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Adaptability and productive potential of initial material from grass pea (*Lathyrus sativus* L.)

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Abstract

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The adaptive properties of six grass pea varieties (BGE027129, BGE015741, BGE025277, LAT4362, LA5108 and LAT5038) were studied by the signs plant height (cm), aboveground mass weight (leaves + stems) (g), pods per plant, seeds per plant, seed weight per plant (g) and nodule weight (g). The study was conducted in 2014-2016 in the experimental field of the Institute of Forage Crops, Pleven, Bulgaria. Varieties with high general and specific adaptive ability, relative stability and selection value on the traits studied were identified. BGE027129 was characterized by high selective value of the number of pods, number of seeds and seed weight per plant, and BGE015741 by the plant height, number of seeds and seed weight per plant, respectively. Interest for the combinatorial selection is the variety BGE025277 by the plant height and the seed weight per plant, which are combined with good homeostaticity and relative stability to the environment. The varieties BGE027129, BGE015741 and BGE025277 can be used as parental components in breeding programs to create grass pea varieties with a larger number of seeds and pods per plant, and higher weight of seeds.

Keywords: ecological selection; homeostaticity; quantitative traits; regression coefficient; stability

Introduction

Several species of grass pea are known in nature. A greater practical application in agricultural production finds *Lathyrus sativus* L. due to its large biological potential as an alternative to other legumes in many areas of the world (Vaz Patto et al., 2006).

The problem with increasing the production of plant protein remains topical and cannot be successfully resolved without increasing the production of grain legumes. The imperfection of the structure of the sown areas with low holdings of grain legumes and perennial grasses led to a decline in their production and from there decreasing the protein content in general (Pimonov et al., 2009).

Due to the peculiarities of the root system, the grain legumes, including the grass pea are capable of growing on different types of soils (from light to heavy and clay). Its ability to fix atmospheric nitrogen makes it a crop that can be used for cultivation specifically under adverse conditions. The cultivation of grass pea is profitable, resulting in better soil fertility and has a positive effect on the production of the next crop in rotation (Talukdar, 2011).

Legumes and grain crops are an important and specific part of the structure of the sown areas on a global scale. They help to solve the problem of securing the population with high-quality food and livestock with feed, but also provide a high level of diversification. All this makes them equally necessary in different climatic conditions and in the search for new plant forms (Zotikov, 2014). In Turkey grass pea is mostly used as stock-feed, fodder and rarely human consumption (Basaran et al., 2010)

An important task for the selection of the grass pea is the creation of varieties which to more fully realize their biological capabilities in a wide range of soil and climatic conditions (Vorobiev & Vorobiev, 2011).

Productivity and yield are determined by the state of the whole system "genotype-environment", therefore there is a need for a complex approach in the formation of breeding programs aimed at increasing the possibilities for ontogenetic adaptation. The practice has shown that the assessment of the parameters of adaptive capacity and stability of the genotypes in the breeding process allows high accuracy to identify the best of them in the relevant farming area. Onar et al. (2014) consider the grass pea genotypes with higher yield are relevant for future genetic and breeding studies.

The purpose of the study is to define the high yielding grass pea varieties, adapted to the local soil and climatic conditions for the needs of the combinatorial selection by appropriate statistical methods applying.

Material and Methods

The study was conducted in 2014-2016 in the experimental field of the Institute of Forage crops, Pleven, Bulgaria. Sowing was carried out manually in optimal time, according to the technology of cultivation of grass pea. Aboveground and root biomass plant material of 6 grass pea varieties, originating in Spain, vz BGE027129, BGE015741, BGE025277, and from Portugal, vz LAT4362, LA5108, LAT5038 was analyzed.

The following characteristics have been assess in the technical maturity of seeds stage: plant height (cm), aboveground mass weight (leaves + stems) (g), pods per plant, seeds per plant, seed weight per plant (g) and nodule weight (g). Biometric measurements were made to 10 plants of each variety.

