianinov coefficients

Rys. 1. Zaopatrzenie roślin w wodę w okresach wegetacji 2014 i 2015 wyrażone za pomocą współczynników Sielianinova

Table 1. Yield and TKW of yellow lupine in 2014 and 2015
Tab. 1. Plon i masa tysiąca nasion łubinu żółtego w latach badań 2014 i 2015

Combination *Kombinacja*	Seed yield (dt·ha^{-1})			Thousand seeds weight (g)		
	2014	2015	Average 2014-2015	2014	2015	Average 2014-2015
Control / *Kontrola*	17,9	22,5 a-d	21,0 a-c	132,9 f	145,0 b-d	139,0 ef
Bacillus subtilis inoculation	18,1	23,5 ab	20,1 b-d	180,6 cd	132,7 c-e	156,7 cd
nitragine *(Rhizobium)*	16,6	22,1 b-d	21,4 ab	191,0 b-d	175,9 a	183,5 a
PRP SOL	17,6	22,1 b-d	17,9 ef	192,9 b-d	125,8 e	154,6 cd
PRP EBV	16,9	22,7 a-c	20,0 b-d	195,3 bc	128,2 de	161,8 c
PRP SOL+ PRP EBV	17,7	24,4 a	21,5 a	227,6 a	145,7 b-d	180,8 a
PRP SOL + *B. subtilis*	17,0	19,9 e	19,8 cd	150,8 e	108,5 f	129,6 ef
PRP SOL + nitragine	17,1	20,6 c-e	17,9 ef	177,3 d	154,9 b	166,1 bc
PRP EBV + *B. subtilis*	16,8	19,8 e	15,7 g	179,5 cd	145,9 b-d	162,7 c
PRP EBV + *B. subtilis* + nitragine	15,3	20,4 de	19,5 d	205,6 b	149,0 bc	177,3 ab
PRP SOL + *B. subtilis* + nitragine	16,1	19,3 e	17,1 f	192,2 b-d	99,8 f	146,0 de
PRP SOL + PRP EBV + *B. subtilis* + nitragine	16,9	21,0 c-e	19,2 de	203,8 b	173,6 a	188,7 a
p-value	0,997	0,000	0,000	0,000	0,00	0,000
Average / *Średnio*	17,0 b	21,5 a	19,3	185,8 a	140,4 b	163,1
CV	19,0%	8,96%	18,1%	13,9%	17,3%	20,7%
SD	3,22	1,92	3,48	25,94	24,2	33,83
min-max	10,4-22,5	17,9-25,6	10,4-25,6	107,0-244,5	82,1-198,5	82,1-244,5

a, b – different letters denote significant differences between means (Duncan test, p<0,05), p-value, CV – coefficient of variation, SD – standard deviation, min-max – minimum-maximum
a, b – różne litery oznaczają różnice statystycznie istotne między średnimi (test Duncana, p<0,05), p-value – wartość p, CV – współczynnik zmienności, SD – odchylenie standardowe, min-max – minimum-maksimum

Source: own study / Źródło: badania własne

On the other hand, the yield of seeds in 2014 was characterized by higher variability, and the CV was 19.0%. Similarly, in the studies of Sawicka and Pszczółkowski [25] in the unfavorable season for the harvest of seeds, the “Mister” variety of yellow lupine proved to be the least fertile. Prusiński et al. [23] point to the particular sensitivity of yellow lupine's root nodules formation with water deficiency in the rhizosphere. Therefore, weather conditions considerably determine the yield potential. In the case of leguminous plants, this is particularly difficult, as Sawicka and Pszczółkowski [25] show, usually the plants use only 20-30% of their biological potential.

In our studies, in both vegetation seasons, no significant increase in seed yield was observed under the influence of the applied fertilizers and seed inoculation combinations, and even the opposite in 2015 for 8 out of 11 tested variants there was a significant decrease compared to the control of lupine yielding. The highest yield decrease in the 2014 conditions was observed after the application of co-inoculation (*B. subtilis + Rhizobium* from nitragine) in combination with PRP EBV, and in 2015 after the application of the following variants: PRP SOL together with co-inoculation (*B. subtilis + Rhizobium* from nitragine), PRP EBV + *B. subtilis* or PRP SOL + *B. subtilis*. The reason for such a reaction of plants could arise from weather conditions, because in both years periods of drought appeared: in 2014 in June and July, and in 2015 in April and May, which were not favorable to the symbiosis of root nodules bacteria with the crop plant [10]. Reports by Martyniuk and others [13] and Jarecki et al. [7] also showed that the bacterial vaccine used was insufficient to ensure a high yield of narrow-leafed lupine and yellow lupine. Research also reports on the positive effect of nitragine on yields, the mass of a thousand seeds and more intensive root nodules formation and higher germination of yellow lupine seeds [24], and in agricultural practice the use of nitragine has been an important treatment in legume cultivation for years [11]. In the cultivation of bean plants, the bacteria used for seed inoculation may affect plants directly, also by supplying nitrogen for the plants, and indirectly by inducing plant resistance to pathogens and pests [31]. In our research, in both years there was a tendency to higher yields after seed inoculation with *B. subtilis* than *Rhizobium* and they were slightly higher than in the control object.

