Pak. J. Bot., 53(1): 253-259, 2021. DOI: http://dx.doi.org/10.30848/PJB2021-1(16)

EVALUATION OF WHITE LUPIN (*LUPINUS ALBUS* L.) FOR PRODUCTION CHARACTERISTICS AND SYMBIOTIC NITROGEN-FIXATION POTENTIAL

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Abstract

The adaptive properties of seven white lupin (*Lupinus albus*) varieties for the leaf number, plant fresh weight, root length, fresh root weight and number of nodules per plant were studied in a field trial at the Institute of Forage Crops, Pleven, Bulgaria. Varieties with high general and specific adaptive ability, relative stability and selection value were identified. The combination of stability and adaptability parameters and number of leaves per plant determined the KALI and Lucky801 varieties as promising, characterized by a high selection value of the genotype (SVG = 12.83, 11.48). In terms of fresh aboveground mass productivity PI533704 and KALI were of interest showing high stability and high biological potential. PI457938 was highly productive and responsive to improving growing conditions. PI457923 and PI457938 are characterized by a high selection value in respect to the fresh root weight (SVG = 1.11, 0.95) and nodule number (SVG = 5.58, 5.37). The PI457923, PI457938, KALI and Lucky801 varieties can be used in future selection programs to create varieties with higher leaf weight, higher aboveground and root mass and nodule number per plant.

Key words: Adaptability, Homeostaticity, Stress resistance, White lupin.

Introduction

Grain legume cultivation provides multiple environmental benefits to agricultural landscapes in Europe, increases resource efficiency, and contributes to balancing Europe's deficit in plant protein production (Latef & Ahmad, 2015; Preissel *et al.*, 2015). White lupin (*Lupinus albus*) it self is used as feed for livestock and has established a growing market for human consumption due to the development of low alkaloid varieties with a lack of protease inhibitors. Lupin, like other grain legumes is a source of high-quality protein, essential amino acids, oil and other nutritive substances. The major biochemical feature of lupin is the capability to synthesize a high proportion of protein. Due to its coexistence with nodule bacteria lupin possesses high nitrogen-fixing ability to acquire nitrogen from the atmosphere for producing protein and other nitrogen substances (Phan *et al.*, 2007).

White lupin is relatively more tolerant of some abiotic environmental stressors than other legumes and has significant potential for restoring on the poor and polluted soils. Not only the study of productivity, quality, and technology of cultivation but also the adaptive capabilities of genotype have always been of interest to breeders (Vishnyakova, 2008; Coba de la Peña & Pueyo, 2012; Lucas *et al*., 2015).

The assessment of the biological and economic potential of legumes shows that they play a significant role as an ecological factor in nature and therefore these crops need to be more actively involved in adaptive selection. This selection direction will contribute to the fuller realization of their biological abilities (Zhuchenko, 2004 missing in text, Lakic *et al*., 2018).

White lupin is characterized by the cleanest and most energy saving mechanism for nitrogen accumulation because of the symbiotic interaction with nitrogen-fixing bacteria *Rhizobium lupini*. Due to the formation of nodules on the roots, the plants of lupin not only satisfy their own needs but also enrich the soil with biological nitrogen. Under favorable conditions for the symbiosis of one vegetation period the lupin can absorb about 200 kg/ha of nitrogen from the air and through the metabolism to a form accessible to the plant. This allows reducing significantly both the cost of nitrogen fertilizers and the cost of the final product (Parniske, 2008; Slesareva *et al.*, 2014).

The aim of the study was to assess the adaptive capabilities of white lupin varieties on some quantitative signs and to identify appropriate parental components for future selection programs.

Materials and Methods

The study was conducted in 2014-2016 in experimental field of Institute of Forage Crops, Plevan, Bulgaria (43°23'N, 24°34'E, 230 m altitude) on podzolized soil subtype without irrigation. Sowing was done manually in optimal time according to the technology of cultivation of white lupin. Between row space was 50 cm and inter row space 10 cm. Weeding was done manually, no fertilizers were applied and growth period was between 104 and 109 days.

Aboveground and root mass of seven white lupin varieties different originated, i.e., PI457923 (Greece), PI368911 (Czech Republic), PI533704 (Spain), PI457938 (Morocco), KALI (Poland), Zuter (France) and Lucky801 (France) was analyzed.

