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Investigation of the selectivity and effectiveness of different herbicides on the production of white lupin (*Lupinus albus* L.)

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Abstract

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The white lupine in the initial stages of its development has a weak competitive ability with the weed flora, which makes weed control effective and even necessary, but there are not many registered herbicides. The aim of the present study is to investigate the effectiveness and selectivity of the herbicides used in the practice against the weed flora spread on white lupine, as well as to evaluate their effect on grain yield. The experiment was conducted on the experimental field of IRGR – Sadovo in 2022–2023 in two repetitions and experimental plot of 10 m^2 per each variant and sub-variant. The experiment was set up with eight variants: six herbicides with one treatment dose, one herbicide in two doses and one untreated, control variant. In order to investigate the effect of the biostimulant Kaishi, seven subvariants were included in which the biostimulant was added to each herbicide. High selectivity towards white lupine and high efficiency towards weed flora was found in the herbicides *Cycloxidim* and *Fuazifop-P-butyl*, applied in doses of 200 ml/da and 130 ml/da, respectively. The multi-component herbicide *Florasulam+ Clokintout – Messehill+ Piroxulam* at a dose of 26.5 ml/da and the single-component *Arylex™* – at a dose of 5 ml/da, applied together with Kaishi (200 ml/da), showed better selectivity than applied alone. The established significant interaction between herbicide x weed by the two-way analysis of variance proved that the tested herbicides acted effectively on weeds (especially *Polygonum convolvulus* and *Convolvulus arvensis*) and had a positive effect on the yield of forage white lupin compared to the control. The obtained results proved the achievement of good weed control in forage white lupin by tested herbicides that are currently not registered for use in lupin production in Bulgaria, such as *Cycloxidim*, *Fluazifop-P-butyl* and *Imazamox*.

Keywords: Lupinus albus L.; selectivity; phytotoxicity; herbicide; grain yield

Introduction

Cultivation of white lupine is characterized by low energy intensity, low demand for soil fertility and high ability to fix nitrogen (Muraveev et al., 2012; Mulayim et al., 2002). Effective weed control is necessary to ensure the success of lupine in its competition with the weed species for water, nutrients and light (Putnam et al., 1989). During the initial stages of its development, the lupine has a weak competitive ability with regard to the weed flora. This is due to the weak development of the aerial part of the plants, facilitating the penetration of light and consequently, the easier emergence of weeds. The lupine reaches maximum vegetative growth during flowering when it can successfully compete with emerging weeds. The registered herbicides for this crop are not many (Folgard et al., 2015). Knott (1996) found that lupine could be particularly sensitive to post emergence herbicide applications. According to the same author, post emergence application of the herbicide *Fluazifop* provided over 98% weed control without causing damage to the lupine plants. Successful pre-emergence herbicide treatments, that did not result in crop injury, were obtained by using *Pendimethalin* alone or in combination with *Metribuzin* (Knott, 1996). According to Ivany & McCully (1994) the herbicide *Imazethapyr*, after emergence of lupine, caused 15% to 24% crop damage. Hashem et al. (2011) found that the combination of *Paraquat* + *Diquat* in narrow-leaves lupine led to an increase in yields compared to the single application of *Glyphosate* or *Glyphosate* + *Metribuzin*. The dynamic changes in the offered herbicides on the pesticide market, the changing weed associations and the growing demands for the protection of ecosystems impose the need for new studies on the improvement of methods and the means of weed control. Systematic studies are needed to search for "new" herbicides or herbicide combinations with high selectivity for the white lupin (Marinov-Serafimov & Golubinova, 2016).

The aim of the present study is to investigate the effectiveness and selectivity of the herbicides used in practice on the weed flora of white lupine, as well as to evaluate their effect on the grain yield. The new aspect of our work is the investigation of the active ingredient *Arylex™*, which has not yet been tested in the white lupine.

Material and Methods

The experiment was conducted on the experimental field of the Institute of Plant Genetic Resources (IRGR) – Sadovo in 2022–2023, during the optimum period for forage white lupin (in the beginning of May), in two replications. The experimental plot per each variant and sub-variant was 10 m^2. The experiment was set up with eight variants: six herbicides with one treatment dose, one herbicide in two doses and one untreated, control variant (Table 1). In order to investigate the effect of the biostimulant Kaishi, seven sub-variants were included in which the biostimulant was added to each herbicide. Kaishi is a soluble concentrate that contains amino acids obtained by enzymatic hydrolysis of plant proteins. The herbicides were applied in the appropriate doses after the emergence of the plants in the phase third leaf. The effectiveness of the herbicides against the different weeds in the weed association was reported by the double counting (on the 20th and 40th day after treatment with herbicides) of weeds in 1 m^2 plot according to variant using a measuring tape. A 9-point phytotoxicity scale, proposed by the European Weed Research Society (EWRS), reported the selectivity of the herbicides to the lupine plants: point 0 – no damage plants and point 9 – complete destruction of plants. The herbicide effect was accessed on the 7th, 14th and 30th days after treatment with the herbicides. Structural traits of yield (plant height, height to first pod, number of main branches, number of pods and number of grains per plant, number of grains per pod and mass of the grains per plant) were measured in ten normally developed plants from all studded variants during the full maturity phase. The reduction in yield, as a result of the survival by the herbicide weeds, was reported by a one-way analysis of variance. The interaction between the weed,

