

Comparative Evaluation of White Lupine (*Lupinus albus* L.) Accessions for Yield, Seed Quality and Fusarium Wilt Response under Organic Production Conditions

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ABSTRACT

In the present study comparatively evaluated 15 white lupine (*Lupinus albus* L.) accessions for agronomic performance, yield stability, biochemical composition, and response to Fusarium wilt under organic production conditions. Considerable variation was observed among the accessions for growth, productivity, seed quality, and disease response. Accession Lp 425 exhibited the highest agronomic performance, recording the greatest plant height, average daily growth rate, aboveground biomass, and seed weight per plant, while also combining a favorable yield-stability index with a relatively short vegetation period. Lp 01 likewise demonstrated a favorable combination of high productivity, earliness, and yield stability. However, Lp 425 showed comparatively greater susceptibility to Fusarium wilt. In contrast, Lp 125, Lp 251 and Lp 27/7 exhibited the lowest disease incidence and severity, while Lp 125 additionally showed high seed protein concentration and relatively high seed productivity. Overall, Lp 425 and Lp 01 appear promising as sources of high agronomic performance and yield stability, whereas Lp 125 represents particularly valuable genetic material for organic production and breeding because of its favorable combination of seed quality, productivity and low Fusarium wilt tolerance.

Keywords: white lupine, accessions, stability, economic productivity, Fusarium wilt.

INTRODUCTION

White lupine (*Lupinus albus* L.) is defined as one of the most important domesticated lupine species (Prusinski, 2017; Tirdiľová et al., 2020). It originates from the southern Balkans and its natural populations are spread throughout the Eastern Mediterranean basin, where it is used for food and fodder (Abraham et al., 2019; Struti et al., 2020). White lupine is characterized by a rich protein composition, a high-quality fatty acid profile and numerous useful bioactive substances (Prusinski, 2017; Tirdiľová et al., 2020). According to Annicchiarico et al. (2014), the seeds have a higher content of

essential amino acids and important minerals (potassium and iron) compared to other legumes such as faba bean and peas, which are useful as ingredients of health or functional food products. In addition, white lupine is high-productive, relatively tolerant to drought, soil acidity and salinity, improves soil fertility and can contribute to improving agricultural sustainability, food security and reducing malnutrition which is closely related to climate change (Beyene, 2020). From an agronomic point of view, it enriches the soil with nitrogen and phosphorus by forming nodules and proteoid roots (Shu et al., 2007). White lupine can be cultivated under intercropping systems and low-input farming

systems (Stagnari et al., 2017; Zafeiriou et al., 2021). Therefore, it is a good choice for promoting global food security and environmental protection, through sustainable agriculture (Jimenez-Lopez et al., 2020). Considerable genetic variation has been reported among white lupine cultivars for morphological characteristics, duration of the growing period, seed productivity, biochemical seed composition and response to diseases. Georgieva et al. (2018), in an evaluation of 23 white lupine cultivars under the conditions of Central Northern Bulgaria, demonstrated substantial differences among cultivars in plant habit, vegetation period, productivity and seed biochemical composition. The authors also identified differences in susceptibility to *Fusarium oxysporum* f. sp. *lupini*, with several cultivars showing a resistant reaction.

Application of fertilization has significant influence of seed yield increasing (Popović et al., 2013; Božović et al., 2018; Rajčić et al., 2019; Ugrenović et al., 2021; Lakić et al., 2022; Dimitrijević et al., 2024; Georgieva et al., 2025a, b, c; Ilin et al., 2025; Serafimov et al., 2025). The high productive potential and nutritional value of white lupine, as well as its good adaptability, are the reasons for the expansion of its cultivation in agro-climatic regions other than the Mediterranean region (Rychel et al., 2019; Rychel-Bielska et al., 2020; Annicchiarico et al., 2019). For the conditions of the latitude where Bulgaria is located, a trend of decreasing rainfall and increasing temperature during the growing season has been established (Slavov and Georgieva, 2002; Plamenov and Spetsov, 2008). Therefore, of particular importance is the introduction of crops that are not traditional for the country but are tolerant to abiotic and biotic stress. The aim of the present study was a comparative evaluation of white lupine accessions under organic cultivation conditions in terms of seed productivity, stability, biochemical composition and *Fusarium* wilt incidence and severity.

MATERIAL AND METHODS

The field experiment was conducted at the Institute of Forage Crops (Pleven) during the

2019-2021 period under organic farming conditions. The experimental material comprised a collection of 15 white lupine (*Lupinus albus* L.) accessions. The experiment was laid out in a long plot design with three replications. The experimental unit (plot) size was 5 m². Sowing was performed manually at a seeding rate of 35 seeds per m², with an inter-row spacing of 50 cm and an intra-row spacing of 10 cm. Crop management was carried out without the application of chemical fertilizers or pesticides.