The following characteristics were assessed at the initiation of flowering stage after washing the roots of the plants with water: fresh root mass weight (g), root mass length (cm), number of nodules per plant and for the aboveground mass -number of leaves per plant and fresh weight of the aboveground mass (leaves+stems). Biometric measurements were made from 10 plants of each variety.

The method of Kilchevsky & Khotyleva (1985a, b) for the quantitative assessment of the parameters of stability and plasticity was used in the present study. This method is based on variety testing in different environments to reveal general adaptive ability (GAA) and specific adaptive ability (SAA) and their stability (Sgi), selective value of genotype (SVG) for the selection of high productive and stable forms. The stress resistance (Y) of varieties was determined by Rossielle & Hamblin (1981) method. Homeostaticity (Hom) was calculated by the method of Hangilidin (1984). The analysis of adaptability was performed according to the methods proposed by Nascimento *et al.*, (2009), stability parameter Finlay & Wilkinson (1963) and Francis & Kannenberg (1978).

All experimental data were processed statistically by using the computer software GENES 2009.7.0 and Excel for Windows XP (Cruz, 2009) (a long plot method was used, 3 replications).

Results and Discussion

The ability of plant varieties to be stable and produce high yields in different growing years is determined by the resistance of the plants to the adverse environmental factors. The fluctuations in the productivity of varieties in different climatic years are the result of the abrupt variability of the quantitative signs that are components of productivity (Zakharova *et al.*, 2014; Bazitov *et al.*, 2017). In evaluating forage crop varieties, one of the most valuable and important indicators is the aboveground mass of the plant. In the present study the characteristic of the aboveground mass is expressed by two components - number of leaves and weight of the plant (Table 1). The results showed that the varieties whose plants formed more leaves were more variable to the environmental changes. According to the "bi" criterion, the Zuter & Lucky801 varieties are stable and form a relatively large number of leaves per plant. The value of their stability parameter is statistically insignificant therefore their assessment on the other indicators is different.

General adaptive ability (GAA) stands for PI457938, followed by Lucky801 and PI368911. The higher the GAA, the more the genotype is adapted to a variety of growing conditions. The adaptability of the variety under specific environmental conditions expressed by the low values of the GAA and Sgi indicators show that the PI533704 and KALI varieties are the most stable in the sample group. The genotype selection value is a cumulative indicator that combines productivity and stability and is more pronounced in KALI (12.83), Lucky801 (11.48) and PI457938 (10.62). Gorchanenko (2005), Vasileva *et al.*, (2011) found that, in the context of a rapidly changing continental climate, an important indicator characterizing the resistance of the variety to various stress factors is the degree of stress resistance. This parameter generally has a negative sign as its value is smaller, the higher the stress resistance of the genotype.

The regression coefficient (bi) gives close information with the parameter Sgi (%) with respect to the stability of the sign in different environments. By the fresh weight of the whole plant near the "ideal" type are the Lucky801 (bi = 1.12) and Zuter (bi = 1.14) varieties with a regression coefficient slightly above 1. The varieties PI368911 and PI457938 may be characterized as ecologically unstable (bi> 1) but also with a high fresh weight of plants (18-23 g) (Fig. 1). PI533704 is shown as the most stable, both by the regression coefficient and the values of the other parameters. The combination of good stability and plants of relatively high fresh aboveground mass weight place this variety as the most suitable for selection. According to the SVG indicator, the varieties PI457938 (11.13) and KALI (10.03) are also of interest.

Judging by the results for fresh root mass weight almost all varieties can be defined as very stable with a coefficient of "bi" <0.23. An exception is the Lucky801 variety, which is highly variable (bi = 6.14), but placed in favorable environment has been able to form plants with a higher root mass weight (Fig. 1). No significant difference was found between the varieties by their general adaptive ability, although in some of them the values of this indicator were negative. An expression of the behavior of the variety in given specific environmental conditions is the specific adaptive ability (SAA) parameter. As the numerical value of SAA is lower, the variety is more stable for the given attribute. Such features are KALI (0.21), Zuter (0.82) and PI533704 (0.97). The ability of the variety as a result of the regulatory mechanisms of the organism to maintain a certain level of trait in a different environment is represented by the relative stability parameter Sgi %. The lower it is, the more the variety is more stable (the relative stability indicator is the equivalent of the coefficient of variation). According to the data on the level of the trait, the general adaptive ability and stability as a selection value for the selection needs are PI457923 (1.11), PI457938 (0.95) and PI533704 (0.84) varieties.

