AGRICULTURAL ACADEMY

INSTITUTE OF FORAGE CROPS - PLEVEN

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CREATION OF STARTING MATERIAL AND NEW VARIETIES OF THE SPECIES LATHYRUS SATIVUS L. AND LUPINUS ALBUS L. FOR THE NEEDS OF BREEDING

ABSTRACT

of a dissertation
for the acquisition of a scientific degree "DOCTOR OF SCIENCES"
in scientific specialty "Selection and seed production of cultural plants"
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The dissertation work it includes is written on 357 pages, in which there are 66 tables, 40 figures and a list of the literature used from 471 sources, from 187 in Cyrillic and 284 in Latin.
The research was conducted in the period 2014 - 2021. At the Second Experimental Field and laboratories of the Institute of Forage Crops - Pleven.

The defense of the dissertation will take place at …………………… Institute of Forage Crops – Pleven …………….hours, at a meeting of the Scientific Jury, appointed by order of the Director Institute of Forage Crops No... ....

The materials on the defense are available to those interested in the library of the Institute of Forage Crops - Pleven, "Vl. Vazov" 89.

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1. INTRODUCTION

The high productivity and successes in selection are based on the use of a rich genetic diversity of sources with different valuable qualities. They serve as donors in crossbreeding and recombination of hereditary factors. Most often, limited starting material and its genetic uniformity slow down the selection process and lead to unsatisfactory results. Common ax and white lupine are versatile legumes, rich in protein and with wide possibilities for use in the complete nutrition of farm animals. In our country, these crops are little known compared to traditional peas and fenugreek, but their fresh mass and grain can be successfully used in feeding ruminant and monogastric animals and can be considered as a possible substitute for soybean meal. Their contribution to biological nitrogen in the organic farming system is undeniable and will increase.

Of importance is the fact that crops such as white lupine (Lupinus albus L.) and common ax (Lathyrus sativus L.) can be grown on acidic soils that have low fertility or are highly eroded (especially in the foothills and mountainous regions). . Regardless of the advantages of growing these crops, the Bulgarian variety list lacks registered Bulgarian varieties of lupine and **grass pea**.

2**. PURPOSE AND OBJECTIVES OF THE RESEARCH**

In order to realize the set goal, the experimental work was aimed at performing the following tasks:

1. Morphological, ecological and biochemical assessment of collection specimens of white lupin and **grass pea**.
2. Determination of phenotypic correlations between main traits and establishment of genetic distance in the white lupine and **grass pea** varieties.
3. Evaluation of the elements of productivity of the studied varieties in terms of stability and adaptability.
4. Analysis of the ways of inheritance of economically valuable quantitative traits in F1 and F2 - hybrid generations. Broadcasting prospective numbers suitable for use in the conditions of Central Northern Bulgaria.

3. **MATERIAL AND RESEARCH METHODS**

3.1. Selection material used in research

The scientific research activity, field trials (collection, hybridization, comparative and competition) and experimental work were carried out at the II experimental field of the Institute of Forage Crops - Pleven.

Collection kennel. In the study of samples from the working collection, six cultivars of **grass pea** (BGE027129, BGE025277 and BGE015741 originating from Spain; LAT4362, LA5108 and LAT5038 originating from Portugal and seven cultivars of white lupine PI457923 (Greece); PI368911 (Czech Republic) were included); PI533704 (Spain); PI457938 (Morocco); KALI (Poland); Zuter (France) and Lucky801 (France) provided by foreign gene banks. The influence of abiotic environmental factors was studied under a natural background of crop cultivation. The Polish attempts were made according to the technology for growing the relevant plant species, with a soil subtype of leached chernozem, medium in humus, the mechanical composition of which is sandy clay (Naidenov et al., 1978).

Biometric analysis was performed in two phenological phases of plant development. Biometric measurements were taken on 10 plants of each variety. A biometric characterization of main quantitative signs was made in the relevant phenological phases as follows: in the beginning of flowering phase: - height of the plant (cm) - fresh weight of the plant (aboveground biomass) (g); - number of leaves per plant; - fresh weight of leaves per plant (g); - fresh weight of stems per plant (g); - weight of dry stems (g); - weight of dry root mass (g); - length of roots per plant (cm); - fresh weight of roots per plant (g); - dry weight of roots per plant (g); - number of tubers per plant (g); - weight of tubers per plant (g);- tuber weight (mg); - specific tuber-forming ability; - saturation of the root system of one plant with tubers; aboveground biomass yield (kg da-1); in the technical maturity phase:- plant height (cm); - number of beans per plant; - number of seeds per plant; - number of seeds in one bean; - weight of seeds per plant (g); - single grain weight (g); - seed weight in one bean (g); - seed yield (kg da-1). In the case of common ax varieties in the technical maturity phase, the sign - number of branches was determined, in the case of white lupine varieties in the beginning of flowering phase, the dry weight of the leaves per plant (g).The indicators were also recorded: sowing-beginning of flowering (days), sowing-technical maturity (days), degree of early maturity and duration of the vegetation period (days).

Hybridization nursery. Hybridization was carried out between suitable genotypes, the seeds of which were sown according to seed quantities in rows with 50 cm inter-row and 10 cm intra-row spacing. To achieve this goal, the varieties LA5108, BGE027129 and BGE025277 were used for the **grass pea**, and for the white lupine PI533704, Zuter and Lucky801, characterized by alternately manifested characters. They are neutered and pollinated on average 25-30 each. All plants from the parental components and hybrids were grown according to the scheme P1,F1,F2,P2. Sowing in compact sowing was carried out manually at a row spacing of 0.50 m and 0.05 m within the row, and in sparse sowing at a row spacing of 0.50 m and 0.10 m within the row at a seeding depth of 3 cm.

Comparative Polish experience. The Polish experience is based on four replications with a harvest plot size of 5 m2. The productive possibilities of the following hybrid lines of **grass pea** were studied: - LHL (BGE027129 x LA5108); LHL-2 (BGE025277 x LA5108) and LHL-3 (LA5108 x BGE027129).

Consortium variety experience. The experiment was carried out in four repetitions with a harvest plot size of 10 m2. The productive potential of the hybrid lines of white lupine - L5 (Lucky801 x PI533704), LN1-1 (Lucky801 x PI533704) was studied. Parent cultivars of white lupine were used as controls. The field trials were conducted using the long plot method.

3.2. Applied selection-genetic methods in research.

3.2.1. Statistical processing of the obtained results

The data from the biometric assessment were averaged, and the numerical and metric ones were used to calculate the variance (σ2), the mean square deviation (σ) and the coefficient of variation (CV) according to Dimova and Marinkov (1999). Hierarchical cluster analysis was applied, using Ward (1963) Euclidean distance as a measure of genetic distance. Correlation analysis of the data from the yield structural elements was used in conducting an effective team for several traits. The coefficient of variation (CV%) was used to compare the variability of different traits. Dimova and Marinov (1999) dispersion analysis was used to establish reliable differences between the individual variants and dependencies between yield values and the studied elements.

3.2.2. Selection and genetic evaluation of plant material

The manifestations of heterosis and inbreeding depression were evaluated according to Omarov's methodology (1975). Dominance rates were calculated using the Romero and Frey (1973) formula. The method of Sobolev (1976) was used to determine:-Tn - manifestations of transgression; N - number of genes by which the parental forms differ; D - manifestations of dominance; E - epistatic gene effects;- H2- coefficient of heritability, Pp- coefficient of efficiency of the mass selection. Phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) were determined according to Singh and Chaudhury (1985). Genetic advance (GA) was calculated according to Singh and Chaudhury (1985). Genetic gain (GG) according to (Johnson et al., 1955). The cytoplasmic effect (R) according to Reinhold (2002), the coefficient of early maturity according to Kuzmova (2002).

3.2.3. Parameters for determining ecological stability adaptability

The obtained data were processed by two-factor analysis of variance for each trait to determine the effect of genotype (G), environment (E) and genotype-environment interaction (G x E). The evaluation of the ecological stability of the investigated varieties was made by applying the following methods: Regression analysis - according to Eberhart and Russell, (1966), through the regression coefficient (bi) and the variance of the deviations from the regression (Si2); - Finlay and Wilkinson (1963) by "bi"; Tai (1979) by “ai” and “λi”; Theil (1950) by the 'T' parameter; Analysis of variance: – average Non-covalence by the parameters "W2" of Wricke (1965) and "Wi", of Annicchiarico (1992); Non-parametric analysis using: the 'Pi' parameter and rank (R) model of Lin and Binns (1988); rank (Ri) according to Huehn (1990); adaptability rank according to Nascimento et al. (2009); coefficient of variation (CV, %) according to Francis and Kannenberg, (1978); adaptive capacity (OAS and SAC); genotype stability (Sgi); criterion (GxE)gi; the selection value of the genotype (SCG) according to Kilchevski and Hotyleva (1985a; 1985b); stress resistance (U) according to Rossielle (1981) and homeostaticity (Hom) according to Khangildin (1984). A GGE biplot model was made, following (Yan, 2002). A principal components factor analysis was also performed on the collection of common ax and white lupine cultivars based on the traits and indicators used in the study.