The method of Kilchevsky and Khotyleva (1985a, 1985b) 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 and allows revealing general adaptive ability (GAA) and specific adaptive ability (SAA) and their stability (Sgi), criterion for estimation of the genotype ability to enter into interaction with environment (GxE)gi; selective value of genotype (SVG) for the selection of high productive and stable forms. The stress resistance (Y) of varieties by Rossielle and Hamblin (1981) method was determined. Homeostaticity (Hom) was calculated by the method of Khangildin (1984).

The analysis of adaptability was performed according to the methods proposed by Nascimento et al. (2009), stability parameter by Finlay and Wilkinson (1963) and Francis and Kannenber (1978).

All experimental data were processed statistically with using the computer software GENES 2009.7.0 and Excel for Windows XP (Cruz, 2009).

Results and Discussion

Results

The studied varieties are characterized by various morphological signs. The biology-morphological differences of the used breeding materials determine their reaction to changing conditions of the environment and the formation of certain productivity.

The main climatic parameters amount of rainfall and temperature during the period of the study can be characterized by a strong fluctuation and uneven distribution over the phenological phases of the plant development. The study period covers three consecutive years differing in climatic terms. Fig. 1 presents the data on average monthly temperatures and the amount of precipitated rainfall by months during vegetation. The vegetation 2014 is the most favorable with average monthly air temperatures for April 12.3°C, May 16.7°C and June 20.6°C, and rainfall 139.8 mm, 83.0 mm and 54.3 mm, respectively. As a result of the balanced combination of air temperature and optimum rainfall it has been favorable for plant development. The second year (2015) has relatively higher temperatures in May of 18.8°C and uneven precipitation distribution, characterized by a certain drought in April (43.6 mm) and May (30.6 mm), and a larger quantity in June (95.7 mm). The third year (2016) occupies an intermediate position over the other two years with temperatures in the months of April and May, close to normal (15.3-16.4°C) and rainfall between 73.1 and 76.5 mm.

In the case of grass pea varieties for the signs plant height, pods per plant, seeds per plant, seed weight per plant

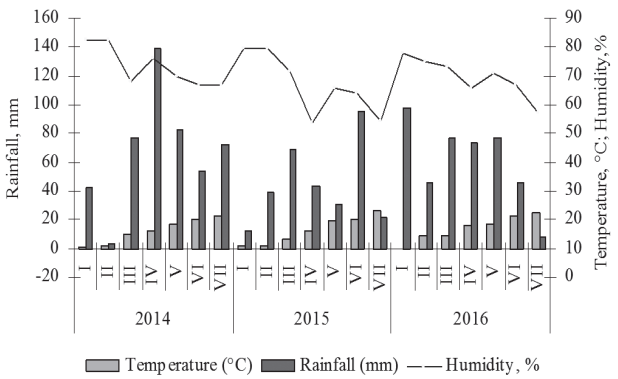

Fig. 1. Climatic characterization of the experimental period

Table 1. Analysis of variance for yield components in grass pea cultivars

Source	df	MS					
		Plant height, cm	Pods per plant	Seeds per plant	Seed weight per plant, g	Aboveground mass (leaves+stems)	Nodule weight, g
Year	2	275.3539**	70.3489**	292.7089**	22.0277**	248.9942**	0.1211ns
Variety	5	32.0085**	23.7302**	65.630**	3.5429*	56.5709**	0.0783ns
Error	10	38.8376	10.3649	70.5062	1.9432	20.2097	0.0630
Corrected Total	17						

* = significant at P < 0.05, ** = significant at P < 0.01, ns = not significant

and aboveground weight of the plant, the factors of varieties and environment conditions are reliable (Table 1). No statistically significant differences were found in the two factors by weight of the nodules per plant. The dispersion analysis shows the significantly stronger influence of environmental conditions on the occurrence of the signs studied in relation to the biological characteristics of the different varieties.