The varieties included in the study differ in their biological potential by number of nodules per plant of 3.40 at KALI to 15.93 at Lucky801 (Fig. 1). The Lucky801 variety is significantly more variable than the others with bi = 6.14. With "bi" values close to 1 are PI533704 and PI457938 which can be attributed to the plastic varieties that produce a sufficient number of plant nodules in both comfortable and unfavorable growing conditions. The varieties exhibit different specific adaptive ability, best shown in KALI (2.25), PI457938 (3.37) and PI368911 (3.41). The varieties PI368911 and PI457938 showed a high selective value of 5.34 and 5.37, respectively.

In the analysis of adaptability and stability along the roots lengtht, PI457923, PI533704 and PI533704 have the advantage. They combine the stability of the attribute (bi<1) and the relatively specific adaptive ability (SAA). The same varieties have high selective value of genotype parameter (6.71-8.68). With higher requirements for specific growing conditions, PI368911 (4.77) and Lucky801 (3.44) are characterized.

Table 1. Parameters of adaptability and stability in white lupin varieties.

Genotypes	b_i	GxEgi	GAA	SAA	Sgi, %	SVG
			Leaf number			
PI457923	0.79**	9.91	-2.18	9.87	54.08	9.93
PI368911	1.36**	18.15	1.00	16.60	77.40	7.44
PI533704	0.67**	14.72	-3.96	8.01	48.62	9.72
PI457938	1.40**	21.95	4.53	17.00	68.09	10.62
KALI	0.74**	9.90	-0.01	9.01	44.12	12.83
Zuter	1.03	1.34	-1.09	12.66	65.41	8.67
Lucky801	1.01	8.53	1.71	12.64	57.08	11.48
			Fresh aboveground mass weight (leaves + stems) (g)			
PI457923	0.72**	29.52	-2.61	10.71	69.20	8.74
PI368911	1.39**	27.70	-0.03	19.50	108.00	5.79
PI533704	0.41**	65.02	1.32	5.33	27.45	16.05
PI457938	1.36**	26.54	5.12	19.19	82.70	11.13
KALI	0.86**	7.90	-0.41	12.15	68.75	10.03
Zuter	1.14**	9.76	-2.97	16.24	107.42	4.90
Lucky801	1.12*	25.39	-0.42	16.42	93.00	7.33
			Fresh root mass weight (g)			
PI457923	0.22**	0.28	0.18	1.04	54.25	1.11
PI368911	0.13**	1.05	0.29	2.19	108.27	0.35
PI533704	0.17**	0.11	-0.14	0.97	60.63	0.84
PI457938	0.02**	0.05	0.23	1.32	66.97	0.95
KALI	0.09**	0.65	-0.61	0.21	18.73	0.88
Zuter	0.22**	0.04	-0.44	0.82	63.23	0.65
Lucky801	6.14**	0.31	0.49	1.59	71.63	1.00
			Nodule number per plant			
PI457923	0.69*	25.37	1.98	5.92	58.04	5.58
PI368911	0.70*	13.69	-0.22	3.41	42.59	5.34
PI533704	0.82	-0.43	-3.02	4.67	89.89	1.55
PI457938	1.19	-2.45	-0.22	3.37	42.15	5.37
KALI	0.59*	1.50	-4.82	2.25	66.09	1.64
Zuter	0.19**	0.37	-1.43	3.95	58.26	3.70
Lucky801	2.81**	112.91	7.72	14.50	91.02	4.60
			Root length (cm)			
PI457923	0.01**	0.61	0.85	1.49	12.29	8.68
PI368911	-	6.85	0.04	4.77	42.07	0.26
PI533704	0.09**	0.12	1.55	2.64	20.58	6.71
PI457938	-	-0.39	0.11	2.16	18.95	6.39
KALI	0.09**	11.72	-1.23	1.44	14.35	6.71
Zuter	0.01**	0.55	-1.87	1.27	13.45	6.48
Lucky801	6.85**	1.57	0.55	3.44	29.01	3.86