3.2.4. Modular organization of the quantitative sign.

The modular organization of the quantitative sign is presented according to the model of Dragavtcev (1995). The module reflects all stages of realization of genetic formulas depending on the level of environmental factors during ontogenesis. The method of orthogonal regression was applied to identify the phenotype by genotype described by Kramer (Dragavtcev, 1995; Dragavtsev, 2002), showing the possibility of evaluating the hybrids common ax and white lupine by genetic-physiological systems at different environmental limits.

3.2.5. Methods for biochemical evaluation of common ax and white lupine cultivars

A biochemical assessment of the varieties and prospective fibride forms was carried out according to the following indicators: crude protein (CP), crude fiber (CW) content according to Kjeldahl; raw ash (SPep) - according to the Weende method; phosphorus (P) and calcium (Ca), % of dry matter (CB) - complexometrically (Sandev, 1979). A De Marton dryness index was calculated (according to Kuzmova, 2003). Data from the studied indicators were processed statistically using Microsoft Office 2002 Excel, Statgraphics Plus 2.1 and the GENES 2009.7.0 Windows XP statistical package (Cruz, 2009).

4. **RESULTS AND DISCUSSION**

4.1. Studies on grass pea (Lathyrus sativus L.)

4.1.1. Genetic distance of common ax cultivars according to morphological characters

The data in Table 7 show the presence of reliable differences in relation to the factors year and genotype in terms of the number of leaves per plant, fresh and dry weight of the roots and weight of the dry root mass of the plant at technical maturity. Genotypic differences were insignificant for plant fresh weight, leaf and stem fresh weight, root length, tuber number and weight, specific tuber forming ability, plant height, number of branches, number and weight of seeds per plant.

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The genotype factor had the strongest influence on the variance values of the indicators: number of tubers per plant, weight of dry stems and number of beans per plant. Relatively close effects of environment and genotype as factors were observed for parameters such as root length and tuber weight. The differences that are observed in terms of weather make it possible for the individual signs to appear within wide limits, on the one hand, and for the formation of certain trends between the individual genotypes, on the other.

The data presented in Table 8 support this thesis. Indicators are observed where, regardless of the effect of environmental conditions, clear trends can be formed between individual genotypes. However, it should be emphasized that for the individual indicators, due to their different genetic basis, the behavior of the studied genotypes is not identical. According to the obtained experimental data, the tested samples are characterized by insignificant differences among themselves regarding this feature. The variation in plant height ranged from 44.13 cm for BGE015741 to LAT5038 52.53 cm, followed by variety LAT4362 50.73 cm and the differences in values were not statistically significant.

The study of the main elements of productivity is an important stage in establishing the best variety for the specific growing conditions. From the analysis of the results, it is clear that the cultivars BGE027129 and LA5108 have the highest values for the number of branches, beans and seeds per plant, respectively 6.00; 15.80; 26.20 and 5.53; 15.53; 28.27.

Table 7. Analysis of the variance of the studied characters in the grass pea samples

Source	DF	MS					
		aboveground fresh weight	leaves number	leaf fresh weight	stem fresh weight	root length	root fresh weight
Year	2	248.9858*	2005.429**	125.8043**	43.6038*	3.7164ns	0.2807**
Variety	5	56.571ns	233.4036*	18.8272ns	12.0657ns	3.772ns	0.1297**
Error	10	20.2107	42.0142	7.9529	7.1766	1.485	0.0187
		root dry weight	nodule number	nodule weight	specific nodulating ability	plant height, cm	тегло на сухите стъбла
Year	2	0.0269**	257.854 ns	0.1212 ns	0.0186 ns	81.9562 ns	9.1743 ns
Variety	5	0.0057**	433.266ns	0.0782ns	0.0469ns	41.5926ns	17.5824*
Error	10	0.0005	145.401	0.0629	0.0662	45.065	3.2305
		number of branches	pods number	Number of seeds per plant	seeds weight per plant	dry root weight	
Year	2	2.4568*	11.2307ns	114.3373ns	13.9387**	0.3516**	
Variety	5	1.2206ns	29.8929*	65.9842ns	4.5483ns	0.0149**	
Error	10	0.3724	8.3551	56.7175	1.4289	0.0026	

*/ ** significant at $p < 0.05 / 0.01$; ns – not significant

Table 8. Characteristic of the investigated varieties grass pea

	Trait/Variety	BGE027129	BGE025277	LAT4362	LA5108	LAT5038	BGE015741	$LSD_{0.05}$	$LSD_{0.01}$
beginning of flowering	aboveground fresh weight	18.07	17.62	19.49	9.28	13.47	21.01	8.17	11.63
	leaves number	47.30	47.40	49.93	33.30	40.87	59.53	11.79	16.77
	leaf fresh weight	8.49	7.79	9.45	4.14	6.51	11.45	5.13	7.29
	stem fresh weight	9.58	9.83	10.04	5.14	6.96	9.56	4.87	6.93
	root length	13.41	11.73	11.59	9.95	11.55	11.09	2.21	3.15
	root fresh weight	0.89	1.04	0.82	0.47	0.66	0.95	0.24	0.35
	root dry weight	0.22	0.19	0.19	0.10	0.13	0.19	0.03	0.05
	nodule number	41.13	28.28	34.32	10.41	12.67	25.27	21.93	31.2
	nodule weight	0.35	0.23	0.27	0.17	0.15	0.59	0.45	0.64
	specific nodulating ability	0.40	0.22	0.32	0.36	0.23	0.62	0.46	0.66
technical maturity	Plant height, cm	49.21	50.67	50.73	45.60	52.53	44.13	19.23	27.36
	dry stems weight	18.07	17.62	19.49	9.28	13.47	21.01	8.17	11.63
	number of branches	6.00	4.92	4.60	5.53	3.73	4.87	2.52	3.58
	pods number	15.80	10.00	12.27	15.53	9.53	14.93	5.85	8.33
	Number of seeds per plant	26.20	16.00	22.80	28.27	23.27	28.53	15.27	21.72
	seeds weight per plant	4.65	4.26	3.17	2.98	2.80	5.52	2.53	3.60
	dry root weight	0.67	0.75	0.72	0.88	0.73	0.92	0.25	0.36

Of the studied set of specimens, grass pea LA5108, although it managed to form a large number of seeds per plant, they were relatively small and therefore their weight per plant did not exceed 3.00 g. The plants from BGE015741 are distinguished by the highest seed mass (5.52 g). A good match between number and weight of seeds per plant was also found in BGE027129 and BGE025277. A difference was also found in the indicators related to the root system of the plants. Regarding the length and weight of roots at technical maturity, LA5108 and BGE015741 are of interest, with values of these parameters above average. In the flowering phase, according to the same characteristics, the varieties BGE025277 (11.73 cm; 1.04 g) and BGE027129 (13.41 cm; 0.89 g) prevail.

By weight of the above-ground mass BGE015741, LAT4362 and BGE027129 significantly exceed the other varieties, especially LA5108 (9.28 g). These cultivars are also defined as desirable in terms of number (25 - 41) and weight of tubers (0.27 g - 0.59 g) per plant and specific tuber forming ability (0.32 - 0.62), although none of them overall does not have maximum values in all these indicators. According to the first two characteristics, LA5108 and LAT5038 varieties performed poorly, and BGE025277 according to specific tuber-forming ability.

The studied cultivars differ in their phenological development. Differences were found from the onset of the phenophase to the beginning of flowering. LA5108 is characterized by the shortest average duration of the sowing - flowering period (57 days). For BGE027129 LAT4362 and BGE025277 this period is within 62-64 days. LAT5038 and BGE015741 cultivars bloomed the latest (67-68 days). The observed differences in the occurrence of individual phenological periods in the studied varieties are preserved until the end of the vegetation period. To the group of early varieties can be attributed LA5108 with an early maturity factor of 1.00 and a duration of vegetation of 91 days. The samples LAT4362 and BGE027129 are characterized as medium early with a coefficient of 1.5 and a vegetation period of 96-98 days. LAT5038 and BGE015741 varieties with a vegetation period of more than 100 days are late ripeners.

The values of genotypic variance (Table 10) for almost all characters (except number of leaves and fresh weight of roots) were lower than the corresponding phenotypic variances such as differences for dry weight of stems, number of branches, number of pods per plant and weight of seeds per plant are smaller compared to the differences in other indicators.