The adaptability of grass pea varieties to the environmental conditions can be assessed by their plasticity, expressed by different criteria (Table 2). From the patterns studied LAT5038 variety is characterized by the highest general adaptive ability (GAA = 3.72) and with a good reaction to the growing conditions (GxE)gi by the height of the plant. With relatively good stability (Sgi) are distinguished BGE025277 and BGE015741, which have the highest value by the indicator selection value of the genotype (SVG). Less LAT4362, LA5108 and LAT5038 are presented according to the indicator selection value of the genotype (SVG), which shows that in different years there will be no advantage at the height of the plant compared to other varieties.

The linear regression coefficient in the number of pods per plant is statistically no significant; therefore the grass pea varieties can be evaluated by other parameters. BGE025277 and BGE015741 can be defined as varieties with best response to the environment (GxE)gi. With the most favorable specific adaptive ability of the genotype is distinguished variety LA5108 (SAA = 1.96) followed by LAT5038. The same varieties also show better stability of the attribute according to the indicator (Sgi). With high selection value of the genotype on this sign are characterized LA5108 (SVG =12.33), BGE027129 (SVG =9.19) and LAT5038 (SVG =8.35).

The regression coefficient (bi) in BGE025277, LAT4362 and LAT5038 by number of seeds per plant significantly exceeds 1 (bi>1), which places these varieties in the group of ecologically unstable varieties, but responsive to the conditions. The highest specific adaptive ability (SAA) was recorded in BGE015741 (4.36) and LA5108 (4.09) and were among the groups of the relatively stable varieties on this attribute. The plants of these varieties form an average of 28-29 seeds per plant. They are of the best performance of

Table 2. Parameters of adaptability and stability in grass pea varieties

Varieties	bi	GxEgi	GAA	SAA	Sgi, %	SVG
	Plant height, cm					
BGE027129	-0.80**	147.62	0.40	5.24	10.64	35.34
BGE025277	0.36**	14.80	1.85	1.21	2.39	47.46
LAT4362	2.24**	69.30	1.92	15.11	29.79	10.69
LA5108	1.94**	46.69	-3.21	13.35	29.29	10.22
LAT5038	-0.46**	161.29	3.72	19.06	36.28	2.05
BGE015741	2.71**	93.56	-4.68	2.14	4.85	38.46
	Pods per plant					
BGE027129	1.22	-0.39	2.79	4.04	25.56	9.19
BGE025277	1.09	17.91	-3.01	5.61	56.06	0.82
LAT4362	1.45	2.66	-0.74	4.98	40.56	4.12
LA5108	0.66	0.22	2.52	1.96	12.62	12.33
LAT5038	1.22	4.10	-3.48	0.72	7.56	8.35
BGE015741	0.36	20.65	1.92	6.11	40.91	4.93
	Seeds per plant					
BGE027129	1.11	17.78	2.02	8.72	33.29	16.07
BGE025277	1.82**	87.96	-8.18	14.66	91.65	-1.03
LAT4362	1.40**	5.95	-1.38	9.62	42.18	11.63
LA5108	-0.65**	154.73	4.09	6.44	22.77	20.79
LAT5038	1.32*	8.87	-0.91	7.43	31.95	14.64
BGE015741	0.99	30.25	4.36	10.42	36.52	16.43
	Seed weight per plant, g					
BGE027129	1.28	0.39	0.76	2.47	53.04	2.29
BGE025277	0.84	0.50	0.36	1.71	40.18	2.62
LAT4362	0.44	1.26	-0.73	0.88	27.73	2.33
LA5108	1.19	0.98	-0.92	2.45	82.14	0.63
LAT5038	1.6	0.50	-1.09	1.27	45.12	1.59
BGE015741	0.65	4.77	1.62	3.58	64.86	2.09
	Aboveground mass weight (leaves + stems), g					
BGE027129	0.37**	15.90	1.58	2.18	12.07	15.33
BGE025277	1.41**	29.67	1.13	10.22	58.04	4.78
LAT4362	1.54**	10.42	3.00	9.80	50.27	7.19
LA5108	0.43**	11.56	-7.21	2.30	24.76	6.39
LAT5038	1.18**	4.88	-3.02	7.23	53.68	4.39
BGE015741	1.08	15.15	4.52	8.43	40.13	10.42