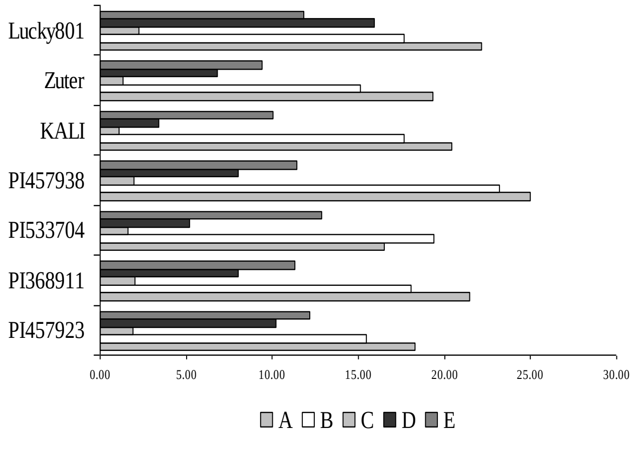
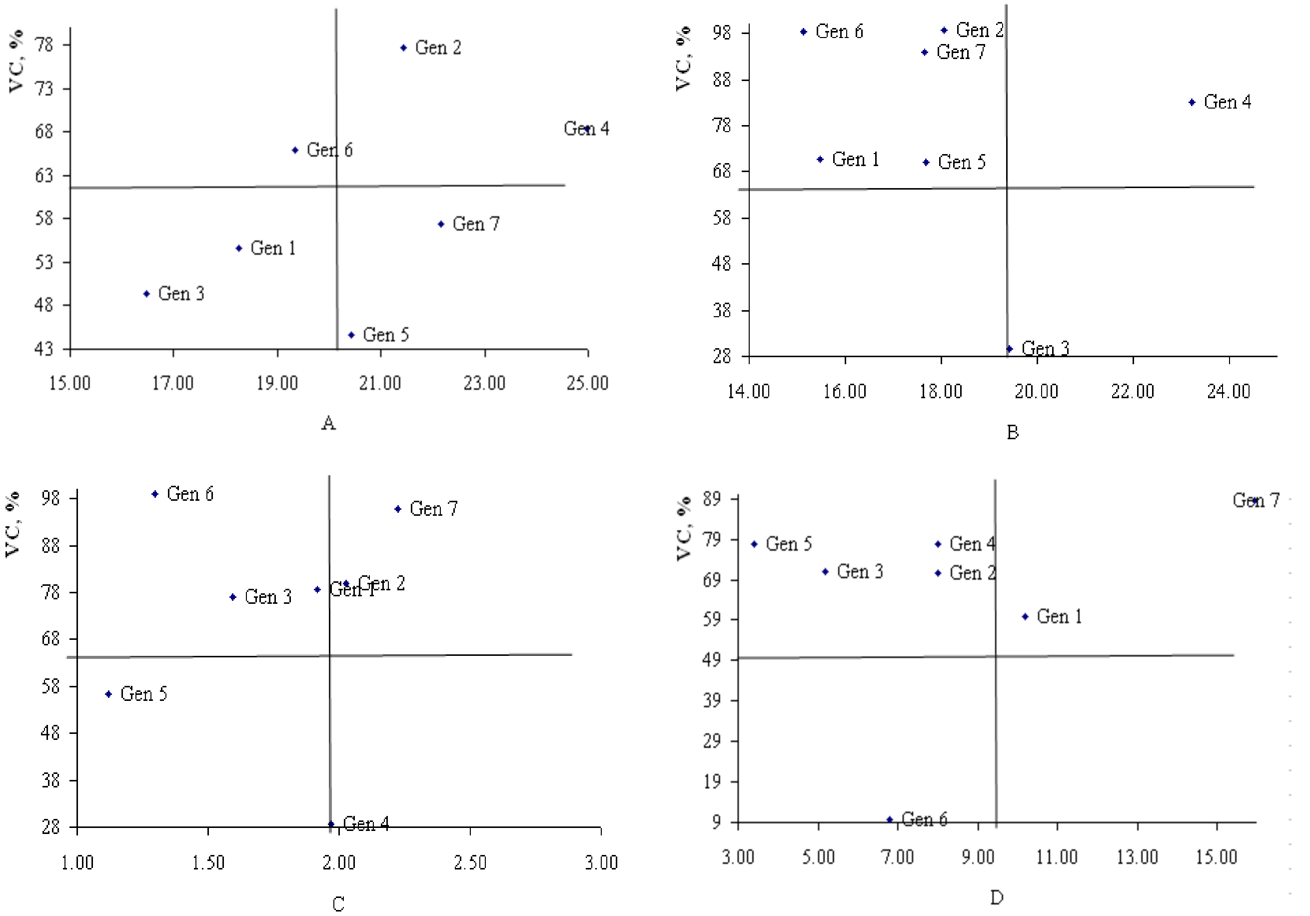


