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YIELDING OF NARROW-LEAVED LUPIN DEPENDING ON VARIETIES, SOWING METHOD AND SOWING RATE*

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Abstract. Field experiments were conducted in the years 2011–2015 in the plots of the Experimental Station in Gorzyń (52°34′ N, 15°53′ E, Poland), belonging to the Poznan University of Life Sciences. The aim of the study was to assess the effect of cultivar, sowing method and seed rate on yield of narrow-leaved lupin. Analyses showed that the narrow-leaved lupin cultivar and weather conditions in the years of the study significantly modified seed yield. A greater seed yield, amounting to 1.98 t·ha^{-1}, was found for cv. Bojar. The adopted sowing method had a limited effect on the volume of seed yield, whereas an increase in sowing rate by 20 seeds m^{2} within the range from 40 to 100 seeds m^{2} contributed to an increase in yield in this species.

Key words: legume, cultivar, single-seed sowing, seed rate

INTRODUCTION

Growing interest in cultivation of legumes results from the need to improve environmental conditions and increase domestic production of fodder protein. Among approx. 250 species belonging to the genus *Lupinus* only three, i.e. *L. albus, L. luteus* and *L. angustifolius*, are crop plants well adapted to soil and climate conditions of the temperate zone [Galek et al. 2006]. Narrow-leaved lupin is the lupin species with a high yielding potential, increased thermal tolerance and a shorter vegetation period [Dueñas et al. 2009, Wiatr et al. 2007]. This species is a valuable protein source and may be used as fodder in the form of seeds, green forage and silage [Faligowska et al. 2014, Lucas et al. 2015, Stanek et al. 2012].

A decisive role in the modification of the volume and quality of seed yield is played by genetic factors, but very often produced effects are also determined by habitat and cultivation conditions. Literature sources frequently indicate considerable variation in yield both between individual lupin species [Pospišil and Pospišil 2015] and their cultivars. Borowska et al. [2015] showed significantly higher yields in traditional cultivars of white lupin and yellow lupin than those of determinate cultivars. However, the same authors recorded an opposite trend in the case of narrow-leaved lupin. Selection of cultivars [Górynowicz et al. 2014] and an appropriately determined seed rate are required for successful lupin production [López-Bellido et al. 2000]. However, the presented variability of lupin cultivars indicates the need to determine appropriate cultivation technologies, which should include both sowing method and seed rate.

It was assumed in the research hypothesis that cv. Bojar and Regent, varying in terms of their morphotypes, differ in their response to applied experimental conditions.

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The aim of this study was to determine yielding of narrow-leaved lupin cultivars – traditional and determinate, depending on sowing method and seed rate.

