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Influence of sowing density on agronomic traits of lupins (*Lupinus* spp.)

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ABSTRACT

The aim of the research conducted on eutric brown soil on the experimental facility of Faculty of Agriculture, University of Zagreb in 2012 and 2013, was to determine the optimal sowing density for two cultivars of white lupin (Teodora and Energy) and a cultivar of narrow-leafed lupin (Arabella). The study included three sowing densities: 60, 75 and 90 germinated seeds/m^2. The cultivars of white lupin achieved significantly higher seed yield, higher 1000 seed weight, higher weight of seeds per plant and higher protein content in the seed, compared to the cultivar of narrow-leafed lupin. The sowing density had no effect on seed yield, but the increase in sowing density above 60 germinated seeds/m^2 significantly reduced the number of pods, the number of seeds and seed weight per plant.

Keywords: *Lupinus angustifolius*; *L. albus*; legume; growing conditions; forage; yield components

Although once widespread in Europe, lupin is today a neglected culture. However, recent years saw the re-intensification of work on creation of new cultivars and enhancement of lupin agronomic properties. The selection of cultivars and correctly determined sowing density are prerequisites for successful lupin production.

The inclusion of lupin in crop rotation positively influences biodiversity and soil fertility as the bacteria at the root of lupin symbiotically absorb nitrogen (N) from air. Lupin plant residues provide the next culture with 32–96 kg N/ha, while the accumulation of nitrogen in lupin biomass ranges from 199–372 kg N/ha, 86% of which is the result of symbiotic fixation (Unkovich et al. 1994).

Lupin can be grown on less fertile, acidic and sandy soils where other crops produce lower yield (Jensen et al. 2004, Doxastakis 2007). It is also very important for crop rotation, especially in organic agricultural production, due to its positive impact on yield of subsequent crops, mainly cereals (Jensen et al. 2004).

From a nutritional standpoint lupin is valued for its high content of protein, dietary fiber, oil and sugar (Erbaş et al. 2005). Protein content in the seeds varies from 32–47% depending on lupin cultivar and growing conditions (Faluyi et al. 2000, Erbaş et al. 2005, Fraser et al. 2005, Böhm et al. 2008). The impact of sowing density on agronomic properties of lupin depends on the cultivar and weather conditions during growing season (Mülayim et al. 2002). Depending on weather conditions, the cultivar and production technology white lupin seed yield ranges from 0.260–1.663 t/ha (Mülayim et al. 2002). In Mülayim's et al. (2002) research seed yield was increasing with sowing density up to 74 plants/m^2 while at the same time 1000 seed weight was decreasing. However, López-Bellido et al. (2000) determined no significant impact of sowing density (20, 40 and 60 plants/m^2) on seed yield, number of seeds per plant or 1000 seed weight, but the increase in sowing density decreased the number of pods per plant. The yield of blue lupin in Germany varied by year and cultivar from 1.76–3.76 t/ha (Böhm et al. 2008). At the same time, the protein yield varied from 365–989 kg/ha.

Lupin adjusts well to different sowing densities as it increases the number of branches and produces the similar number of pods regardless of sowing density or extremely different climatic conditions (López-Bellido et al. 2000).

The aim of this study was to determine the optimal sowing density for cultivars of white and narrow-leafed lupin, and to explore the impact of sowing density on lupin yield and yield components.

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MATERIAL AND METHODS

The studies were conducted on the experimental facility of the Faculty of Agriculture, University of Zagreb in 2012 and 2013. The study included three lupin cultivars: Feodora and Energy (white lupin – *Lupinus albus* L.) and Arabella (narrow-leafed lupin – *L. angustifolius* L.) and three sowing densities: 60, 75 and 90 germinated seeds/m^2. Cv. Arabella is a very early bitter lupin, cv. Feodora is an early to medium early bitter lupin while cv. Energy is a medium early sweet lupin. The experiment was set up using strip-block method in four repetitions. Plot size was 14 m^2 (4 rows × 0.70 × 5 m). The studies were conducted on eutric-brown soil, slightly acidic (pH_{KCl} 5.5), poorly supplied with organic C (0.75%), moderately supplied with nitrogen (0.09% N), well supplied with phosphorus (105.6 mg P/kg of soil) and moderately supplied with potassium (152.7 mg K/kg of soil). Spelt was grown as forecrop. Fertilization was performed before sowing with NPK 10:20:30 fertilizer in the amount of 200 kg/ha. Sowing was performed on April 3rd, 2012 and April 12th, 2013. Weed control was performed by inter-row cultivation. White lupin was harvested on August 1st, 2012 and August 6th, 2013, while the harvest of narrow-leafed lupin took place on July 9th, 2012 and July 26th, 2013. Seed yield, seed moisture and 1000 seed weight were determined after the harvest. The following characteristics were analyzed on the sample of 10 plants per plot taken before harvest: plant height, height at the beginning of inflorescence, number of pods per plant, number of seeds per plant and seed weight per plant. Harvest index was calculated as the ratio of seed weight per plant and total plant weight. Protein content in the seed was determined for each cultivar as an average across all sowing densities. Total nitrogen was determined by the Kjeldahl method (AOAC 2002) and converted into protein by multiplication by a factor of 6.25. The obtained data was analyzed using variance, while the *t*-test verified average values.