Fig. 1. Productive capabilities of white lupin varieties on the tested signs A - Leaf number per plant, B - Fresh aboveground mass weight (leaves + stems) C - Fresh root mass weight, D - Nodule number per plant, E - Root mass length.

The magnitude and stability of the studied characteristics of the white lupin varieties is represented by the Francis & Kannenberg (1978) method by the corresponding coefficient of variation (Fig. 2). The average value of the attribute and its variance coefficient for each variety divide the coordinate system into four quadrants. In the quadrant, located at the bottom right of the coordinate system, varieties with high ecological stability and high productivity fall. For the number of leaves per plant, Y are the Lucky801 and KALI varieties. KALI is farther away from the abscissa, indicating its greater variability. These varieties are most preferred in the selection to create more wrapped genotypes. The varieties PI368911 and PI533704 located above this quadrant are more variable and exhibit responsiveness only under favorable environmental conditions. The arrangement of the varieties on the bottom left of the PI457923 and PI533704 coordinate system reveals their stability but also weaker potential with respect to the attribute.



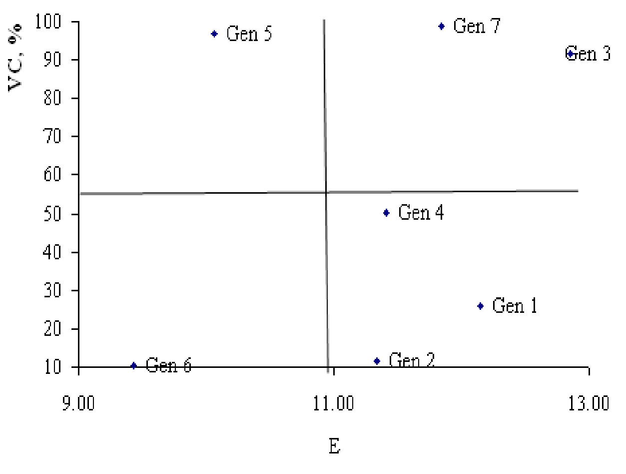


Fig. 2. Stability and distribution of varieties by the parameters studied in white lupin (according to Francis & Kannenberg, 1978)
A - Leaf number per plant, B - Fresh aboveground mass weight (leaves + stems) C - Fresh root mass weight, D - Nodule number per plant, E - Root mass length
Gen1 - PI457923; Gen2 - PI368911; Gen3 - PI533704; Gen4 - PI457938; Gen5 - KALI; Gen6 - Zuter; Gen7 - Lucky801

By weight of the fresh mass of the whole plant variety PI457938 retains its position. The most preferred from the selection point of view is PI533704 variety, which is highly productive and is the least varied with other varieties.

From fresh root mass weight, it is clear that a selection compromise can be done to the PI457938 variety, which is characterized by the lowest variability of the attribute and the root mass weight around the average for the group of varieties studied. The PI368911 and Lucky801 varieties have higher values of the trait, but are also highly dependent on changing environmental conditions.

On the basis of the method proposed by Francis & Kannenberg (1978) it is not possible to define a clear favorite that is stable and at the same time forms a large number of nodules per plant. The Zuter variety is the most stable and definitely stands better than others, but it does not from more nodules than the other varieties. In the opposite quadrant are the PI457923 and Lucky801 varieties, which form the most nodules per plant but are also very variable, especially Lucky801.

By the root length trait, the lowvariable varieties PI457923, PI368911 and PI457938 make impression. The lowest position occupied PI368911, not ranked by the sign of the more unstable PI457938. In this quadrant, the most preferred is PI457923, whose plants form long roots and are very poorly influenced by the adverse effects by the environmental factors.

Table 2. Parameters of homeostaticity (Hom) and stress resistance (Y) of white lupin varieties.