To evaluate the phenotypic and agronomic traits, 15 representative plants were randomly selected and analyzed from each accession per replication at full maturity. The following indicators were recorded during the vegetation period: duration of vegetation period (days), plant height (PH, cm), average daily growth rate (ADGR, cm/day), aboveground biomass (AGB, g DM/plant). The biometric characteristics of plants at full maturity included: 1st pod height (cm), pods number/plant, seeds number/plant, 1000 seeds mass (g), seed weight/plant (g), pod length and pod width.

The ecological stability of the studied accessions was estimated using the following analyzes and parameters: *regression analysis* - according to Finlay and Wilkinson (1963), where the regression coefficient (b_i) was calculated (Eberhart and Russell, 1966), *variance analysis* - through ecovalence (W_i) (Wricke, 1962) and stability variance (σ^2) (Shukla, 1972), and *non-parametric analysis* - by the yield and stability index (YSi) of Kang (1993). The coefficient of variation (CVi, %) (Francis and Kannenberg, 1978) was used for additional evaluation.

The incidence and severity of *Fusarium oxysporum* f. sp. *lupini* was estimated under conditions of natural field infestation according to the scale of Ishikawa et al. (2005) with some modifications of Shaban et al. (2011). Healthy survived plants were those with no visual symptoms of the disease. The infected plants were estimated by longitudinal sections of stem and root. Disease severity was determined according to a scale based on 0-4 grades according to the percentage of inside browning through the

stem and root: 0 = healthy, 1 = 0-25% browning, 2 = >25-50% browning, 3 = >50-75% browning and 4 = >75-100% browning. The chemical composition of seeds was determined as crude protein (CP) by Kjeldal method and crude fiber (CF) by Weende system (AOAC, 2010). The GGE biplot analysis was applied to evaluate genotype productivity and stability simultaneously across environments, based on the framework proposed by Yan (2002). The model was constructed using singular value decomposition (SVD) of the first two principal components (PC1 and PC2). The data were environment-centered (G+GE) using an unscaled formatting method (Scaling = 0), and the biplot was based on a genotype-focused singular value partitioning (SVP = 1). The axes of the biplot were defined by the primary eigenvalues of PC1 and PC2, representing the respective percentages of the total G+GE variation. All experimental data

were processed statistically using the computer software GENES for Windows XP (Cruz, 2009) and Statgraphics Plus (1995) for Windows Ver. 2.1.

RESULTS AND DISCUSSION

The three experimental years were different in terms of meteorological conditions, which is a prerequisite for an objective assessment of the white lupine accessions (Table 1). The first year was characterized by the highest values of average daily air temperature and rainfalls for the growing season (March-July) - 17.0°C and 376 mm, respectively. The most unfavorable conditions for lupine development and the lowest values (15.7°C and 139 mm, respectively) were established in the second year. The third year occupied an intermediate position with a temperature of 16.4°C and rainfalls of 281 mm.

Table 1. Meteorological conditions during the experimental period

Years	Months					Average/Sum
	III	IV	V	VI	VII	
	Temperatures					
2019	10.1	12.2	17	22.3	23.6	17.0
2020	5.2	9.8	17.4	20.5	25.7	15.7
2021	8.2	12.3	16.9	21	23.5	16.4
	Precipitations					
2019	35.2	116.8	82.8	89.9	51	376
2020	8.5	14.5	39.4	36.7	39.4	139
2021	95.3	67.9	71.9	45.0	0.8	281

The studied accessions showed an average duration of vegetation period of 112 days, with a variation of 109 to 117 days. Lp 01, Lp 21, Lp 23, Lp 254 and Lp 425 were characterized by a short vegetation period, and Lp 06 and Lp 27/7 by a longer one, Figure 1.

The data regarding the morphological characteristics of PH, ADGR and AGB are presented in Table 2. Lp 425, followed by Lp 28/1, demonstrated the fastest growth rate and the greatest height. In Lp 425, the excess for the respective indicators was 21.8 and 19.5% compared to the average values for the group. Lp 425 and Lp 28/1, as well as Lp

251, were also characterized by increased biomass accumulation. The greater plant height and aboveground biomass observed in Lp 425 may provide a potential competitive advantage against weeds; however, weed suppression was not directly evaluated in the present experiment. The differences in the direction of increase ranged from 10.4 to 36.0% compared to the average value for the group. In contrast, Lp 10, Lp 23 and Lp 25 demonstrated the lowest values regarding PH, ADGR and AGB. High positive correlations were found between PH and AGB ($r=0.916$), PH and ADGR ($r=0.993$), and ADGR and AGB ($r=0.935$).