RESULTS AND DISCUSSION

In both years, the obtained plant density at harvest was up to 5% lesser compared to researched sowing density. In 2012, the cv. Energy achieved significantly highest seed yield (3033 kg/ha), while in 2013 there were no statistically significant differences in yield among cultivars of white lupin (Tables 1 and 2). In both years the cultivar of narrow-leafed lupin Arabella achieved significantly lower seed yield compared to two cultivars of white lupin. Lower seed yield in 2013 was the result of insufficient rainfall during lupin flowering. In June of 2013, there was 50% less rainfall compared to the long-term average, while during the same period in 2012 there was 31.3% more rainfall compared to the long-term average (Table 3). At the same time, average daily temperature during June, July and August 2013 was lower compared to the year 2012 which resulted in late ripening of lupins (Table 4). Significant yield variability in different weather conditions is the result of low stability of lupins yield as stated by Jensen et al. (2004). Sowing density had no effect on lupins yield. Similar results were obtained by López-Bellido et al. (2000) who identified lupin's adaptability to

Table 1. Yield and yield components of lupins cultivars at different sowing density in 2012

Management factor	Seed yield (kg/ha)	1000 seed weight (g)	Plant height (cm)	Height to the beginning of inflorescence (cm)	Height under first pod (cm)	Pod number per plant	Seed number per plant	Seed weight per plant (g)	Harvest index	Protein content in seed (g/kg)
Cultivar										
Feodora	2675^{b}	223.8^{b}	63.0^{b}	33.8^{b}	41.3^{b}	6.3^{b}	21.3^{b}	5.7^{b}	0.45^{a}	373.5^{a}
Energy	3033^{a}	290.7^{a}	84.3^{a}	47.5^{a}	51.9^{a}	3.9^{c}	16.1^{c}	7.1^{a}	0.42^{b}	367.7^{a}
Arabella	1967^{c}	135.2^{c}	47.0^{c}	28.9^{c}	33.8^{c}	8.9^{a}	29.7^{a}	4.2^{c}	0.46^{a}	308.5^{b}
Plant density (seeds/m^2)										
60	2455	213.8	41.3^{b}	35.0^{b}	41.0	7.9^{a}	26.9^{a}	5.4^{a}	0.45	–
75	2594	214.3	51.9^{a}	36.9^{ab}	42.6	6.2^{b}	22.3^{b}	4.4^{b}	0.45	–
90	2625	221.5	33.8^{c}	38.2^{a}	43.5	5.1^{b}	18.0^{c}	3.7^{c}	0.44	–

Values followed by the same letter within the year are not significantly different at the 5% level of probability

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Table 2. Yield and yield components of lupins cultivars at different sowing density in 2013

Management factor	Seed yield (kg/ha)	1000 seed weight (g)	Plant height (cm)	Height to the beginning of inflorescence (cm)	Height under first pod (cm)	Pod number per plant	Seed number per plant	Seed weight per plant (g)	Harvest index	Protein content in seed (g/kg)
Cultivar										
Feodora	2130[a]	309.8[b]	76.2[b]	52.4[b]	58.0[b]	5.4	19.4	4.7[a]	0.38[a]	405.2[a]
Energy	1925[a]	378.9[a]	88.8[a]	64.4[a]	69.6[a]	5.4	20.0	4.6[a]	0.36[a]	413.2[a]
Arabella	403[b]	133.6[c]	46.7[c]	12.2[c]	31.4[c]	5.4	17.1	2.0[b]	0.20[b]	353.4[b]
Plant density (seeds/m^2)										
60	1557	275.0	73.9	42.6	53.3	6.4[a]	22.8[a]	6.1[a]	0.31	–
75	1405	280.1	69.1	42.7	51.9	5.5[a]	18.5[b]	4.8[b]	0.31	–
90	1496	267.3	68.5	43.8	53.9	4.3[b]	15.2[b]	4.0[c]	0.32	–

Values followed by the same letter within the year are not significantly different at the 5% level of probability

different growing conditions as the reason of the lack of sowing density influence on its yield.

In both years of research the cv. Energy had significantly highest 1000 seed weight (290.7 g in 2012, and 378.9 g in 2013). The 1000 seed weight of narrow-leafed lupin (cv. Arabella) was 135.2 g in 2012 and 133.6 g in 2013. The obtained values of 1000 seed weight of white lupin coincide with those obtained by Mülayim et al. (2002) and Erbaş et al. (2005).