Table 1. Experimental treatments on white lupin

Variants and sub-variants	Trade name (Tested dose)	Active sustance g/l (g/kg)	Crop	Application time
1	Untreated check	–	white lupin	
2	Kalos (200 ml/da)	480 g/l *Bentazon*	white lupin	post-emergence
2.1	Kalos (200 ml/da) + Kaishi – (200 ml/da)	480 g/l *Bentazon*	white lupin	post-emergence
3	Corello Duo (26.5 ml/da)	14.2 g/kg *Florasulam*+ 70.8 g/kg *Clokintout – Messehill*+ 70.8 g/kg *Piroxulam*	white lupin	post-emergence
3.1	Corello Duo (26.5 ml/da) + Kaishi – (200 ml/da)	14.2 g/kg *Florasulam*+ 70.8 g/kg *Clokintout – Messehill*+ 70.8 g/kg *Piroxulam*	white lupin	post-emergence
4	Stratus Ultra (200 ml/da)	100 g/l *Cycloxidim*	white lupin	post-emergence
4.1	Stratus Ultra (200 ml/da) + Kaishi – (200 ml/da)	100 g/l *Cycloxidim*	white lupin	post-emergence
5	Kvelex (5ml/da)	*Arylex™* active	white lupin	post-emergence
5.1	Kvelex (5 ml/da) + Kaishi – (200 ml/da)	*Arylex™* active	white lupin	post-emergence
6	Fusilad Forte (130 ml/da)	150 g/l *Fluazifop-P-butyl*	white lupin	post-emergence
6.1	Fusilad Forte (130 ml/da) + Kaishi – (200 ml/da)	150 g/l *Fluazifop-P-butyl*	white lupin	post-emergence
7	Pulsar (80 ml/da)	40 g/l *Imazamox*	white lupin	post-emergence
7.1	Pulsar (80 ml/da) + Kaishi – (200 ml/da)	40 g/l *Imazamox*	white lupin	post-emergence
8	Pulsar (100 ml/da)	40 g/l *Imazamox*	white lupin	post-emergence
8.1	Pulsar (100 ml/da) + Kaishi – (200 ml/da)	40 g/l *Imazamox*	white lupin	post-emergence

herbicide and weed × herbicide and the yield was explained by two-factor dispersion analysis. The correlation analysis was used to show whether a single weed from weed flora had a suppressing effect on the white lupin yield or whether the harmful effect is expressed by the total number of weeds. The analyzes were performed using the statistical software SPSS 19 for Windows.

Results and Discussion

The assessment of the selectivity of the studied herbicides on the white lupin plants are presented in Table. 2. The herbicides *Cycloxidim* (200 ml/da) and *Fluazifop-P-butyl* (130 ml/da) showed high selectivity (score 1) to white lupin, as the differences with the subvariants of both herbicides were insignificant. Similar results were reported by Folgart et al. (2015) who found effective weed control by the vegetative herbicide *Fluazifop-P-butyl*, without damage on white lupin plants. The herbicide *Imazamox*, applied in a low dose (80 ml/da), was less selective (score 2.8), causing slight damages on lupin plants; its subvariant, with application of Kaishi, the phytotoxic effect was slightly underestimated (score 2.5). According to Juhász et al. (2024), the herbicide *Imazamox* in high doses is highly phytotoxic to white lupin, causing extensive damage. The strongest phytotoxicity on plants was reported of the herbicides *Bentazon* (200 ml/da) and *Arylex™* (5 ml/da), score 4.3 and 4.2 respectively. A difference was observed between *Arylex™* and its subvariant, which had a score of 3.7. Dewitte et al. (2006) reported similar results with *Bentazon* (652 g/ha), which caused obvious necrosis and inhibition of crop growth. The Kaishi biostimulator showed the best result on plants treated with two of the herbicides: *Florasulam + Clokintout–Messehill + Piroxulam* (26.5 ml/da) and *Arylex™* (5 ml/da).