b_i – Regression coefficient Finlay and Wilkinson's regression model; GAA – general adaptive ability; SAA – specific adaptive ability; Sgi% – relative stability of the genotypes; σ(GxE)gi – criterion for estimation of the genotype ability to enter into interaction with environment; SVG – selective value of genotype
Significant at P = 0.05 (*), P = 0.01(**)

the selection value of the genotype (SVG) (20.79 and 16.43) – an indicator that combines the effect of the general (GAA) and the specific adaptive ability (SAA).

The seed weight (seed productivity) is depending on the values of the structural elements number of pods per plant, number of seeds in pod and 1000 seed weight. On this sign with the highest value of SAA is characterized BGE015741 (3.58) and BGE027129 (2.47), while with the lowest – LAT4362 (0.88) and LAT5038 (1.27). With a good combination of the parameter selection value of the genotype and the seed weight are distinguished BGE027129 and BGE025277.

From the varieties tested regarding the stability of the aboveground mass weight, an interest represent BGE027129 and LA5108 with a linear regression coefficient respectively bi = 0.37 and bi = 0.43. BGE025277 and LAT4362 can be referred to the varieties, clearly delineating their responsiveness to the favorable environment. Under appropriate conditions, the weight of aboveground mass weight of the plants can be significantly increased. Close to the ideal genotype on this attribute can be defined a variety LAT5038 with very

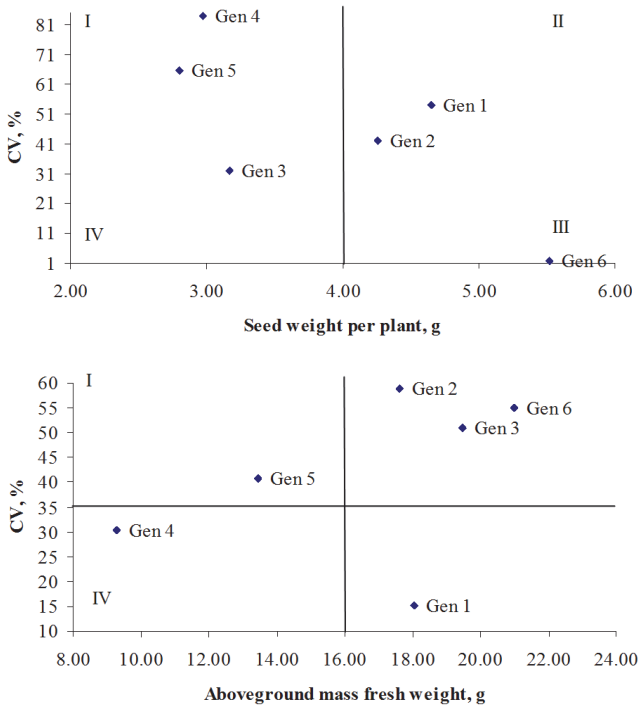

Fig. 2. Stability and distribution of varieties by the parameters studied in grass pea (according to Francis and Kannenberg, 1978) Gen 1 – BGE027129, Gen 2 – BGE025277, Gen 3 – LAT4362, Gen 4 – LA5108, Gen 5 – LAT5038, Gen 6 – BGE015741

well demonstrated value of the bi parameter. With the highest general adaptive ability and selection value are characterized BGE027129 (1.58, 15.33) and BGE015741 (4.52, 10.42).

