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Adaptability and Stability of White Lupin Cultivars

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Abstract. Need to create cultivars combining high potential productivity and resistance to stressful environmental factors appears a new priority in the plant breeding. The present study aimed to estimate adaptability and stability of eleven white lupin cultivars regarding seed productivity and main yield components. The experiment was conducted during 2014–2016 at the Institute of Forage Crops (Pleven), by using randomized block design. The obtained results showed a significant genotype–environment interaction for all studied traits (with exception of pod length and pod width). The calculated parameters determined environmental stability in regard to the main traits in genotypes as it follows: for the plant height–Amiga and Kijewskij Mutant, for number of pods per plant–Nahrquell and Amiga, for seeds per plant–Ascar and Amiga, for the first pod height–Kijewskij Mutant and BGR 6305, for seed weight per plant–BGR 6305 and Garant, for 1000 seed weight–Shienfield Gard and Garant. Cultivar Hetman was stable, but had low values of the studied traits and exhibited low adaptive ability (bi<1). Based on the conducted study, cultivars BGR 6305, Amiga and Garant could be used as source material in lupin breeding program for development and selection of stable and high–productive lines.

Keyword*:* adaptability, cultivars, environment, stability, white lupin.

Introduction

White lupin is relatively new innovative crop in contemporary crop production and agriculture. Unlike other ancient traditional crops (wheat, peas, soybeans) it has become a cultural species later. There is an increasing interest in this crop during the 20th century [ARTYUKHOV, 2015]. Nowadays, only two cultures in the world are able to meet the needs of modern intensive livestock, and they are soybeans and white lupin.

The difference between them is that soybean is suitable for growing in conditions of warm and humid climate, and white lupin–in countries with dry and cool climate.

White lupin has the highest productive potential compared to other lupin species. The seeds contain about 40 % protein and 10–12 % fats [BONCIU *et al.,* 2018; BONEA *et al.,* 2018; GROZEA et al., 2017, STOLERU *et al.,* 2016]. Unlike the soybean seeds, lupin does not contain trypsin inhibitors, so it is possible to be used in the animal feeding without heat treatment [GATAULINA, 2014; ARTYUKHOV, 2015].

The importance and use of lupin are determined by its valuable properties: high protein content in grain and green mass, nitrogen fixing ability, enrichment of the soil by easily soluble nutrients [BUTNARIU and SAMFIRA, 2012; IANCULOV *et al.,* 2005, STOLERU *et al.,* 2018. DIMITRIU *et al.,* 2016; GEORGIEVA *et al.,* 2018; BUTNARIU and CAUNII, 2013]. The cultivation of white lupin is a prerequisite for the development of organic farming [SAVVITCHEVA *et al.,* 2014].

Principally, the need to create cultivars combining high potential productivity and resistance to stressful environmental factors appears a new priority in the plant selection [BUTNARIU *et al.,* 2012, STOLERU *et al.,* 2012. BAGIU *et al., 2012*; BUTNARIU and CORADINI, 2012]. The more soil and climatic conditions for plant development deteriorate, the more the role of genetic determination of the traits and ecological stability of genotype increases (i.e. adaptive breeding) [NIKIFOROVA, 2015].

The interaction genotype–environment in quantitative traits (including productivity) is concluded in the fact that in different years or locations they are arranged differently [PUTNOKY *et al.,* 2013, BUTNARIU *et al.*, 2014; BUTNARIU and GIUCHICI, 2011].

This is what is considered as the effect of interaction in the dispersion analysis [BUTU *et al.*, 2014c. SAMFIRA *et al.*, 2015, BUTNARIU *et al.*, 2015b; BUTU *et al.*, 2014b].

The importance of GE interactions in national cultivar evaluation and breeding programs has been demonstrated in almost all major crops [PETRACHE *et al.*, 2014, BUTNARIU *et al.*, 2014, BARBAT 2013, BUTU *et al.*, 2015].

Various statistical methods (parametric and non–parametric) have been proposed in order genotype × environment interactions to be evaluated [ASHREI and GHAREEB, 2015]. There is a need for complex studies of existing plant collections [KHAIDIZAR *et al.*, 2012].

The importance of the gene pool of white lupin species (especially forms with different habitus), and studying their genetic diversity determines the success in the breeding of this crop [SAUK *et al.*, 2008, [VARDANIAN *et al.*, 2018; STOLERU *et al.*, 2018].