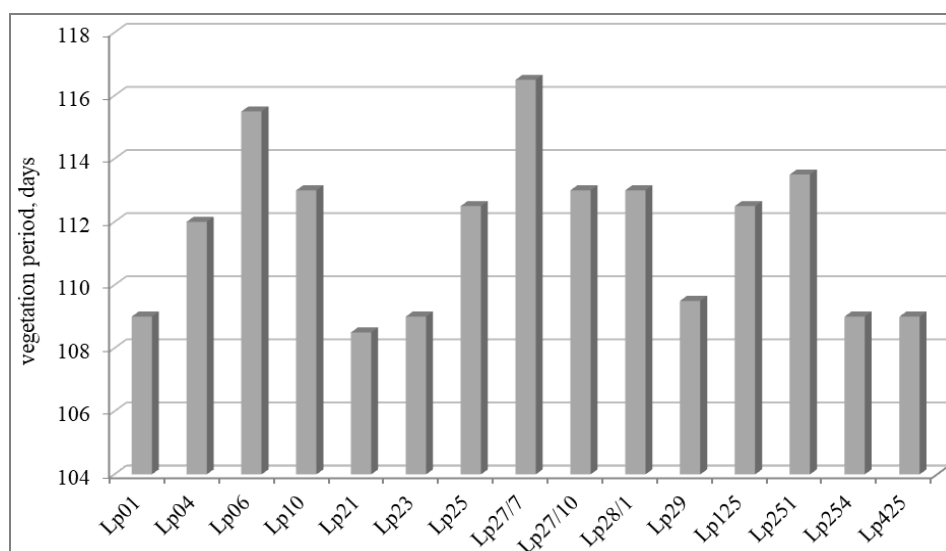


Figure 1. Duration of vegetation period in white lupine accessions

The analysis of biometric data (Table 3) concerning the trait of 1st pod height showed variation within relatively narrow limits. Lp 425, Lp 27/7, and Lp 01 set their 1st pods higher (38.3-39.9 cm), while in most of the genotypes, the 1st pod was located at 31-34 cm. The number of pods per plant averaged 13.0, with the highest number for Lp 251 (14.4), Lp 254 (14.5) and Lp 425 (15.8). The biological potential of Lp 10 and Lp 25

determined the development of a smaller number of pods (9.5), as the differences compared to the other genotypes were statistically significant ($p \leq 0.05$). Lp 251, Lp 254 and Lp 425 not only formed a large number of pods (60-70) but also managed to feed a considerable number of seeds (60.0-69.7). Despite the smaller number of pods, Lp 27/10 also formed a large number of seeds (63).

Table 2. Morphological parameters in white lupine accessions

Accessions	AGB		PH		ADGR		Average arithmetic rank
	g/plant	rank	cm	rank	cm/day	rank	
Lp 01	38.58 ef	4	80.2 ef	4	0.73 fg	3	4
Lp 04	37.13 cdef	7	80.0 ef	5	0.73 g	3	5
Lp 06	33.78 bcd	11	78.5 ef	7	0.70 ef	4	7
Lp 10	22.68 a	15	54.4 a	13	0.49 a	10	13
Lp 21	38.49 ef	5	74.8 d	8	0.68 de	5	6
Lp 23	31.02 b	13	67.7 c	11	0.62 c	8	11
Lp 25	24.70 a	14	62.1 b	12	0.56 b	9	12
Lp 27/7	35.75 cdef	9	82.1 f	3	0.73 g	3	5
Lp 27/10	37.05 cdef	8	82.1 f	3	0.74 g	2	4
Lp 28/1	39.13 f	3	82.2 f	2	0.74 g	2	2
Lp 29	32.65 bc	12	73.0 d	10	0.68 de	5	9
Lp 125	37.89 def	6	73.5 d	9	0.67 d	6	7
Lp 251	40.13 f	2	79.0 ef	6	0.73 g	3	4
Lp 254	34.62 bcde	10	73.5 d	9	0.66 d	7	9
Lp 425	48.23 g	1	90.3 g	1	0.84 h	1	1
min	22.68		54.4		0.49		
max	48.23		90.3		0.84		
average	35.46		75.6		0.69		
VC, %	48.8		47.1		43.6		

AGB - aboveground biomass; PH - plant height; ADGR - average daily growth rate. Values within each column followed by the same letter are **not significantly different**, whereas values followed by different letters are **significantly different** according to the statistical test used ($P < 0.05$). Rank indicates the relative ranking of each accession for the respective trait. VC - coefficient of variation.