Polygonum convolvulus L., *Convolvulus arvensis* L. and *Chenopodium album* L. were found to be the most common weeds during the study period (Table 3). All tested herbicides showed relatively good control over the total number of weeds, varied between 64 number/m^2 and 113 number/m^2 compared to the control (147 number/m^2). The herbicides *Bentazon* (200 ml/da) and *Arylex™* (5 ml/da) achieved good control on *Polygonum convolvulus* L. and *Chenopodium album* L. The polycomponent herbicide *Florasulam + Clokintout–Messehill+ Piroxulam* at a dose of 26.5 ml/da was effective against *Polygonum convolvulus* L., but not against *Convolvulus arvensis* L. and *Chenopodium album* L.. The herbicides *Fluazifop-P-butyl* (130 ml/da) and *Imazamox* (100 ml/da) demonstrated good results on self-sowings of wheat. According to Folgart et al. (2015) *Fluazifop* provides over 95% control on annual bluegrass (*Poa annua* L.) without causing visual damage on lupin.

All studied herbicides affected positively the yield of white forage lupine, but with no proven differences be-

Table 2. Selectivity of some herbicides on forage white lupin assessed by EWRS 9-point scale average for the 2022-2023

Variants and subvariants	Active sustance g/l (g/kg)	2022			2023			Average for the 2022–2023
		DAT***						
		7	14	30	7	14	30	
1	Untreated check	–	–	–	–	–	–	-
2	480 g/l *Bentazon*	2.0	4.5	6.0	3.0	6.5	4.0	4.3
2.1	480 g/l *Bentazon* + Kaishi	2.0	3.5	4.0	4.0	7.0	5.0	4.3
3	14.2 g/kg *Florasulam* + 70.8 g/kg *Clokintout – Messehill* + 70.8 g/kg *Piroxulam*	4.0	5.0	5.0	2.0	5.5	4.5	4.0
3.1	14.2 g/kg *Florasulam* + 70.8 g/kg *Clokintout – Messehill* + 70.8 g/kg *Piroxulam* + Kaishi	2.0	3.0	2.0	2.5	4.5	3.0	2.8
4	100 g/l *Cycloxidim*	1.0	1.0	1.0	1.0	1.0	1.5	1.1
4.1	100 g/l *Cycloxidim* + Kaishi	1.0	1.0	1.0	1.0	1.0	1.0	1.0
5	Arylex™ active	4.5	6.0	4.5	2.0	5.0	3.0	4.2
5.1	Arylex™ active + Kaishi	2.5	4.0	3.5	2.5	6.0	6.0	3.7
6	150 g/l *Fluazifop-P-butyl*	1.0	1.0	1.0	1.0	1.0	1.0	1.0
6.1	150 g/l *Fluazifop-P-butyl* + Kaishi	1.0	1.0	1.0	1.0	1.0	1.0	1.0
7	40 g/l *Imazamox* (80 ml/da)	3.0	3.5	3.5	2.0	2.5	2.0	2.8
7.1	40 g/l *Imazamox* + Kaishi	2.0	2.5	2.0	2.5	3.0	3.0	2.5
8	40 g/l *Imazamox* (100 ml/da)	3.5	4.5	3.5	4.0	4.5	3.0	3.8
8.1	40 g/l *Imazamox* + Kaishi	3.0	4.0	3.0	3.5	5.0	6.5	4.0

Legend: ***DAT – Days After Treatment

Table 3. Weed species and number of weeds per 1m² plot in white lupin

Vari-ants	Treatments	Number and types of weeds per 1 m² plot				
		Polygonum convolvulus L.	*Convolvulus arvensis* L.	*Chenopodium album* L.	Self-sowing of *Triticum aestivum* L.	Total number of weeds
1	Untreated check	63	20	11	50	147
2	480 g/l *Bentazon* (200 ml/da)	29	5	9	15	64
3	14.2 g/kg *Florasulam* + 70.8 g/kg *Clokintout – Messehill* + 70.8 g/kg *Piroxulam* (26.5 ml/da)	34	20	29	3	87
4	100 g/l *Cycloxidim* (200 ml/da)	69	7	16	5	109
5	*Arylex™* active (5 ml/da)	19	24	4	63	113
6	150 g/l *Fluazifop-P-butyl+adhesive* (130 ml/da)	51	15	13	1	87
7	40 g/l *Imazamox* (80 ml/da)	42	28	17	6	108
8	40 g/l *Imazamox* (100 ml/da)	48	24	4	1	88

tween them and the control (Table 4). The highest average differences compared to the other herbicides were found for *Florasulam+ Clokintout – Messehill + Piroxulam* (26.5 ml/da), *Fluazifop-P-butyl* (130 ml/da) and *Bentazon* (200 ml/da), respectively 4.580, 4.505 and 3.910.