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Table 10. Genetic components of variation of quantitative traits in grass pea specimens

Trait/Variety	Min.	Max.	CVG (%)	CVP (%)	GA	GG	Vg	Ve	H2 (%)
aboveground fresh weight	5.24	28.94	21.12	27.43	5.55	56.16	12.12	20.21	64.27
leaves number	17.40	75.40	17.22	14.00	20.28	28.78	63.80	42.01	82.00
leaf fresh weight	1.99	20.02	23.89	35.13	2.65	72.89	3.62	7.95	57.76
stem fresh weight	3.25	16.40	14.99	31.23	1.25	64.77	1.63	7.18	40.52
root length	9.00	14.94	7.56	10.50	1.29	21.73	0.76	1.49	60.63
root fresh weight	0.26	1.21	23.87	16.93	0.56	34.78	0.04	0.02	85.56
root dry weight	0.04	0.28	24.88	12.76	0.17	27.10	-	-	91.95
nodule number	1.00	62.00	38.65	47.72	16.39	97.99	95.96	145.4	66.44
nodule weight	0.10	1.31	24.31	86.82	0.04	178.15	0.01	0.06	19.52
specific nodulating ability	0.17	1.17	-	-	0.08	218.7	-0.01	0.07	-41.14
Plant height, cm	31.20	58.00	-	-	0.70	58.61	-1.16	45.07	-8.35
dry stems weight	2.86	12.75	40.88	33.51	13.47	169.99	4.78	3.23	81.63
number of branches	2.40	6.00	12.26	14.09	2.81	85.21	0.28	0.37	69.49
pods number	6.40	21.40	18.75	20.16	17.54	142.81	7.18	8.36	72.05
Number of seeds per plant	5.80	36.80	6.66	28.96	3.31	229.93	3.09	56.72	14.04
seeds weight per plant	0.60	8.81	29.79	35.05	7.88	316.67	1.04	1.43	68.58
dry root weight	0.23	0.90	13.87	11.10	0.81	111.51	-	-	82.40

Vg: - genetic variance; Ve: - phenotypic variance; GA - genetic progress; GG - genetic gain; PCV (%) - phenotypic coefficient of variation GCV (%) - genotypic coefficient of variation; H2 (%): heritability in a broad sense;

Genotypic variance values ranged from 0.01 for tuber weight to 95.96 for tuber number. Genotypic variance was relatively low for stem fresh weight, root length and fresh weight, tuber weight, number of branches and seed weight per plant, with a numerical value close to unity.

The number of tubers (145.40) and the number of seeds per plant (56.72) are distinguished with the highest phenotypic variance, and with minimal (0.02; 0.06; 0.07) root dry weight, tuber weight and specific tuber-forming ability. Higher phenotypic variance was also observed for plant height (45.07), Number of leaves per plant (42.01) and plant fresh weight (20.21). This indicates that these are traits highly influenced by the rearing environment.

High PCV and GCV values for tuber number and weight, stem dry weight, seed weight per plant and leaf fresh weight indicate that there is considerable variability in these traits and that selection based on them can be effective. GCV values ranged from 6.66% and 7.56% for number of seeds per plant and root length to 38.65% and 40.88% for number of tubers per plant and dry stem weight. The variation of PCV values is stronger, with the weakest for root length (10.50%) and dry root weight (11.10%). Strong variation was found for tuber weight and number (47.72%; 86.82%), for fresh leaf weight (35.13%) and for seed weight per plant 35.05%. According to the obtained data, moderate values of PCV and GCV were reported for number of leaves (17.22%; 14.00%), for number of branches (12.26%; 14.09%), number of pods per plant (18.75%; 20.16%) and root dry weight mass (13.87%; 11.10%), and the root length trait had low values of PCV and GCV. In this study, PCV was relatively greater than GCV for tuber number and weight, leaf and stem fresh weight, seed number and weight per plant, and plant fresh weight; however, for the traits number of leaves, fresh and dry weight of roots, weight of dry stems and weight of dry root mass, GCV values exceeded those of PCV, indicating the high proportion of genotypic effect in the phenotypic manifestation of these traits. Heritability values are useful in predicting the expected genetic progress achieved in the selection process. Its values vary from 14.04% for the number of seeds per plant to 91.95% for the dry weight of the roots. According to the interpretation of this coefficient, the heritability of tuber weight (19.52%) and number of seeds per plant is medium, and for the other characters it is high. The traits that have high heritability such as root dry weight, root fresh weight (85.56%), stem dry weight (81.63%), number of leaves per plant (82.00%), number of pods per plant (72.05%) and number branches (69.49%) indicate the relatively small influence of environmental factors on the phenotype and selection for such traits can be relatively easy due to the high additive effect. The genetic advance data for the traits number of leaves and tubers per plant, dry stem weight and number of pods per plant show that when we select the top 5.00% high-yielding genotypes as parents, plants with improved expression of these traits can be selected in the progeny i.e. the mean genotypic value of the new population for these parameters will be increased. The combination of high values of the genetic advance with high heritability suggests the presence of an additive type of their inheritance.

Table 11. Eigenvalues and vectors of the correlation matrix for 17 characters in grass pea varieties

Trait	PC1	PC2	PC3
aboveground fresh weight	0.302	0.059	0.173
leaves number	0.295	-0.052	0.261
leaf fresh weight	0.296	-0.040	0.201
stem fresh weight	0.284	0.178	0.123
root length	0.197	0.281	-0.333
root fresh weight	0.274	0.166	0.248
root dry weight	0.299	0.168	-0.075
nodule number	0.263	0.180	-0.255
nodule weight	0.271	-0.244	0.083
specific nodulating ability	0.186	-0.382	-0.047
Plant height, cm	0.178	0.344	-0.051
dry stems weight	0.289	-0.181	-0.071
number of branches	0.242	-0.112	-0.449
pods number	0.127	-0.314	-0.437
Number of seeds per plant	0.065	-0.393	-0.190
seeds weight per plant	0.283	-0.090	0.214
dry root weight	-0.016	-0.404	0.335
aboveground fresh weight			
leaves number	56.61	26.73	10.41
leaf fresh weight	0.5661	0.8334	0.9374
stem fresh weight	9.623	4.5439	1.7689

PC1; PC2; PC3 = principle components 1, 2 and 3 respectively;

Traits that have high heritability coefficient values combined with moderate genetic advance (GA) as a percentage of the study population mean, i.e. plant fresh weight, leaf fresh weight, number of branches and seed weight per plant suggest that the applied team in their improvement can be successful. Three eigenvalues were extracted (Table 11). greater than unity, which determines the choice of three components. They explain 93.75% of the total variation. The first component explains 56.61%, the second 26.73%, the third 10.41% of the total variation. The lowest values of the first principal component (Table 12) have the varieties BGE025277 and BGE015741, which are distinguished by high values of fresh weight of stems, weight of seeds per plant, fresh weight of leaves, number of tubers and fresh weight of roots . LA5108 and LAT5038 had the highest values.

Figure 10 presents the distribution of genotypes according to their values for the principal components PC1 and PC2. According to the values of the second principle component, the first position is occupied by BGE025277, followed by LAT5038, which has positive values of all three main components. The formation of the second principal component is related to the traits root length, tuber number and plant height. The signs fresh weight of stems and roots are involved in the formation of all three principle components and cannot be strictly attributed to any one of them. The studied genotypes are divided into four groups.

The first group with positive values on PC1 and PC2 includes only variety LAT5038, which is distinguished by tall plants, with a small number of leaves, with low fresh biomass weight (leaves and stems). The second group is represented by LA5108 with high expression of the characters number of beans and seeds per plant and weight of dry root mass, but also with lower values of number and weight of tubers per plant.

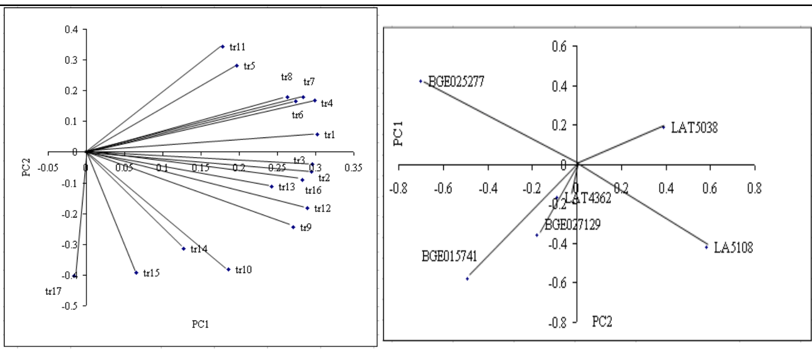
The third group unites the cultivars BGE015741, LAT4362 and BGE027129 located in the quadrant with negative PC1 and PC2 and having high values of plant fresh weight, number of leaves, fresh weight of leaves and stems, length of roots, number and weight of tubers and number of seeds per a plant. In the quadrant bounded by negative PC1 and positive PC2, variety BGE025277 is located alone.