Table 3. Biometric characteristic in white lupine accessions

Accessions	FPH	PNP	SNP	SWP	TSM	PL	PW
Lp 01	38.3	13.1	54.9	18.66	365.45	8.22	1.41
Lp 04	33.9	13.3	58.2	17.36	317.61	8.41	1.27
Lp 06	32.7	13.0	56.1	15.20	276.54	8.84	1.35
Lp 10	29.4	9.5	41.5	11.11	283.35	8.51	1.28
Lp 21	37.7	13.6	60.2	18.22	327.96	8.49	1.30
Lp 23	31.3	12.6	54.7	15.52	304.91	8.74	1.30
Lp 25	33.1	9.5	39.2	12.61	296.99	8.87	1.25
Lp 27/7	38.6	12.3	56.1	15.94	261.82	8.86	1.26
Lp 27/10	37.1	12.8	63.0	17.57	268.83	8.76	1.31
Lp 28/1	36.0	13.9	63.8	17.37	279.01	8.76	1.32
Lp 29	32.8	12.3	49.1	14.57	300.17	8.44	1.34
Lp 125	33.8	14.0	59.5	17.84	321.02	8.71	1.32
Lp 251	34.5	14.4	60.0	18.56	328.58	8.94	1.33
Lp 254	32.5	14.5	60.3	15.54	286.21	8.00	1.28
Lp 425	39.9	15.8	69.7	20.93	318.05	9.00	1.34
average	34.8	13.0	56.4	16.47	302.43	8.64	1.31
CV (%)	8.7	13.1	31.4	15.2	9.2	3.3	3.1
LSD _{0.05}	1.43	1.89	6.43	2.06	7.02	0.14	0.03

FPH - 1st pod height (cm), PNP - pods number/plant, SNP - seeds number/plant, SWP - seed weight/plant, TSM - 1000 seeds mass (g), PL - pod length, PW - pod width.

The trait of seed weight per plant varied from 11.11 (Lp 10) to 20.93 g (Lp 425). The genetic potential of Lp 425 (20.93 g), Lp 01 (18.66 g) and Lp 251 (18.56 g) defined them as high-productive, whose relative values exceeded the average group value by 27.1, 13.3 and 12.7%. In addition, Lp 01 and Lp 251 produced the largest seeds, with a mass of 1000 seeds of 365.45 and 328.58 g, respectively. The studied accessions did not differ essentially regarding pod length and pod width. The two traits varied within

narrow limits. The range of variability for the pod length was from 8.22 to 9.00 cm, and for the pod width - from 1.25 to 1.41 cm. The variance analysis of the data showed that the year had the strongest and significant influence on the variation of all traits except for pod length (Table 4). The genotype factor was determinant only for the pod length manifestation. The genotype $\times$ environment interaction effect was weakest and significant only for plant height and 1st pod height.

Table 4. ANOVA regarding main quantitative traits in white lupine accessions

Source	Df	PH (MS)	PH (F)	FPH (MS)	FPH (F)	PNP (MS)	PNP (F)	SNP (MS)	SNP (F)
E (Y)	2	21 970.14***	167.88	4 837.13***	247.55	1 658.88**	262.90	29792.32**	183.95
Genotype	14	193.30*	1.48	24.15ns	1.24	14.53*	2.30	289.29*	1.79
G $\times$ E	28	130.87*	-	19.54*	-	6.31ns	-	161.96ns	-
Corr. Total	44								
Source	Df	SWP (MS)	SWP (F)	TSM (MS)	TSM (F)	PL (MS)	PL (F)	PW (MS)	PW (F)
E (Y)	2	2 117.16**	179.57	17 834.40**	18.98	0.16ns	1.95	0.20**	66.67
Genotype	14	21.59*	1.83	2 971.83**	3.16	0.34**	4.15	0.005 ^{ns}	1.67
G $\times$ E	28	11.79 ^{ns}	-	939.86 ^{ns}	-	0.082 ^{ns}	-	0.003 ^{ns}	-
Corr. Total	44								

E (Y) - Environment (Year); Corr. Total - Corrected total, PH - plant height, FPH - 1st pod height (cm), PNP - pods number/plant, SNP - seeds number/plant, SWP - seed weight/plant, TSM - 1000 seeds mass (g), PL - pod length, PW - pod width; * Significance at P<0.05; ** - P<0.01; *** - P<0.001; ns – nonsignificant.

In a comparative study of varieties (genotypes, accessions), special attention should be paid to the assessment concerning

yield stability, which represents the realization of relatively constant productivity at different environmental limits. Such

cultivars are characterized by less genotype $\times$ environment interaction, better overall adaptability, and relative constancy in the manifestation of their genetic characteristics. The phenotypic stability of white lupine accessions, expressed by the variation coefficient (CV_i) (Francis and Kannenberg, 1978), showed that the seed weight/plant was highly unstable to environmental changes (Table 5). Lp 251 (20.39%), Lp 10 (22.22%)

and Lp 25 (26.19%) exhibited relatively less variability. From the breeding point of view, accessions with high productivity and well-expressed stability are desirable. In the present study, such accession was Lp 251.

According to the values of the stability coefficient b_i , Lp 10 ($r=0.37$), Lp 25 ($r=0.52$) and Lp 254 ($r=0.59$) were stable, but low-productive. Lp 251 can be defined as stable ($r=0.47$) and high-productive, Table 5.