The major objective of this research was to study the adaptation of white lupin by assessing the effects of genotype, environment and their interaction in terms of seed productivity.

Material and methods

The study was conducted during the period 2014–2016 at the Institute of Forage Crops (Pleven). Sowing was made by hand, in optimum sowing time (the 3rd decade of March), according to the technology of cultivation under organic farming conditions. No fertilizers and pesticides were applied. Plant material was analyzed from 11 cultivars of white lupin (*Lupinus albus* L.): Astra, Nahrquell, Ascar, BGR 6305, Shienfield Gard, WAT, Kijewskij Mutant, Hetman, Start, Amiga (with origin Poland) and Garant (with origin Ukraine). The field experimental design was laid out by using randomized complete block design. Following land preparation, the 11 genotypes were grown in an adjusted density of 50 plants/m^2. Each plot unit consisted of eleven rows of 5 m broad × 2 m length spaced 50 cm apart. The following traits at full maturity were reported: plant height (cm), height to first pod (cm), pods per plant, number of seeds per plant, seed weight per plant (g), 1000 seeds weight, pod length (cm), pod width (cm) (Table 1).

Table 1.

Seed productivity and yield components in white lupin cultivars (2014–2016)

Cultivars	Plant height	First pod height	Pods per plant	Seeds per plant.	Seed weight per plant.	1000 seed weight	Pod length	Pod width
Astra	68cd	27d	11bc	46bc	13.63f	308.00d	7.13bc	1.08ab
Nahrquell	76d	27d	11bc	36bc	9.69bcd	276.64bcd	6.64abc	1.16abc
Ascar	72d	23c	13c	42bc	12.39def	308.17d	7.29bc	1.25bc
BGR 6305	72d	23c	13c	49c	13.48ef	290.24cd	7.51c	1.21abc
Shienfield Gard	80d	29d	10bc	39bc	10.52bcdef	266.10bcd	7.03bc	1.14abc
WAT	49ab	19b	11bc	37bc	8.59bc	221.49ab	6.47ab	1.13abc
Kijewskij Mutant	54bc	23c	8ab	32ab	7.89b	240.98bc	7.19bc	1.09ab
Hetman	39a	15a	6a	21a	3.69a	174.50a	5.97a	1.07a
Start	47ab	18b	12bc	44bc	9.93bcde	230.92abc	7.12bc	1.23abc
Amiga	49ab	20b	9ab	33ab	7.84b	230.09abc	7.26bc	1.28c
Garant	51ab	19b	12c	44bc	11.64cdef	277.92bcd	6.82abc	1.14abc

a, b, c, d, e, f – statistically proven differences in P=0.05

The obtained data were processed by two–factor analysis of variance for each trait for determine of effects of genotypes (G), (E) environments and genotype environment interaction (G × E). The estimation of the ecological stability of the tested cultivars was done through the application of next methods: regression analysis [EBERHART and RUSSELL, 1966; CAUNII *et al.*, 2015; IANCULOV *et al.*, 2004] in which the regression coefficient (bi), the variance of the deviations from regression (Si^2) were determined; Tai [TAI, 1979], (ai; λi); Theil [THEIL, 1950], (T); analysis of variance–mean variance component (PP) [PLAISTED and PETERSON, 1959]; ecovalence (W^2), Wricke [WRICKE, 1965] and Annicchiarico [ANNICCHIARICO, 1992]; nonparametric analysis by use of P_i parameter и rank (R) [LIN and BINNS, 1988]. Plaisted and Peterson's mean variance component (PP) was a measure of a variety's contribution to the GE interaction and was computed from a total of pair–wise analysis [PLAISTED and PETERSON's 1959].

Annicchiarico's method proposed a reliability index (W_i) which estimates the probability of a particular genotype (cultivar) to present a performance below the environmental average or below any standard used. GGE biplot model was done, which uses singular value decomposition of first two principal components [YAN, 2002. SAMFIRA *et al.,* 2014; BUTNARIU; 2012; BUTU *et al.,* 2014a, STOLERU *et al.,* 2016].

Spearman correlation coefficients between yield and stability parameters were produced. All experimental data were processed statistically with using the computer software GENES 2009.7.0 for Windows XP [CRUZ, 2009].

Results and discussion

The period of study covered years with different meteorological conditions (Figure 1).