The magnitude and stability of the seed weight per plant and aboveground mass of grass pea is represented by the Francis and 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 third quadrant varieties with high ecological stability, high productivity falls.

For the trait seed weight per plant BGE025277 and BGE025277 are located very close to the abscissa of the coordinate system. These varieties are most important for the selection. The varieties that would be placed in the second quadrant are also of interest. They are high productive but high variable as well. In such a situation is BGE027129, which expresses responsiveness only in favorable conditions of the environment. The position of LAT4362 in the fourth quadrant testifies to its stability on this attribute, but also more limited biological possibilities with regard to the seed weight. In the first quadrant falls high variable and low productive varieties LA5108 and LAT5038.

For the selection of the grass pea in the limiting conditions of the environment it is extremely important that the high productivity is combined with high ecological stability. With high values of aboveground mass and with the lowest variability is distinguished BGE027129, located in the third quadrant of the coordinate system. In the second quadrant are the high productive of aboveground mass BGE025277, LAT4362 and BGE015741 varieties. The high value of their variation coefficient defines them as ecologically unstable. In the first and fourth quadrant are respectively the varieties LAT5038 and LA5108, distinguished by a lower appearance of the attribute.

By applying the Centroid method proposed by Nascimento et al. (2009) to determine the adaptability of varieties in different environments it was found that the variety LA5108 is characterized by the worst adaptation by the seed weight and aboveground mass weight (Table 3). Not one of the groups of varieties is rank I, characterizing the patterns with the best general adaptive ability. The results obtained confirm the behavior of this variety determined by the previous parameters. With good adaptability on favorable conditions (rank VI) the varieties BGE027129 and LAT4362 are distinguished for the number of seeds per plant. The same rank is LAT5038 on the number of pods and the number of seeds per plant, aboveground mass weight and seed weight per plant.

The homeostaticity criterion determines the ability of varieties to maintain low variability of the signs determining productivity. In this sense, homeostaticity (Hom) is in correlation with the coefficient of variation (CV) and characterizes the stability of the attribute in a changing environment (Khangildin, 1984).

For the period of study with the best relative persistence of the genotype (homeostasis) and the high values of the characteristics tested, the varieties are distinguished as follows: BGE025277 by plant height and seed weight; LA5108 by plant height and number of pods per plant; BGE015741 by aboveground mass weight and number of seeds per plant, and BGE027129 by aboveground mass weight (Table 4).

In the studied grass pea collection, it was found that not every high homeostasis genotype has a high level of stress resistance (Y). This is probably due to the different genetic systems

Table 3. Estimation of parameters of adaptability of grass pea for yield's components, based on the methodologies of centroid (Nascimento et al., 2009)