In the synthesis from 2014-2015, no positive impact of the tested fertilization and inoculation variants on the yield of yellow lupine has been proven. The use of combined PRP SOL fertilization and PRP EBV foliar spraying, as well as the use of nitragine inoculation, resulted in only a negligible increase in seed yield by 0.5 and 0.4 dt·ha^{-1}, respectively. In earlier studies, Sulewska et al. [28] have published the highest increase in maize grain yield was demonstrated after the combined use of PRP SOL with PRP EBV spraying. Borowiak et al. [2] indicate that the fertilization of PRP in both forms has a positive effect on the parameters of photosynthesis activity in the studied plants of spring barley, winter wheat and maize, with a stronger effect observed after the use of PRP EBV in maize. In turn, in the our research, the highest yield decrease, amounting to 5.3 dt·ha^{-1}, was recorded after application of *B. subtilis* seed inoculation and PRP EBV spraying.

The weight of one thousand yellow lupine seeds in our research amounted to an average of 163.1 g (Table 1) and was higher by 27.4 g than that obtained in the post-registration experiments of the Central Research Center for Testing Varieties and 15.7 g from the study by Prusiński and Kaszkowiak [22] “Polo” variety. In the Faligowska and Szukała experiments [5], the mass of one thousand seeds of the “Mister” yellow lupine seeds was also lower than in the our research and amounted to an average of 128.6 g. The use of each of the tested combinations in dry 2014 resulted in a significant TKW (thousand kernels weight) increase compared to the control, the largest the increase, by 94.7 g, took place after the combined use of PRP fertilizers. In turn, in more favorable conditions in 2015, significantly higher than in the TKW control object was obtained after nitragine seed inoculation (increase by 30.9 g) and the use of both fertilizers (PRP SOL + PRP EBV) with co-inoculation (*B. subtilis* + *Rhizobium*) (increase by 28.6 g). In the synthesis with years for 9 combinations, the TKW increase in comparison to the control was confirmed, the highest after co-inoculation with PRP SOL + PRP EBV or after nitragine inoculation, by 49.7 and 44.5 g respectively. In turn, Jarecki and Bobrecka-Jamro [8], on the contrary, recorded a decrease in the weight of a thousand soybean seeds inoculated with nitragine. In previous studies, the use of PRP SOL in winter wheat decreased TKW, in spring barley a favorable tendency of its growth was noted, whereas in maize there was a significant increase in this mass (by 4.9 g) compared to controls [27, 29].

In the synthesis from both years, each of the fertilization variants tested, the combination of seed inoculation, significantly increased the height of yellow lupine plants, which on average in the study years was 73.7 cm. The use of *B. subtilis* inoculation, PRP SOL + PRP EBV fertilization, PRP EBV, PRP EBV + co-inoculation (*B. subtilis* + *Rhizobium*), and in particular the nitragine inoculation significantly stimulated the growth of yellow lupine plants. After inoculation, the lupine plants were higher by 11.1 cm compared to the control ones.

Table 2. Plant height and number of branches, average from the years 2014-2015
Tab. 2. Wysokość roślin i liczba rozgałęzień średnio z lat badań 2014-2015