MATERIAL AND METHODS

Field experiments were conducted in the years 2011–2015 at the Experimental Station in Gorzyń (52°34′ N, 15°53′ E), belonging to the Poznan University of Life Sciences on soil classified as very good rye complex, quality classes IVa and IVb. The trial was carried out on grey-brown podzolic soil under ordinary growing conditions. The three-factorial experiments were performed in the split-split-plot design with four replications in plots of 24 m^2. The first factor was the cultivar (traditional – Bojar; determinate – Regent). The second factor was the sowing method (row sowing; single-seed sowing). The third factor was the seed rate (40, 60, 80, 100 germinating seeds per 1 m^2). Row spacing was 15 cm and sowing depth was 3–4 cm. In the autumn a multicomponent fertilizer Polifoska 4 was applied at 15 kg $N \cdot ha^{-1}$, 21.8 kg $P \cdot ha^{-1}$, 58,1 kg $K \cdot ha^{-1}$. Depending on weather conditions in a given year narrow-leaved lupin was sown in the first or second decade of April. Prior to sowing seeds were dressed with Vitavax 200 FS (200 g·dm ^{3}, active substance carboxin and tiuram) and they were inoculated with Nitragina *(Bradyrhizobium* sp.). In each year of culture weed control was performed following sowing by spraying Afalon Dyspersyjny 450 SC (1.25 $dm^3 \cdot ha^{-1}$, active substance linuron) and additionally monocotyledonous weeds were treated with Leopard 05 EC or Leopard Extra 05 EC (both applied at 2.0 $dm^3 \cdot ha^{-1}$, active substance quizalofop-p-ethyl). Pest control was provided by treatment with Fastac 100 EC (0.1 $dm^3 \cdot ha^{-1}$, as cypermethrin). As a preventive measure against a fungus *Colletotrichum* sp. causing anthracnose 2-3 sprayings were performed using Bravo 500 SC (2.0 $dm^3 \cdot ha^{-1}$, as chlorothalonil) or Gwarant 500 SC (2.0 $dm^3 \cdot ha^{-1}$, as chlorothalonil). Prior to harvest plants were desiccated using Reglone 200 SL (2.5 $dm^3 \cdot ha^{-1}$, as diquat). Cultivation measures were performed following good agricultural practice for this species. After emergence and before harvest the number of plants per 1 m^2 was recorded, while before harvest from each plot a total of 10 plants were collected to determine the number of pods and seeds per plant, 1000-seed weight in grams (seeds collected from the harvested seed mass; 2 x 500 seeds were counted and weighed). Lupin was harvested annually in August using a 1.5 m wide Wintersteiger Classic Plot Combine. Seed yield was determined at a 15% moisture content.

All data were processed using the one-way analysis of variance (ANOVA) with the SAS package. The means of treatments were compared using Tukey's Multiple Range test and the least significant difference (LSD) was declared at $P<0.01$ and $P<0.05$. Relationships between seed yield and its components were determined based on Pearson's correlation coefficients.

RESULTS AND DISCUSSION

In comparison to other crop species legumes, including lupin, exhibit greater variability in yielding over the years as a result of their high sensitivity to weather conditions [Górynowicz et al. 2014, Jensen et al. 2004, Podleśny and Podleśna 2010, Pospišil and Pospišil 2015]. According to Podleśna et al. [2014], total precipitation and its distribution are of greatest importance for the volume of seed yield. In the analysed period considerable fluctuations were observed in temperature and total precipitation, as presented in Table 1 including the calculated hydrothermal factor proposed by Sielianinow. Mean temperature in the vegetative growth period of lupin was 12.7–14.4°C and total precipitation was 237.7– 435.9 mm. Particularly adverse conditions during the vegetative growth period of lupin were observed in 2011, which resulted first of all

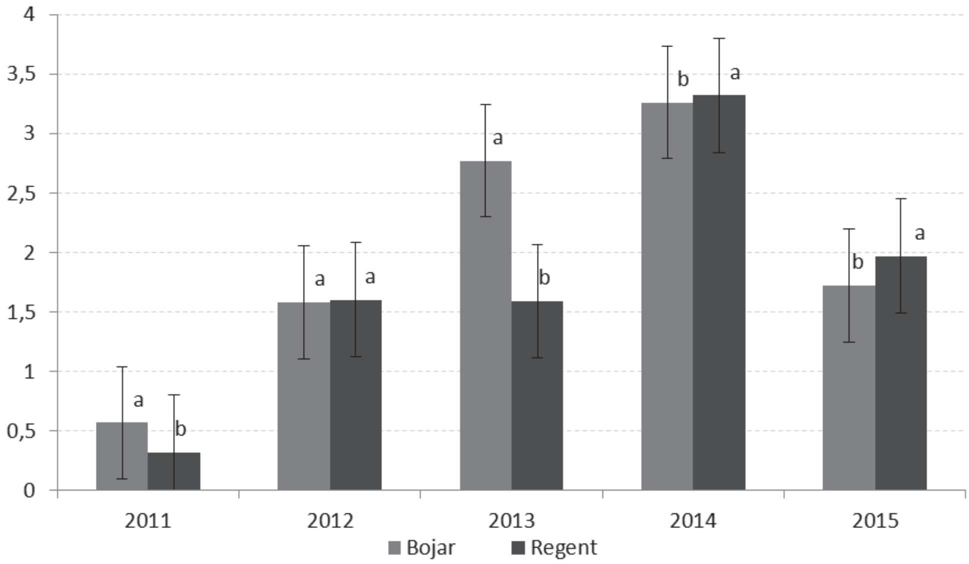
Table 1. Characteristic of weather conditions in Meteorological Station in Gorzyń