Table 5. Stability parameters in white lupine accessions

Accessions	CV_i	b_i	Wi^2	σ^2	YSi
Lp 01	45.93	1.23	4.94	6.94	15.00+
Lp 04	44.67	1.17	2.75	3.15	13.00+
Lp 06	47.82	1.04	0.13	-1.38	4.00
Lp 10	22.22	0.37***	37.25	62.86	-10.00
Lp 21	28.98	0.72	7.58	11.50	11.00+
Lp 23	47.54	1.09	0.76	-0.30	5.00+
Lp 25	26.19	0.52 **	21.98	36.42	-8.00
Lp 27/7	62.66	1.55 **	28.28	47.33	2.00
Lp 27/10	57.62	1.50 **	23.73	39.46	4.00
Lp 28/1	43.53	1.02	0.04	-1.54	7.00+
Lp 29	46.15	1.00	0.01	-1.61	3.00
Lp 125	46.48	1.41*	16.07	26.19	10.00+
Lp 251	20.39	0.47 **	26.17	43.68	-2.00
Lp 254	29.00	0.59 *	15.89	25.89	-7.00
Lp 425	47.23	1.32 *	9.87	15.47	14.00+

CV_i - coefficient of variation, b_i - regression coefficient, Wi^2 - ecovalence, σ^2 - stability variance, YSi - yield and stability index.

Accessions Lp 27/7 ($r=1.55$), Lp 27/10 ($r=1.50$), Lp 125 ($r=1.41$) and Lp 425 ($r=1.32$) had regression coefficients considerably exceeding unity, which is an indication of responsiveness to changing environmental conditions. Irrespective of the fact that Lp 425 was high-variable, it was the most productive. Under suitable conditions, it can realize considerable productivity. For the remaining genotypes, the linear regression coefficient was nonsignificant. The values of the other stability parameters are taken into account. Stability variance σ^2 and ecovalence Wi^2 had the lowest values in Lp 28/1, Lp 29, Lp 23 and Lp 06. Therefore, these accessions can be defined as stable, with seed weight per plant close to the average of the studied group. According to Kang's (1993) parameter YSi, Lp 01 (15.00+) and Lp 425 (14.00+) exhibited high stability. High positive

evaluations were also received by Lp 04 (13.00+), Lp 21 (11.00+) and Lp 125 (11.00+), combining high stability and relatively good seed weight per plant. Based on the stability parameters, a ranking of the studied variants was made (Table 6). Lp 28/1 and Lp 29 occupied the first two positions in the ranking regarding stability parameters b_i , Wi^2 and σ^2 , and positions 6 and 10 - in terms of CV_i and YSi, respectively. It can be said that they were relatively less sensitive to changes in environmental conditions, compared to other genotypes. In the ranking of the parameters YSi and CV_i , the first positions were occupied by Lp 01 and Lp 425, and Lp 251 and Lp 10, respectively. Differences in the stability assessment of individual parameters are due to the fact that the different assessment methods are based on different concepts of stability.

Table 6. Ranking of stability parameters in white lupine accessions

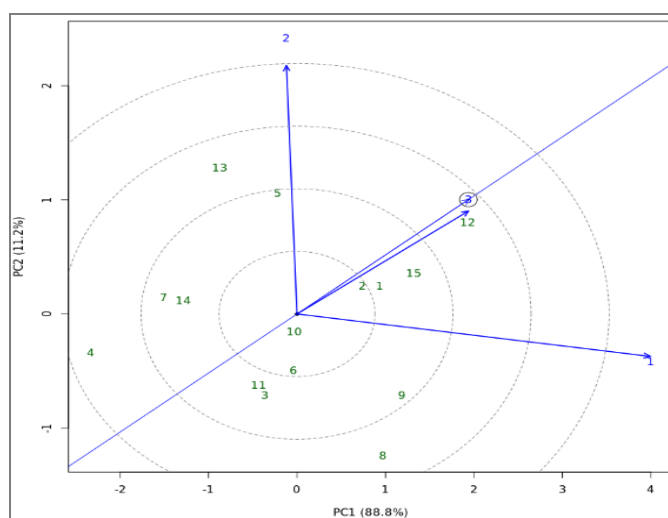
Accessions	CV_i	b_i	Wi^2	σ^2	YSi
Lp 01	8.00	1.00	6.00	6.00	1.00
Lp 04	7.00	1.00	5.00	5.00	3.00
Lp 06	13.00	1.00	3.00	3.00	8.50
Lp 10	2.00	4.00	15.00	15.00	15.00
Lp 21	4.00	1.00	7.00	7.00	4.00
Lp 23	12.00	1.00	4.00	4.00	7.00
Lp 25	3.00	3.00	11.00	11.00	14.00
Lp 27/7	15.00	3.00	14.00	14.00	11.00
Lp 27/10	14.00	3.00	12.00	12.00	8.50
Lp 28/1	6.00	1.00	2.00	2.00	6.00
Lp 29	9.00	1.00	1.00	1.00	10.00
Lp 125	10.00	2.00	10.00	10.00	5.00
Lp 251	1.00	3.00	13.00	13.00	12.00
Lp 254	5.00	2.00	9.00	9.00	13.00
Lp 425	11.00	2.00	8.00	8.00	2.00

CV_i - coefficient of variation, b_i - regression coefficient, Wi^2 - ecovalence, σ^2 - stability variance, YSi - yield and stability index.

