The Potential of White Lupin (*Lupinus albus* L.) Seed and Biomass Yield in organic Farming

Potencijal prinosa sjemena i biomase bijele lupine (*Lupinus albus* L.) u ekološkoj proizvodnji

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Poljoprivreda / Agriculture

ISSN: 1848-8080 (Online)
ISSN: 1330-7142 (Print)

https://doi.org/10.18047/poljo.28.1.3

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ISSN 1330-7142
UDK=582.736.309:631.164.24
https://doi.org/10.18047/poljo.28.1.3

THE POTENTIAL OF WHITE LUPIN (*Lupinus albus* L.) SEED AND BIOMASS YIELD IN ORGANIC FARMING

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Original scientific paper
Izvorni znanstveni članak

SUMMARY

Lupin is a very promising crop for seed and biomass production in organic farming. The aim of this research, conducted in 2018 and 2019 at the experimental facility of the Faculty of Agriculture, University of Zagreb, was to determine the white lupin seed and biomass yield, depending on the sowing density. The trial was laid out according to a randomized block design with four replications. The research included two white lupin varieties, Feodora and Energy, respectively, and three sowing densities: 50, 70, and 90 seeds m^{-2}. In 2018, the Energy variety achieved a higher green mass and dry matter yield than the **Feodora** ***variety, and tended to produce the insignificantly higher yields than*** **Feodora** ***over all the tested sowing densities in 2019. The green mass and the dry matter yield increased with an increase in the sowing density. In 2019, the weather conditions were more favorable for the lupin growth and development, and a higher yield was achieved if compared to that of 2018. The Energy variety achieved a significantly higher seed yield in 2018. The seed yield increased with an increase in the sowing density. In both research years, the number of pods and seed weight per plant decreased with an increase in the sowing density. These parameters' lowest values were achieved at the sowing density of 90 seeds m^{-2}. A tendency of a harvest index decrease was detected along with an increase in the sowing density, but the differences were very small.***

Keywords: white lupin, biomass yield, seed yield, yield components

INTRODUCTION

Lupin is an unjustifiably neglected legume in Europe these days. The lupin seeds are rich in protein, and they are used in a way similar to that of the soybean, that is, they could be its alternative, reducing Europe's dependence on the soybean import. Due to its high seed protein content, lupin can be used as an alternative protein source for livestock feeding (Gresta et al., 2010; Abraham et al., 2019). Due to a high green mass yield, lupin can also be used for the green manure, especially in organic production (Erbaş et al., 2005; Carranca et al., 2009). In crop rotation, the legumes inhibit the pest and disease cycles and prevent the grass-type crops' weed problems (Yuvaraj et al. 2020). Compared to other crops, the advantage of lupin in organic production originates from a possibility of atmospheric nitrogen binding. It was discovered that lupin can symbiotically bind 147–400 kg N ha^{-1} (Howieson et al., 1998), and the amount of bound nitrogen is related to a total biomass yield (Cheriere, 2016). Subsequent to lupin cultivation, a large amount of nitrogen-rich biomass remains in the soil, which makes it a very desirable precrop for most crops, especially on the sandy soils (Jensen et al. 2004). On the poorer soils, lupin achieves a higher yield than some other legumes, but it does not tolerate the soils with the high pH values (Huyghe, 1997). Today, when the efforts are being invested to increase the arable land biodiversity, the introduction of neglected crops into production is becoming more important. A greater inclusion of legumes in the crop rotation increases crop diversity, has a beneficial effect on the soil fertility and its enzymatic activity, and contributes to a reduction in the usage of mineral fertilizers and greenhouse gas emissions (Jasińska & Kotecki, 2001; Stagnari et al.

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2017; Symanowicz et al. 2018). The breeding program's objective is to obtain the lupin varieties with the improved properties that differentiate it from other legumes. One of the disadvantages of lupin usage—that is, a high content of bitter alkaloids— is eliminated in the new lupin varieties, so lupin can now be used without restrictions or special preparation. Given that little data are available on the reaction of lupin varieties to different agroecological conditions, this study's aim was to determine the seed and biomass yield depending on the sowing density, in order to facilitate a promotion of lupin's introduction into the crop rotation.