Information about the correlative relationships between the signs is also provided by the applied PC analysis, through the magnitude of the angle that the vectors of two signs make. The vectors of the traits fresh weight of stems, fresh weight of roots, dry weight of roots and number of tubers form sharp angles, indicating the presence of a positive relationship between them. The relationship between number of leaves and fresh weight of leaves is similar. Positive correlations were also found between specific tuber-forming ability and number of pods per plant, number of branches, dry stem weight, dry stem weight and root length. The presented cluster analysis was made on the basis of the obtained data from the investigated signs. From figure 11 it can be seen that on the dendrogram the samples are in two main clusters.

Table 12. Values of varieties by principal components

Varieties	Principal components		
	PC1	PC2	PC3
BGE027129	-0.18	-0.36	-0.18
BGE025277	-0.70	0.42	-0.70
LAT4362	-0.09	-0.17	-0.09
LA5108	0.58	-0.42	0.58
LAT5038	0.39	0.19	0.39
BGE015741	-0.49	-0.58	-0.49

PC1; PC2; PC3 = principle components 1, 2 and 3 respectively;



A **B**

Figure 10. Projection of the grass pea varieties and signs on the vector plane.
A – for the quantitative signs: tr1 - fresh weight of the plant; tr2 - number of leaves; tr3 - leaf fresh weight; tr4 - fresh weight of stems; tr5 - length of roots; tr6 - fresh weight of roots; tr7 - dry weight of roots; tr8 - number of tubers; tr9 - tuber weight; tr10 - specific tuber-forming ability; tr11- plant height; tr12 - weight of dry stems; tr13 - number of branches; tr14 - number of beans per plant; tr15 - number of seeds per plant; tr16 - seed weight per plant; tr17 - weight of dry root mass;
B – for varieties grass pea – 1 - BGE027129, 2 - BGE025277, 3 - LAT4362, 4 - LA5108, 5 - LAT5038 и 6 - BGE015741;

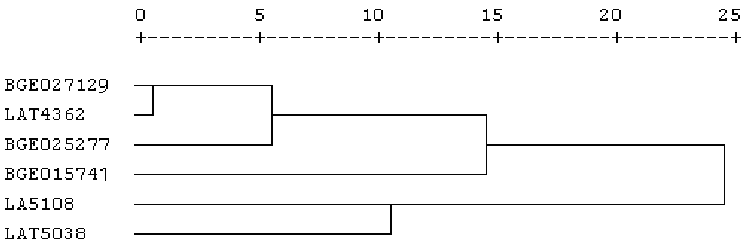


Figure 12. Dendrogram (2014-2016) of grass pea specimens (*Lathyrus sativus* L.)

The first cluster located in the lower part of the dendrogram is represented by two varieties LA5108 and LAT 5038. The second cluster is covered by the remaining varieties formed in two subclusters. A separate place is occupied by BGE01574. Within this subcluster, the most closely related, with the fewest distance units, are the cultivars LAT4362 and BGE02712. The variety BGE02527 can also be assigned to their group. Genetically most distant are BGE02712 and LAT4362 from the second cluster compared to LAT 5038 from the first.

5.1.2. **Trait evaluation of grass pea cultivars for ecological stability**

The results of the variance analysis (Table 15) show that it is relevant to study both the mean value of all the studied characters (plant height, plant fresh weight, number of seeds per plant, weight of seeds per plant and number of tubers per plant).

As well as an assessment of their stability and the genotype (variety) - environment (year) interaction effect. No statistically significant differences were found between the cultivars in terms of fresh weight of the root mass. The largest proportion of total variance was accounted for by the effect of trial years on plant height, plant fresh weight, number of seeds per plant and seed weight per plant, followed by cultivar genotype for tuber number per plant.

Table 16 shows the response of a set of varieties according to the investigated characteristics. The varieties LAT5038 and LAT4362 are characterized by the highest values of the trait plant height (figure 13), but also by the highest regression coefficient (bi=2.71; bi=2.24), and in the second variety it is very well proven. BGE015741 exhibits very good stability (bi=0.06); to growing conditions, but the plants of this variety are the smallest. BGE025277 is also stable and takes the second position according to the characteristic values.

The parameters based on the analysis of variance (PP, W2 and Wi) determined it as the most stable in terms of plant height. The cultivar BGE027129 was inferior with a regression coefficient approaching unity (bi=0.80) and according to the W2 parameter of Wricke (1965) quite responsive to improvements in environmental conditions.

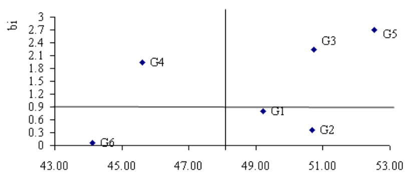
Cultivars exhibit different environmental stability and responsiveness in terms of stem fresh weight per plant. According to the values of the parameters bi, PP and W2, LAT5038 and LAT4362, which is also a very good fresh biomass productivity, can be attributed to the group of stable varieties.

Variety BGE027129 combines good productivity. The overall evaluation of all parameters defines it as the closest to the ideal genotype of the group of varieties in this respect. The high regression coefficient (bi>1) shows that BGE025277 and LA5108 are characterized by greater variability compared to the other varieties, but grown on a high agrophone (under comfortable conditions) they can express their biological capabilities very well.

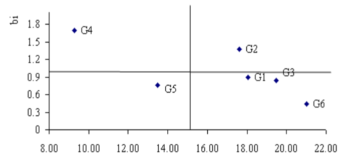
Table 15. Analysis of variance for plant seed weight stability and grain yield elements of grass pea cultivars (*Lathyrus cultivars* L.) (2014-2016)

Source of variation	Df	MS					
		Plant height, cm,	Stems fresh weight, g	Number of seeds per plant	Seeds weight per plant	Root mass Fresh weight, g	Nodule number per plant
Environments (E)	2	1376.7693**	966.4065**	1463.5444**	25077.4166**	10.6097*	19.9694**
Genotypes (G)	5	160.0427**	131.0643**	328.1511**	252.9347**	0.1438	173.1761**
G x E nteractions	10	559.188**	145.8959**	352.5311**	190.1807**	0.1006	87.8828**
E/G	12	695.4516**	282.6477**	537.70**	4338.0533**	1.8521	76.5639**
E/ BGE027129	2	163.0427**	174.7171**	427.40**	7330.5683**	1.0505	25.40**
E/ BGE025277	2	33.2667*	311.1312**	1122.20**	3171.6552**	1.6972	42.1167**
E/ LAT4362	2	1168.0667**	144.3432**	509.40**	2719.5408**	1.2539	176.60**
E/ LA5108	2	917.60**	609.3791**	254.0667**	4886.202**	2.905	1.40
E/ LAT5038	2	1841.8667**	109.581**	323.2667**	2665.4516**	1.2977	21.6667**
E/ BGE015741	2	48.8667	346.7342**	589.8667**	5254.9022**	2.9085	384.40
Total	17						

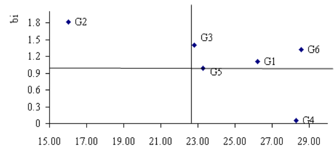
*/ ** significant at $p < 0.05 / 0.01$



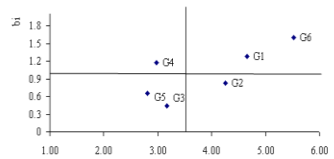
A



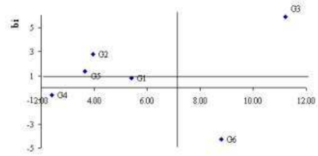
B



C



D



E

Figure 13. Selection significance of grass pea varieties according to the coefficient of linear regression (bi) and the value of the investigated characters
G1 - BGE027129; G2 - BGE025277; G3 - LAT4362; G4 - LA5108; G5 -LAT5038; G6 - BGE015741; A - plant height, B - fresh biomass weight, C - number of seeds per plant, D - weight of seeds per plant, E - number of tubers per plant;

Table 16. Estimation of adaptability and stability parameters for the characters of the studied grass pea cultivars

Variety	Eberhart and Russell (1966)		Tai (1979)		Plaisted and Peterson (1979)	Wricke (1965)	Annicchiarico (1992)
	bi	Si^2	ai	λi	PP	W^2	W_i
plant height, cm							
BGE027129	0.08**	6.25**	-0.80	18.68	146.88	1519.41	85.48
BGE025277	0.36**	0.93*	0.36	3.34	67.19	191.23	98.36
LAT4362	2.24**	5.20**	2.24	15.93	99.89	736.22	91.13
LA5108	1.94**	20.09**	1.94	60.72	86.32	510.15	82.26
LAT5038	2.71**	62.89**	2.71	188.72	155.08	1656.07	86.95
BGE015741	0.06**	-0.07	-0.46	-0.06	114.44	978.80	79.31
Stems fresh weight, g							
BGE027129	0.89	18.59**	0.89	56.37	20.25	97.82	108.65
BGE025277	1.37**	3.21**	1.37	10.21	18.06	61.32	85.86
LAT4362	0.84	12.11**	0.84	36.92	18.57	69.81	76.32
LA5108	1.69**	58.11**	1.70	174.83	41.26	447.85	63.25
LAT5038	0.76	6.42**	0.76	19.83	17.48	51.62	54.44
BGE015741	0.44**	125.88**	0.44	378.18	58.22	730.54	88.51

*/ ** significant at $p < 0.05$ / 0.01

The variety LAT5038 is also stable (bi=0.99), but it, together with LAT4362, is low productive and does not represent selection interest on this basis. BGE025277 can be defined as the most variable and the least productive.

