

GENOTYPE - ENVIRONMENT INTERACTION IN QUANTITATIVE TRAITS FORMATION IN WHITE LUPINE (*Lupinus albus* L.) ACCESSIONS

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Abstract

The search for genotypes with high productivity and stability is a key aspect in modern breeding programs that aim to develop genotypes with high manifestations in different ecological regions. The purpose of this study was to estimate the phenotypic stability of 15 white lupine accessions regarding productivity and stability of main quantitative traits. A field trial was conducted during the period 2016-2018, at the Institute of Forage Crops (Pleven, Bulgaria). It was used a randomized block method. The genotype influence was strongest regarding 1st pod height (55.16%), pod length (45.21%) and 1000 seeds weight (34.43%). The stability parameters for plant height determined Lp 27 and Lp 27\10 as stable and high-growing. Lp 4 was of interest regarding pod length, pod width, and seed weight, and Lp 1 was in a favorable position concerning 1000 seeds mass. Lp 6 was the closest to the ideal type, combining high productivity with stability in terms of main quantitative traits. Suitable parental components in combinative breeding for the development of high yielding cultivars were Lp 1, Lp 4 and, Lp 6, which exhibited stability and productivity in main traits.

Key words: quantitative traits, lupine, genotype-environment interaction.

INTRODUCTION

White lupine (*Lupinus albus* L.) is one of four economically important species of the genus *Lupinus*. It is a well-known, economically important, large-seed species. White lupine is a promising annual legume crop suitable for forage, human consumption and green manuring (Atnaf et al., 2015). Compared to other legumes, it is relatively more tolerant of abiotic stress conditions and has a proven potential for resilience in cultivation on poor or polluted soils. In the future, the germplasm identification with tolerance to abiotic stresses associated with climate changes could allow cultivation into a wider range of agroclimatic conditions (Coba et al., 2012).

Lupine breeding is currently focused on the estimation, and development of varieties for both animal feed and human diet, to address food safety and the influence of climate changes (Abraham et al., 2019). According to Annicchiarico & Thami-Alami (2012) and Atnaf et al. (2018), modern breeding programs should focus on yield stability, abiotic stress resistance, seed quality, disease tolerance and late ripening. Phenotypic stability is two basic types, stability in a biological and an agronomic sense. In the biological sense,

stability is the ability of a genotype to maintain permanent production in different environments with little variation between them. Stability in the agronomic sense shows that the genotype reacts positively to improvements in soil-climatic conditions of the environment, and its manifestations are above average in different locations (Sabaghnia et al., 2015).

According to Milioli et al. (2018), the search for genotypes with high productivity and stability is very important in breeding programs that aim to obtain genotypes with high manifestations in different ecological regions. The interaction genotype $\times$ environment strongly influences genotype manifestation, which complicates the selection of new cultivars. One way to use this interaction is to identify genotypes with high productive potential and phenotypic stability in different environments.

The purpose of this study was to estimate the phenotypic stability of white lupine accessions regarding productivity and stability of main quantitative traits.

MATERIALS AND METHODS

The study was conducted during the period 2016-2018, at the Institute of Forage Crops

(Pleven, Bulgaria). The objects of the study were 15 white lupine (*Lupinus albus* L.) accessions: Lp 1, Lp 4, Lp 6, Lp 10, Lp 21, Lp 23, Lp 25, Lp 27, Lp 28, Lp 29, Lp 27\1, Lp 27\3, Lp 27\7, Lp 27\10, Lp 28\1. It was used a randomized block method (Barov, 1982), with a plot size of 4 m² and three replicates. Sowing was done at the end of March, by hand, with an interrow spacing of 50 cm, intrarow spacing of 10 cm and a depth of 2-3 cm. Lupine plants were grown under organic farming conditions without the use of pesticides and fertilizers. The biometric characteristic of plants included the following traits: 1st pod height (cm), plant height (cm), pods number per plant, pod length (cm), pod width (cm), seeds number per plant, 1000 seeds mass (g), seed weight per plant (g). Data on the main quantitative traits of the studied accessions are presented in Figure 1.

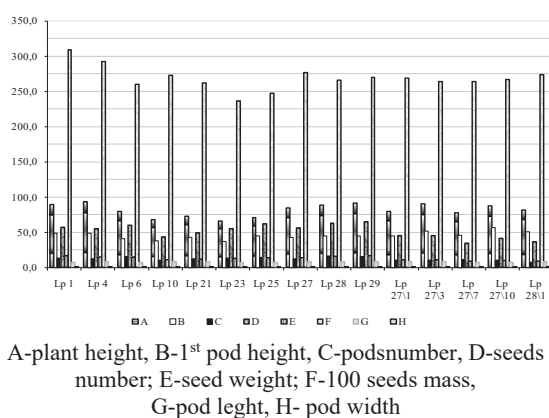


Figure 1. Main quantitative traits in white lupine accessions

The data obtained were processed by analysis of variance for all traits for determining the influence of genotype (accessions) (G), environment (E), and $G \times E$ interaction. Estimation of the ecological stability of the lupine accessions was performed using the following analyzes and parameters: *variance analysis* - mean variance component (PP) (according to Plaisted & Peterson, 1979), ecovalence (W^2) (Wricke, 1965) and stability variance (W_i) (Annicchiarico, 1992) respectively; *regression analysis* - regression coefficient (b_i) and the variance of the deviations from regression (S_i^2) according to Eberhart & Russell (1966), parameters a_i (linear response to the environmental effects) and λ_i (deviation from the linear response)

according to Tai (1979); *non-parametric analysis* - by using parameter P_i according to the model of Lin & Binns (1988) and the coefficient of total adaptability (A) (Valchinkov, 1990).

The mean variance component (PP) (Plaisted & Peterson, 1979) was a measure of a cultivar's contribution to the $G \times E$ interaction, and the reliability index (W_i) (Annicchiarico, 1992) estimated the probability of a genotype to show a manifestation below the environmental average or below any standard used.