MATERIALS AND METHODS

The research was conducted at the experimental facility of the Faculty of Agriculture in Zagreb in 2018 and 2019, on an organically farmed arable land (45^0 49′ N, 16^0 1′ E). The trial involved two white lupin varieties, *Feodora* (Südwestdeutsche Saatzucht GmbH & Co. KG, Germany) and Energy (Terrena Poitou sca, France), and three sowing densities: 50, 70, and 90 germinated seeds m^{-2}. The trial was laid out according to a randomized block design with four replications. The trials were conducted on an anthropogenic eutric cambisol (Vidaček at al., 1994). The upper soil layer was acidic (pH in 1 M KCl = 4.96), poorly supplied with humus (1.62%), and well-supplied with nitrogen (0.12%). The soil was well-supplied with the plant-available phosphorus (AL - P_2O_5 = 21.5 mg 100 g^{-1} soil) and potassium (AL - K_2O = 23.0 mg 100 g^{-1} soil). Spelt was cultivated as a forecrop. The fertilization was performed prior to sowing with 200 kg ha^{-1} of 5:10:10 organic *Proeco* fertilizer. Sowing was performed on 6 April 2018 and 1 April 2019. No separate seed inoculation was performed, but lupin was involved in crop rotation for several years in the same field, during which the seed inoculation was performed. Plot size amounted to 14 m^2 (4 rows x 0.70 m row spacing x 5 m length). Weed control was performed by an inter-row cultivation. The samples for green biomass yield determination were taken from two middle rows, that is, from an area amounting to 1 m^2 at the end of lupin flowering stage, BBCH 69 (Hack et al. 1992). Subsequent to the drying at the temperature of 70 °C, the dry matter yield was determined.

Lupin was harvested on 23 August 2018 and 7 August 2019. The seed yield and moisture were determined subsequent to the harvest. Previously, the 10-plant harvest samples per plot were taken, and the following traits were analyzed: plant height, height at the flowering stage commencement, height under the first pod, number of pods per plant, number of seeds per plant and seed weight per plant. The harvest index was calculated as ratio of a seed weight per plant and total plant weight. The obtained data were analyzed by the MSTAT-C software program (1990).

Weather conditions

The weather conditions during research were different, considering the precipitation quantity and the monthly mean air temperature. During the 2019 white lupin growing season, 44.9 mm more precipitation was received than in 2018 and 40 mm more than the long-term average (Table 1). A precipitation distribution was not uniform, and there was 30.4 mm more precipitation in June 2018 when compared to the long-term average and 57 mm more precipitation when compared to 2019. However, during the flowering stage in May 2019, 79 mm more precipitation was received if compared to 2018 and 79.1 mm more precipitation if compared to the long-term average. This exerted a positive effect on the flowering and pod formation, and a higher white lupin seed yield was achieved in 2019.

Table 1. Total monthly precipitation (mm) during the 2018 and 2019 growing seasons and a long-term average (1981-2010) in Zagreb-Maksimir

Tablica 1. Ukupna količina oborina (mm) tijekom vegetacijske sezone 2018. i 2019. godine i višegodišnji prosjek (1981. – 2010.) za Zagreb-Maksimir

Month / *Mjesec*	**Precipitation** / *Oborine* (mm)		
	Growing season *Vegetacijska sezona*		**Long-term average** *Višegodišnji prosjek*
	2018	2019	1981-2010
April / *travanj*	65.8	81.1	59.5
May / *svibanj*	68.7	147.7	68.6
June / *lipanj*	127.8	70.8	97.4
July / *srpanj*	85.2	76.8	71.4
August / *kolovoz*	40.7	56.7	96.2
Total / *ukupno*	388.2	433.1	393.1

In both research years, the monthly mean air temperature during the growing season was higher than the long-term average, by 2.7 °C in 2018 and by 1.3 °C in 2019 (Table 2). In 2018, the largest deviation was recorded in April and May, when the average monthly temperature was 4.7 °C and 3 °C higher than the long-term average, respectively. The high temperatures in May exerted a negative effect on the lupin flowering stage. In May 2019, the average monthly air temperature was 2.8 °C lower than the long-term average, which exerted a positive impact on the lupin flowering and pod formation, in addition to a higher precipitation quantity. In June 2019, the average monthly temperature was 4.2 °C higher than the long-term average. However, due to a sufficient precipitation quantity from the previous period, this did not negatively affect the lupin seed yield.

Table 2. The monthly mean air temperature (°C) during the 2018 and 2019 growing seasons and a long-term average (1981-2010) in Zagreb-Maksimir

Tablica 2. Srednje mjesečne temperature zraka (°C) tijekom vegetacijske sezone 2018. i 2019. godine i višegodišnji prosjek za Zagreb-Maksimir

Month / *Mjesec*	**Mean montly air temperature** / *Srednja mjesečna temperature zraka (°C)*		
	Growing season / *Vegetacijska sezona*		**Long-term average** / *Višegodišnji prosjek*
	2018	2019	1981-2010
April / *travanj*	16.1	12.4	11.4
May / *svibanj*	19.5	13.7	16.5
June / *lipanj*	21.4	23.8	19.6
July / *srpanj*	22.5	22.9	21.5
August / *kolovoz*	23.7	23.5	20.8

RESULTS AND DISCUSSION

In the year 2018, the Energy variety achieved a significantly higher green mass and dry matter yield when compared to the Feodora variety (Table 3).