Table 16. Estimation of adaptability and stability parameters for the characters of the studied grass pea cultivars

Variety	Eberhart and Russell (1966)		Tai (1979)		Plaisted and Peterson (1979)	Wricke (1965)	Annicchiarico (1992)
	bi	Si^2	ai	λi	PP	W^2	W_i
Number of seeds per plant							
BGE027129	1.11	49.76**	1.11	149.8	50.42	256.11	93.99
BGE025277	1.82**	126.01**	1.82	378.5	92.52	957.91	32.68
LAT4362	1.40**	11.53**	1.40	35.16	43.32	137.85	82.00
LA5108	0.05**	60.80**	-0.65	182.4	132.58	1625.60	90.85
LAT5038	0.99	33.19**	0.99	100.1	45.07	167.00	82.94
BGE015741	1.32**	66.05**	1.32	198.7	57.90	380.83	97.87
Seeds weight per plant							
BGE027129	1.28**	0.16	1.32	1.07	71.67	880.78	109.75
BGE025277	0.83**	0.22	0.87	1.24	27.29	141.24	99.75
LAT4362	0.44**	1.43*	0.81	4.90	38.18	322.66	67.04
LA5108	1.18**	0.32	1.08	1.57	22.27	57.58	42.29
LAT5038	0.65**	0.42	0.80	1.84	39.40	342.97	64.86
BGE015741	1.60**	7.32**	1.12	22.59	28.21	156.57	99.95

*/ ** significant at $p < 0.05$ / 0.01

The most successful combination between stability and responsiveness in plant seed productivity was shown by variety BGE025277 (bi=0.83; PP=27.29; W2=141.24; Wi=99.75). The level of the symptom in him increases with the improvement of the growing conditions, with a deterioration of the conditions, it slightly decreases. On this basis, LAT4362 and LAT5038, which are low productive, respond poorly to improving the environment.

For them, the regression coefficient is bi=0.44 and bi=0.65. BGE015741 and BGE027129 according to stability parameters were the most variable in different growing media. Such varieties require a high level of farming in order to produce the maximum number of grains per plant. According to the Si^2 indicator, BGE027129 and BGE027129 are the most stable cultivars in different growing environments in terms of number of tubers per plant, while cultivars LAT4362, LAT5038 and BGE015741 can be characterized as ecologically unstable. They make the most of the favorable conditions of the environment for the formation of the sign. LA5108 is characterized by the smallest number of tubers per plant, which is also distinguished by a very low value of the Si^2 index.

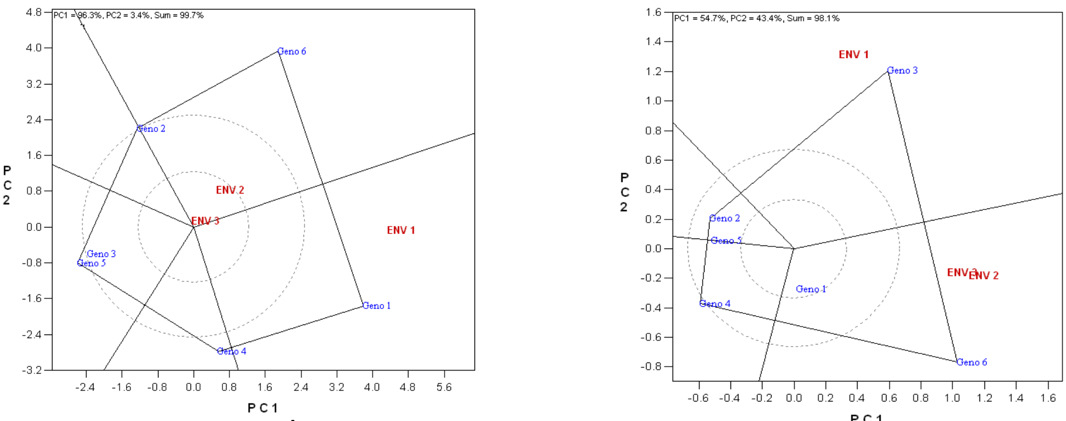
The GGE biplot is presented in the form of a polygon (figure 14), the concentric circles visualize the distance between the varieties and the "ideal genotype" that should be located in their center.

The varieties farthest from the center are marked on the vertices of the polygon. All varieties fall within this range. The lines dividing the polygon into sectors represent a set of hypothetical environments. The variety forming the corner of the polygon for each sector has the highest value for the studied trait in the environment that falls within that sector.

Table 16. Estimation of adaptability and stability parameters for the characters of the studied grass pea cultivars

Variety	Eberhart and Russell (1966)		Tai (1979)		Plaisted and Peterson (1979)	Wricke (1965)	Annicchiarico (1992)
	bi	Si^2	ai	λi	PP	W^2	W_i
Nodule number per							
BGE027129	0.79	9.13**	0.77	28.00	11.41	46.99	67.95
BGE025277	2.80	6.20**	2.90	18.52	11.80	53.60	37.25
LAT4362	5.87	24.50**	6.13	69.12	25.49	281.66	132.59
LA5108	0.050	-0.09	-0.66	-0.18	9.62	17.16	31.49
LAT5038	1.36	6.01**	1.38	18.63	10.50	31.93	41.48
BGE015741	-4.24	52.75**	-4.52	153.10	-4.24**	35.44	80.94

*/ ** significant at $p < 0.05 / 0.01$



A B

Figure 14. The GGE biplot for seed weight per plant (A) and number of tubers per plant (B) (2014-2016)
GENO 1 - BGE027129; GENO 2 - BGE025277; GENO 3 - LAT4362; GENO 4 - LA5108; GENO 5 - LAT5038; GENO 6 - BGE015741; ENV - 1; 2 and 3 are 2014 respectively; 2015 and 2016;

The results of the GGE biplot analysis for seed weight showed that the first two principal components (PC1 and PC2) determined 99.70% of the total variation of the trait as a result of genotype-environment interaction. In the conducted research, the vertices of the polygon are occupied by the varieties BGE027129, BGE025277, LA5108, LAT5038 and BGE015741. The variety BGE027129 best showed its biological potential in 2014, BGE015741 in 2015 and 2016. The location of 2016 near the center of the concentric circles defines it as the most suitable environment for development. It was found that the closest to the "ideal" genotype in this respect were the varieties BGE025277, LAT4362 and LAT5038, followed by LA5108, BGE027129 and BGE015741.

In terms of number of tubers per plant, the first position is taken by BGE027129, characterized by the best combination of stability and trait level. The most favorable years for its development were 2015 and 2016. According to average productivity, the remaining varieties can be ranked in descending order in the following sequence BGE015741>LAT4362>AT5038> BGE025277 >LA5108. BGE015741 and LAT4362 are characterized by the strongest variability of the trait, variety LA5108 is characterized by the best stability, but also the lowest productivity.

The average value of the trait and its coefficient of variation for each variety divide the coordinate system into four quadrants (Figure 15). Varieties with high ecological stability and high productivity fall into the third quadrant. For the trait plant seed weight, it is BGE015741, followed by BGE025277, which is less productive and is located very close to the abscissa of the coordinate system. These varieties are most important for selection.

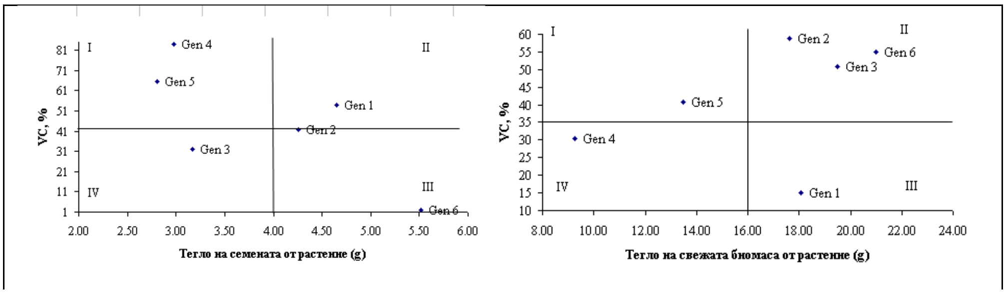


Figure 15. Stability of grain productivity and fresh mass indicators according to Francis and Kannenberg, (1978) and distribution of varieties according to the value of the coefficient of variation (VC, %)
Gen 1 - BGE027129; Gen 2- BGE025277; Gen 3 - LAT4362; Gen 4 - LA5108, Gen 5 - LAT5038; Gen 6 – BGE015741;

The varieties that would occupy a place in the second quadrant are also of interest, they are highly productive, but also highly variable. In such a situation is the variety BGE027129, which shows responsiveness only in favorable environmental conditions. The placement of variety LAT4362 in the fourth quadrant testifies to its stability in this trait, but also more limited biological possibilities in terms of seed weight per plant. In the first quadrant fall the highly variable and low productive varieties LA5108 and LAT5038.

