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RESPONSES OF WHITE LUPINE ACCESSIONS TO ENVIRONMENTAL STRESSES UNDER ORGANIC CULTIVATION

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In the present study, a comparative assessment of 15 white lupine accessions was made regarding productivity, stability, biochemical composition, and tolerance to Fusarium wilt under organic cultivation conditions. The results showed that accession Lp 425 was distinguished by the highest values in terms of plant height (90.3 cm), average daily growth rate (0.84 cm/day), aboveground biomass (48.23 g/plant) and seed productivity (20.93 g/plant). According to the values of the stability parameter YSi, Lp 01 (15.00+) and Lp 425 (14.00+) exhibited ecological stability. The same accessions were also characterized by a short vegetation period (109 days). Regarding seed quality, increased protein content was demonstrated by Lp 27/10, Lp 21, and Lp 125 (367.15-371.95 g/kg DM), and tolerance to *F. oxysporum* – by Lp 251, Lp 27/7, and Lp 125.The complex assessment regarding main quantitative characteristics, stability and vegetation period determined Lp 425 (rank 1) as the most suitable for organic growing. Despite the relatively high percentage of infected plants and disease severity score (compared to the others), Lp 425 realized the highest productivity. A good evaluation, although with a lower rank (2), was received by Lp 01.

Key words: accessions, Fusarium wilt, productivity, stability, white lupine

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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).

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 tolerance to Fusarium wilt.

MATERIAL AND METHODS

The field experiment was conducted at the Institute of Forage Crops (Pleven) during the period 2019-2021. The object of research was a collection of 15 accessions of white lupine (*Lupinus albus).* The long plot design method was used, in a triple repetition of the variants. The sowing was carried out by hand, at a rate of 35 seeds per m^2. Plants were grown for forage under organic farming conditions without the use of fertilizers and pesticides. 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), width seed (pod width).

The ecological stability of the studied accessions was estimated using the following analyzes and parameters: *regression analysis* – according to FINLAY & WILKINSON (1963*)*, where the regression coefficient (bi) was calculated; *variance analysis* – through ecovalence (Wi) (WRICKE, 1962) and stability variance (σ^2) (SHUKLA, 1972), and *non-parametric analysis* – by the yield and stability index (YSi) of KANG (1988). The coefficient of variation (CVi, %) (FRANCIS & KANNENBERG, 1978) was used for additional evaluation.

The tolerance of the lupine accessions to *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 model was applied, which uses the single decomposition of the value of the first two principal components (PC1 and PC2) (YAN, 2002).

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. Correlations were made for the examined traits.

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.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. 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.

The data regarding the morphological characteristics of PH, ADGR and AGB are presented in Table 1. 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. This is an indicator determining a higher competitiveness of the varieties. In this case, the differences in the direction of increase ranged from 10.4 to 36.0% compared to the average value for the group.