Years	Months						III–VIII Sum/Mean
	III	IV	V	VI	VII	VIII	
Precipitation (mm)							
2011	22.1	8.3	25.5	48.9	176.3	28.0	309.1
2012	10.2	20.8	39.1	108.4	133.9	109.8	422.2
2013	30.1	13.0	71.8	110.7	54.1	28.4	308.1
2014	45.7	63.2	103.2	49.1	79.7	95.0	435.9
2015	53.6	32.7	17.6	49.7	72.7	11.4	237.7
Mean for long-term	37.1	49.1	53.4	61.2	76.3	60.7	337.8
Temperature (°C)							
2011	3.9	11.0	14.2	18.3	17.9	18.8	14.0
2012	5.7	8.7	15.1	16.0	19.0	18.6	13.9
2013	-2.6	8.2	14.2	17.6	20.1	18.7	12.7
2014	6.4	10.6	13.3	16.9	21.8	17.6	14.4
2015	5.1	8.4	13.1	16.2	19.2	22.1	14.0
Mean for long-term	3.1	8.1	14.5	17.0	18.7	18.3	13.3
Sielianinow's hydrothermic coefficient							
2011	1.83	0.24	0.58	0.86	3.18	0.48	1.19
2012	0.58	0.77	0.83	2.18	2.27	1.90	1.42
2013	-	0.51	1.63	2.03	0.87	0.49	0.30
2014	2.30	1.92	2.50	0.94	1.18	1.74	1.76
2015	3.39	1.25	0.43	0.99	1.22	1.66	1.49

< 0.5 – severe drought; 0.51–0.69 – drought; 0.70–0.99 – poor drought; ≥ 1 – fault drought

from high temperatures in April and June, as well as dramatically low precipitation levels in April, May and June of that year. In turn, the most advantageous conditions for the cultivation of narrow-leaved lupin were recorded in 2014, in which a favourable distribution of precipitation and the highest total precipitation, i.e. 435.9 mm, were recorded.

Variation in weather conditions observed in the years of the study had a direct effect on yielding of narrow-leaved lupin. The lowest yield of seeds was reported in 2011 and in cv. Bojar it amounted to 0.57 t·ha^{-1}, while in cv. Regent it was 0.32 t·ha^{-1}. In turn, the highest yield was recorded in the year with the most favourable precipitation conditions (2014), when it amounted to 3.26 and 3.32 t·ha^{-1}, respectively (Fig. 1). On average for the analysed years of the study a greater seed yield was found in the traditional cultivar (1.98 t·ha^{-1}), while that of the determinate cultivar was by 0.22 t·ha^{-1} (12.5%) lower.



Mean marked with the same letter are not significantly different P<0.05

Fig. 1. Seed yield of narrow leaved lupin depending on varieties (t·ha^{-1})

Water access in this critical period determines yielding of legumes [Faligowska et al. 2017]. Podleśny and Podleśna [2010] reported the highest yields of seeds in the years with the greatest precipitation total in June, particularly in the flowering period of narrow-leaved lupin. Moreover, those authors indicated a lesser sensitivity to water deficit in traditional cultivars rather than determinate ones, which was also confirmed in this study.

The adopted sowing method significantly modified the yield of seeds in narrow-leaved lupin. A higher seed yield was reported in the case of row sowing (1.91 t·ha^{-1}) and it was higher than that produced using single-seed sowing by 0.08 t·ha^{-1}, i.e. 4.2% (Table 2). When investigating the effect of sowing method in lupin growing Sims [1976] showed that an increase in sowing precision promotes higher yields of seeds in that species. Also Podleśny and Podleśna [2011] reported a higher yielding of peas in treatments with single-seed sowing in comparison to row sowing.