In 2013 the increase in plant height was the result of increased precipitation during lupins vegetative development compared to the year 2012. In both years of research the cv. Energy had the highest stem, the greatest height at the beginning of inflorescence and the greatest height under first pod. In 2012, the greatest plant height was recorded at the sowing density of 75 germinated seeds/m^2 while the greatest height at the beginning of inflorescence were recorded at sowing densities of 75 and 90 germinated seeds/m^2 (Table 1). In 2013 the influence of sowing density on these parameters was not statistically significant (Table 2).

In 2012 a larger number of pods per plant was recorded compared to 2013 which was the result of more favorable distribution of rainfall during lupin growth. In 2012, the cv. Arabella had the highest number of pods per plant (8.9), while the cv. Energy had the lowest number of pods (3.9). In 2013, there were no significant differences among the cultivars of lupins in the number of pods per plant. In both years of research the highest number of pods per plant was achieved at the lowest sowing density (60 germinated seeds/m^2), and in 2013 at the density of 75 germinated seeds/m^2.

In 2012, the cv. Arabella achieved the highest number of seeds per plant (29.7), while in 2013 the differences between cultivars were not significant. In both years the highest number of seeds per plant was achieved at the lowest sowing density (26.9 in 2012 and 22.8 in 2013).

In 2012, the cv. Energy had the highest weight of seeds per plant (7.1 g), while in 2013 the cvs. Feodora and Energy had the highest weight of seeds per plant which was the result of signifi-

Table 3. Total monthly precipitation (mm) during the 2012 and 2013 growing seasons and long-term average (1981–2010) in Zagreb-Maksimir, Croatia

Month	Growing season 2012	Growing season 2013	Long-term average 1981–2010
April	51.3	56.1	59.5
May	81.8	94.0	68.6
June	127.9	48.7	97.4
July	56.3	33.2	71.4
August	9.8	145.2	96.2
Total	327.1	377.2	393.1

Table 4. Mean monthly air temperature (°C) during the 2012 and 2013 growing seasons and long-term average (1981–2010) in Zagreb-Maksimir, Croatia

Month	Growing season 2012	Growing season 2013	Long-term average 1981–2010
April	12.5	13.0	11.4
May	16.7	16.4	16.5
June	22.0	20.0	19.6
July	24.2	23.3	21.5
August	24.0	22.5	20.8

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cantly higher 1000 seed weights in these cultivars. The highest seed weight per plant was achieved at the sowing density of 60 germinated seeds/m^2, and it amounted to 5.4 g in 2012 and 6.1 g in 2013. In both years of research higher number of pods, number of seeds and higher seed weight per plant were recorded at the lowest sowing density (Tables 1 and 2). López-Bellido et al. (2000) cited the weight of seeds per plant as the most important component of yield which has the largest direct and indirect impact on seed yield of white lupin.

In 2012, the cvs. Feodora and Arabella achieved the highest harvest index (0.45 and 0.46, respectively); while in 2013 the highest harvest index was obtained by cvs. Feodora and Energy (0.38 and 0.36, respectively). Sowing density had no effect on the harvest index in any year of investigation. Harvest index did not change with an increase in sowing density which coincides with the results of Herbert (1977), but not with those of López-Bellido et al. (2000) who found varying impact of sowing density on harvest index depending on the year of investigation. In two out of four years, they obtained significantly higher harvest index at lower sowing density, and concluded that lupin was not adapted for seed production at higher densities.

In both years of research the cultivars of white lupin (Feodora and Energy) achieved significantly higher protein content in the seed than the cultivar of narrow-leafed lupin (Arabella) (Tables 1 and 2). Achieved protein content in white lupin seed was higher compared to the results of Erbaş et al. (2005), while the protein content in seed of narrow-leafed lupin coincides with the results of Fraser et al. (2005) and Böhm et al. (2008).

In conclusion, seed yield and yield components depended on weather conditions during the growing season. The cultivars of white lupin achieved significantly higher seed yield than the narrow-leafed lupin. The cv. Energy achieved the highest 1000 seed weight. The cv. Arabella achieved the highest number of pods and seeds per plant, but low 1000 seed weight prevented it from reaching higher yields. Sowing density had no effect on lupins seed yield, but the increase in sowing density above 60 germinated seeds/m^2 significantly reduced the number of pods, the number of seeds and seed weight per plant. Therefore, sowing density of 60 germinated seeds/m^2 could be recommended for lupin seed production. Harvest index was low, especially in the year with unfavorable weather conditions. White lupin cultivars are more suitable for production of proteins as they achieved higher seed yield and seed protein content.

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