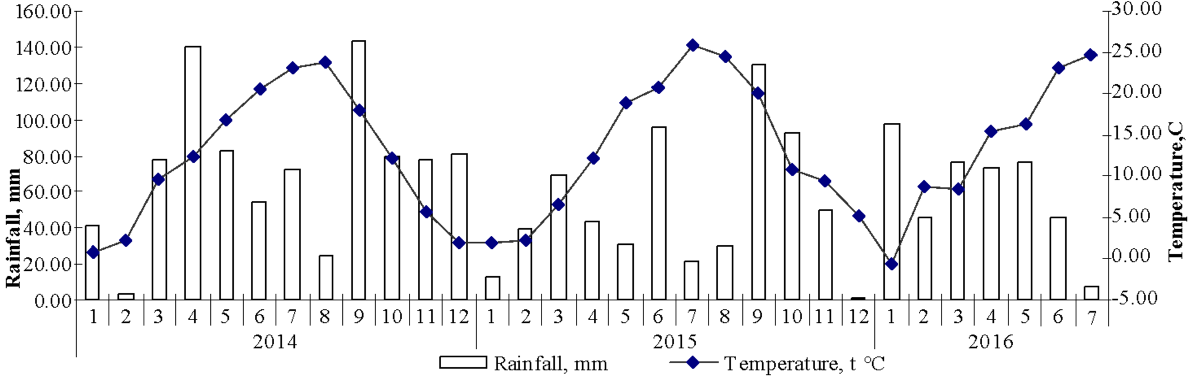


***Figure 1*. Climatic characterization of the experimental period (2014–2016).**

The experimental years 2015 and 2016 had similar conditions. They were characterized by considerably lower sums of vegetation rainfall, as compared to 2014 (39.0 and 34.3 %, respectively) as well as higher daily air temperature (0.3 °C and 1.1 °C, respectively).

Table 2.

Analysis of variance for stability for yield components in white lupin cultivars

Source of variation	Df	Mean sum of squares for the traits studied							
		Plant height	First pod height	Pods per plant	Seeds per plant	Seed weight per plant	1000 seed weight	Pod length	Pod width
Environments (E)	2	17469.77**	4403.033**	1005.004**	19352.97**	1130.712**	10663.26**	2.7451*	0.024
Genotypes (G)	10	1786.958**	294.461**	38.9382**	580.106**	76.466**	15262.3**	1.7671	0.0475
G×E interactions	20	229.7668**	15.3605**	14.7814**	219.2657**	13.0304**	4082.168**	0.86	0.0325
Env/Gen	22	1797.04**	414.2398**	104.8016**	1958.693**	114.6378**	4680.449**	1.0314	0.0317
Env/Gen–1	2	2004.398**	354.5737**	140.2723**	3130.965**	222.1132**	4456.416**	0.2437	0.0061
Env/Gen–2	2	2232.193**	546.9919**	70.3836**	789.1249**	45.3712**	1776.01**	0.1132	0.0469
Env/Gen–3	2	2079.497**	390.9324**	133.7539**	2655.39**	178.2604**	7492.871**	0.4297	0.0684
Env/Gen–4	2	1587.15**	439.0579**	132.9916**	2382.283**	110.8116**	6976.019**	0.5403	0.0283
Env/Gen–5	2	4789.387**	754.4772**	31.5679**	970.7836**	75.7929**	99.8263**	2.3893*	0.0579
Env/Gen–6	2	2056.135**	386.7843**	262.9375**	3921.754**	223.1221**	948.0961**	3.5028	0.0175
Env/Gen–7	2	1486.34**	420.8304**	78.7804**	1371.254**	97.5973**	521.5084**	0.1303	0.0043
Env/Gen–8	2	594.9837**	169.0897**	40.5769**	686.7889**	27.8479**	1132.959**	0.5317	0.0403
Env/Gen–9	2	872.6704**	290.5009**	139.2037**	2520.392**	105.5773**	5236.059**	0.1713	0.0292
Env/Gen–10	2	1057.09**	382.3999**	68.0389**	1429.492**	96.9228**	1295.954**	2.7196	0.0373
Env/Gen–11	2	1007.598*	421**	54.3109**	1687.398**	77.5996**	21549.22**	0.5733	0.0124
RESIDUO 32									

Significant at P = 0.05 (*), ** P = 0.01(**) Gen 1 – Astra; Gen 2 – Nahrquell; Gen 3 – Ascar; Gen 4 – BGR 6305; Gen 5 – Shienfield Gard; Gen 6 – WAT; Gen 7 – Kijewskij Mutant; Gen 8 – Hetman; Gen 9 – Start; Gen 10 – Amiga; Gen 11 – Garant

The most favourable for white lupin growth and development was the year 2014, with the sum of vegetation rainfall of 425.8 mm and the average daily air temperature of 16.5 °C.