It was done the GGE biplot model, which uses single decomposition of the first two principal components (Yan, 2002). All experimental data were processed statistically with using the computer software GENES 2009.7.0 for Windows XP (Cruz, 2009).

RESULTS AND DISCUSSIONS

Analysis of variance

Analysis of genotype-environment interaction is essential at all levels of the breeding process - determining the ideotype, selecting parents for hybridization, selection based on different indicators and yield. Table 1 presents the results of the two-factor analysis of variance for the quantitative traits studied. It was found that the influence of the three factors - genotype, environment (year) and their interaction on the trait formation was significant.

Significant GE interaction was a prerequisite for a more detailed analysis of the observed interaction. The effects of this interaction suggest that genotypes can be selected for adaptation to a specific environment.

The studied accessions differed essentially in their genetic nature, especially in terms of 1st pod height, pod length and 1000 seeds mass. For these traits, the influence of the genotype on the phenotypic expression of the trait was crucial and had the strongest influence (55.16%, 45.21%, 34.43%). The effect of the other two factors (environment and genotype-environment interaction) on their manifestation was less pronounced, indicating that they were genetically deterministic and, to a small extent, change with changes in environmental conditions.

Table 1. Mean squares in analysis of variance of white lupine accessions regarding main quantitative traits

Source of variation	DF	Plant height	% from total	1 st pod height	% from total	Pods number	% from total	Seeds number	% from total
Genotype	14	737.28**	26.53	226.15**	55.16	50.38**	29.86	865.58**	19.96
Environment	2	12179.31**	62.62	390.29**	13.60	829.05**	17.55	13498.23**	44.47
G × E	28	150.77**	10.85	64.03**	31.24	44.37**	52.59	771.17**	35.57
Error	84	1.37		1.39		0.62		1.84	
		Seed weight	% from total	Pod length	% from total	Pod width	% from total	1000 seeds mass	% from total
Genotype	14	58.72**	26.31	1.32**	45.21	0.01**	12.07	2560.66**	34.43
Environment	2	645.84**	41.34	3.08**	15.07	0.23**	39.66	17293.08**	33.21
G × E	28	36.09**	32.34	0.58**	39.73	0.02**	48.28	1089.56**	29.3
Error	84	0.53		0.08		0.002		38.0	
CorrectTotal	128								

*significant at $P < 0.05$; ** at $P < 0.01$; ns = not significant

The environment factor had the highest influence in the total variation in plant height (62.62%), seeds number (44.47%) and seed weight (41.34%). This was an indication that the environment plays a major role in the manifestation of these traits, and the genotype factor was of secondary importance. The performance of the genotype for seeds number and seed weight was below 27%, which would hinder the selection process for the development of new high-yielding cultivars.

Ecological stability

Regarding pods number and pod width, the GE interaction was essential (52.59%, 48.28%). For other traits (except for plant height), the GE effect was relatively high.

This indicated that genotypes responded differently to changes in environmental conditions, which was a prerequisite for assessing their ecological stability (Table 2).

Table 2. Parameters of phenotypic stability in white lupine accession regarding main quantitative traits

Accessions	Eberhart & Russell (1966)		Tai (1979)		Lin & Binn (1988)	Plaisted & Peterson (1979)	Wricke (1965)	Annicchiarico (1992)
	bi	Si ²	ai	λi	Pi	PP	W ²	W _i
plant height								
Lp 1	1.24**	42.24**	1.24	68.42	95.50	44.64	222.31	104.87
Lp 4	1.50**	26.12**	1.50	42.48	0.00	68.46	489.11	108.97
Lp 6	1.08	7.01**	1.08	11.78	246.86	27.65	31.96	95.27
Lp 10	0.54**	1.55*	0.55	3.03	977.70	55.22	340.72	79.66
Lp 21	0.64**	3.14**	0.65	5.62	642.25	43.94	214.48	86.14
Lp 23	0.67**	44.23**	0.68	71.65	809.49	51.65	300.77	76.41
Lp 25	0.96	37.55**	0.96	60.89	467.26	35.16	116.07	83.75
Lp 27	0.87	90.03**	0.87	145.22	342.00	51.37	297.64	98.53
Lp 28	1.53**	87.14**	1.54	140.57	68.80	89.86	728.74	97.80
Lp 29	1.52**	33.72**	1.53	54.72	26.18	74.03	551.41	103.62
Lp 27\1	1.06	5.54**	1.06	9.43	246.72	26.97	24.34	96.03
Lp 27\3	1.23**	7.57**	1.24	12.69	38.16	34.93	113.49	108.48
Lp 27\7	0.33**	0.2409	0.33	0.93	668.68	89.51	724.80	87.70
Lp 27\10	0.91	3.97**	0.91	6.93	140.56	27.08	25.63	105.25
Lp 28\1	0.86**	3.57**	0.87	6.30	275.19	28.35	39.84	98.26
1 st pod height								
Lp 1	0.98	2.48**	0.98	4.53	43.03	11.10	8.46	105.04
Lp 4	1.70**	0.60	1.71	1.47	24.48	12.92	28.95	104.05
Lp 6	1.49	0.02	1.49	0.56	113.50	11.57	13.76	87.98
Lp 10	0.07**	0.90	0.07	1.76	337.13	25.27	167.19	77.50
Lp 21	1.13	59.10**	1.14	95.52	116.84	26.35	179.32	86.27
Lp 23	0.91	3.65**	0.91	6.42	237.11	11.45	12.39	78.64
Lp 25	5.014**	5.29**	5.02	7.90	0.00	86.73	855.52	80.00
Lp 27	0.15**	0.33	0.15	1.03	159.73	13.83	39.05	91.52
Lp 28	1.706*	23.45**	1.71	38.20	52.29	19.03	97.32	92.51
Lp 29	1.55*	18.24**	1.56	29.84	64.03	16.77	72.05	92.17
Lp 27\1	0.51	2.35**	0.51	4.30	107.65	12.16	20.38	95.96
Lp 27\3	0.38*	1.14**	0.38	2.34	38.25	12.52	24.42	109.36
Lp 27\7	0.09	9.61**	0.09	15.71	178.54	31.37	235.54	92.99
Lp 27\10	0.61	3.50**	0.61	6.16	4.54	12.06	19.28	120.02
Lp 28\1	0.58	3.11**	0.58	5.51	40.38	12.08	19.46	107.57