In 2018, the green mass yield increased significantly with an increase in the sowing density and ranged from 18.4 to 26.0 t ha^{-1} (Table 3). However, in 2019, no significant difference was detected between the sowing densities of 70 and 90 seeds m^{-2}, although a noticeable trend of a green mass yield increase was existent, along with an increase in the sowing density. In 2018, the significantly lowest dry matter yield was achieved at the lowest sowing density, while a difference between the two higher densities was not statistically significant. In 2019, the dry matter yield ranged from 3.2 to 4.1 t ha^{-1}, but the differences were not statistically significant. López-Bellido et al. (2000) state that the plant density has a greater impact on a dry matter yield increase than on the seed yield, which coincides with this research's results.

Table 3. Green mass and the white lupin dry matter yield depending on a variety and sowing density in 2018 and 2019

Tablica 3. Prinos zelene mase i suhe tvari bijele lupine u ovisnosti o sorti i gustoći sjetve u 2018. i 2019. godini

Variety / *Sorta*	**Sowing density (seeds m^{-2})** / *Gustoća sjetve (sjemenki m^{-2})*	**Green mass yield** / *Prinos zelene mase (t ha^{-1})*	**Dry matter yield** / *Prinos suhe tvari (t ha^{-1})*	**Green mass yield** / *Prinos zelene mase (t ha^{-1})*	**Dry matter yield** / *Prinos suhe tvari (t ha^{-1})*
		2018		2019	
Feodora	50	16.9	2.2	18.4	3.1
	70	20.0	2.9	23.9	3.6
	90	24.0	3.1	24.6	4.2
Energy	50	19.9	2.9	20.2	3.3
	70	22.7	3.8	23.8	3.8
	90	27.9	4.2	26.5	4.0
Mean variety /	*Feodora*	20.3 b	2.7 b	22.3	3.6
Prosjek sorata	*Energy*	23.5 a	3.6 a	23.5	3.7
Mean sowing density / *Prosjek gustoća sjetve*	50	18.4 c	2.6 b	19.3 b	3.2
	70	21.3 b	3.3 a	23.8 a	3.7
	90	26.0 a	3.7 a	25.5 a	4.1

The values followed by the same letter within the year are not significantly different at the 5% probaibility level.

At the end of May 2019, during the lupin flowering stage, the temperatures were lower, with a sufficient amount of precipitation (Tables 1 and 2), which exerted a favorable effect on the flowering and pod formation. Therefore, both varieties achieved a higher seed yield in 2019 (Table 5). However, a difference in the seed yield between varieties was statistically significant only in 2018, when the Energy variety achieved a higher seed yield (Tables 4 and 5). Other researchers also cite the influence of weather conditions on the lupin seed yield, especially during the flowering and pod formation periods (Podleśny and Podleśna, 2011; Cheriere, 2016; Annicchiarico et al., 2018).

Table 4. Seed yield and the white lupin yield components depending on a variety and sowing density in 2018

Tablica 4. Prinos sjemena i komponenata prinosa bijele lupine u ovisnosti o sorti i gustoći sjetve u 2018. godini

Variety / *Sorta*	**Sowing density** / (seeds m^{-2}) *Gustoća sjetve (sjemenki m^{-2})*	**Seed yield** / *Prinos sjemena (kg ha^{-1})*	**Plant height** / Visina biljke (cm)	**Height to the beginning of inflorescence** / *Visina do početka cvati (cm)*	**Height under first pod** / *Visina do prve mahune (cm)*	**Pod number per plant** / *Broj mahuna po biljci*	**Seed number per plant** / *Broj sjemenki po biljci*	**Seed weight per plant** / *Masa sjemena po biljci (g)*	**Harvest indeks** / *Žetveni indeks*
Feodora	50	1442	46.7	29.1 e	32.6	6.7	21.2	6.7	0.44
	70	1587	52.4	34.6 d	37.6	6.0	20.0	6.3	0.42
	90	1727	53.0	36.7 cd	39.4	5.3	18.6	5.4	0.39
Energy	50	1561	65.0	38.2 bc	41.2	7.7	20.6	8.9	0.36
	70	1780	65.1	39.5 b	43.1	8.1	27.0	9.4	0.38
	90	1804	66.4	43.7 a	47.6	6.1	19.0	6.5	0.33
Mean variety / *Prosjek sorata*	*Feodora*	1585 b	50.7 b	33.5 b	36.6 b	6.0 b	19.9	6.1 b	0.42 a
	Energy	1715 a	65.5 a	40.5 a	43.9 a	7.3 a	22.2	8.3 a	0.36 b
Mean sowing density / *Prosjek gustoća sjetve*	50	1501 b	55.9	33.6 c	36.9 c	7.2 a	20.9	7.8 a	0.40
	70	1683 a	58.7	37.0 b	40.3 b	7.1 a	23.5	7.9 a	0.40
	90	1765 a	59.7	40.2 a	43.5 a	5.7 b	18.8	5.9 b	0.36