Analyses of variance. The problem with the relationship between potential plant productivity and ecological stability of the cultivars has an increasing practical meaning. Knowledge of the needs of the plants to the external environment and their responsibility for improvements of growing conditions in a time of global climate changes is of paramount importance. Studying ecological plasticity of the cultivars in testing definitely plays an important role in their regional distribution.

The environmental conditions for each of the study years are unique to the formation of the traits which are subject of the present study. The results of variance analysis confirmed the differences in terms of the conditions of years (Table 2).

The genotype and environment as factors had a significant meaning for all traits (with exception of pod length and pod width). The interaction genotype–environment was also significant, which was an objective precondition for determining the stability parameters. In the unfavorable 2015 the differences in individual traits between cultivars are retained. The trend of reducing the value of the trait during the favorable year (2014) for each genotype is different.

Stability and adaptability analysis of the cultivars. The yield components that determine the yield level have always represented a particular interest to the researchers. Their variability (depending on the cultivar and environmental conditions) is related to the biological potential of the plant and its adaptability [GATAULINA *et al.*, 2014, BONEA *et al.*, 2017, PENTEA et al., 2016, STOLERU *et al.*, 2012].

Table 3a.

Estimates of the adaptability and stability parameters for the seed productivity and yield components in investigated cultivars

Cultivars	Eberhart and Russell (1966)		Tai (1979)		Theil (1950)	Plaisted and Peterson (1959)	Wricke (1965)	Annicchiarico (1992)	Lin and Binns (1988)
	bi	Si^2	ai	λi	T	PP	W^2	W_i	Pi
Plant height									
Astra	1.12**	9.37**	1.12	16.00	99.25	44.78	74.35	111.61	21.09
Nahrquell	1.16**	54.26**	1.16	90.06	96.21	60.77	248.80	121.32	80.36
Ascar	1.12**	60.22**	1.12	99.92	95.48	58.74	226.66	113.50	131.14
BGR 6305	0.94	125.97**	0.94	208.41	87.67	73.81	391.09	112.27	172.64
Shienfield Gard	1.72**	60.71**	1.72	100.51	98.02	205.64	1829.24	120.07	177.33
WAT	1.04	233.51*	1.04	385.83	82.8	102.65	705.69	67.44	517.42
Kijewskij Mutant	0.97	1.36**	0.97	2.80	99.82	38.75	8.63	88.87	667.9
Hetman	0.60**	15.86	0.60	26.75	95.75	89.13	558.19	60.97	714.72
Start	0.74**	0.79	0.74	1.85	99.80	57.87	217.17	77.59	728.07
Amiga	0.82**	0.44	0.82	1.30	99.88	48.10	110.57	81.27	828.08
Garant	0.78**	24.25**	0.78	40.60	96.22	58.58	224.95	81.72	1217.68
First pod height									
Astra	0.92	9.77**	0.92	16.67	94.66	5.46	35.32	114.97	15.38
Nahrquell	1.17*	–0.21	1.17	0.20	99.95	4.35	23.19	119.44	10.36
Ascar	0.99	0.01	0.99	0.56	99.83	2.33	1.14	102.96	45.53
BGR 6305	1.05	–0.33	1.05	0.00	99.99	2.39	1.79	104.76	42.5
Shienfield Gard	1.37**	–0.03	1.37	0.48	99.92	12.49	111.98	130.17	0.874
WAT	0.98	1.08*	0.98	2.33	99.31	2.64	4.54	82.61	104.67
Kijewskij Mutant	1.03	–0.29	1.03	0.07	99.98	2.29	0.64	104.02	43.85
Hetman	0.65**	–0.23	0.65	0.17	99.88	11.26	98.58	67.24	213.56
Start	0.85*	–0.26	0.85	0.13	99.95	3.86	17.82	81.53	128.04
Amiga	0.98	0.53	0.98	1.42	99.57	2.51	3.05	85.53	96.73
Garant	1.02	2.61**	1.02	4.86	98.68	3.07	9.16	79.78	107.62

Significant at P = 0.05 (*), ** P = 0.01(**)

In this study, the stability of quantitative traits of white lupin cultivars defined by the stability parameters was presented in Table 3.