pods number								
Lp 1	1.28	-0.25	1.28	0.12	6.47	7.88	9.11	97.62
Lp 4	1.48*	0.71	1.49	1.66	14.44	9.69	29.40	87.48
Lp 6	1.17	1.12*	1.17	2.33	0.04	7.74	7.57	119.76
Lp 10	0.64	0.127	0.65	0.09	13.45	8.29	13.74	83.80
Lp 21	1.11	0.15	1.11	0.29	9.36	7.23	1.87	91.58
Lp 23	1.10	2.95**	1.10	5.28	11.09	8.04	10.98	100.06
Lp 25	2.48**	23.09**	2.48	37.50	28.03	34.97	312.60	77.95
Lp 27	1.64**	11.05**	1.65	18.27	28.18	14.27	80.71	78.89
Lp 28	2.02**	1.13*	2.02	2.27	0.12	17.63	118.37	106.78
Lp 29	1.81**	6.39**	1.81	10.77	0.00	15.28	92.04	99.11
Lp 27\1	0.13**	7.57**	0.14	12.66	3.84	16.54	106.19	72.70
Lp 27\3	0.16**	10.88**	0.16	17.99	4.20	17.00	111.25	67.65
Lp 27\7	0.05**	0.93	0.06	1.96	12.09	18.38	126.77	74.72
Lp 27\10	0.03**	0.05	0.02	0.39	11.52	16.50	105.75	70.77
Lp 28\1	0.02**	0.112	0.02	0.28	30.47	17.45	116.29	53.65
seeds number								
Lp 1	1.31**	1.79*	1.31	3.42	79.42	143.88	175.64	106.40
Lp 4	1.27**	30.68**	1.27	49.82	163.62	148.46	226.99	99.60
Lp 6	0.95	79.07**	0.96	127.62	0.01	149.73	241.15	108.68
Lp 10	0.76**	4.66**	0.76	8.03	225.36	138.71	117.73	82.42
Lp 21	0.91*	8.93**	0.91	14.89	123.87	132.07	43.34	92.23
Lp 23	1.08	73.08**	1.09	117.98	195.43	149.10	234.09	97.97
Lp 25	2.62**	400.10**	2.62	643.26	395.93	659.53	5950.88	79.77
Lp 27	1.87**	163.96**	1.87	263.88	333.08	294.16	1858.75	84.49
Lp 28	2.11**	9.95**	2.11	16.45	65.55	329.72	2257.04	98.44
Lp 29	1.66**	7.79**	1.66	12.99	5.48	201.25	818.25	112.74
Lp 27\1	0.16**	175.74**	0.17	282.99	30.19	287.10	1779.74	74.90
Lp 27\3	0.27**	480.81**	0.27	773.28	0.99	341.64	2390.55	67.96
Lp 27\7	0.03	0.12	0.01	0.07	400.73	289.80	1809.91	57.42
Lp 27\10	0.04**	9.36**	0.04	15.65	178.10	279.19	1691.16	70.21
Lp 28\1	0.04**	11.93**	0.04	19.71	428.66	306.57	1997.82	57.89
seed weight								
Lp 1	1.51**	0.12	1.51	0.06	0.23	7.66	22.15	127.75
Lp 4	1.18	1.53*	1.18	3.00	5.78	6.44	8.45	111.95
Lp 6	0.92	4.48**	0.93	7.74	0.24	7.01	14.87	107.14
Lp 10	0.8	0.23	0.81	0.90	15.51	6.12	4.93	83.15
Lp 21	0.88	0.12	0.88	0.06	13.07	5.80	1.34	92.37
Lp 23	1.06	7.72**	1.07	12.95	24.69	7.88	24.58	87.03
Lp 25	2.06**	26.77**	2.06	43.49	33.35	21.61	178.38	79.27
Lp 27	1.99**	1.31*	1.99	2.56	13.89	13.68	89.54	82.25
Lp 28	2.15**	2.58**	2.15	4.60	7.53	16.67	122.99	95.83
Lp 29	1.69**	0.19	1.70	0.19	0.33	9.45	42.22	116.79
Lp 27\1	0.22**	7.95**	0.23	13.27	7.33	12.46	75.94	72.58
Lp 27\3	0.53*	45.32**	0.54	73.35	0.03	19.54	155.22	63.13
Lp 27\7	0.01**	0.128	0.02	0.00	29.11	13.65	89.17	61.59
Lp 27\10	0.05**	0.07	0.05	0.59	19.47	12.72	78.79	68.20
Lp 28\1	0.08**	0.56	0.08	1.36	32.48	14.82	102.33	60.51
pod length								
Lp 1	2.38	0.33	3.04	0.20	0.39	-0.16	0.787	93.40
Lp 4	0.17	0.32	0.20	0.06	0.33	-0.21	0.313	101.26
Lp 6	0.56	0.17	0.35	0.78	0.58	-0.09	1.575	91.38
Lp 10	0.65	0.31	0.49	0.03	0.40	-0.22	0.127	101.07
Lp 21	1.01	0.07	1.02	0.64	0.70	-0.13	1.203	95.94
Lp 23	1.08	0.22	1.12	0.18	0.64	-0.20	0.344	92.81
Lp 25	3.98	0.33	5.41	0.93	0.52	0.09	3.682	80.74
Lp 27	2.85	0.12	3.73	0.02	0.04	-0.05	2.034	95.45
Lp 28	2.12	0.32	2.65	0.12	0.10	-0.19	0.541	100.51
Lp 29	1.06	0.26	1.09	0.12	0.21	-0.21	0.231	102.94
Lp 27\1	0.16	0.32	0.20	0.05	0.21	-0.21	0.338	102.83
Lp 27\3	0.14	0.32	0.30	0.06	0.30	-0.20	0.340	101.85
Lp 27\7	0.31	0.27	0.01	0.04	0.64	-0.20	0.370	95.98
Lp 27\10	0.05	0.15	1.31	0.04	1.46	-0.10	1.559	92.69
Lp 28\1	0.09	0.17	0.18	0.43	0.70	0.04	3.047	100.71
pod width								
Lp 1	1.02	0.32	0.99	0.03	0.0006	-0.32	0.055	90.04
Lp 4	0.13	0.33	1.41	0.04	0.0009	-0.32	0.060	97.78
Lp 6	0.91	0.32	1.03	0.03	0.002	-0.32	0.048	91.83
Lp 10	0.86	0.33	1.04	0.00	0.0022	-0.33	0.002	103.56
Lp 21	0.93	0.33	1.02	0.00	0.0025	-0.33	0.001	97.36
Lp 23	0.98	0.33	1.00	0.01	0.0034	-0.33	0.011	95.04
Lp 25	2.32	0.29	0.60	0.11	0.0044	-0.31	0.193	83.33
Lp 27	1.90	0.31	0.73	0.05	0.0059	-0.32	0.094	91.93
Lp 28	0.83	0.33	1.05	0.01	0.007	-0.33	0.011	99.93
Lp 29	0.04	0.33	1.32	0.03	0.0092	-0.32	0.045	94.78