Genotypes	Parameters			
	X_{opt}	X_{lim}	Y	Hom
	Leaf number			
PI457923	29.18	16.00	-13.18	2.53
PI368911	40.53	14.00	-26.53	1.04
PI533704	25.85	12.60	-13.25	2.52
PI457938	44.51	11.00	-33.51	1.09
KALI	30.70	13.00	-17.70	2.58
Zuter	34.04	11.40	-22.64	1.30
Lucky801	36.64	9.94	-26.70	1.44
	Fresh aboveground mass weight (leaves + stems) (g)			
PI457923	25.99	6.06	-19.93	1.10
PI368911	40.53	4.16	-36.37	0.46
PI533704	25.85	4.31	-21.54	3.03
PI457938	44.51	14.72	-29.79	0.94
KALI	30.70	6.85	-23.85	1.06
Zuter	34.04	5.60	-28.44	0.49
Lucky801	36.64	5.71	-30.93	0.61
	Fresh root mass weight (g)			
PI457923	2.96	0.93	-2.04	0.94
PI368911	4.58	0.79	-3.79	0.98
PI533704	2.69	0.72	-1.97	0.90
PI457938	3.47	1.34	-2.13	4.92
KALI	1.49	0.88	-0.61	2.65
Zuter	2.29	0.88	-1.41	0.64
Lucky801	4.03	0.75	-3.28	0.03
	Nodule number per plant			
PI457923	16.00	3.60	-12.40	1.37
PI368911	11.60	3.80	-7.80	1.60
PI533704	8.60	1.60	-7.00	0.90
PI457938	11.00	4.20	-6.80	1.73
KALI	12.00	1.20	-10.80	0.38
Zuter	8.60	1.75	-6.85	7.72
Lucky801	89.40	8.40	-81.00	0.22
	Root length (cm)			
PI457923	13.9	10.6	-3.30	13.9
PI368911	16.9	8.4	-8.50	16.9
PI533704	16	11	-5.00	16
PI457938	14	9.72	-4.28	14
KALI	11.8	8.6	-3.20	11.8
Zuter	10.9	7.98	-2.92	10.9
Lucky801	15.9	9.94	-5.96	15.9

X_{opt} – the average value on the sign with an optimal background on the growing, X_{lim}- the average value on the sign at limiting conditions of growing, Y- Stress resistance, Hom - homeostaticity

For the period of study with the best homeostasis (Table 2) and high values for the tested features are the PI457923 varieties by number of leaves, plant nodules and root lengths; PI457938 by fresh root mass weight and number of nodules; PI533704 by fresh plant weight and root length, and Lucky801 along the root length.

The stress resistance parameter does not always correspond to the homeostaticity of the variety. Parallelism is only observed by the number of leaves and fresh above ground mass weight of the plant. By the fresh root weight Zuter is among the stress-resistant varieties, but on homeostasis it yields to almost all varieties. Similar is the position of PI533704 in the number of nodules per plant and in most of the varieties along the root length.

By applying nonparametric and rank methods to assess and determine the adaptability of varieties in different environments, PI457923 was found to have the worst adaptation by number of leaves and the three adaptive parameters (Table 3). Zuter may be defined as a genotype with a relatively good adaptive ability, both on this sign and on the fresh aboveground mass weight; KALI variety by the fresh aboveground mass weight, by number of nodules and root lengths; PI457923 by fresh root mass weight and PI457938 by number of nodules per plant.

Despite the existence of a certain discrepancy, the assessment done by these parameters generally confirms the behavior of the varieties determined by the previous parameters.

Table 3. Estimation of parameters of adaptability of white lupin varieties based on the nonparametric methods of Huehn (1990), Lin and Binns (1988) and Nascimento *et al*., (2009).