The results obtained regarding plant height (Table 3a) showed consistency between the parameters and determined cultivars Kijewskij Mutan and Amiga as the most adaptive to different environments, although they did not form very high plants. To the group of ecologically unstable cultivars can be referred Shienfield Gard and Nahrquell whose plants reached up to 80 cm. In terms of the first pod height, according to the regression coefficient (bi), cultivars Kijewskij Mutant (bi=1.03) and BGR 6305 (bi=1.05) presented themselves the best and came close to the ideal genotype. The other parameters of stability had a similar assessment. As in the first trait (plant height), Shienfield Gard and Nahrquell exhibited specific adaptability.

The number of pods and seeds per plant and seed weight per plant determine to the greatest extent the yield value (Table 3b). In terms of pods per plant was established that selectively valuable were cultivars which formed a greater pods and exhibited a good stability and total adaptability.Such cultivars grown at high agricultural practices can manifest their maximal biological potential. Among the studied genotypes to this category can be referred Nahrquell (bi=0.87; T=89.44; PP=2.53; W^2=4.32; W_i=103.81) and Amiga (bi=0.86; T=99.85; PP=2.46; W^2=3.62; W_i=76.58).

Table 3b.

Estimates of the adaptability and stability parameters for the seed productivity and yield components in investigated cultivars

Cultivars	Eberhart and Russell (1966)		Tai (1979)		Theil (1950)	Plaisted and Peterson (1959)	Wricke (1965)	Annicchiarico (1992)	Lin and Binns (1988)
	bi	Si^2	ai	λi	T	PP	W^2	W_i	Pi
Pods per plant									
Astra	1.24	–0.2	1.24	0.21	98.76	3.12	10.76	99.19	3.63
Nahrquell	0.87	0.13	0.87	0.76	89.44	2.53	4.32	103.81	3.61
Ascar	1.16	7.21**	1.16	12.44	89.44	4.62	27.17	102.97	0.95
BGR 6305	1.15	7.34**	1.15	12.66	89.2	4.63	27.3	104	0.85
Shienfield Gard	0.58**	0.03	0.58	0.58	97.85	5.15	32.9	89.31	10.33
WAT	1.59	21.45**	1.59	35.91	84.49	13.9	128.43	58.58	13.23
Kijewskij Mutant	0.93	–0.29	0.93	0.07	99.9	2.23	1.06	73.2	15.14
Hetman	0.63*	2.83**	0.63	5.2	85.42	5.34	35	47.99	32.67
Start	1.23	–0.2	1.23	0.21	99.82	3.08	10.36	104.27	2.8
Amiga	0.86	–0.28	0.86	0.09	99.85	2.46	3.62	76.58	15.23
Garant	0.76	0.97	0.76	2.14	95.51	3.48	14.7	109.37	2.44
Seeds per plant									
Astra	1.33**	–0.11	1.33	0.36	99.98	72.24	393.08	108.96	15.76
Nahrquell	0.67**	0.15	0.67	0.75	99.88	71.6	386.02	88.75	38.08
Ascar	1.23**	6.70**	1.23	11.62	99.51	54.63	200.96	99.49	39.21
BGR 6305	1.11**	133.33**	1.11	220.56	89.71	77.13	446.41	107.68	44.03
Shienfield Gard	0.71**	58.93**	0.71	97.74	88.8	80.01	477.83	92.1	64.35
WAT	1.44**	175.62**	1.44	290.31	91.77	147.58	1214.97	47.95	140.19
Kijewskij Mutant	0.87**	23.01**	0.87	38.53	96.87	47.96	128.13	73.8	183.46
Hetman	0.60**	29.11**	0.6	48.56	92.14	94.79	639.07	39.68	204.78
Start	1.18**	41.71**	1.18	69.35	96.94	58.44	242.47	103.14	217.29
Amiga	0.89**	22.57**	0.89	37.79	97.06	46.38	110.9	74.71	221.44
Garant	0.96	46.17**	0.96	76.74	94.94	49.55	145.47	103.84	577.04

Significant at P = 0.05 (*), ** P = 0.01(**)

Ascar, BGR 6305 and Start represented also a certain interest. They had low stability, but the greatest number of pods and they were responsive to the environment in which they are developed. These cultivars would react positively to improving the growing conditions. According to most of the stability parameters, Amiga exhibited a similar reaction to the environment and regarding the number of seeds per plant. BGR 6305, Astra, Start and Ascar had higher values of this trait and were characterized as unstable upon change of environmental conditions.