Seed rate evaluated in this study significantly modified the yield of seeds. An increase in seed rate by 20 seeds m^2 within the range of 40 up to 100 seeds m^2 contributed to an increase in yields in that species. For both sowing methods an increase in seed rate caused an increase in the yield of seeds, while only in single-seed sowing a significant effect was observed for the seed rate of 80 seeds m^2. Apart from the treatment with the lowest of the evaluated seed rates (40 seeds m^2), a greater yield of seeds was recorded for lupin grown using row sowing as the sowing method. The greatest difference in the yield of seeds in terms of the adopted sowing method was observed at the seed rate of 100 seeds m^2, as the produced seed yield in the case of row sowing was by 0.27 t·ha^{-1} (13.8%) greater than in single-seed sowing. Pospišil and Pospišil

Table 2. Yield, loss of plant and yield components depending on varieties, sowing method and sowing rate (mean for years 2011–2015)

Factor	Number of plants per 1 m^2		Loss of plants (%)	Number of pods per plant	Number of seeds per pod	Number of seeds per plant	MTN (g)	Seed yield ($t \cdot ha^{-1}$)
	after emergence	before harvest						
Cultivar								
Bojar	67 a	59 b	11.9	10.0 a	3.4 b	33.3 a	166.3 a	1.98 a
Regent	70 a	64 a	8.6	8.2 b	3.5 a	28.2 b	142.9 b	1.76 b
Sowing method								
Row sowing	70 a	68 a	2.8	8.1 b	3.4 a	30.0 a	156.1 a	1.91 a
Single-seed sowing	67 b	56 b	16.4	9.3 a	3.4 a	32.5 a	153.1 b	1.83 b
Sowing rate								
40	49 d	48 d	2.0	11.1 a	3.3 a	36.3 a	152.9 b	1.58 d
60	61 c	57 c	7.0	9.3 b	3.4 a	32.1 b	154.3 a	1.80 c
80	76 b	65 b	14.5	8.0 c	3.5 a	29.4 b	155.4 a	2.01 b
100	89 a	78 a	12.3	7.1 d	3.5 a	26.1 c	155.8 a	2.10 a

Numbers marked with the same letter are not significantly different $P<0.05$

[2015] showed no significant effect of seed rate on the yield of seeds in white and narrow-leaved lupin. Corbett et al. [2001] recorded a significant increase in the yield of seeds in narrow-leaved lupin at the increase in seed rate from 35 to 60 seeds m^2, although an increase in the number of germinating seeds above 75 seeds m^2 did not cause any further increase in the seed yield.

The analysis of yield components in this study depending on the cultivar showed a significantly greater number of plants per 1 m^2, number of seeds per pod and lesser losses of plants in the determinate cultivar. In relation to the traditional cultivar it was also characterised by significantly lower values of the other yield components expressed in the number of pods, number of seeds per plant and the thousand seed weight. Similar results, except for the thousand seed weight, were reported by Podleśny and Podleśna [2010]. A study by Borowska et al. [2015] indicated a higher seed yield in the determinate narrow-leaved lupin cultivar as a result of a greater number of pods per plant than in the case of the traditional cultivar.

The adopted sowing method significantly modified the number of plants both before and after harvest, with greater values recorded in treatments with row sowing, where additionally a lower share of plant losses in the plantation (2.8%) and a greater thousand seed weight were observed. In the opinion of Podleśny and Podleśna [2011], single-seed sowing facilitates their uniform distribution, thus limiting competition between plants and as a result it is possible to appropriately modify morphological traits of plants.