Genotypes	Rank по Huehn (1990)				Lin and Binns (1988)			Nascimento *et al*., (2009)
	2014	2015	2016	Average	Pi (+)	Pi (-)	Pi general	Rank
	Leaf number							
PI457923	3	7	1	4	117.50	14.18	48.62	IV
PI368911	6	1	6	4	7.92	15.85	13.21	VI
PI533704	5	4	4	4	174.10	14.76	67.87	IV
PI457938	7	2	7	5		4.00	2.67	VI
KALI	4	5	2	4	95.36	3.61	34.19	V
Zuter	2	3	3	3	54.81	13.84	27.50	V
Lucky801	1	6	5	4	30.97	5.29	13.85	VII
	Fresh aboveground mass weight (leaves + stems) (g)							
PI457923	5	6	1	4	171.50	28.85	76.40	V
PI368911	6	2	4	4	7.92	46.98	33.96	II
PI533704	7	3	7	6	174.10	0.09	58.09	III
PI457938	4	1	6	4	0.00	15.48	10.32	VI
KALI	1	4	2	2	95.36	19.53	44.81	V
Zuter	2	5	3	3	54.81	60.24	58.43	V
Lucky801	3	7	5	5	30.97	42.02	38.33	V
	Fresh root mass weight (g)							
PI457923	2	4	1	2	3665.39	0.198	1221.93	III
PI368911	4	3	3	3	3829.00	0.587	1276.72	IV
PI533704	3	1	5	3	3761.05	0.400	1253.95	IV
PI457938	6	6	6	6	3934.73	0.212	1311.72	IV
KALI	5	5	5	5	3864.08	0.403	1288.30	IV
Zuter	1	2	2	2	3712.63	0.533	1237.90	IV
Lucky801	7	7	7	7	0.00	0.265	0.18	VI
	Nodule number							
PI457923	4	6	6	5	237.62	7.84	84.43	VII
PI368911	1	5	4	3	292.82	20.05	110.97	V
PI533704	3	4	1	3	237.62	49.01	111.88	IV
PI457938	2	3	2	2	216.32	33.62	94.52	V
KALI	5	2	3	3	338.00	62.24	154.16	IV
Zuter	7	1	5	4	259.92	13.94	95.93	V
Lucky801	6	7	7	7	0.00	22.09	14.73	VI
	Root mass length (cm)							
PI457923	4	6	3	4	810.84	0.029	270.30	III
PI368911	5	4	5	5	818.10	0.054	272.74	IV
PI533704	1	2	1	1	795.21	0.058	265.11	IV
PI457938	6	5	6	6	820.53	0.028	273.53	IV
KALI	2	1	2	2	799.20	0.075	266.45	IV
Zuter	3	3	5	4	811.24	0.025	270.43	IV
Lucky801	7	7	7	7	0.00	0.017	0.01	I

Rank I: High general adaptability; Rank II: Specific adaptability to favorable environments; Rank III: Specific adaptability to adverse environments; Rank IV: Partially adapted; Rank V: Adaptability overall average; Rank VI: Specific adaptability to favorable environments; Rank VII: Adaptability specific to unfavorable environments.
In a favorable environment (Pi +) and in an unfavorable environment (Pi -)

Savvitcheva *et al*., (2014) had reported that the genetic potential of productivity (green mass or seeds) in lupin is directly dependent on the plant's architectonics, the presence and length of lateral branches along the main stem and the duration of the vegetation period. According to Gorchanenko (2005), one of the main indicators characterizing the plant's resistance to the effects of environmental factors is homeostasis, which is the universal biological property of any organism in its relationship to the external environment. The author believes that homeostasis is a condition of the organism that demonstrates the ability of the genotype to minimize the effect of the adverse effects of the environment. He found also that, in the context of a rapidly changing continental climate, an important indicator characterizing the resistance of the variety to various stress factors is the degree of stress resistance. This parameter generally has a negative sign as its value is smaller, the higher the stress resistance of the genotype. According to Abrosimova & Fadeeva (2015) and Popovic *et al*., (2016; 2017; 2018), the selection work aimed only for creating high yield varieties and could lead to a loss of ecological stability of the genotype. They consider that since the average value of the attribute and the sensitivity of the genotype to the environment are relatively independent and genetically determined by themselves, the selection work related to environmental stability must be continually controlled. Dimova & Petrovska (2010) demonstrated the close findings for maize populations.

Based on the field trial carried out, the statistical processing of the experimental data and the mathematical analysis of the general and specific adaptive ability and the stability of the characteristics of the studied varieties, following conclusion can be drawn:

The PI457923, PI457938, KALI and Lucky801 varieties can be used in future selection programs to create varieties with higher leaf weight, higher aboveground and root mass and nodule number per plant.

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(Received for publication 28 October 2018)