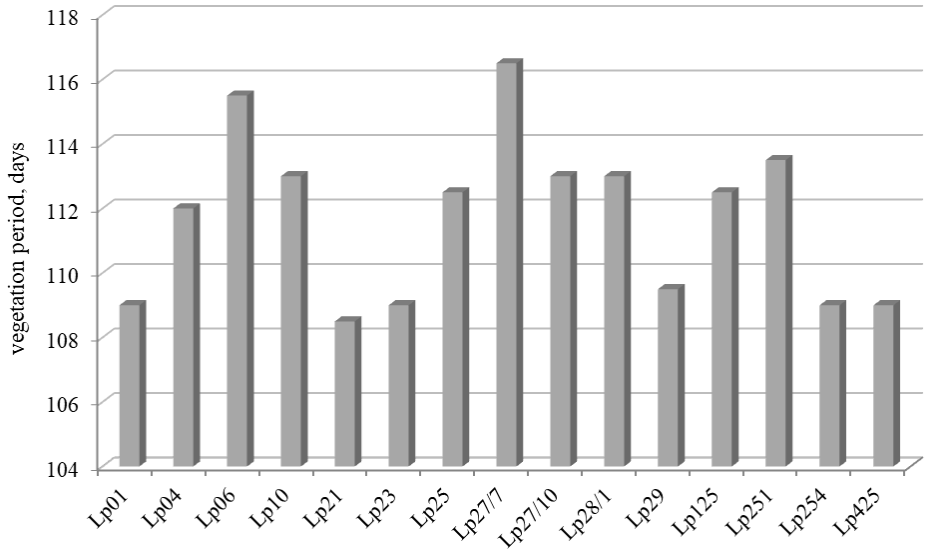


Figure 1. Duration of vegetation period in white lupine accessions

Table 1. Morphological parameters in in white lupine accessions

Accessions	AGB		PH		ADGR		Average arithm rank
	g/plant	rank	cm	rank	cm/day	rank	
Lp01	38.58 ef	4	80.2 ef	4	0.73 fg	3	4
Lp04	37.13 cdef	7	80.0 ef	5	0.73 g	3	5
Lp06	33.78 bcd	11	78.5 ef	7	0.70 ef	4	7
Lp10	22.68 a	15	54.4 a	13	0.49 a	10	13
Lp21	38.49 ef	5	74.8 d	8	0.68 de	5	6
Lp23	31.02 b	13	67.7 c	11	0.62 c	8	11
Lp25	24.70 a	14	62.1 b	12	0.56 b	9	12
Lp27/7	35.75 cdef	9	82.1 f	3	0.73 g	3	5
Lp27/10	37.05 cdef	8	82.1 f	3	0.74 g	2	4
Lp28/1	39.13 f	3	82.2 f	2	0.74 g	2	2
Lp29	32.65 bc	12	73.0 d	10	0.68 de	5	9
Lp125	37.89 def	6	73.5 d	9	0.67 d	6	7
Lp251	40.13 f	2	79.0 ef	6	0.73 g	3	4
Lp254	34.62 bcde	10	73.5 d	9	0.66 d	7	9
Lp425	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

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).

The analysis of biometric data (Table 2) 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).

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.

Table 2. Biometric characteristic in white lupine accessions

Accessions	FPH	PNP	SNP	SWP	TSM	PL	PW
Lp01	38.3	13.1	54.9	18.66	365.45	8.22	1.41
Lp04	33.9	13.3	58.2	17.36	317.61	8.41	1.27
Lp06	32.7	13.0	56.1	15.20	276.54	8.84	1.35
Lp10	29.4	9.5	41.5	11.11	283.35	8.51	1.28
Lp21	37.7	13.6	60.2	18.22	327.96	8.49	1.30
Lp23	31.3	12.6	54.7	15.52	304.91	8.74	1.30
Lp25	33.1	9.5	39.2	12.61	296.99	8.87	1.25
Lp27/7	38.6	12.3	56.1	15.94	261.82	8.86	1.26
Lp27/10	37.1	12.8	63.0	17.57	268.83	8.76	1.31
Lp28/1	36.0	13.9	63.8	17.37	279.01	8.76	1.32
Lp29	32.8	12.3	49.1	14.57	300.17	8.44	1.34
Lp125	33.8	14.0	59.5	17.84	321.02	8.71	1.32
Lp251	34.5	14.4	60.0	18.56	328.58	8.94	1.33
Lp254	32.5	14.5	60.3	15.54	286.21	8.00	1.28
Lp425	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 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 3). The genotype factor was determinant only for the pod length manifestation. The genotype × environment interaction effect was weakest and significant only for plant height and 1st pod height.

Table 3. ANOVA regarding main quantitative traits in white lupine accessions

Source	df	Mean squares			
		PH	FPH	PNP	SNP
Environment (year)	2	21 970.14***	4 837.13***	1 658.88**	29 792.32**
Genotype	14	193.30*	24.15ns	14.53*	289.29*
Genotype×environment	28	130.87*	19.54*	6.31ns	161.96ns
Corrected Total	44				
		SWP	TMS	PL	PW
Environment (year)	2	2 117.16**	17 834.40**	0.16ns	0.20**
Genotype	14	21.59*	2.971.83**	0.34**	0.005ns
Genotype×environment	28	11.79ns	939.86ns	0.082ns	0.003ns
Corrected Total	44				

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 × 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 (CVi) (Francis and Kannenberg,1978), showed that the seed weight/plant was highly unstable to environmental changes (Table 4). 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 bi, 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. 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. Therefore, the values of the other stability parameters are taken into account.

Stability variance σi^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 productivity 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 productivity.