Lp 27\1	1.29	0.32	0.91	0.02	0.0106	-0.32	0.042	100.45
Lp 27\3	1.22	0.32	0.93	0.02	0.0109	-0.33	0.038	101.22
Lp 27\7	0.16	0.33	1.26	0.02	0.0129	-0.33	0.023	96.21
Lp 27\10	2.02	0.30	0.69	0.08	0.0327	-0.32	0.131	89.37
Lp 28\1	0.95	0.33	1.02	0.01	0.049	-0.33	0.022	98.71
1000 seeds mass								
Lp 1	0.82**	764.30**	0.82	1228.88	-	394.02	2370.99	110.24
Lp 4	1.82**	93.26**	1.82	150.44	470.22	344.95	1821.43	104.53
Lp 6	1.58**	171.55**	1.58	276.27	3343.71	297.18	1286.37	92.92
Lp 10	1.42**	3.43**	1.42	6.04	1800.00	219.27	413.78	99.34
Lp 21	1.54**	197.83**	1.54	318.55	3235.56	294.69	1258.56	93.80
Lp 23	0.22**	8.48**	0.22	14.12	4191.31	309.27	1421.80	85.05
Lp 25	1.79**	369.22**	1.79	593.94	2342.24	408.26	2530.55	85.94
Lp 27	1.64**	701.53**	1.64	1127.96	555.56	454.22	3045.25	96.74
Lp 28	1.39**	14.01**	1.39	23.07	1949.58	217.06	389.07	96.54
Lp 29	1.53**	56.51**	1.53	91.42	2266.89	254.80	811.78	97.47
Lp 27\1	0.43**	324.97**	0.43	522.73	2905.00	336.23	1723.73	95.94
Lp 27\3	0.03**	293.72**	0.04	472.33	1375.15	646.44	5198.08	91.59
Lp 27\7	0.11**	25.96**	0.11	42.07	1934.83	443.56	2925.83	93.26
Lp 27\10	0.60**	766.54**	0.60	1232.43	3736.22	419.91	2660.99	94.04
Lp 28\1	0.72**	880.46**	0.72	1415.53	3289.42	434.80	2827.73	96.44

*significant at $P < 0,05$; ** at $P < 0,01$; ns = not significant

Plant height

On the basis of plant height, accessions Lp 6 ($bi = 1.08$), Lp 27 ($bi = 0.87$) and Lp 27\10 ($bi = 0.91$) can be identified as the most valuable. The estimation of ecological stability showed that accessions with higher plants exhibited more pronounced instability ($bi > 1$), but under intense growing conditions, they could demonstrate their biological potential. In regions where such conditions cannot be provided, genotypes with regression coefficient $bi < 1$ (such as Lp 21 and Lp 10) would be more suitable.

1st pod height

Lp 1 and Lp 23 had the lowest stability index according to the parameters of Plaisted & Peterson (1979) and Wricke (1965) (11.10, 11.45 and 8.46, 12.39, respectively). According to the model of Eberhart & Russell, the values of the regression coefficient in these accessions were close to the ideal genotype ($bi \approx 1$), but Lp 1 had an advantage that it formed its 1st pod at a higher height. The calculated stability parameters in Lp 25, Lp 4, Lp 28 and Lp 29 were high ($bi > 1$), which means that this trait is variable and affected by climatic differences over the years. With stable parameters were hybrid populations (Lp 27\1, Lp 27\3, Lp 27\7, Lp 27\10, Lp 28\1), which implies stabilization of the trait in subsequent generations, as well as Lp ($bi = 0.07$) and Lp 27 ($bi = 0.15$).

Pods number per plant

Comparing the accessions by pods number and stability of the trait, Lp 6 was distinguished by a favorable combination of a large pods number (15-16) with their low variability. Its

good stability evaluation was confirmed by all parameters. Lp 28, Lp 25 and Lp 29 also formed a considerable number of pods, but stability parameters defined them as responsive only under favorable environmental conditions. When the cenotic environment deteriorates, Lp 10 and hybrid populations are more suitable for growing, because they form fewer pods but exhibit greater stability.