Combination	Plant height [cm]	Number of branches [amount of pieces]
Control	69,3 d	2,5 a
Bacillus subtilis inoculation	74,2 bc	2,4 a-c
nitragine (*Rhizobium*)	80,4 a	2,6 a
PRP SOL	72,5 b-d	2,1 c
PRP EBV	74,1 bc	2,3 a-c
PRP SOL+ PRP EBV	74,0 bc	2,4 a-c
PRP SOL + *B. subtilis*	72,7 b-d	2,1 c
PRP SOL + nitragine	71,8 cd	2,2 bc
PRP EBV + *B. subtilis*	72,0 b-d	2,4 a-c
PRP EBV + *B. subtilis* + nitragine	75,9 b	2,3 a-c
PRP SOL + *B. subtilis* + nitragine	73,2 b-d	2,2 bc
PRP SOL + PRP EBV + *B. subtilis* + nitragine	73,2 b-d	2,4 ab
p-value	0,000	0,016
Average	73,7	2,31
CV	7,13%	13,66%
SD	5,25	0,31
min-max	61,9-91,1	1,1-2,9

a, b – different letters denote significant differences between means (Duncan test, p<0,05), p-value, CV – coefficient of variation, SD – standard deviation, min-max – minimum-maximum
a, b – różne litery oznaczają różnice statystycznie istotne między średnimi (test Duncana, p<0,05), p-value – wartość p, CV – współczynnik zmienności, SD – odchylenie standardowe, min-max – minimum-maksimum

Source: own study / Źródło: badania własne

Table 3. Yield structure and fresh matter of aboveground part and roots, average from the years 2014-2015
Tab. 3. Elementy struktury plonu oraz świeża masa części nadziemnej i korzenia średnio z lat badań 2014-2015

Combination *Kombinacja*	Number of		Seed weight on the plant [g]	Weight [g on the plant]		N : K
	Pods	Seeds		aboveground part (N)	roots (K)	
	on the plant [amount of pieces]					
Control / *Kontrola*	8,1 b-d	24,9 de	3,3 bc	13,36 a	1,18 a-c	11,43 bc
Bacillus subtilis inoculation	8,5 a-c	27,5 b-d	3,7 ab	12,56 a-c	0,98 b-d	13,20 ab
nitragine (*Rhizobium*)	8,1 b-d	34,0 a	4,1 a	14,25 a	1,25 a	11,61 bc
PRP SOL	8,5 a-c	29,2 bc	3,8 ab	12,95 ab	0,92 d	14,08 a
PRP EBV	8,7 ab	30,1 bc	3,7 ab	13,22 a	1,05 a-d	12,76 ab
PRP SOL+ PRP EBV	8,7 ab	30,6 b	3,9 ab	13,60 a	1,06 a-d	13,14 ab
PRP SOL + *B. subtilis*	7,2 d	23,3 e	2,9 c	10,98 c	0,95 cd	11,56 bc
PRP SOL + nitragine	8,3 a-c	29,5 bc	3,7 ab	11,24 bc	1,11 a-d	10,10 c
PRP EBV + *B. subtilis*	7,7 cd	26,7 c-e	3,6 ab	11,35 bc	1,04 a-d	12,12 a-c
PRP EBV + *B. subtilis* + nitragine	9,2 a	28,8 bc	3,9 ab	13,76 a	1,19 ab	11,59 bc
PRP SOL + *B. subtilis* + nitragine	8,4 a-c	26,6 c-e	3,8 ab	13,47 a	1,21 a	11,05 bc
PRP SOL + PRP EBV + *B. subtilis* + nitragine	8,6 a-c	30,9 b	4,2 a	14,02 a	1,23 a	11,39 bc
p-value	0,00	0,000	0,001	0,000	0,007	0,024
Average	6,9	28,7	3,7	12,89	1,09	12,01
CV	22,6%	23,07%	22,86%	21,26%	21,56%	21,07
SD	1,54	6,61	0,85	2,74	0,23	2,53
min-max	6,9-12,3	15,1-44,2	2,2-5,5	6,2-21,7	0,4-1,9	6,8-22,8

a, b – different letters denote significant differences between means (Duncan test, p<0,05), p-value, CV – coefficient of variation, SD – standard deviation, min-max – minimum-maximum
a, b – różne litery oznaczają różnice statystycznie istotne między średnimi (test Duncana, p<0,05), p-value – wartość p, CV – współczynnik zmienności, SD – odchylenie standardowe, min-max – minimum-maksimum *Source: own study / Źródło: badania własne*

Table 4. Correlation coefficients for seed yield of yellow lupine and its structure elements in 2015 and 2016
Tab. 4. Współczynniki korelacji dla plonu nasion łubinu żółtego i elementów jego struktury w latach badań 2015 i 2016

Yield structure	Number of pods per plant	Number of seeds per plant	Thousand seeds weight
2014			
Number of seeds per plant	0,803**		
Thousand seeds weight	0,754**	0,842**	
Yield	0,128	-0,206	0,057
2015			
Number of seeds per plant	0,572**		
Thousand seed weight	0,287*	0,647**	
Yield	0,403*	0,031	-0,044

**- p<0,01, *-p<0,05

Source: own study / Źródło: badania własne

In yellow lupine, excessive branching of plants is undesirable, because it causes longer growing vegetation and increases the unevenness of ripening, without contributing to the increase in seed yield [22]. Plants in our experiments usually produced 2 branches. The least branched plants were after using PRP SOL only or with *B. subtilis* inoculation (Table 2).