Based on the stability parameters, a ranking of the studied variants was made (Table 5). Lp 28/1 and Lp 29 occupied the first two positions in the ranking regarding stability parameters bi, Wi^2 and σ^2, and positions 6 and 10 – in terms of CVi 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 CVi, 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 4. Stability parameters in white lupine accessions

Accessions	CV_i	bi	Wi^2	σ^2	YSi
Lp01	45.93	1.23	4.94	6.94	15.00+
Lp04	44.67	1.17	2.75	3.15	13.00+
Lp06	47.82	1.04	0.13	-1.38	4.00
Lp10	22.22	0.37***	37.25	62.86	-10.00
Lp21	28.98	0.72	7.58	11.50	11.00+
Lp23	47.54	1.09	0.76	-0.30	5.00+
Lp25	26.19	0.52 **	21.98	36.42	-8.00
Lp27/7	62.66	1.55 **	28.28	47.33	2.00
Lp27/10	57.62	1.50 **	23.73	39.46	4.00
Lp28/1	43.53	1.02	0.04	-1.54	7.00+
Lp29	46.15	1.00	0.01	-1.61	3.00
Lp125	46.48	1.41*	16.07	26.19	10.00+
Lp251	20.39	0.47 **	26.17	43.68	-2.00
Lp254	29.00	0.59 *	15.89	25.89	-7.00
Lp425	47.23	1.32 *	9.87	15.47	14.00+

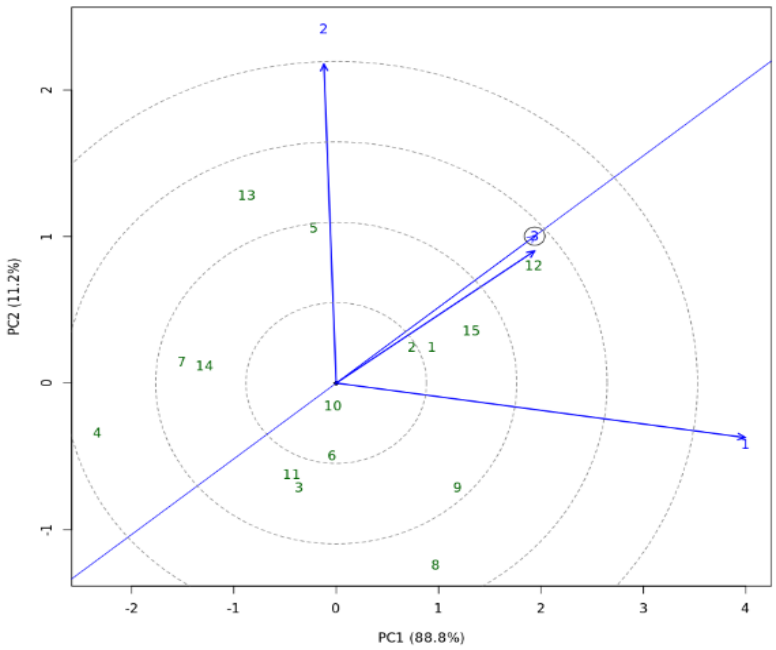
CV_i - coefficient of variation (Francis & Kannenberg, 1978), b_i - regression coefficient (EBERHART & RUSSELL, 1966), Wi^2 - ecovalence Wricke (1962), σ^2 - stability variance (SHUKLA, 1972), YSi - yield and stability index (KANG, 1993)

Table 5. Ranking of stability parameters in white lupine accessions

Accessions	CV_i	bi	Wi^2	σ^2	YSi
Lp01	8.00	1.00	6.00	6.00	1.00
Lp04	7.00	1.00	5.00	5.00	3.00
Lp06	13.00	1.00	3.00	3.00	8.50
Lp10	2.00	4.00	15.00	15.00	15.00
Lp21	4.00	1.00	7.00	7.00	4.00
Lp23	12.00	1.00	4.00	4.00	7.00
Lp25	3.00	3.00	11.00	11.00	14.00
Lp27/7	15.00	3.00	14.00	14.00	11.00
Lp27/10	14.00	3.00	12.00	12.00	8.50
Lp28/1	6.00	1.00	2.00	2.00	6.00
Lp29	9.00	1.00	1.00	1.00	10.00
Lp125	10.00	2.00	10.00	10.00	5.00
Lp251	1.00	3.00	13.00	13.00	12.00
Lp254	5.00	2.00	9.00	9.00	13.00
Lp425	11.00	2.00	8.00	8.00	2.00

CV_i - coefficient of variation (Francis & Kannenberg, 1978), b_i - regression coefficient (EBERHART & RUSSELL, 1966), Wi^2 - ecovalence Wricke (1962), σ^2 - stability variance (SHUKLA, 1972), YSi - yield and stability index (KANG, 1993)

GGE biplot analysis shows the total variation of a trait due to genotype×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 accesssions 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.