Seed rate analysed in this study had a significant effect on the number of plants per area unit both after emergence and before harvest. An optimal number of plants per unit area before harvest were obtained at the adopted seed rate of 60 seeds m^2. An increase in seed rate contributed to an increase in plant losses during vegetative growth period of narrow-leaved lupin, with the highest value of this trait reported at the adopted rate of 80 plants per 1 m^2. Moreover, an increase in seed rate at 40–100 seeds m^2 caused a significant reduction in the number of pods per plant, number of seeds per plant and an increase in the thousand seed weight between the treatment with the lowest of the adopted seed rates, i.e. 40 germinating seeds m^2, and the rates of 80 and 100 seeds m^2. López-Bellido et al. [2000] when assessing variability in the yield of seeds and yield components in white lupin depending on seed rate (20, 40, 60 seeds m^2) showed no significant effect of this factor on the yield, the number of seeds per plant and thousand seed weight, while they reported a reduction in the number of pods per plant with an increase in seed rate. Pospišil and Pospišil [2015] found that an increase in the rate above 60 germinating seeds m^2 significantly reduced the number of pods, number of seeds and seed weight per plant, thus in the opinion of those authors the recommended seed rate should be 60 seeds m^2.

Variable weather conditions in the years of the study and cultivation factors had a significant effect on the yield of seeds and its components. The lowest values of seed yield and a greater variability of seed yield, expressed in the coefficient of variability, was recorded irrespective of the sowing method in cv. Regent (Table 3). In turn, in cv. Bojar single-seed sowing turned out

Table 3. Variation of narrow leaved lupin features depending on varieties and sowing method (mean for years 2011–2015)

Variety	Sowing method	Variable	Average	Min	Max	SD	CV
Bojar	row sowing	1	64	44	94	19.4	30.5
		2	9.5	2.0	15.3	4.76	49.8
		3	3.5	3.0	3.8	0.30	8.5
		4	33.0	5.6	59.7	19.2	58.1
		5	167.3	156.4	183.6	13.5	8.1
		6	2.02	0.48	3.70	1.19	59.2
	single-seed sowing	1	55	50	61	5.37	9.8
		2	9.6	2.6	14.0	4.19	43.7
		3	3.5	3.0	4.1	0.41	11.6
		4	33.4	7.8	54.7	16.7	50.0
		5	165.2	150.5	181.5	14.2	8.6
		6	1.95	0.66	3.02	0.97	50.9
Regent	row sowing	1	72	45	110	24.9	34.4
		2	7.2	2.0	11.1	3.74	51.9
		3	3.5	2.7	4.0	0.51	14.7
		4	26.7	6.3	43.6	14.7	55.1
		5	144.9	133.9	158.6	10.7	7.4
		6	1.82	0.33	3.41	1.12	61.7
	single-seed sowing	1	56	43	63	8.57	15.1
		2	8.5	2.2	15.2	4.68	54.8
		3	3.4	2.9	4.0	0.40	11.7
		4	29.6	6.4	50.8	16.0	54.0
		5	140.9	125.8	154.5	10.4	7.4
		6	1.71	0.30	3.24	1.04	60.9

SD – standard deviation; CV – coefficient of variation; (1) Number of plants before harvest per 1 m^2, (2) Number of pods per plant, (3) Number of seeds per pod, (4) Number of seeds per plant, (5) MTN, (6) Seed yield (t·ha^{-1})

to be a factor stabilising the volume of seed yield, which resulted from lower values of standard deviation and the coefficient of variability in the case of the number of plants per unit area, number of pods per plant and the number of seeds per plant.

Pearson's correlation coefficient between the yield of seeds and yield components depending on the cultivar and sowing method showed a varied correlation between these parameters (Table 4). Indexes of simple correlation determined in this study indicate that the yield of seeds in the traditional cultivar (Bojar) at the use of row sowing as the sowing method was most strongly correlated with the number of seeds per plant and the number of pods per plant. In turn, in the case of single-seed sowing for this cultivar the strongest relationship of yield with the number of seeds per pod, number of plants per unit area, followed by the number of seeds and the number of pods per plant. In the determinate cultivar (Regent) at both sowing methods the strongest

Table 4. Correlation of coefficients for seed yield and yield's components of narrow leaved lupin as affected of variety and sowing method