In the conducted studies, the use of PRP EBV together with seed co-inoculation (*B. subtilis* + *Rhizobium*) favorably increased the number of pods formed on the plant, and the difference compared to the control object was 1.1 and was statistically significant (Table 3). The use of other variants of fertilization and seed inoculation did not lead to significant changes in this characteristic with regard to controls. After applying 7 of 11 tested variants of fertilization and seed inoculation, there was an increase in the number of seeds per plant compared to the control, with the highest of 9.1 g recorded after using nitragine. The weight of seeds of the plant was stable feature and on average amounted to 3.7 g, while higher than the control the weight of seeds of the plant was recorded on the object where nitragine inoculation was applied (by 0.8 g) or PRP SOL and EBV along with co-inoculation (*Rhizobium* + *B. subtilis*), which has been proven statistically. Podleśny and Podleśna [18] on the yellow lupine "Polo" proved that the temperature might influence the yield structure. Test plants under conditions of high temperature during the flowering period formed less pods and seeds than growing in optimal thermal conditions. In both years of our research, the air temperature was optimal, the average temperature of individual months did not exceed 24°C, while water shortages appeared, which limited the setting and filling of pods.

The traditional yellow lupine varieties are characterized by a greater increase in fresh weight and higher productivity from self-terminating varieties [21]. In our research, the fresh mass of the aboveground part of the traditional "Mister" variety was on average 12.89 g (Table 3). After application of the tested fertilizers and inoculations, no significant increase was observed in both the fresh mass of the aboveground part and the roots. However, the use of PRP SOL + *B. subtilis*, PRP SOL + *Rhizobium* and PRP EBV + *B. subtilis* led to a significant reduction in the fresh mass of the aboveground part of the plant, and the use of PRP SOL of roots. In turn, in the studies of Borowiak et al. [2] PRP SOL fertilizer used in the cultivation of maize, spring barley and wheat, contrary to our research, positively influenced the dry mass of aboveground parts and roots. The few studies on the effect of inoculation in the cultivation of leguminous plants indicate that microorganisms are able to synthesize phytohormones such as auxins and cytokinins, which stimulate the development of root hairs in this group of plants. Niewiadomska and Swędrzyńska [15] obtained a greater mass of root and aboveground parts of alfalfa after inoculation with the tested bacterial strains. In the our experiment, the use of nitragine caused only a favorable tendency to increase the fresh weight of roots and aboveground parts of the plants while maintaining a favorable, low ratio of fresh mass of the aboveground part to the fresh root mass. Low values of this ratio were also observed in plants fertilized with PRP SOL along with nitragine seed inoculation. According to Podleśny and Podleśna [20] legumes producing a greater root mass, with a low ratio of aboveground weight to root mass, are more resistant to drought.

The grain yield of leguminous plants is generally well correlated with the elements of its structure, such as: the number of pods per plant, the number of seeds in the pod and the weight of one thousand seeds [1]. In the our research, the yield of seeds was dependent on weather conditions. This feature was more stable, as evidenced by lower values of coefficients of variation and standard deviation in 2015, in which, moreover, the dependence of yield on the number of pods per plant was confirmed (Table 4). Similarly in studies by Panasiewicz et al. [17] the number of pods per plant was the feature, that most strongly determined the yielding of yellow lupine, while in the case of narrow-leaved lupine in the studies of Barczak et al. [1] yield was the most correlated with the mass of one thousand seeds, secondly with the number of pods per plant, and in the least with the number of seeds in the pod. The calculated values of correlation coefficients in 2015 did not show any significant dependence of yielding yellow lupine on the number of seeds per plant and the weight of one thousand seeds. On the other hand, in 2014, no dependence of the yield on the elements of its structure was found, which was probably caused by periods of drought during plant vegetation. In both years, however, a strong relationship between the number of pods and the number of seeds per plant and the number of seeds per plant with a mass of one thousand seeds was noticed.