The effectiveness of the herbicides on the weed flora was determined using the two-factor analysis of variance (Table 5). The interaction *herbicide x weed* was significant, which was an indicator of the effective action of the tested herbicides on weeds. In contrast, Petrova et al. (2022 a, b) found that the *herbicide x weed* interaction had a little effect on the chickpea and *Vicia ervilia* L. yields.

The conducted correlation analysis established that average for the both years of the experiment, the greatest influence on the yield of white lupin had the weed *Polygonum convolvulus* L. (r = 0.588), without statistically proved differences at P = 0.05 (Table 6). The weeds *Polygonum convolvulus* L. (r = 0.434) and *Convolvulus arvensis* L. (r = 0.427) formed a large part of the total number of weeds. The total number of weeds had a suppressive effect on the yield (r = 0.588). An

Table 4. The effect of herbicides on the white lupin yield in two-year experiment

Active substance/Tested dose	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
480 g/l *Bentazon* (200 ml/da)	3.910	0.301	3.307	4.513
14.2 g/kg *Florasulam* + 70.8 g/kg *Clokintout – Messehill* + 70.8 g/kg *Piroxulam* (26.5 ml/da)	4.580	0.301	3.977	5.183
100 g/l *Cycloxidim* (200 ml/da)	3.620	0.301	3.017	4.223
Arylex™ active (5 ml/da)	3.780	0.301	3.177	4.383
150 g/l *Fluazifop-P-butyl+adhesive* (130 ml/da)	4.505	0.301	3.902	5.108
40 g/l *Imazamox* (80 ml/da)	3.040	0.301	2.437	3.643
40 g/l *Imazamox* (100 ml/da)	3.080	0.301	2.477	3.683

Table 5. Interaction of number of weeds (Factor B), herbicide (Factor A) and interaction factors A x B with the white lupin yield average for the 2022–2023

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	70.288	13	5.407	5.972	0.000
Intercept	1004.350	1	1004.350	1109.254	0.000
Factor A	22.453	6	3.742	4.133	0.002
Factor B	6.820	1	6.820	7.533	0.008
Factor A * Factor B	41.015	6	6.836	7.550	**0.000**
Error	50.704	56	0.905		
Total	1125.343	70			
Corrected Total	120.992	69			

Table 6. Correlation dependencies between the species of weeds and number of weeds in a crop of white lupin

Weeds	*Polygonum convolvulus* L.	*Convolvulus arvensis* L.	*Chenopodium album* L.	Self-sowing of *Triticum aestivum* L.	Common weeds	Yield per plant
Polygonum convolvulus L.	1	-0.164	0.323	-0.615	0.434	0.588
Convolvulus arvensis L.		1	-0.004	0.177	0.427	0.433
Chenopodium album L.			1	-0.502	0.218	-0.007
Self-sowing of *Triticum aestivum* L.				1	0.285	-0.220
Common weeds					1	0.537
Yield per plant						1

interesting relationship was observed between the self-sowing of *Triticum aestivum* L. and *Chenopodium album* L. An increase in the density of the self-sowing of *Triticum aestivum* L. lead to a decrease in the density of *Chenopodium album* L. (r = -0.502) and vice versa. A similar relationship was found between *Polygonum convolvulus* L. and the self-sowing of wheat. As the density of self-sowing of *Triticum aestivum* L. increased, the density of *Polygonum convolvulus* L. decreased (r = -0.615) and *vice versa.* Petrova et al. (2022a) found that two main weed species (*Amaranthus retroflexus* L. and *Convolvulus arvensis* L.) formed the total number of weeds and significantly reduced chickpea yield.

Conclusions

The results of the experiment demonstrated that good weed control can be achieved in forage white lupin using a wide range of herbicides as *Cycloxidim*, *Fluazifop-P-butyl* и *Imazamox*, currently not registered in Bulgaria for lupin production. Clear phytotoxicity in lupin plants was observed by *Bentazon* – 200 ml/da, *Arylex*™ – 5 ml/da and *Imazamox* – 80 ml/da, however the negative herbicide effect was reduced to a certain extent with the help of the Kaishi applied at the dose 200 ml/da. High selectivity to lupin plants was established in herbicides *Cycloxidim* and *Fluazifop-P-butyl*. The same herbicides did not cause a negative impact on yield. Comparing the harmfulness of the weeds, *Polygonum convolvulus* L. was the one that strongly affected the lupin yield. *Polygonum convolvulus* L. and *Convolvulus arvensis* L. formed the large proportion of the total number of weeds during the experimental period.

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