In terms of plant productivity (expressed through seed weight per plant) (Table 3c), of practical interest was cultivar, combining maximal seed weight and low variability of the trait. In our research, particular attention deserved BGR 6305 and Start with seed weight above 11 grams and regression coefficient (bi) between 0.97 and 1.00. Astra was distinguished with the most weighty seeds (>13 g). This cultivar had a certain responsiveness (bi=1.47) and together with Ascar and WAT formed a group of intensive cultivars which should be grown in conditions of high level of agrotechnology.

Table 3c.

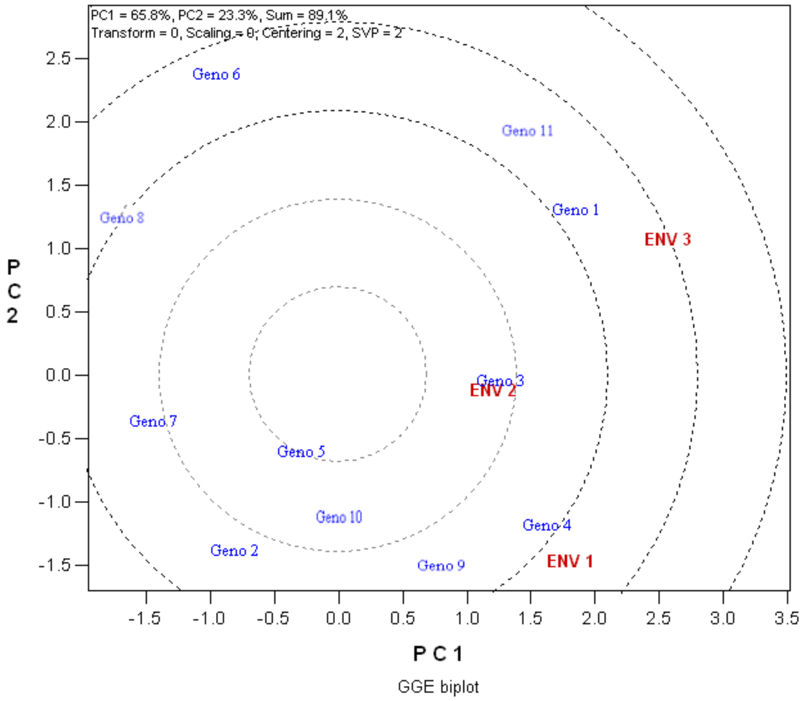
Estimates of the adaptability and stability parameters for the seed productivity and yield components in investigated cultivars

Cultivars	Eberhart and Russell (1966)		Tai (1979)		Theil (1950)	Plaisted and Peterson(1959)	Wricke (1965)	Annicchiarico (1992)	Lin and Binns (1988)
	bi	Si^2	ai	λi	T	PP	W^2	W$_i$	Pi
Seed weight per plant									
Astra	1.47**	0.14	1.47	0.75	99.63	6.09	46.37	127.52	1.64
Nahrquell	0.66*	0.03	0.66	0.59	98.61	4.11	24.81	92.58	2.22
Ascar	1.27	7.88**	1.27	13.54	92.06	5.48	39.68	105.57	3.28
BGR 6305	1.00	4.52**	1.00	8.01	92.44	3.17	14.57	120.39	8.06
Shienfield Gard	0.84	1.77*	0.84	3.47	95.21	2.90	11.53	98.93	12.8
WAT	1.45**	4.54**	1.45	8.02	96.23	6.98	56.05	40.05	12.92
Kijewskij Mutant	0.95	2.47**	0.95	4.62	95.05	2.65	8.85	65.42	18.03
Hetman	0.52**	–0.23	0.52	0.14	99.38	6.22	47.84	26.79	22.54
Start	1.01	–0.11	1.01	0.37	99.63	1.90	0.71	96.68	25.17
Amiga	0.97	0.39	0.97	1.20	98.71	2.06	2.42	63.72	26.49
Garant	0.86	0.89	0.86	2.01	97.28	2.55	7.78	111.45	68.86
1000 seed weight									
Astra	2.10**	116.61**	2.10	192.77	95.24	927.81	2703.05	115.07	1047.41
Nahrquell	1.31**	78.74**	1.31	130.47	91.93	718.59	420.64	105.65	1495.92
Ascar	–1.58**	3388.26**	–1.58	5590.52	18.04	2791.88	23038.38	103.74	1724.55
BGR 6305	2.56**	423.42**	2.56	699.07	88.99	1227.66	5974.13	105.01	2552.1
Shienfield Gard	–0.24**	29.07**	–0.24	48.44	46.63	961.27	3068.12	98.12	3868.04
WAT	0.40**	528.70**	0.40	872.83	0.00	889.65	2286.74	81.51	3939.89
Kijewskij Mutant	–0.08**	342.95**	–0.08	566.38	0.00	982.64	3301.24	88.34	6336.14
Hetman	–0.95**	171.82**	–0.95	283.67	72.46	1403.10	7888.05	60.66	6925.59
Start	2.31**	35.47**	2.31	58.99	98.76	995.86	3445.44	82.89	7581.82
Amiga	0.46**	726.30**	0.46	1198.95	0.00	931.49	2743.18	84.19	8467.38
Garant	4.71**	29.84**	4.71	48.66	99.74	3134.35	26774.39	90.46	15401.6