BGE027129 located in quadrant three of the coordinate system stands out with high above-ground biomass values and the lowest variability.

In the second quadrant are the highly productive of fresh biomass BGE025277, LAT4362 and BGE015741. The high value of their coefficient of variation defines them as ecologically unstable. In the first and fourth quadrants are respectively the varieties LAT5038 and LA5108, distinguished by a lower manifestation of the trait.

5.1.4. Application of the ecological-genetic model in the selection of grass pea

5.1.4.1. Modular organization of the quantitative sign in the grass pea

Table 22 presents the influence of the environment on five modules determining the productivity of above-ground and root biomass of six cultivars of common ax. The formation of the module number of seeds per plant is the result of the mutual influence of number of beans per plant and number of seeds per bean. Environmental limits directly affect the expression of both component traits. The variety BGE027129 is an ecologically more stable expression of which it occupies the first or second position in the rank analysis. Such compensatory reactions were also found in the other varieties and this is the reason why the variety BGE015741 overall moved to the better second position in the resulting trait number of seeds per plant together with BGE027129.

Table 22. Influence of environmental conditions on the modules seed productivity per plant and number of seeds per plant in common ax varieties (by reported value)

Variety	Year								
	2014	2015	2016	2014	2015	2016	2014	2015	2016
Module I. Seed productivity per plant									
	Component trait 1			Component trait 12			Resultant trait		
	Seeds per plant			Weight of one seed (g)			Seed weight per plant (g)		
BGE027129	22.00	19.80	37.00	0.316	0.253	0.135	6.947	5.010	5.01
BGE025277	9.00	5.80	33.00	0.528	0.991	0.174	4.753	5.747	5.75
LAT4362	15.00	19.20	34.00	0.291	0.150	0.085	4.358	2.888	2.89
LA5108	29.00	35.00	21.00	0.191	0.079	0.131	5.541	2.752	2.75
LAT5038	14.00	22.40	28.00	0.307	0.121	0.097	4.300	2.720	2.72
BGE015741	16.00	34.40	35.00	0.384	0.256	0.252	6.142	8.809	8.81

The weight of the tubers per plant and saturation of the root system with tubers are included as structural elements of the root system mass module of a plant. In the studied group of varieties, BGE025277 and LAT5038 recorded the highest average value for the last trait (4.54-4.22) and the stable second position in rank. In the final ranking according to the resulting trait weight of the root system, BGE025277 took first place, and BGE027129, LAT4362 and BGE015741 took second place.

The root system weight of LA5108 plants was the lowest. When ranking the common ax varieties from the working collection by grain productivity for the studied period (Table 22), BGE015741 and BGE027129 stand out with stable positions (ranks 2-1-1 and 1-3-3, respectively). Variety BGE025277 occupies the third position with ranks 4-2-2. These varieties are highly productive, and no statistically significant differences were found between those with the second and third rank. The lowest average yields were found in varieties LAT4362 (67.6 kg da-1) and LAT5038 (64.9 kg.da-1), which were ranked 4 and 6, respectively.

Table 22. Influence of environmental conditions on the modules seed productivity per plant and number of seeds per plant in common ax varieties (by reported value)

Variety	Year								
	2014	2015	2016	2014	2015	2016	2014	2015	2016
Module II: Number of seeds per plant									
	Component trait 1			Component trait 12			Resultant trait		
	pods number per plant			Number of seeds per pod			Number of seeds per plant		
BGE027129	11.00	17.60	19.00	1.90	1.13	1.95	22.00	19.80	37.00
BGE025277	7.00	6.40	17.00	1.29	0.91	2.01	9.00	5.80	33.00
LAT4362	7.00	12.60	17.00	2.11	1.52	2.00	15.00	19.20	34.00
LA5108	13.00	16.20	17.00	2.28	2.16	1.23	29.00	35.00	21.00
LAT5038	8.00	10.60	10.00	1.63	2.11	3.00	14.00	22.40	28.00
BGE015741	9.00	21.40	14.00	1.69	1.61	2.48	16.00	34.40	35.00

Table 22. Influence of environmental conditions on the modules seed productivity per plant and number of seeds per plant in common ax varieties (by reported value)

Variety	Year								
	2014	2015	2016	2014	2015	2016	2014	2015	2016
Module III: fresh plant weight									
	Component trait 1			Component trait 12			Resultant trait		
	fresh leaves weight			fresh stems weight			fresh plant weight		
BGE027129	11.767	9.018	4.67	6.11	11.869	10.77	20.79	17.98	15.44
BGE025277	8.861	11.924	2.58	8.01	16.401	5.07	20.79	24.41	7.65
LAT4362	13.58	11.972	2.79	9.881	14.842	5.39	25.55	24.72	8.18
LA5108	5.574	4.344	2.50	5.65	6.224	3.54	9.92	11.87	6.04
LAT5038	10.833	6.717	1.99	8.80	8.820	3.25	17.55	17.62	5.24
BGE015741	20.021	11.539	2.79	8.92	10.657	9.10	31.56	19.58	11.89

Table 22. Influence of environmental conditions on the modules seed productivity per plant and number of seeds per plant in common ax varieties (by reported value)

Variety	Year								
	2014	2015	2016	2014	2015	2016	2014	2015	2016
Module IV: nodule weight per plant									
	Component trait 1			Component trait 12			Resultant trait		
	number of nodules per plant			nodule weight			nodule weight per plant		
BGE027129	62.00	27.60	33.80	0.0079	0.0074	0.011	0.491	0.205	0.36
BGE025277	19.63	23.40	41.80	0.0128	0.0082	0.006	0.252	0.192	0.25
LAT4362	38.17	43.80	21,00	0.0085	0.0064	0.009	0.324	0.281	0.19
LA5108	14.44	15.80	1,00	0.0097	0.0176	0.100	0.140	0.278	0.10
LAT5038	30.00	7.00	1,00	0.0073	0.0181	0.100	0.219	0.127	0.10
BGE015741	28.80	31.00	16,00	0.0455	0.0096	0.010	1.311	0.297	0.16

Table 22. Influence of environmental conditions on the modules seed productivity per plant and number of seeds per plant in common ax varieties (by reported value)

Variety	Year								
	2014	2015	2016	2014	2015	2016	2014	2015	2016
Module V: fresh root weight									
	Component trait 1			Component trait 12			Resultant trait		
	saturation of the root system of one plant with nodule			nodule weight per plant			fresh root weight		
BGE027129	2.006	4.351	2.181	0.491	0.205	0.36	0.985	0.892	0.785
BGE025277	4.782	5.104	3.745	0.252	0.192	0.25	1.205	0.980	0.9362
LAT4362	3.565	3.007	2.488	0.324	0.281	0.19	1.155	0.845	0.4728
LA5108	5.000	1.640	2.636	0.140	0.278	0.10	0.7	0.456	0.2636
LAT5038	5.046	3.858	3.746	0.219	0.127	0.10	1.105	0.490	0.3746
BGE015741	0.858	2.734	5.769	1.311	0.297	0.16	1.125	0.812	0.923

The data presented in Table 24 for the average green biomass yield show that only variety LA5108 (371 kg da-1) has statistically proven differences compared to all other varieties.