The values followed by the same letter within the year are not significantly different at the 5% probability level.

Table 5. Seed yield and the white lupin yield components depending on a variety and sowing density in 2019

Tablica 5. Prinos sjemena i komponenata prinosa bijele lupine u ovisnosti o sorti i gustoći sjetve u 2019. godini

Variety / *Sorta*	**Sowing density** / (seeds m^{-2}) *Gustoća sjetve (sjemenki m^{-2})*	**Seed yield** / *Prinos sjemena* (kg ha^{-1})	**Plant height** / *Visina biljke* (cm)	**Height to the beginning of inflorescence** / Visina do početka cvati *(cm)*	**Height under first pod** / *Visina do prve mahune (cm)*	**Pod number per plant** / *Broj mahuna po biljci*	**Seed number per plant** / *Broj sjemenki po biljci*	**Seed weight per plant** / *Masa sjemena po biljci (g)*	**Harvest indeks** / Žetveni *indeks*
Feodora	50	3124	70.7	33.7	45.6	10.1 a	35.6 a	9.1 a	0.45 a
	70	3341	72.5	42.1	50.9	7.0 bc	23.8 cd	6.1 c	0.39 cd
	90	3544	72.6	45.5	55.3	5.3 d	18.1 d	4.7 d	0.39 d
Energy	50	3132	84.9	45.0	53.6	8.2 b	32.6 a	9.9 a	0.41 bc
	70	3251	87.9	51.9	58.9	7.5 bc	31.3 ab	9.7 a	0.42 b
	90	3416	86.2	54.2	61.5	6.4 cd	25.2 bc	7.7 b	0.39 cd
Mean variety / Prosjek sorata	*Feodora*	3267	71.9 b	40.5 b	50.6 b	7.4	25.8 b	6.6 b	0.41
	Energy	3337	86.3 a	50.4 a	58.0 a	7.4	29.7 a	9.1 a	0.41
Mean sowing density / *Prosjek gustoća sjetve*	50	3128 b	77.8	39.4 b	49.6 b	9.1 a	34.1 a	9.5 a	0.42
	70	3296 b	80.2	47.0 a	54.9 ab	7.3 b	27.6 b	7.9 b	0.40
	90	3480 a	79.4	49.9 a	58.4 a	5.8 c	21.6 c	6.2 c	0.39

The values followed by the same letter within the year are not significantly different at the 5% probaibility level .

In both research years, the seed yield increased with an increase in the sowing density, from 50 to 90 seeds m^{-2} (Tables 4 and 5). In 2018, the significantly lowest seed yield was achieved at the lowest sowing density, while the differences between the two higher densities were not statistically significant. In 2019, the significantly highest seed yield was achieved at the sowing density of 90 seeds m^{-2}. Sowing the white lupin at the lower densities contributes to the lower production costs, but higher densities contribute to the more uniform plants and an earlier seed maturation due to a higher seed production on the main stem (Clapham & Elbert-May, 1989).

In both research years, the Energy variety had the highest plant height, which is also associated with a higher biomass yield. In addition, the Energy variety had the highest height up to the inflorescence commencement and the highest height under the first pod (Tables 4 and 5). In 2018, the highest height up to the inflorescence commencement was achieved by the Energy variety at a sowing density of 90 seeds m^{-2}. The sowing density did not exert a significant effect on the plant height, but both the height up to the inflorescence commencement and the height under the first pod increased with an increase in the sowing density.