Significant at P = 0.05 (*), ** P = 0.01(**)

An essential difference between cultivars was found regarding the trait 1000 seed weight, which was in the range from 174 g (Hetman) to 308 g (Astra and Ascar). The low value of the deviation from the regression (Si^2) in Nahrquell (78.74), Shienfield Gard (29.07) and Garant (29.84) as well as the values of other parameters showed stability of the trait in these cultivars under changing environmental conditions in a wide range. The large–seeded cultivars (Astra and BGR) with seed weight above 290 g were ecologically unstable (bi>1), significantly exceeding 1 and with a strong deviation of the regression line (Si^2).

Biplot analysis. The results from GGE biplot analysis showed that the first two principal components (PC1 and PC2) determined 89.1 % of the total variation caused by the genotype–environment interaction (Figure 2). GGE biplot, which was presented as concentric circles revealed that Shienfield Gard was the most productive genotype among the studied cultivars.



ENV 1 – 2014; ENV 2 – 2015; ENV3 – 2016
Geno 1 – Astra; Geno 2 – Nahrquell; Geno 3 – Ascar; Geno 4 – BGR 6305; Geno 5 – Shienfield Gard; Geno 6 – WAT; Geno 7 – Kijewskij Mutant; Geno 8 – Hetman; Geno 9 – Start; Geno 10 – Amiga; Geno 11– Garant

Figure 2. GGE–biplot for comparison genotypes and environments

It was established that Shienfield Gard, Amiga, Kijewskij Mutant and Ascar were close to the greatest extent to the so–called "ideal" genotype with regard to productivity and stability. In accordance with their productivity, the cultivars can be arranged in the following sequence:

Astra>BGR 6305>Ascar>Garant > Shienfield Gard>Start>Nahrquell > WAT >Amiga>Kijewskij Mutant>Hetman.

Relationship among stability parameters. Spearman's rank correlation was computed between seed productivity and stability parameters (Table 4). Significant (P≤0.01) positive rank correlation coefficients were obtained between seed weight per plant and W_i (r=0.932).

Table 4.

Estimates of Spearman correlations between seed productivity and the methods of stability and adaptability for the analysis of the effectiveness of different algorithms to identify genotypes of *Lupinus albus*

	bi	Si^2	ai	λi	T	PP	W^2	W_i	Pi
Si^2	0.486								
ai	0.990**	0.486							
λi	0.486	0.990**	0.486						
T	–0.219	–.0894**	–0.219	–0.895**					
PP	0.379	0.286	0.379	0.284	0.011				
W^2	0.379	0.286	0.379	0.284	0.011	0.990**			
W_i	0.270	0.116	0.270	0.116	–0.246	–0.301	–0.301		
Pi	–0.304	–0.317	–0.304	–0.316	0.231	–0.437	–0.437	–0.054	
Seed weight per plant	0.541	0.366	0.541	0.367	–0.407	–0.107	–0.107	0.932**	–0.15

*, ** Significant at ($P < 0.05$) and ($P < 0.01$) respectively, bi–regression coefficient; Si^2–deviations from regression; ai, λi, T–stability parameters of Tai (1979) and Theil (1950); PP–variance component; W^2–ecovalence; W_i–reliability index

This result revealed that the use of W_i as a tool to estimate the performance of white lupin genotypes in future selection programs would favor the simultaneous development of stable and high–productive genotypes. The significant positive correlation between PP and W^2 (r=0.99) stability parameters suggests that these parameters would play similar roles in stability ranking of the genotypes. However, other stability statistics (Si^2, λi) indicated significant negative associations with T (r= −0.894 and r = −0.895) and positive non–significant correlation with seed productivity. Thus, a selection based on these stability parameters would be less useful when yield is the main purpose of selection.