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

Fig. 2. GGE biplot regarding productivity in white lupine accessions

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 productivity is above the average for the group, and they also deserve attention.

Table 6. Reaction of white lupine accessions to F. oxysporum f. sp. lupine

Accessions	Healthy plants, %	Infected plants, %	*Disease severity score
Lp01	98.3 ef	1.7bc	0.8b
Lp04	98.3 ef	1.7bc	1.3c
Lp06	98.8 efg	1.2ab	1.0bc
Lp10	94.0 a	5.9e	2.8e
Lp21	97.5 de	2.5c	2.0d
Lp23	95.6 b	4.4d	3.0e
Lp25	96.1 bcd	3.9d	2.0d
Lp27/7	99.8 g	0.2a	0.3a
Lp27/10	96.1 c	3.9d	0.8b
Lp28/1	98.8 efg	1.2ab	1.0bc
Lp29	97.5 cde	2.5c	1.3c
Lp125	99.6 fg	0.4a	0.3a
Lp251	99.8 g	0.2a	0.3a
Lp254	97.8 e	2.2bc	2.8e
Lp425	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

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 6). 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.

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.

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 7). Lp 01 also received a good evaluation, although with a lower rank.

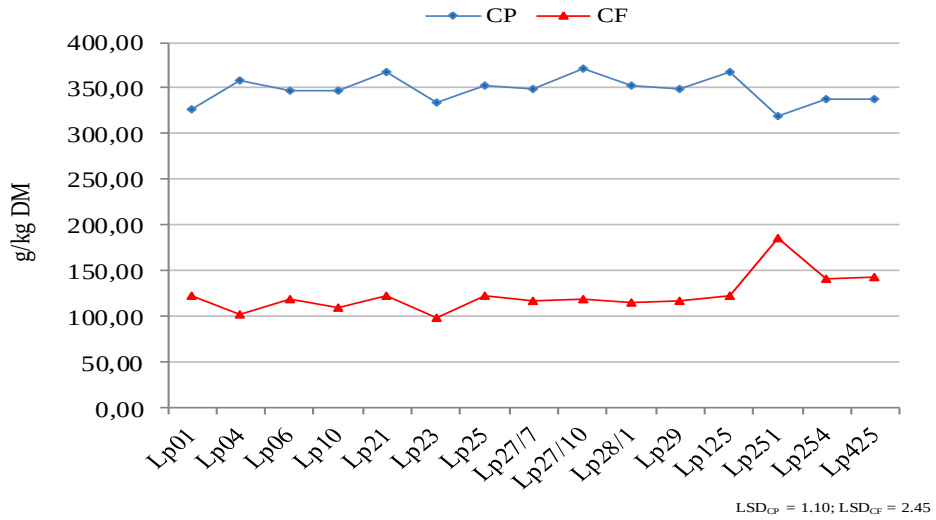


Figure 3. Biochemical composition seeds in white lupine accessions

Table 7. Ranking in terms of main quantitative traits and stability in lupine accessions

Accessions	VP	AGB	ADGR	SWP	YSi	Average arithmetic rank
Lp01	1	4	3	2	1	2
Lp04	3	7	3	8	3	5
Lp06	6	11	4	12	8.5	8
Lp10	4	15	10	15	15	12
Lp21	1	5	5	4	4	4
Lp23	1	13	8	11	7	8
Lp25	4	14	9	14	14	11
Lp27/7	7	9	3	9	11	8
Lp27/10	4	8	2	6	8.5	6
Lp28/1	4	3	2	7	6	4
Lp29	2	12	5	13	10	8
Lp125	4	6	6	5	5	5
Lp251	5	2	3	3	12	5
Lp254	1	10	7	10	13	8
Lp425	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 (KANG, 1993)

Correlation of tested traits

The correlation coefficients between the investigated signs were established (Table 8). Positive correlations were proven between 1st pod height and pods number/plant (r=0.515), seeds number/plant (r=0.625) and seed weight/plant (r=0.772). Pods number/plant correlates positively and very strongly with seeds number/plant (r=0.932) and seed weight/plant (r=0.876).