Table 24. Influence of the environmental conditions on the seed yield and green mass modules of grass pea varieties (by reported value and by rank)

Variety	Year			(kg.da^{-1})	Ranks			
	2014	2015	2016	2012-2014	2014	2015	2016	Average
	Module: Grain yield							
BGE027129	138.90	100.20	100.20	113.10^{b}	1	3	3	2
BGE025277	95.10	114.90	115.00	108.30^{ab}	4	2	2	3
LAT4362	87.20	57.80	57.80	67.60^{a}	5	4	4	4
LA5108	110.80	55.00	55.00	73.60^{ab}	3	5	5	4
LAT5038	86.00	54.40	54.40	64.90^{a}	6	6	6	6
BGE015741	122.80	176.20	176.20	158.40^{c}	2	1	1	1
	Module aboveground fresh yield							
BGE027129	831.60	719.20	617.60	722.80^{b}	1	4	1	2
BGE025277	831.60	976.40	306.00	704.70^{b}	2	2	4	3
LAT4362	1022.00	988.80	327.20	779.30^{b}	3	1	3	2
LA5108	396.80	474.80	241.60	371.10^{a}	4	6	5	5
LAT5038	702.00	704.80	209.60	538.80^{ab}	5	5	6	5
BGE015741	1262.40	783.20	475.60	840.40^{b}	6	3	2	4

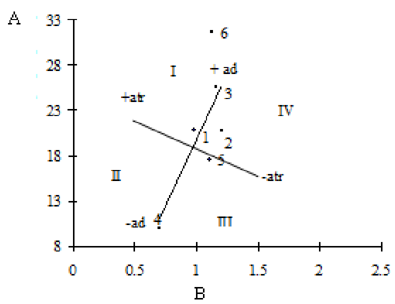
Different letters (a, b, c. . .) in the same column indicate a significant difference between treatments at $p < 0.05$

For the selection of this crop, the variety BGE027129 is of interest, which, in addition to high grain yield, has biological capabilities to develop greater above-ground biomass. It together with LAT4362 occupy the best positions according to this indicator and are rated with rank 2. In third position after them with rank 3 is the grade BGE025277.

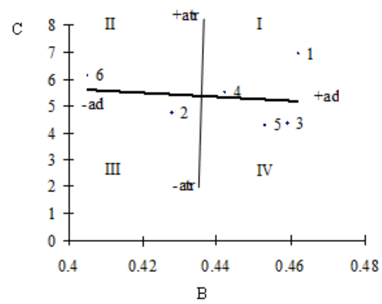
The highest yield (840.40 kg.da-1) is characterized by the variety BGE015741, but it also shows great variability (from rank 6 in 2014 to rank 2 in 2016) and is rated with an average rank of 4 for the period of research.

5.1.4.2. Method of orthogonal regressions. Genotype identification by phenotype.

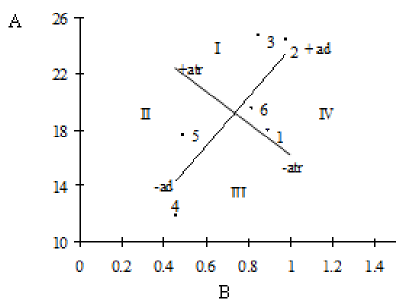
On the coordinate system in Figure 16, the abscissa shows the value of the weight of the root system of each of the gras pea samples, and on the ordinate the corresponding values are the weight of the fresh biomass or the weight of the grain of a plant (at technical maturity).



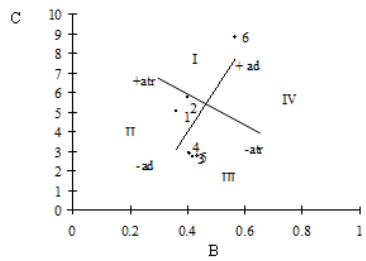
2014 - beginning of flowering



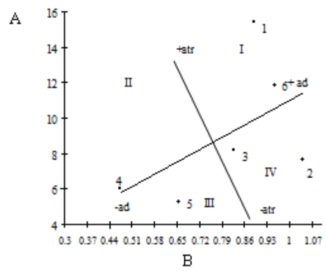
2014 - technical maturity



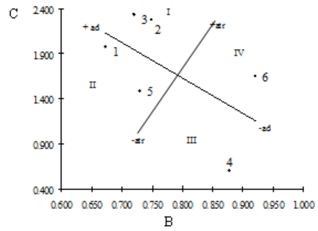
2015 - beginning of flowering



2015 - technical maturity



2016 - beginning of flowering



2016 - technical maturity

Figure 16. Distribution of mean values of grass pea varieties along the orthogonal regression line
A - weight of green biomass per plant (g), B - weight of root mass per plant (g), C - weight of seeds per plant (g),
1 - BGE027129; 2 - BGE025277; 3 - LAT4362; 4 - LA5108; 5 - LAT5038, 6 - BGE015741

When crossing varieties from the first quadrant, new genotypes with a better combination of desirable favorable genes and characterized by a positive shift along the genetic-physiological systems of attraction and adaptability can be expected. With positive adaptability and attraction are BGE027129 and LAT4362 in the favorable year 2014 in terms of fresh biomass weight. When plant development proceeds under restrictive conditions (2015) a shift of BGE027129 to the fourth quadrant is found.

Of special selection value are the genotypes in the first quadrant with adaptability, but with "weak" genes for attraction. LAT4362 retains its place in the first quadrant grown under unfavorable conditions, which suggests that it possesses gene complexes ensuring its good development in different micro-ecological niches.

From the point of view of hybrid variability, the variety BGE025277 is also of interest, which, when the cenotic situation worsened (2015), moved from the second to the first quadrant, occupying the best position in terms of adaptability.

In the negative part of the regression line are the varieties LA5108 and LAT5038. Their location in the second and third quadrants defines them as genotypes with weak adaptive capacity. LAT5038, unlike LA5108 placed under limiting conditions, moved into the second quadrant, indicating that it has a better combination of attraction genes.

In the technical maturity phase, BGE027129 has the highest grain productivity and occupies the upper right corner of the first quadrant. From its location on the coordinate system, it is clear that it possesses a reliable set of genes determining its genetic variability (attraction genes) and adaptation, but manifested only in optimal breeding conditions. In the same quadrant is the variety LA5108, which is located very close to the line of adaptability, which means that it carries weaker attraction genes.

The phenomenon of different directionality occurs under unfavorable conditions (2015). Only variety BGE015741 falls from the second to the first quadrant by passing from the negative to the positive part of the regression line, thus showing the best adaptive capacity. The cultivars LAT4362, LA5108 and LAT5038, under the same growing conditions, moved to the extreme left in the third quadrant, showing that the genetic control over adaptability in them is redefined unfavorably.

5.1.5. Genetic analysis of quantitative traits in grass pea hybrids

During the selection of nitrogen fixation - productivity of the common ax varieties, in addition to the presence of valuable genes related to signs determining the productivity of the above-ground mass of the plant, it is necessary to pay attention to signs determining specific tuber-forming ability, number and weight of tubers, length of roots, root system weight etc. Therefore, the F1-F2 hybrids and their parental forms were analyzed in the research (Table 25) in order to establish the mode of inheritance of the investigated traits.

Table 25. Distinctive features of the studied parental components

Trait/Variety	BGE027129	BGE025277	LA5108
compacted sowing			
Root mass fresh weight (g)	0.24a	0.65c	0.41b
Leaves fresh weight (g)	14.21b	9.12ab	4.19a
Aboveground fresh weight (g)	10.74a	5.23a	7.86a
Nodule number	9.78a	25.61a	10.63a
Nodule weight (g)	0.09a	0.11a	0.21a
thin sowing			
Root mass fresh weight (g)	0.42a	0.53ab	0.69b
Leaves fresh weight (g)	6.06b	13.85c	1.78a
Aboveground fresh weight (g)	4.74a	11.74b	3.47a
Nodule number	5.46a	17.61b	5.93a
Nodule weight (g)	0.03a	0.14b	0.07a

Different letters (a, b, c. . .) in the same column indicate a significant difference between treatments at $p < 0.05$

From the data presented in Table 26, it can be seen that in dense cropping, the traits root fresh weight, leaf fresh weight, plant aboveground biomass and tuber weight per plant showed a negative true heterosis reaching -86.81% -88.05% for the hybrid BGE025277 x LA5108 by number and weight of tubers per plant. An exception is the cross between LA5108 and

BGE027129, in which true heterosis is positive for tuber number. Plants from this cross, as well as the reciprocal, are distinguished by the highest level of depression.

Table 26. Biometric data of the quantitative characteristics of the investigated graqss pea crosses in dense cropping

Хибридни комбинации	F_1	F_2	Хетерозис F_1 (%)		Депресия F_2 (%)	Степени на диминиране	
	x	x	хипотетичен	истински		in F_1 (h_{p1})	in F_2 (h_{p2})
свежо тегло на корените							
LA5108 x BGE027129	0.34b	0.59c	4.62	-17.07	-73.53	0.18	6.24
BGE027129 x LA5108	0.15a	0.19a	-53.85	-63.41	-26.67	-2.06	-3.18
LA5108 x BGE025277	0.64b	1.32d	20.75	-1.54	-106.3	0.92	13.17
BGE025277 x LA5108	0.209c	0.435b	-60.57	-67.85	-108.1	-2.68	-1.58
свежо тегло на листата							
LA5108 x BGE027129	3.304a	4.323ab	-64.09	-76.75	-30.84	-1.18	-1.95
BGE027129 x LA5108	3.95a	7.14b	-57.07	-72.2	-80.76	-1.05	-0.82
LA5108 x BGE025277	4.658b	3.021a	-30.01	-48.93	35.14	-0.81	-2.95
BGE025277 x LA5108	7.701c	4.995ab	15.72	-15.56	35.14	0.42	-1.35
надземна биомаса на растението							
LA5108 x BGE027129	4.761a	8.655b	-48.81	-55.67	-81.79	-3.15	-0.9
BGE027129 x LA5108	2.622a	6.338ab	-71.81	-75.59	-141.7	-4.64	-4.11
LA5108 x BGE025277	7.518b	4.11a	14.87	-4.35	45.33	0.74	-3.7
BGE025277 x LA5108	5.505b	3.01a	-15.89	-29.96	45.32	-0.79	-5.38

Different letters (a, b, c. . .) in the same column indicate a significant difference between treatments at $p < 0.05$

Root fresh weight per plant was inherited positively dominantly (0.92) in LA5108 x BGE025277, intermediately (0.18) in LA5108 x BGE027129, and negatively superdominantly in their reciprocals. With the exception of BGE027129 x LA5108, in the remaining hybrid combinations, epistatic gene interactions play a major role in the inheritance of the trait. Negative overdominance characterized the inheritance of the traits leaf fresh weight and plant aboveground biomass in LA5108 x BGE027129 regardless of the crossing direction. With a similar type of inheritance are the hybrids obtained from crossing LA5108 with BGE025277.