The development of cultivars with

high yield and wide adaptability is the final target of plant breeders. However, the achievement of this aim is more complicated due to genotype–environment interaction [KHALIFA *et al.,* 2013]. Some researchers [TAN *et al*., 2012; TURK and ALBAYRAK, 2012] established different sensitivity of pea genotypes to changes in environmental conditions. Our study confirmed the influence of the environment (years) as well as the interaction genotype–environment on the productivity similar to most of quantitative traits in annual legume crops.

In case of statistically significant interaction genotype–environment, particularly when it comes to the year conditions, it is necessary to be carried out an assessment of phenotypic stability of the most important traits. Similarly, σi2 and Wi described stable faba bean genotypes in another study [TEMESGEN, 2015]. Karimizadeh and collab. also reported that low–yielding lentil genotypes were the most stable compared to high–yielding ones, using the same parameters [KARIMIZADEH *et al.,* 2012]. Akhtar and collab. established the existence of a positive association between linear response (bi) and mean yield performance in mung bean genotypes [AKHTAR *et al.,* 2010]. They suggested that both linear and non–linear components of G × E interaction should be considered as the criterion of stability of a particular genotype. Melo and collab. found that in common bean [MELO *et al.* 2007] there was a low association between the methods Ammi and Lin and Binns [AMMI and LIN and BINNS 1988], and Ammi and Eberhart and Russell [AMMI and EBERHART and RUSSELL 1966], and there was a lack of correlation between Lin and Binns [LIN and BINNS 1988], and Eberhart and Russell [EBERHART and RUSSELL 1966].

The results from a study of Mpayo showed that some common bean genotypes had good attributes of one or two stability parameters but lack others in various variables including yield [MPAYO, 2010]. According to the authors the crossing of two genotypes could result in segregation with performance of the relevant attributes. Akçura and collab. have used 4 parametric and 2 nonparametric stability indexes for evaluating 20 durum wheat genotypes [AKÇURA *et al.,* 2009]. The results from these relationships revealed that only one of them could be sufficient in order to select genotypes of interest in a durum wheat breeding program

Some researchers reported high correlation coefficients obtained in the studied cultures between the parameters PP, σ2, Wi, and λ [KILIC, 2012; AHMADI *et al*., 2015]. The authors considered that the stability data can be used as parallel methods in selecting genotypes with high stability and moderately high yield. When analyzing genotypes of *Vicia faba*, Temesgen and collab. conclude that a statistically significant positive relationship between the stability parameters implies that they can give similar results in the assessment of genotypes in terms of stability and variability [TEMESGEN *et al.,* 2015]. In agreement with our results, Guendouz and Hafsi found that some of the stability parameters (non–parametric statistics) do not correlate with the mean yield [GUENDOUZ and HAFSI, 2017]. According to the authors, the superior genotype should be the one with the lowest superiority index (Pi) value, leading to the negative correlation between yield and Pi–value.

Conclusions

The obtained results showed a significant genotype–environment interaction for all studied traits (with exception of pod length and pod width) in 11 white lupin cultivars. The calculated parameters determined environmental stability in regard to the main traits in genotypes as it follows: for the plant height–Amiga and Kijewskij Mutant, for number of pods per plant–Nahrquell and Amiga, for seeds per plant–Ascar and Amiga, for the first pod height–Kijewskij Mutant and BGR 6305, for seed weight per plant–BGR 6305 and Garant, for 1000 seed weight–Shienfield Gard and Garant. High responsiveness to environment improvement was demonstrated by the followed cultivars: Shienfield Gard and Nahrquell on the first pod height and plant height; BGR 6305, WAT and Start on pods and seeds per plant; Astra on seed weight per plant and 1000 seed weight. Cultivar Hetman was stable, but had low values of the studied traits and exhibited low adaptive ability (bi<1). Based on the conducted study, cultivars BGR 6305, Amiga and Garant could be used as source material in white lupin breeding program for development and selection of stable and high–productive lines.

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