Genotipos	Rank	Prob(I)	Prob(II)	Prob(III)	Prob(IV)	Prob(V)	Prob(VI)	Prob(VII)
Plant height								
BGE027129	III	0.1083	0.0814	0.2513	0.1107	0.1616	0.1032	0.1835
BGE025277	V	0.1077	0.0805	0.1275	0.0878	0.2883	0.1194	0.1888
LAT4362	VI	0.0891	0.2091	0.0558	0.0676	0.1499	0.35	0.0785
LA5108	II	0.0827	0.2732	0.0688	0.1131	0.1992	0.1786	0.0844
LAT5038	III	0.0950	0.0947	0.1901	0.1873	0.1872	0.1071	0.1385
BGE015741	VI	0.1300	0.1888	0.0861	0.0982	0.1643	0.2173	0.1154
Pods per plant								
BGE027129	VI	0.1961	0.1526	0.0585	0.0569	0.1692	0.1996	0.1670
BGE025277	IV	0.0900	0.0967	0.1644	0.2222	0.1816	0.0958	0.1493
LAT4362	V	0.0934	0.1124	0.0895	0.1058	0.3316	0.1093	0.1580
LA5108	VII	0.1539	0.1028	0.0675	0.0606	0.1777	0.1254	0.3121
LAT5038	VI	0.1713	0.2107	0.0631	0.0646	0.1378	0.2313	0.1212
BGE015741	IV	0.0785	0.0832	0.1779	0.2690	0.1699	0.0831	0.1385
Seeds per plant								
BGE027129	VI	0.1091	0.0956	0.0789	0.0733	0.2292	0.3100	0.1039
BGE025277	II	0.0519	0.5127	0.0492	0.1489	0.0932	0.0921	0.0521
LAT4362	VI	0.0783	0.1117	0.0666	0.0838	0.2887	0.2927	0.0782
LA5108	III	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
LAT5038	VI	0.1720	0.0765	0.1162	0.0688	0.1955	0.2046	0.1664
BGE015741	V	0.1025	0.0813	0.1044	0.0822	0.3216	0.1954	0.1127
Seed weight per plant								
BGE027129	V	0.1061	0.1002	0.1121	0.1052	0.2363	0.1063	0.2339
BGE025277	VII	0.0902	0.0825	0.1110	0.0974	0.2525	0.0893	0.2772
LAT4362	III	0.0213	0.0206	0.7239	0.0797	0.0651	0.0213	0.0680
LA5108	IV	0.0622	0.0645	0.1817	0.2924	0.1804	0.0635	0.1552
LAT5038	VI	0.2539	0.2059	0.0438	0.0435	0.0664	0.3209	0.0656
BGE015741	III	0.0409	0.0409	0.3268	0.3116	0.1230	0.0412	0.1156
Aboveground mass weight (leaves + stems)								
BGE027129	VII	0.0713	0.0566	0.0774	0.0596	0.1437	0.0643	0.5272
BGE025277	V	0.1274	0.1487	0.0906	0.0974	0.2225	0.1506	0.1629
LAT4362	VI	0.1409	0.203	0.0602	0.0632	0.1796	0.2258	0.1273
LA5108	IV	0.0231	0.0247	0.066	0.7777	0.0458	0.0245	0.0382
LAT5038	VI	0.2036	0.1596	0.0671	0.0649	0.1471	0.2139	0.1437
BGE015741	V	0.0895	0.1065	0.1193	0.1725	0.2613	0.1035	0.1473

Rank I: high general adaptability; Rank II: specific adaptability to favorable environments; Rank III: Specific adaptability to adverse environments; Rank IV: Partially adapted; RankV: Adaptability overall average; Rank VI: specific adaptability to favorable environments; Rank VII: Adaptability specific to unfavorable environments.

Table 4. Parameters of homeostaticity (Hom) and stress resistance (Y) of grass pea varieties

Variety	X_{av}	Parameters			
		X_{opt}	X_{lim}	Y	Hom
Plant height, cm					
BGE027129	49.21	55.6	44.6	-11	6.75
BGE025277	50.67	52.8	47.8	-5	77.22
LAT4362	50.73	67.2	37.0	-30.2	0.36
LA5108	45.60	60.8	34.8	-26	0.44
LAT5038	52.53	68.4	31.2	-37.2	7.59
BGE015741	44.13	47.0	40.8	-6.2	8.60
Pods per plant					
BGE027129	16	18.8	11	-7.8	1.86
BGE025277	10	16.6	7	-9.6	0.32
LAT4362	12	17.2	7	-10.2	0.54
LA5108	16	17.4	13	-4.4	11.25
LAT5038	10	10.6	8	-2.6	1.00
BGE015741	15	21.4	9	-12.4	1.27
Seeds per plant					
BGE027129	26	36.8	19.8	-17	0.47
BGE025277	16	33.2	5.8	-27.4	0.04
LAT4362	23	34.2	15	-19.2	0.27
LA5108	28	35.0	20.8	-14.2	1.09
LAT5038	23	28.4	14	-14.4	0.31
BGE015741	29	35.2	16	-19.2	1.27
Seed weight per plant					
BGE027129	4.65	6.976	1.97	-5.006	0.68
BGE025277	4.26	5.747	2.28	-3.467	1.65
LAT4362	3.17	4.30	2.33	-1.97	4.94
LA5108	2.98	5.57	0.60	-4.97	0.29
LAT5038	2.80	4.20	1.48	-2.72	0.22
BGE015741	5.52	8.80	1.65	-7.15	0.09
Aboveground mass weight (leaves + stems)					
BGE027129	18.07	20.88	15.44	-5.44	8.06
BGE025277	17.62	28.32	7.65	-20.67	0.14
LAT4362	19.49	26.81	8.18	-18.63	0.21
LA5108	9.28	11.22	6.04	-5.18	2.09
LAT5038	13.47	19.63	5.24	-14.39	0.17
BGE015741	21.01	28.94	11.89	-17.05	0.47