GGE biplot analysis shows the total variation of a trait due to genotype $\times$ environment interaction and is represented by the first and second principal components (PC1 and PC2). The graphical representation of the GGE biplot analysis (Figure 2) showed that a significant part (88.8%) of the total variance of the accessions was due to the first principal component PC1, and a small part (11.2%) - to the second component PC2. Lp 28/1, which was located inside the smallest concentric circle, can be determined as the most stable. In the same concentric circle, but in its periphery, Lp 23 and Lp 04

were located. On the other hand, Lp 10, Lp 27/7, Lp 125 and Lp 251 were farthest from the center and their location defined them as low adaptive. The same accessions would show good responsiveness under improving environmental conditions.

The projections of a considerable part of the genotypes were located in the second (after the ideal center) concentric circle. Some of them, such as Lp 01 and Lp 425, were located in the right half of the coordinate system, indicating that their seed weight per plant is above the average for the group, and they also deserve attention.



1 - Lp 01; 2 - Lp 04; 3 - Lp 06; 4 - Lp 10; 5 - Lp 21; 6 - Lp 23; 7 - Lp 25; 8 - Lp 27/7; 9 - Lp 27/10; 10 - Lp 28/1; 11 - Lp 29; 12 - Lp 125; 13 - Lp 251; 14 - Lp 254; 15 - Lp 425.

Figure 2. GGE biplot regarding seed weight per plant in white lupine accessions

In the present study, the assessment of the degree of attack by *F. oxysporum* f. sp. *lupini* was conducted under a natural infection background. The results showed that the tested accessions differed in their susceptibility to *F. oxysporum* (Table 7). Lp 10, Lp 23 and Lp 425 were characterized by the highest percentage of infected plants and disease

severity score (5.9% and 2.8, 4.4% and 3.0, 4.3% and 2.8, respectively). Lp 27/7, Lp 251 and Lp 125 had low sensitivity because the disease severity score was only 0.3, and the percentage of healthy plants was 99.6-99.8%. Accessions without disease symptoms were not found.

Table 7. Reaction of white lupine accessions to *F. oxysporum* f. sp. *Lupine*

Accessions	Healthy plants, %	Infected plants, %	*Disease severity score
Lp 01	98.3 ef	1.7bc	0.8b
Lp 04	98.3 ef	1.7bc	1.3c
Lp 06	98.8 efg	1.2ab	1.0bc
Lp 10	94.0 a	5.9e	2.8e
Lp 21	97.5 de	2.5c	2.0d
Lp 23	95.6 b	4.4d	3.0e
Lp 25	96.1 bcd	3.9d	2.0d
Lp 27/7	99.8 g	0.2a	0.3a
Lp 27/10	96.1 c	3.9d	0.8b
Lp 28/1	98.8 efg	1.2ab	1.0bc
Lp 29	97.5 cde	2.5c	1.3c
Lp 125	99.6 fg	0.4a	0.3a
Lp 251	99.8 g	0.2a	0.3a
Lp 254	97.8 e	2.2bc	2.8e
Lp 425	95.7 b	4.3d	2.8e

* 0 = healthy, 1 = 0-25 % browning, 2 = >25-50% browning, 3 = >50-75 % browning and 4 = >75-100 % browning.

The seed biochemical evaluation included the determination of crude protein and crude fiber content (Figure 3). The average content of CP and CF was 348.19 and 124.04 g/kg DM, respectively. Lp 27/10, Lp 21 and Lp 125 can be defined as high-quality accessions due to the high protein content of the seeds (371.95, 367.60 and 367.15 g/kg DM, respectively). The excess (compared to the group average) was between 5.4 and 6.8%.

The same accessions were also characterized by a fiber content lower than the average value for the group. Lp 23 and Lp 04 also had a favorable composition. Despite their lower protein content, they had the lowest fiber content (98.75 and 101.75 g/kg DM, respectively). The correlation analysis of the data showed a negative dependence with a medium value ($r=-0.522$) between CP and CF content.