Table 8.Correlation dependences of traits in white lupine genotypes

Paremeter	FPH	PNP	SNP	SWP	TSM	PL
PNP	0.515*	-	-	-	-	-
SNP	0.625*	0.932**	-	-	-	-
SWP	0.772**	0.876**	0.881**	-	-	-
TSM	0.234	0.306	0.109	0.496	-	-
PL	0.221	0.002	0.127	0.151	-0.251	-
PW	0.311	0.423	0.319	0.494	0.542*	-0.081

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

A strong and proven positive correlation dependence was shown by the trait seeds number/plant with seed weight/plant (r=0.881). The same sign is the relationship between 1000 seeds mass and pod width (r=0.542).

The found correlation coefficients between 1000 seeds mass and pod length (r=-0.251) and between pod width and pod length (r=-0.081) are negative, but weak and unreliable.

Findings similar to the present study have been reported in other annual legumes such as chickpeas (KUMAWAT *et al*., 2022). Researchers agree that morphological characterization of specimens is an essential component for genotypic identification, differentiation and evaluation of the best lines and promising numbers.

VISHNYAKOVA (2008), GUDOSHNIKOVA *et al.* (2012) and GATAULINA *et al*. (2013) consider that the study of the biological capabilities of the genotype, which have always been of great interest to breeders, acquire particular relevance when natural resources are scarce.

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 *et al.*, 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 (LAKIĆ *et al.*, 2022a, 2022b; ZHEKOVA *et al.*, 2022; VASILEVA *et al*., 2023; POPOVIĆ *et al*., 2022; 2024). 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 productivity 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 & 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×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 367.15 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

Based on a comparative evaluation of 15 white lupine accessions according to a complex of traits and parameters under conditions of organic growing, the following conclusions can be drawn: Accession Lp 425 was distinguished by the highest values in terms of plant height (90.3 cm), average daily growth rate (0.84 cm/day), aboveground biomass (48.23 g/plant) and seed productivity (20.93 g/plant). According to the values of the stability parameter YSi, Lp 01 (15.00+) and Lp 425 (14.00+) exhibited ecological stability. The same accessions were also characterized by a short vegetation period (109 days). Regarding seed quality, increased protein content was demonstrated by Lp 27/10, Lp 21, and Lp 125 (367.15-371.95 g/kg DM), and tolerance to *F. oxysporum* – by Lp 251, Lp 27/7, and Lp 125. The complex assessment regarding main quantitative characteristics, stability and vegetation period determined Lp 425 (rank 1) as the most suitable for organic growing. Despite the relatively high percentage of infected plants and disease severity score (compared to the others), Lp 425 realized the highest productivity. A good evaluation, although with a lower rank (2), was received by Lp 01.

A strong positive correlation was found between 1st pod height and seed weight/plant (r=0.772); pods number/plant and seeds number/plant (r=0.932) and seed weight/plant (r=0.876); seeds number/plant and seed weight/plant (r=0.881).

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ODGOVORI BELE LUPINE NA STRESNE USLOVE ŽIVOTNE SREDINE U ORGANSKOM UZGOJU

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Izvod

U ovoj studiji je izvršena komparativna procena 15 aksesia bele lupine u pogledu produktivnosti, stabilnosti, biohemijskog sastava i tolerancije na fuzariozno uvenuće u uslovima organskog gajenja. Rezultati su pokazali da se akcesia Lp 425 odlikuje najvišim vrednostima u pogledu visine biljke (90,3 cm), prosečne dnevne stope rasta (0,84 cm/dan), nadzemne biomase (48,23 g/biljci) i produktivnosti semena (20,93 g/biljci). Prema vrednostima parametra stabilnosti ISi, ekološku stabilnost su pokazali Lp 01 (15,00+) i Lp 425 (14,00+), iste karakteriše i kratak vegetacioni period (109 dana). Što se tiče kvaliteta semena, povećan sadržaj proteina su pokazali Lp 27/10, Lp 21 i Lp 125 (367,15-371,95 g/kg DM), a tolerancija na *F. okisporum* – Lp 251, Lp 27/7 i Lp 125. Utvrđena je kompleksna procena stabilnosti i stabilnosti vegetacije u pogledu glavnih karakteristika vegetacije, 425 (rang 1) kao najpogodniji za organski uzgoj. I pored relativno visokog procenta zaraženih biljaka i skora težine bolesti (u poređenju sa ostalima), Lp 425 je ostvario najveću produktivnost. Dobru ocenu, iako sa nižim rangom (2), dobio je Lp 01.

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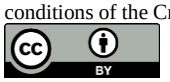

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