5. Conclusions

1. The year 2015 was the most favorable in terms of the yield of seeds, with good water availability for plants, in which the yield was determined by the number of pods per plant.
2. The studies did not show a beneficial effect of the used fertilizer combinations and seed inoculation on the yielding of yellow lupine. The use of the majority of examined vari-

ants contributed to the yield reduction, the highest after the application of PRP EBV together with the seed inoculation of *B. subtilis* before sowing.

3. Inoculation of seeds with nitragine resulted in a significant increase in the weight of one thousand seeds, the number and mass of seeds on the plant, and a statistically proven increase in the fresh mass of the aboveground and root parts. Among the tested variants, the highest mass of one thousand seeds and the weight of seeds per plant were obtained after the use of PRP SOL and PRP EBV together with coinoculation (*B. subtilis* + *Rhizobium*).

6. References

[1] Barczak B., Nowak K., Knapowski T., Ralcewicz M., Kozera W.: Reakcja łubinu wąskolistnego (Lupinus angustifolius L.) na nawożenie siarką. Cz. I. Plon oraz wybrane elementy jego struktury. Fragmenta Agronomica, 2013, 30(2), 23-34.

[2] Borowiak K., Niewiadomska A., Sulewska H., Szymańska G., Głuchowska K., Wolna-Maruwka A.: Effect of PRP SOL and PRP EBV nutrition on yield, photosynthesis activity and soil microbial activity of three cereal species. Fresenius Environmental Bulletin, 2016, 25(6), 2026-2035.

[3] Faligowska A., Bartos-Spychała M., Panasiewicz K.: Wpływ okresu przechowywania na wartość siewną i wigor zaprawionych nasion łubinu wąskolistnego. Progress in Plant Protection/Postępy w Ochronie Roślin, 2012, 52(4), 1151-1155.

[4] Faligowska A., Szukała J.: Wpływ szczepienia nasion i nawożenia azotem na cechy biometryczne roślin strączkowych. Zeszyty Problemowe Postępów Nauk Rolniczych 2010, 550, 201-209.

[5] Faligowska A., Szukała J.: Wpływ deszczowania i systemów uprawy roli na wigor i wartość siewną nasion łubinu żółtego. Nauka Przyroda Technologie, 2012, 6, 2, #26.

[6] Faligowska A., Panasiewicz K., Szymańska G., Bartos-Spychała M.: Jakość siewna nasion łubinu żółtego w zależności od wybranych czynników agrotechnicznych. Progress in Plant Protection, 2013, 53(2), 293-296.

[7] Jarecki W., Bobrecka-Jamro D., Jarecka A.: Reakcja łubinu wąskolistnego (Lupinus angustifolius L.) na dawkę startową azotu. Polish Journal of Agronomy, 2015, 21, 28-33.

[8] Jarecki W., Bobrecka-Jamro D.: Reakcja roślin soi na szczepienie nasion nitraginą oraz nawożenie startowe azotem. Nauka Przyroda Technologie, 2016, 10, 1, #12.

[9] Klama J., Wolna-Maruwka A., Niewiadomska A.: Wpływ koinokulacji bakteriami diazotroficznymi na rozwój siewek pszenicy zwyczajnej. Nauka Przyroda Technologie 2010, 4(6), 1-7.

[10] Korsak-Adamowicz M., Starczewski J., Dopka D.: Oddziaływanie niektórych zabiegów agrotechnicznych na brodawkowanie soi. Fragmenta Agronomica, 2007, 24, 3, 232–237.

[11] Kozłowski S., Swędrzyński A., Zielewicz W.: Rośliny motylkowe w środowisku przyrodniczym. Woda Środowisko Obszary Wiejskie, 2011, 11, 161-181.

[12] Kurasiak-Popowska D., Szukała J., Mystek A.: Wpływ niektórych czynników agrotechnicznych na wigor nasion łubinu żółtego i wąskolistnego. Zeszyty Problemowe Postępów Nauk Rolniczych, 2003, 495, 179–190.

[13] Martyniuk S., Kozieł M., Stalenga J.: Effect of various strains of symbiotic bacteria on yields and nodulation of Lupine and Soybean. Journal of Research and Applications in Agricultural Engineering, 2013, 58(4), 67-70.

[14] Molga M.: Podstawy klimatologii rolniczej. PWRiL, Warszawa, 1986, 544-547.