The Energy variety achieved a higher pod number and seed weight per plant in 2018, while the same variety achieved a higher seed number and seed weight per plant in 2019 (Tables 4 and 5). Therefore, this variety achieved a higher seed yield in both research years. The number of pods and seeds and the seed weight per plant decreased with an increase in the sowing density in both research years, and the significantly lowest values of these parameters were achieved at the sowing density of 90 seeds m^{-2} (Tables 4 and 5). In 2019, an interaction was significant, and both varieties achieved the highest pod and seed number per plant and the seed weight per plant at the sowing density of 50 seeds m^{-2}. Other researchers also report a decrease in the pod and seed number with an increase in the plant density, especially on the branches, with a simultaneous increase in the seed yield (Herbert, 1977).

López-Bellido et al. (2000) did not observe the differences in the white lupin seed yield between the investigated plant densities. Simultaneously, as the plant density increased, the number of pods decreased, and the number of seeds per pod and the seed weight per plant remained unchanged. Pod number is the white lupin's most important yield component, and it is suitable for assessing the crop management impact in different environments (Withers, 1984; López-Bellido et al. 2000). The number of pods and seeds has a greater role in determining the yield than an individual seed mass (Duthion & Pigeaire, 1986).

In both research years, a tendency was existent of a decrease in the harvest index, with an increase in the sowing density, but the differences were very small (Tables 4 and 5). In 2019, the Feodora variety achieved the highest harvest index at the lowest sowing density. Although the differences in the harvest index were very small, the results are consistent with those of López-Bellido et al. (2000), who found that the harvest index decreased with an increase in the plant density.

CONCLUSION

In the 2018, the Energy lupin variety achieved a higher green mass and dry matter yield when compared to the Feodora variety. With an increase in sowing density, the green mass yield increased too, but a significant difference was detected only in 2018. In 2019, weather conditions were more favorable for the white lupin growth and development, so a higher seed yield was achieved if compared to that of 2018. The Energy variety achieved a significantly higher seed yield in 2018. In both research years, the seed yield increased with an increase in the sowing density.

The Energy variety achieved the highest seed weight per plant. In both research years, the number of pods per plant and the seed weight per plant decreased with an increase in the sowing density, and the significantly lowest values of these parameters were achieved at the sowing density of 90 seeds m^{-2}. In both research years, a tendency was existent of a decrease in the harvest index, with an increase in the sowing density, but the differences were very small.

According to the results obtained, lupin is suitable for the cultivation in northwestern Croatia, and greater inclusion in the crop rotation would contribute not only to an increase in biodiversity but also to a safer protein production, as a soybean alternative. However, research should be continued in more varieties in order to find the ones that are more tolerant to the growth season stress.

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POTENCIJAL PRINOSA SJEMENA I BIOMASE BIJELE LUPINE (*Lupinus albus* L.) U EKOLOŠKOJ PROIZVODNJI

SAŽETAK

Lupina je vrlo obećavajuća kultura za proizvodnju sjemena i biomase u ekološkoj proizvodnji. Cilj istraživanja provedenih na pokušalištu Agronomskoga fakulteta Sveučilišta u Zagrebu tijekom 2018. i 2019. godine bio je utvrditi prinos sjemena i biomase bijele lupine u ovisnosti o gustoći sjetve. Pokus je postavljen prema slučajnome bloknom rasporedu u četiri ponavljanja. U istraživanju su bile dvije sorte bijele lupine, **Feodora** ***i*** **Energy*****, i tri gustoće sjetve: 50, 70 i 90 sjemenki/m²^{2}. Sorta*** **Energy** ***ostvarila je u 2018. godini veći prinos zelene mase i suhe tvari u odnosu na sortu*** **Feodora*****. U 2019. godini veći prinos sorte*** **Energy** ***nije bio statistički značajan. Prinos zelene mase i suhe tvari povećavao se s povećanjem gustoće sjetve. U 2019. godini vremenske su prilike bile povoljnije za rast i razvoj lupine, te je ostvaren veći prinos sjemena u odnosu na 2018. godinu. Sorta*** **Energy** ***ostvarila je značajno veći prinos sjemena u 2018. godini. U obje godine istraživanja prinos sjemena rastao je s povećanjem gustoće sjetve. Broj mahuna i masa sjemena po biljci smanjivali su se s povećanjem gustoće sjetve, te su najmanje vrijednosti navedenih parametara ostvarene kod gustoće sjetve od 90 sjemenki/m^{2}. U obje godine istraživanja zabilježena je tendencija smanjenja žetvenoga indeksa s povećanjem gustoće sjetve, ali razlike su bile vrlo male.***

Ključne riječi: lupina, prinos biomase, prinos sjemena, komponente prinosa

(Received on April 20, 2022; accepted on May 15, 2022 – *Primljeno 20. travnja 2022.; prihvaćeno 15. svibnja 2022.)*