Variety	Sowing method	Variable	Number of plants before harvest per 1 m^2	Number of pods per plant	Number of seeds per pod	Number of seeds per plant	MTN	Seed yield ($t \cdot ha^{-1}$)
			(1)	(2)	(3)	(4)	(5)	(6)
Bojar	row sowing	1	1.000					
		2	0.565	1.000				
		3	0.428	0.967**	1.000			
		4	0.509	0.989**	0.937*	1.000		
		5	0.315	-0.568	-0.710	-0.572	1.000	
		6	0.642	0.939*	0.843	0.951*	-0.337	1.000
	single-seed sowing	1	1.000					
		2	0.534	1.000				
		3	0.820	0.649	1.000			
		4	0.581	0.986**	0.600	1.000		
		5	0.312	-0.608	0.064	-0.571	1.000	
		6	0.899*	0.827	0.910*	0.828	-0.070	1.000
Regent	row sowing	1	1.000					
		2	0.098	1.000				
		3	0.141	0.993**	1.000			
		4	0.141	0.994*	0.929*	1.000		
		5	0.394	-0.853	-0.735	-0.815	1.000	
		6	0.324	0.912*	0.887*	0.949*	-0.613	1.000
	single-seed sowing	1	1.000					
		2	0.838	1.000				
		3	0.845	0.994**	1.000			
		4	0.845	0.994**	0.628	1.000		
		5	0.297	0.009	-0.506	-0.059	1.000	
		6	0.809	0.965**	0.623	0.961**	0.099	1.000

*P < 0.05 and **P < 0.01

relationship of the yield of seeds was observed for the number of seeds and the number of pods per plant, and also at the use of row sowing for the number of seeds per pod while in single-seed sowing an equally significant correlation was found between the yield of seeds and the number of plants per unit area before harvest. A study by Faligowska and Szukała [2015] on the traditional narrow-leaved cv. Baron indicated the strongest correlation of the yield of seeds with the number of pods per plant and the number of seeds per plant. Irrespective of sowing method in the traditional cultivar and in cv. Regent in the case of row sowing a negative correlation was found for the yield of seeds with the thousand seed weight.

CONCLUSION

The narrow-leaved lupin cultivar and weather conditions in the years of the study significantly modified the yield of seeds. A higher seed yield was recorded in cv. Bojar, in which it amounted to 1.98 $t \cdot ha^{-1}$. Sowing method significantly modified the volume of seed yield. The mean yield of seeds produced in the case of row sowing was 1.91 $t \cdot ha^{-1}$, while in the case of single-seed sowing it was 1.83 $t \cdot ha^{-1}$. An increase in seed rate by 20 seeds m^2 within the range from 40 to 100 seeds m^2 contributed to an increase in yields in that species.

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PLONOWANIE ŁUBINU WĄSKOLISTNEGO W ZALEŻNOŚCI OD ODMIANY, SPOSOBU SIEWU I GĘSTOŚCI SIEWU

Synopsis. Doświadczenia polowe przeprowadzono w latach 2011–2015 na polach Zakładu Doświadczalno-Dydaktycznego Gorzyń należącego do Uniwersytetu Przyrodniczego w Poznaniu. Celem badań była ocena plonowania łubinu wąskolistnego w zależności od odmiany, sposobu siewu oraz gęstości siewu. Badania wykazały, że odmiana łubinu wąskolistnego oraz warunki pogodowe w latach badań istotnie modyfikowały plon nasion. Wyższym plonem nasion charakteryzowała się odmiana Bojar i wynosił on 1,98 $t \cdot ha^{-1}$. Sposób siewu w małym stopniu modyfikował wielkość plonu nasion natomiast zwiększanie gęstości siewu o 20 $nasion \cdot m^{-2}$ w zakresie od 40 do 100 $nasion \cdot m^{-2}$ przyczyniało się do wzrostu plonu tego gatunku.

Słowa kluczowe: łubin wąskolistny, odmiana, siew punktowy, gęstość siewu

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