Seeds number

For the three experimental years of the study, accessions with more pods formed the most seeds. However, they had unsatisfactory stability, except for the Lp 6. It had a regression coefficient close to 1 ($bi = 0.95$) and a relatively low parameter W^2 of Wricke (1965), putting it in the group of stable genotypes. The parameters of Eberhart & Russell (1966), Tai (1979), and Plaisted & Peterson (1979) evaluated hybrid populations as stable concerning this trait. It had a regression coefficient close to 1 ($bi = 0.95$) and relatively low parameter W^2 of Wricke (1965), putting it in the group of stable genotypes. The parameters of Eberhart & Russell (1966), Tai (1979), and Plaisted & Peterson (1979) evaluated hybrid populations (Lp 27\1, Lp 27\3, Lp 27\7, Lp 27\10, Lp 28\1) as stable concerning this trait.

Pod length

With respect to the pod length, the parameters of Eberhart & Russell (1966) and Tai (1979) were not statistically significant, so the assessment of their environmental stability can be conducted by using the other parameters. With lowest stability parameter W^2 (according

to Wricke, 1965), was distinguished Lp 10, as well as Lp 29 and Lp 4, whose plants had long pods. These accessions were evaluated similarly by the reliability index (Wi) of Annicchiarico (1992). Lp 27\1 and Lp 27\3 were of interest because they also exhibited similar stability and formed long pods. Lp 28\1 had the longest pods, but contradictory estimates of its stability give reason to believe that the breeding process will be longer.

Pod width

The ecological stability of this trait can also be better evaluated by using parameters based on variance analysis. The low values of the stability index W^2 in all accessions indicated that the considered trait is principally low-variable, and it is difficult to respond to changes in the environment. Lp 4 and Lp 10, as well as Lp 27\1 and Lp 27\3, had the widest pods and good stability also for the parameter Wi. Accessions Lp 25 and Lp 27\10 exhibited greater variability in pod width under change of the environmental limits.

Seed weight

Assessment regarding this characteristic showed that Lp 23 had very good stability ($bi = 1.06$) but relatively low seed weight per plant. At Lp 4, the regression coefficient values were slightly higher ($bi = 1.18$), but it can also be characterized as stable and with seed weight above the average for the group. The other stability parameters also defined Lp 4 as a stable genotype. Also, of interest was Lp 6, which was highly productive, with a value close to

that of Lp 4, but it showed better stability in terms of the parameters PP, W^2 and Wi.

Accessions Lp 1, Lp 28 and Lp 29 exhibited essential variability in the stability of the trait considered (despite its high productivity), which gives reason to believe that it is considerably affected by changes in climatic conditions. In contrast, the plants of Lp 27\1, Lp 27\3, Lp 27\7, Lp 27\10, Lp 28\1 did not succeed to form a high seed weight but manifested extremely stability of the trait.

1000 seeds mass

The regression coefficient (bi) in most of the accessions tested substantially exceeded 1, which was a prerequisite for being considered that they had low stability, but responsiveness in improving environmental conditions. Lp 1 performed yourself very well, and its stability was at a good level according to the parameters " bi " (0.82), "PP" (394.02) and "Wi" (110.24). The behavior of Lp 27\1, Lp 27\3, Lp 27\7, Lp 27\10 and Lp 28\1 in this trait was similar to the seed weight. Of interest was Lp 28\1, which was characterized by medium-heavy seeds in combination with high ecological stability.

Adaptability

To obtain objective information on the adaptability of the white lupine genotypes, the coefficient of total adaptability (A) was calculated (Table 3), which allows an additional assessment of their productive capabilities.

This coefficient gives an advantage to highly productive genotypes with better stability ($bi < 1.0$).

Table 3. Coefficient of total adaptability (Valchinkov, 1990)

Accessions	Plant height	1 st pod height	Pods number	Seeds number	Seed weight	Pod length	Pod width	1000 seeds mass
Lp 1	7.73	3.90	11.98	56.08	15.72	5.13	0.15	2.273
Lp 4	7.89	3.181	11.27	53.76	14.08	7.84	1.61	1.108
Lp 6	6.86	2.65	14.54	59.13	14.03	6.87	0.29	1.022
Lp 10	6.21	4.602	10.32	42.62	10.37	7.29	0.41	1.308
Lp 21	6.64	3.185	11.11	47.98	11.25	6.73	0.26	1.083
Lp 23	5.887	2.783	12.5	53.81	11.7	6.28	0.19	2.148
Lp 25	6.16	-0.519	12.36	59.91	12.01	2.84	-1.17	0.694
Lp 27	7.58	4.165	11.03	53.89	11.75	4.96	-0.65	1.124
Lp 28	7.32	2.797	14.47	61.44	13.42	5.89	0.42	1.267
Lp 29	7.62	2.893	13.8	63.2	15.00	7.06	1.25	1.171
Lp 27\1	6.92	3.989	10.6	45.22	10.66	7.98	0.01	2.263
Lp 27\3	7.80	4.761	10.06	45.08	10.97	7.92	0.06	3.011
Lp 27\7	7.42	5.623	11.55	34.84	9.49	7.3	1.03	2.752
Lp 27\10	7.86	5.018	10.36	41.76	10.16	8.07	-0.82	2.061
Lp 28\1	7.31	4.463	8.15	36.33	9.69	9.2	0.31	2.021

In general, white lupine accessions exhibited a high coefficient of adaptability based on pods number, seeds number and seed weight, and low values in pod width and 1000 seeds mass. Most of the accessions manifested similar adaptability in plant height. Lp 6 and Lp 29 deserve special attention because they were characterized by high total adaptation in pods number, seeds numbers, and seed weight. Lp 27\10 and Lp 28\1 were highly adaptable in plant height and pod length. Genotypes with high adaptation are of breeding value on condition that they exhibit low variability of a given trait at different environmental limits. In the present study, Lp 1, Lp 4, Lp 6, Lp 28 and Lp 29 combined high average productivity (seed weight per plant) with relatively low variability and high adaptability.