X_{av} – the average value on the sign for the period of study, 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

in the patterns, responsible for the specific reaction of the individual to the stress factors of the environment. According to the number of pods per plant, the LAT5038 has the highest stress resistance although it gives LA5108 the value of the homeostasis. A similar discrepancy is obtained by the seed weight per plant, where the variety LAT5038 is characterized by very good stress resistance, but also with very low homeostaticity.

Discussion

The assessment of the environment as a background for selection of genotypes appears to be one of the key issues in increasing the effectiveness of the breeding process. According to Kilchevsky (1993), the error in the choice of the environment in each stage of the breeding process leads to an inadequate assessment of the genotypes and the loss of valuable selection material.

According to the opinion of Filipenko (2008), the studied variety, the set of different factors (sowing times, predecessors, plant protection systems) used in a given geographic point allow with great credibility to predict the behavior of genotypes in other territories.

Strizhkova (2003) considers that the 1000 seed weight to the highest extent corresponds with the criterion of adaptability. It is an integration character that characterizes the final result of the interaction of the genotype with the environment in the process of ontogenetic formation of productivity.

Nikiforova (2015) reported that, as a result of the correlation analysis, there was no relationship between the average seed productivity and the relative stability of the genotype, suggesting that in a group of varieties there could be both, relatively stable and unstable, and high and low productive as well.

Basaran et al. (2013) found the strongest positive correlations between main stem number and leaflet length and, between seed yield per plant and pod number per plant in grass pea accessions. Our results for plant dry weight support these of Basaran et al. (2011) and Lakić et al. (2018).

The main feature of adaptive selection is the control of environmental stability in the breeding process. The need for such control is determined by the fact that the average value of the attribute and the environmental sensitivity are under independent genetic control and are relatively independent. The selection in such conditions, where phenotypically realized only the genetic system of productivity, could lead to a random drift of genes that determine the stability and to be lost (Kilchevsky & Khotyleva, 1997).

A selection aimed at adverse environmental factors implies the presence of environmental plasticity in the initial material. Therefore, the need for a complex assessment arises to obtain more complete information on the reaction of the varieties to the conditions of the environment. As a result of the study of grass pea varieties in the parameters of adaptability, specimens were selected, which are appropriate to be used in the selection as initial material for the purpose of creating new varieties with high ecological stability and adaptability.

The characteristics assessed could be used for further selection of grass pea genotypes.

Conclusions

Grass pea varieties with high general and specific adaptive ability, relative stability and selection value on the traits studied were identified.

BGE027129 was characterized by high selective value by the number of pods, number of seeds and seed weight per plant, and BGE015741 by the plant height, number of seeds and seed weight per plant.

The varieties BGE027129, BGE015741 and BGE025277 can be used as parental components in breeding programs to create varieties with a larger number of seeds and pods per plant, and higher weight of seeds.

Interest for the combinatorial selection is the variety BGE025277 by the plant height and the seed weight per plant, which are combined with good homeostaticity and relative stability to the environment.

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