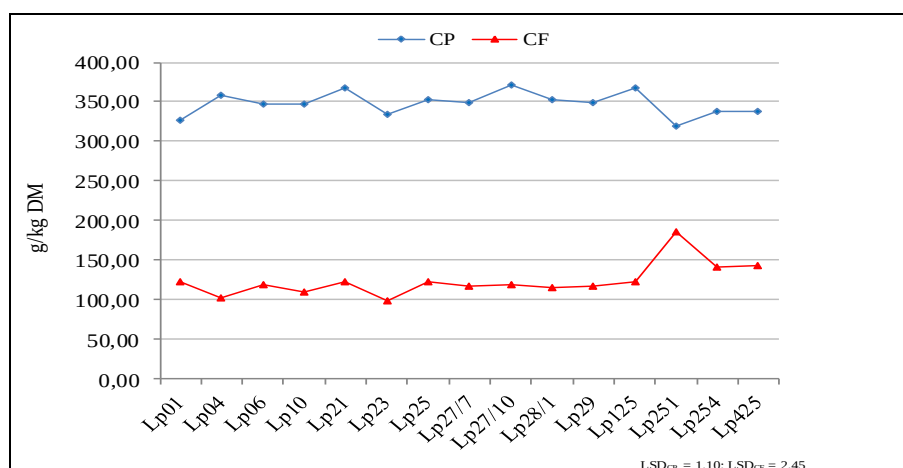


Figure 3. Biochemical composition seeds in white lupine accessions

The comprehensive assessment regarding the main quantitative characteristics, stability and duration of the vegetation period determined Lp 425 (rank 1) as the most

suitable for organic growing (Table 8). Lp 01 also received a good evaluation, although with a lower rank.

Table 8. Ranking in terms of main quantitative traits and stability in lupine accessions

Accessions	VP	AGB	ADGR	SWP	YSi	Average arithmetic rank
Lp 01	1	4	3	2	1	2
Lp 04	3	7	3	8	3	5
Lp 06	6	11	4	12	8.5	8
Lp 10	4	15	10	15	15	12
Lp 21	1	5	5	4	4	4
Lp 23	1	13	8	11	7	8
Lp 25	4	14	9	14	14	11
Lp 27/7	7	9	3	9	11	8
Lp 27/10	4	8	2	6	8.5	6
Lp 28/1	4	3	2	7	6	4
Lp 29	2	12	5	13	10	8
Lp 125	4	6	6	5	5	5
Lp 251	5	2	3	3	12	5
Lp 254	1	10	7	10	13	8
Lp 425	1	1	1	1	2	1

VP - vegetation period, ADGR - average daily growth rate, AGB - aboveground biomass, SWP - seed weight per plant, YSi - yield and stability index.

The vegetation period in white lupine is characterized by great variability. Early ripening is a valuable characteristic because, in Eastern Europe, it is mainly grown as a spring crop Kurlovich (2002). In Old World lupins, the duration of periods to flowering and ripening is determined by species, cultivar and environmental conditions (Buirchell and Cowling, 1998). In the experimental conditions, the early accessions ripened in 109 days, and the late-ripening ones - 8 days later. Malyshkina et al. (2020) reported a considerably longer duration of 121-161 days, and Naumkin et al. (2016) - a shorter duration (94-102 days). Early ripening cultivars can avoid severe drought during the summer period. In general, a short growing season is an important characteristic in annual legumes, given the global climate change (Tesfahun, 2018) and the established persistent trend of warming and drought in the region (Zhekova et al., 2022).

The morphological characteristics of plant height, growth rate and biomass amount determine the competitiveness of crop species against weeds. According to many

researchers, plant height is one of the highly variable characteristics in white lupine. Písaříková and Zralý (2009) observed a variation from 75 to 100 cm, Kurlovich (2002) - from 30 to 130 cm, and Hibstu (2016) - from 44.81 to 83.1 cm. Paolini and Faustini (2005) indicated that tall cultivars "capture" a higher percentage of photosynthetically active radiation (PAR) and accumulate biomass faster. This is why they are more effective at weed suppressing than short varieties. Under the present experiment conditions, the morphological parameters of PH, ADGR and AGB had the highest variation coefficient, respectively, 47.1 (ranging from 54.4 to 90.3 cm), 43.6 (from 0.49 to 0.84 cm/day) and 48.8 % (from 22.68 to 48.23 g/plant). This was also confirmed by the dispersion analysis of the data, which shows the trait expression under the environmental influence. In a study with 25 white lupine genotypes, Beyene (2020) found a variation in the characters of pods number, seed weight per plant and pod length as follows: 24.85-48.10, 24.57-59.42 g, 5.91-7.61 cm. In another similar experiment with

35 lupine genotypes, Gonzalez-Andre et al. (2007) indicated values for pod numbers and seed weight per plant from 17.5 to 45.6 and from 26.6 to 60.3 g, respectively. Blinnik et al. (2022) reported that in a collection of white lupine cultivars, a large proportion of cultivars were low productive (average 4.2 g seeds/plant). Only in some of the cultivars, the seed weight per plant exceeded 6.0 g - a value that is considerably lower than that found in the present study. Obviously, the genotype and environmental conditions are determinative for the trait manifestations.