GGE biplot analysis

By applying the graphical analysis of GGE biplot, genotypes combining good productivity and high stability can be identified. The results indicated that the first two major components (PC1 and PC2) accounted for 94.9% of the total variation (PC1 = 78.8%; PC2 = 16.1%), which was the result of the GE interaction (Figure 2).

For breeding purposes, suitable genotypes are those that have high positive values for the two major components and have a shorter vector.

In the first quadrant, with positive values of PC1 and PC2, were situated Lp 4, Lp 6, Lp 29 and Lp 1. Lp 29 and Lp 1 had the highest values on PC1 (abscissa), and therefore the highest productivity. In both accessions, the short vector implied greater stability and adaptation to a wide range of environments. Lp 4 was also stable (short vector), but it was located closer to the origin of the coordinate system and was, therefore, less productive.

In the second quadrant, with positive values on PC1 but negative ones on PC2, were located Lp 28, Lp 27, Lp 25 and Lp 23. Judging by the vector length, these accessions can be assigned to the group of unstable genotypes. In terms of productivity, Lp 28 occupied the third position after Lp 1 and Lp 29, while Lp 27 came close by Lp 4 and Lp 6.

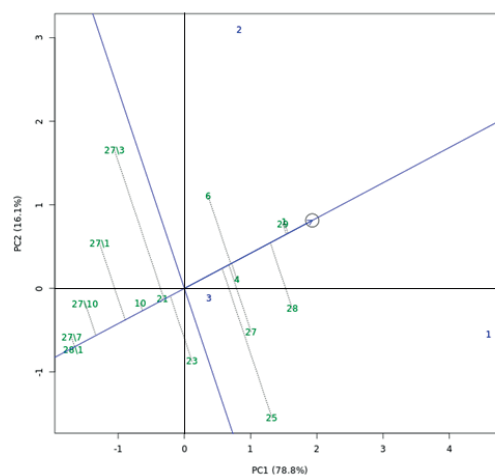


Figure 2. GGE biplot analysis in white lupine accessions

The third and fourth quadrants contained four (Lp 21, Lp 10, Lp 27\10, Lp 27\7 and Lp 28\1) and two (Lp 27\3; Lp 27\1) genotypes, respectively, characterized by lower productivity compared to others. The variability of Lp 27\3 and Lp 27\1 was more pronounced since they were located at a greater distance from the perpendicular axis. Stable in this respect were Lp 27\7 and Lp 28\1, but they were the least productive among the group of accessions participating in the study.

Correlation analysis

Analysis of the genotype evaluation data, expressed in a numerical form, could not give a clear understanding of the effectiveness of each of the methods used to determine stability. In some cases, arrangement by different parameters for each accession is reflected in its ranking differently against the whole group. It is also not clear what the compromise is between the expression of a trait and its stability in the final genotype estimation. The results of the correlation analysis presented in Table 4 can provide a reply somewhat.

Positive and significant correlations were found between seed weight and the parameters "A" ($r = 0.975$) of Valchinkov (1990), "Wi" ($r = 0.947$) of Wricke (1965), "bi" ($r = 0.671$) of Eberhart & Russell (1966) and "ai" ($r = 0.672$) of Tai (1979). The non-parametric method for assessing the stability of Lin & Binn (1988) showed a negative and mean relationship ($r = -0.661$) with productivity (seed weight).

The correlations between “A” and “Wi” ($r = 0.912$), “bi” ($r = 0.817$) and “ai” ($r = 0.818$) were positive, high and statistically significant.

Table 4. Correlations between stability parameters and productivity in white lupine accessions

	bi	Si ²	ai	λi	Pi	PP	W ²	Wi	A
Si ²	0.031								
ai	0.990 **	0.032							
λi	0.030	0.990 **	0.032						
Pi	-	-	-	-					
PP	0.230	0.057	0.232	0.056					
W ²	0.105	0.649 **	0.104	0.649 **	0.340				
Wi	0.105	0.650 **	0.104	0.650 **	0.341	0.990 **			
A	0.594 *	-	0.595 *	-	0.625 *	0.577 *	0.57 7*		
seed weig ht	0.817 **	-	0.818 **	-	0.587 *	0.217	0.21 7	0.912 **	
	0.671 **	-	0.672 **	-	0.661 **	0.316	0.31 6	0.947 **	0.975 **

*/** Correlation is significant at the 0.05 / 0.01 level

Relatively higher was the correlation value between “W2” and “PP” (1979), which reached $r = 0.990$, with significance at a very high statistical level. The dependences of the parameters “PP” and “W2” with the indices “Si2” ($r = 0.649$) and “λi” ($r = 0.650$) were also quite high.

The estimation of the productivity of a genotype depended not only on its biological potential but also on the environmental conditions in which that potential has realized. Changes in environmental conditions caused to some extent yield instability and corresponding specific response by the genotype (Dyakov & Trunova, 2010).

According to Nascimento et al. (2013), in plant breeding, when the aim is to select stable genotypes, a detailed study of the genotype-environment interaction is crucial (Nascimento et al., 2013). In this study, productivity was considerably influenced by the factor environment, secondarily by the GE interaction and relatively less by the factor genotype. Ashrei & Ghareeb (2015) reported similar results in their studies when assessing the stability of the main traits in white lupine cultivars. The authors indicated that the environmental impact was the predominant source of variation, followed by GE interaction and genotype effect. Arega et al. (2018) have obtained similar results for soybean cultivars. The analysis of variance

showed that the yield was significantly influenced by the environment, genotype and their interaction, with values of 57.4%, 20.9% and 19.8% of the total variation.