[15] Niewiadomska A., Swędrzyńska D.: Effect of the co-inoculation of lucerne (Medicago sativa L.) with Sinorhizobium meliloti and Herbaspirillum frisingense in relation to the interactions between bacterial strain. Archives of Environmental Protection, 2011, 37(4), 37-48.

[16] Palta J.A., Turner N.C., French R.J., Buirchell B.J.: Physiological responses of lupin genotypes to terminal drought in a Mediterranean-type environment. Annals of applied biology, 2007, 150(3), 269-279.

[17] Panasiewicz K., Koziara W., Sulewska H., Szukała J., Faligowska A., Szymańska G., Ratajczak K., Strzelińska J., Sobieszczański R.: Produkcyjność wybranych gatunków roślin bobowatych w warunkach uprawy uproszczonej w obrębie pola produkcyjnego. Nauka Przyroda Technologie, 2016, 10, 1, #6.

[18] Podleśny J., Podleśna A.: Wpływ wysokiej temperatury w okresie kwitnienia na wzrost, rozwój i plonowanie łubinu żółtego. Acta Agrophysica, 2012, 19(4): 825-834.

[19] Podleśny J.: Rośliny strączkowe w Polsce – Perspektywy uprawy i wykorzystanie nasion. Acta Agrophysica, 2005, 6(1), 213–224.

[20] Podleśny J., Podleśna A.: Wpływ różnych poziomów wilgotności gleby na rozwój i plonowanie dwóch genotypów łubinu białego (Lupinus albus L.). Biuletyn IHAR, 2003, 228, 315-322.

[21] Prusiński J.: Dynamika gromadzenia świeżej i suchej masy oraz azotu przez rośliny tradycyjnej i samokończącej odmiany łubinu żółtego (Lupinus luteus L.). Acta Scientiarum Polonorum. Agricultura, 2005, 4(2), 57-72.

[22] Prusiński J., Kaszkowiak E.: Zastosowanie flurprimidolu w uprawie nasiennej łubinu żółtego (Lupinus luteus L.). Acta Scientiarum Polonorum. Agricultura, 2005, 4(1), 107-116.

[23] Prusiński J., Borowska M., Kaszkowiak E.: Nodulacja łubinu żółtego (Lupinus luteus L.) w zależności od przedplonu, szczepienia nasion Bradyrhizobium lupini i genisteiny. Journal of Central European Agriculture, 2012, 13(4), 822–836.

[24] Pytlarz-Kozicka M.: Wpływ ochrony roślin i szczepienia nitraginą na zdrowotność i plonowanie dwóch odmian łubinu żółtego. Progress in Plant Protection, 2010, 50, 47–51.

[25] Sawicka B., Pszczółkowski P.: Odporność odmian łubinu żółtego na Fusarium spp. Fragmenta Agronomica, 2014, 31(1), 83-94.

[26] Schumacher H., Paulsen H. M., Gau A. E, Link W., Jürgens H. U., Sass O., Dieterich R.: Seed protein amino acid composition of important local grain legumes Lupinus angustifolius L., Lupinus luteus L., Pisum sativum L. and Vicia faba L. Plant Breeding, 2011, 130:156–164.

[27] Sulewska H., Koziara W., Panasiewicz K., Niewiadomska, A.: Reakcja pszenicy ozimej i jęczmienia jarego na nawożenie PRP SOL. Journal of Research and Applications in Agricultural Engineering, 2011, 56(4), 129-133.

[28] Sulewska H., Ratajczak K., Szymańska G., Panasiewicz K., Niewiadomska A.: Response of maize to use the PRP SOL and PRP EBV fertilizers. Journal of Research and Applications in Agricultural Engineering, 2016, 61(4), 182-187.

[29] Sulewska H., Szymańska G., Śmiatacz K., Koziara W., Niewiadomska A.: Efekty stosowania PRP SOL w kukurydzy uprawianej na ziarno. Journal of Research and Applications in Agricultural Engineering, 2013, 58(4), 161-166.

[30] Stachowski P.: Evaluation of meteorological droughts in post-mining areas in Poland in Konin area. Central Pomeranian Scientific Society for Environmental Protection. Annual Set the Environ. Protect, 2010, 12, 587.

[31] Waraczewska Z., Niewiadomska A., Kosicka-Dziechciarek D.: Zastosowanie drobnoustrojów o działaniu synergistycznym w procesie biologicznego wiązania azotu. Woda Środowisko Obszary Wiejskie, 2017, 17, 2(58).

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