The phenotypic stability of cultivars is a reflection of the interaction between the genetic characteristics of an individual and the environment. Cultivars with higher phenotypic stability have less expressed genotype-environment interaction, better general adaptability, and relative constancy in the manifestations of their genetic features (Tsenov and Atanasova, 2015; Ivanov et al., 2018). Various parameters are known to evaluate phenotypic stability, and the parameter YSi of Kang (1993) is one of the most reliable parameters for simultaneous evaluation of yield and stability. It gives a summary evaluation for yield and stability, which is useful for ranking cultivars according to their economic value (Akçura et al., 2005). In a study of 23 cultivars and accessions in the North-Eastern part of Belarus, Malyshkina et al. (2020) identified four accessions (CH 35-13, CH 17-14, CH 54-08, CH 12-13) combining high productivity with stability. Naumkin et al. (2016) determined cultivars Dega, Desnyansky 2, and Alyi Parus as adaptable and high-yielding for the Central Black zone region of Russia. Shcherbyna et al. (2021) tested promising lupine cultivars and lines, and then grouped them according to their yield and environmental stability. The authors found that Chabansky cultivar and lines 247/6, 824/34, 122/6 were less productive but stable ($bi = 1.027-1.092$). Among the various methods for determining ecological stability, the GGE biplot analysis is also applied, which allows simultaneous evaluation of yield and stability (Yan, 2002). In an assessment of a white lupine collection, Mulugeta et al. (2018) confirmed the

reliability of GGE biplot analysis to visualize the interaction genotype $\times$ environment.

Fusarium wilt (caused by *Fusarium oxysporum* f. sp. *lupini*) is considered the most serious disease in white lupine (Jensen et al., 2004; Horoszkiewicz Janka et al., 2013). It can have an essential negative effect on plant development and lead to serious economic losses (Zian et al., 2013). Identification of cultivars with expressed resistance to the pathogen is an alternative and environmentally friendly method for disease control, especially under organic production. In the present experiment, a low percentage of infected plants was found, from 0.2 to 5.9%, with disease severity score of 0.3 to 3.0. Similarly, Yagovenko et al. (2022) made a comparative evaluation of newly selected lupine cultivars in terms of susceptibility to Fusarium wilt under an artificial infection background. They defined Alyi parus, Mitchurinskiy, and Pilgrim as tolerant cultivars with an attack rate below 13%. Interesting results were obtained by Mohamed et al. (2009) in artificial infection with *Fusarium oxysporum* f. sp. *lupini* and under field conditions. Under artificial infection, mutant lines number 23, 33 and 37/3, and cultivars Giza-1 and Dijon-2 had the lowest attack index (from 0.00 to 6.95%). Under field conditions, the best values in terms of wilted plants (%) and surviving plants (%) were demonstrated by 23, 37/3, Dijon-2 and Sohag-2. Other researchers also reported for genotypes with expressed resistance to Fusarium wilt (Raza et al., 2000; Ali et al., 2009; Sampaio et al., 2020).

As a legume crop, the crude protein content in white lupine seeds is a determinant for their quality and nutritional value. The amount of crude protein in the studied accessions was in the range of 318.90 to 371.95 g/kg DM. Different authors reported a different range of protein content in white lupine seeds: 33-47% (Huyghe, 1997), 30-40% (Hofmanova et al., 2014), 34.8-41.0% (Naumkin et al., 2016), 28.55-35.81% (Beyene, 2020). Determinants for this are the genotype and environmental conditions (Huyghe, 1997).

CONCLUSIONS

The three-year evaluation demonstrated substantial variation among white lupine accessions in agronomic performance, yield stability, seed composition and response to Fusarium wilt under low-input conditions. Lp 425 was the most productive accession, exhibiting the highest plant height, average daily growth rate, aboveground biomass and seed weight per plant, together with a favorable yield–stability index and short vegetation period. Lp 01 also combined high productivity, earliness and favorable yield stability. However, Lp 425 showed comparatively greater susceptibility to Fusarium wilt, indicating that high productivity was not necessarily associated with disease tolerance. Lp 125, Lp 251 and Lp 27/7 exhibited the lowest disease incidence and severity, while Lp 125 additionally showed high seed protein concentration and relatively high seed productivity. Therefore, Lp 425 and Lp 01 appear promising primarily for high agronomic performance and stability, whereas Lp 125 represents particularly valuable material for organic production and breeding because of the combination of seed quality, productivity and low Fusarium wilt incidence. Further multi-location trials and controlled *Fusarium* inoculation experiments are required to confirm the stability, adaptability and disease response of the most promising accessions under different environmental and production conditions.

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