According to Ivanov et al. (2018), cultivars characterized by higher phenotypic stability of productivity, have also pronounced GE interaction and relative persistence in the manifestation of their genetic characteristics. Similar dependence, but in terms of plant height and 1st pod height was found by Pan et al. (2007), Singh et al. (2007) and Satish et al. (2007) in common bean. In the present study, Lp 25 and Lp 29 formed a considerable number of pods per plant, but they had unpredictable behavior due to the essential deviation from regression. Similar results for the stability of this trait have been reported by Ceyhan et al. (2012) when evaluating pea genotypes.

In the present study, accessions Lp 25 and Lp 28 were distinguished by an increased number of seeds per plant, with high instability, but also with good responsiveness to environmental conditions. Mahmud et al. (2007) have pointed similar results in chickpeas. They concluded that varieties with a higher number of seeds per plant, coupled with high regression coefficients and high regression deviation, were distinguished with good adaptation to the environment. These results supported the studies of Demirbas et al. (2016) and Karakoy et al. (2018), who found that none of the chickpea genotypes with high average (in terms of seed productivity and seeds number per plant) were very stable.

It is important for the breeder to use methods in which genotype stability is associated with high average yield. Among the various methods, the GGE biplot enables the genotypes to be analyzed simultaneously, taking into account high seed yield and stability (Yan et al., 2007; Yan, 2016). Unfortunately, as noted above, high stability is often associated with low levels of productivity and vice versa (Tsenov et al., 2004; Tsenov and Gubatov, 2019). Many researchers (Roostaei et al., 2014; Gubatov et al., 2017) considered that the application of some of the evaluation methods makes it possible to identify cultivars that compromise a high yield with stability of the background

of the studied group. Our results of GGE biplot defined Lp 29 and Lp 1 as optimally combining high performance with relative stability.

The results of the correlation analysis of stability and adaptability parameters with productivity partially supported the researches of Kilic (2012) and Ahmadi et al. (2015). The authors reported high correlation coefficients of "PP" with "Si²", " λ " and "Wi". They considered that these parameters can be used in parallel when selecting genotypes with high stability and moderate expression of the value of the corresponding trait.

According to Cargnelutti Filho et al. (2009), the different methods and analyses used to evaluate cultivars (hybrids) can provide considerable information, and only one would be sufficient to select the best genotypes. However, even at strong relationship between methods, ranking genotypes may be different between different methodologies.

CONCLUSIONS

It was established significant influence of the factors of genotype, environment and genotype-environment interaction on the formation of main quantitative traits in white lupine accessions. The genotype influence was strongest regarding 1st pod height (55.16%), pod length (45.21%) and 1000 seeds weight (34.43%). The factor of the environment had the highest influence in the total variation in plant height (62.62%), seeds number (44.47%) and seed weight (41.34%) (41.34%).

The stability parameters for plant height determined Lp 27 and Lp 27\10 as stable and high-growing. Lp 4 was of interest regarding pod length, pod width, and seed weight, and Lp 1 was in a favorable position concerning 1000 seeds mass.

From a breeding point of view, Lp 6 was the closest to the ideal type, combining high productivity with ecological stability in terms of main quantitative traits (pod numbers, seed numbers and seed weight). Suitable parental components in combinative breeding for the development of high yielding cultivars were Lp 1, Lp 4 and, Lp 6, which exhibited stability and productivity in main traits.

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REFERENCES

- Abraham, M.E., Ganopoulos, I., Madesis, P., Mavromatis, A., Mylona, P., Nianiou-Obeidat, I., Parissi, Z., Polidoros, A., Tani, E., Vlachostergios, D. (2019). The Use of Lupin as a Source of Protein in Animal Feeding: Genomic Tools and Breeding Approaches. *International Journal of Molecular Sciences*, 20(4), 1-27.
- Ahmadi, J., Vaezi, B., Shaabani, A., Khademi, K., Fabriki Ourang, S., Pour-Aboughadareh, A. (2015). Non-parametric Measures for Yield Stability in Grass Pea (*Lathyrus sativus* L.) Advanced Lines in Semi Warm Regions. *J. Agr. Sci. Tech.*, 17, 1825-1838.
- Annicchiarico, P. (1992). Cultivar adaptation and recommendation from alfalfa trials in Northern Italy. *Journal of Genetics and Plant Breeding*, 4, 269-278.
- Annicchiarico, P., Thami-Alami, I. (2012). Enhancing white lupin (*Lupinus albus* L.) adaptation to calcareous soils through selection of lime-tolerant plant germplasm and bradyrhizobium strains. *Plant Soil*, 350, 131-144.
- Arega, A., Dabessa, A., Tola, M., Dabala, C. (2018). Genotype and genotype by environment interaction and grain yield stability of medium maturity groups of soybean [*Glycine max* (L.) Merrill] varieties in Western Oromia, Ethiopia. *African Journal of Plant Science*, 12(9), 227-237.
- Ashrei, A.A.M., Ghareeb, Z.E. (2015). Genotype - environment interaction for yield in lupin (*Lupinus albus* L.) Egypt. *J. Plant Breed.* 19 (5), 239-256.
- Atnaf, M., Tesfaye, K., Dagne, K. and Wegary, D. (2015). Extent and pattern of genetic diversity in Ethiopian white lupin landraces for agronomical and phenological traits. *African Crop Science Journal*, 23(4):327-341.
- Atnaf, M., Wegary, D., Dagne, K., Tesfaye, K. (2018). Genotype by environment interaction and grain yield stability of Ethiopian white lupin (*Lupinus albus* L.) landraces. *Exp. Agric.*, 54, 943-956.
- Barov, V. (1982). Analysis and schemas of the field trial. NAPS, Sofia, Bulgaria.
- Cargnelutti Filho, A., Storck, L., Riboldi, J., Guadagnin, J.P. (2009). Associação entre métodos de adaptabilidade e estabilidade em milho. *Ciência Rural*, 39(2), 340-347.
- Coba de la Peña, T., Pueyo, J.J. (2012). Legumes in the reclamation of marginal soils, from cultivar and inoculant selection to transgenic approaches. *Agron. Sustain. Dev.*, 32, 65-91.
- Cruz, C.D. (2009). Programa Genes: Biometria. version 7.0. University of Federal Viçosa, Viçosa, Brazil.

- Demirbas, A.T., Durukan, H., Erdem, H. (2016). The impacts of the biochar addition in different doses on yield and nutrient uptake of the chickpea plant (*Cicer arietinum* L.) under the conditions with and without incubation. *Fresen. Environ. Bull.* 26, 8328-8336.
- Dyakov, A.B., Trunova M.B. (2010). Relationship between the parameters of stability and adaptability of varieties. *Oilseed crops*, 1, 142-143.
- Eberhart, S.A., Russel, W.A. (1966). Stability parameters for comparing varieties. *Crop Science*, V.6, 36-40.
- Gubatov, T., Tsenov, N. & Yanchev, I. (2017). Correlation between the ranking of winter wheat genotypes by grain yield and stability through various statistical approaches. *Bulgarian Journal of Agricultural Science*, 23(1), 92-101.
- Ivanov, G., Uhr, Z., Delchev, G. (2018). Estimation of yield and stability of varieties of common winter wheat grown under organic and conventional agriculture. *New Knowledge Journal of Science*, 7-2, 265-272.
- Karakoy, T., Ton, A., Anlarsal, A.E. (2018). Genotype x environment interactions and stability analysis for the yield and yield components in winter chickpea (*Cicer arietinum* L.). *Fresenius Environmental Bulletin*, 27(9), 6291-6296.
- Kilic, H. (2012). Assessment of parametric and nonparametric methods for selecting stable and adapted spring bread wheat genotypes in multi-environment. *J. Anim. Plant Sci.*, 22, 390-398.
- Lin, C.S., Binns, M.R. (1988). A superiority measure of cultivar performance for cultivar x location data. *Can. J. Plant Sci.* 68, 193-198.
- Mahmud, F., Ullah, Z. and Huda, K.M.K. (2007). Genotype-Environment Interaction For Seed Yield and Yield Contributing Characters in Chickpea (*Cicer arietinum* L.). *Bangladesh J.Pl. Breed Genet.* 20, 09-12.
- Milioli, A.S., Zdziarski, A.D., Woyann, L.G., Santos, R., Rosa, A.C., Madureira, A. and Benin, G. (2018). Yield stability and relationships among stability parameters in soybean genotypes across years. *Chilean journal of agricultural research* 78(2), 299-309.
- Nascimento, M., Peternelli, L.A., Cruz, C.D., Nascimento, A.C.C., Ferreira, R.P., Bhering, L.L. and Salgado, C.C. (2013). Artificial neural networks for adaptability and stability evaluation in alfalfa genotypes. *Crop Breeding and Applied Biotechnology*, 13, 152-156.
- Plaisted, R.L. and Peterson, L.C. (1979). A technique for evaluating the ability of selection to yield consistently in different location and seasons. *Am. Potato J.* 36, 381-385.
- Roostaei, M., Mohammadi, R. & Amri, A. (2014). Rank correlation among different statistical models in ranking of winter wheat genotypes. *The Crop Journal*, 2(2-3), 154-163.
- Sabaghnia, N., Karimizadeh, R. and Mohammadi, M. (2015). Graphic analysis of yield stability in new improved lentil (*Lensculinaris* Medik.) genotypes using nonparametric statistics. *Acta Agriculturae Slovenica* 103(1), 113-127. doi:10.14720/aas.2014.103.1.12.
- Tai, G.C.C. (1979). Analysis of genotype – environment interactions of potato yield. *Crop Sci.*, 19, 434.
- Tsenov, N. & Gubatov, T. (2019). Comparison of basic methods for estimating the size and stability of grain yield in winter wheat. *Rastenievadni nauki*, 55(5), 9-19 (Bg).
- Tsenov, N., Kostov, K., Gubatov, T. & Peeva, V. (2004). Study on the genotype x environment interaction in winter wheat varieties. I. Grain quality. *Field Crops Studies*, 1(1), 20-29 (Bg).
- Wricke, G. (1965). Zur berechnung der ökovalenz bei sommerweizen und hafer. *Pflanzenzüchtung* 52: 127-138.
- Yan, W. (2002). Singular-value partitioning in biplot analysis of multi-environment trial data. *Agron. J.* 94: 990-996.
- Yan, W. (2016). Analysis and handling of $G \times E$ in a practical breeding program. *Crop Science* 56, 2106-2118. doi:10.2135/cropsci2015.06.0336.
- Yan, W., Kang, M.S., Ma, B., Woods, S., Cornelius, P.L. (2007). GGE biplot vs. AMMI analysis of genotype-by-environment data. *Crop Science* 47(2), 643-653. doi:10.2135/cropsci2006.06.0374.
- Ceyhan, E., Kahraman A., Ates, M.K., Karadas, S. (2021). Stability analysis on seed yield and its components in peas. *Bulg. J. Agric. Sci.*, 18(6), 905-911.
- Pan, R.S., Singh, A.K., Rai, M., Kumar, S. (2007). Stability analysis of yield and its components in bush type French bean. *Veg. Sci.*, 33(2), 145-148.
- Singh, A.K., Tomer, A.K., Tyagi, K., Singh, P.P. (2007). Stability analysis for yield and its components in French bean (*Phaseolus vulgaris* L.). *Legume Res.*, 30(3), 166-172.
- Satish, D., Jagadeesha, R.C., Patil, R.K. and Masuthi, D. (2017). Genotype x environment interaction and stability analysis in Recombinant inbred lines of French bean for growth and yield components. *Journal of Pharmacognosy and Phytochemistry*, 6(5), 216-219.
- Valchinkov, S. (1990). Method of classifying genotypes with relatively high and stable yields. *Research of University of Agriculture*, XXXV, References 4, 161-165 (Bg).