Table 26. Biometric data of the quantitative characteristics of the investigated graqss pea crosses in dense cropping

Хибридни комбинации	F_1	F_2	Хетерозис F_1 (%)		Депресия F_2 (%)	Степени на диминиране	
	x	x	хипотетичен	истински		in F_1 (h_{p1})	in F_2 (h_{p2})
брой грудки на растение							
LA5108 x BGE027129	31.5b	16.5a	208.67	196.33	47.62	50.11	29.62
BGE027129 x LA5108	10.408a	3.845a	1.99	-2.09	63.06	0.48	-29.93
LA5108 x BGE025277	14.5b	51.5b	-19.98	-43.38	-255.2	-0.48	8.91
BGE025277 x LA5108	3.379a	12a	-81.35	-86.81	-255.1	-1.97	-1.63
тегло грудки на растение							
LA5108 x BGE027129	0.183bc	0.198bc	22.22	-23.42	-8.2	0.37	-1.21
BGE027129 x LA5108	0.07a	0.044a	-59.62	-74.7	37.14	-1	-2.86
LA5108 x BGE025277	0.126ab	0.52c	-25.04	-48.72	-333.3	-0.54	7.2
BGE025277 x LA5108	0.028a	0.115ab	-82.53	-88.05	-310.7	-1.79	-1.64

Different letters (a, b, c. . .) in the same column indicate a significant difference between treatments at $p < 0.05$

The F1 dominance value of LA5108 x BGE027129 shows that the inheritance of leaf fresh weight trait is negative dominant type and in the reciprocal cross BGE027129 x LA5108 the inheritance is positive dominant.

According to the fresh biomass weight of a plant, it is noticeable that the hybrid plants obtained from crossing LA5108 with BGE025277 are not depressed, while those resulting from crossing LA5108 with BGE027129 especially BGE027129 x LA5108 have a high degree of depression regardless of the favorable growing medium (thinning). Plants from the last cross under the adverse cropping environment showed no depression and a non-allelic type of inheritance of the trait (Table 27).

The lower value of the indicator degree of dominance in the second generation (F2) compared to the first (F1) determines the importance of the dominant genes in the inheritance of the traits. With a change in the medium limit (cultivation under thin cropping, (Table 27) some differences in the response of the hybrid plants to the growing medium are also observed. According to the signs fresh weight of the roots, fresh weight of the leaves and weight of the aboveground biomass of the plant the true heterosis is negative analogous to medium limit in dense cropping.

At the same seeding rate, the plants of LA5108 x BGE027129 and the reciprocal have a negative sign of the transgression coefficient. The number of genes influencing the manifestation of the trait by which the parents are distinguished is different.

In LA5108 on BGE025277 regardless of the crossing direction and the environment limit, the parents differ by 1-2 genes. In the LA5108 x BGE027129 cross, especially in the thinned crop (33.01; 20.07), it is much larger.

Table 27. Biometric data of the quantitative traits of the studied crosses grass pea in sparse sowing

Hybrids	F_1	F_2	Heterosis F_1 (%)		Depression F_2 (%)	Degrees of dominance	
	x	x	hypothetical	true		in F_1 (h_{p1})	in F_2 (h_{p2})
root mass fresh weight, g							
LA5108 x BGE027129	0.46b	0.936b	-17.12	-33.33	-103.5	-0.7	5.64
BGE027129 x LA5108	0.112a	0.306a	-79.82	-83.77	-173.2	-3.28	-3.69
LA5108 x BGE025277	0.333ab	0.989b	-45.41	-51.74	-197	-3.46	9.48
BGE025277 x LA5108	0.109a	0.323a	-82.13	-84.2	-196.3	-6.26	-7.18
leaf fresh weight							
LA5108 x BGE027129	2.392a	2.616a	-38.98	-60.53	-9.36	-0.71	-1.22
BGE027129 x LA5108	5.462ab	4.325ab	39.34	-9.87	20.82	0.72	0.38
LA5108 x BGE025277	4.749ab	6.512b	-39.23	-65.71	-37.12	-0.51	-0.43
BGE025277 x LA5108	7.85b	10.767c	0.45	-43.32	-37.16	0.01	0.98
aboveground fresh weight							
LA5108 x BGE027129	3.58a	3.485a	-12.79	-24.47	2.65	-0.83	-1.95
BGE027129 x LA5108	3.487a	2.552a	-15.05	-26.43	26.81	-0.97	-4.89
LA5108 x BGE025277	8.037b	8.401c	5.68	-31.54	-4.53	0.1	0.39
BGE025277 x LA5108	5.885ab	6.152b	-22.62	-49.87	-4.54	-0.42	-0.7

Different letters (a, b, c. . .) in the same column indicate a significant difference between treatments at $p < 0.05$

The crosses LA5108 x BGE027129 and LA5108 x BGE025277 exhibit negative dominance in fresh weight of the roots, with dominant gene actions prevailing in the latter.

Table 27. Biometric data of the quantitative traits of the studied crosses grass pea in sparse sowing

Hybrids	F_1	F_2	Heterosis F_1 (%)		Depression F_2 (%)	Degrees of dominance	
	x	x	hypothetical	true		in F_1 (h_{p1})	in F_2 (h_{p2})
nodule number							
LA5108 x BGE027129	44.667b	44.75a	684.32	653.24	-0.19	165.84	332.38
BGE027129 x LA5108	7.34a	10.427a	28.88	23.78	-42.06	7	40.27
LA5108 x BGE025277	15.667a	73.667b	-6.1	-11.03	-370.2	-1.1	123.14
BGE025277 x LA5108	3.65a	17.165a	-78.12	-79.27	-370.3	-14.08	1.04
nodule weight per plant							
LA5108 x BGE027129	0.318b	0.253a	536	354.29	20.44	13.4	20.3
BGE027129 x LA5108	0.04ab	0.056a	-20	-42.86	-40	-0.5	0.6
LA5108 x BGE025277	0.079ab	0.43b	-24.76	-43.57	-444.3	-0.74	18.57
BGE025277 x LA5108	0.018a	0.095a	-82.86	-87.14	-427.8	-2.49	-0.57

Different letters (a, b, c. . .) in the same column indicate a significant difference between treatments at $p < 0.05$

By tuber weight per plant, hybrids exhibited negative true heterosis in both growing environments. An exception is LA5108 x BGE027129, which has high heterosis (354.29) and predominant epistatic gene interactions in crop thinning. Transgression coefficients (Tp) for fresh weight of roots per plant (Table 28) were positive for the LA5108 x BGE025277 combination, and at the thinned seeding rate the reciprocal cross was almost twice as high (2.42), (Table 29).

Negative values of epistatic gene interactions in some crosses under changing environmental conditions indicate suppression of dominant allele expression leading to lower phenotypic expression of the trait. The values of broad sense heritability coefficients (H2) and selection efficiency coefficients (Pp) are high for LA5108 x BGE025277, which indicates that in the general phenotypic expression of this trait, the genotype has a relatively high share in both condensed and diluted sowing.

In the hybrid plants from this cross, selection by phenotype can start already in the early generations (F2 – F3). In LA5108 x BGE027129 with thinning of the crop, the parameter (Pp) for the selection efficiency has a negative sign, indicating that despite the high heritability, the selection for this trait will be effective in the later hybrid generations (F5 – F6). Regarding the fresh weight of the leaves, a positive transgression (Tp) was found for all combinations in dense cropping. In the LA5108 x BGE025277 combination, both the reciprocal and the transgression were higher than the other hybrid crosses, even at a thinning of the crop where all the values of this indicator were negative.

Table 28. Values of the gene parameters of the quantitative traits of the studied grass pea crosses in the F2 hybrid generation in a dense crop

Crosses/ Parameters	T_n	N	D	E	H^2	Pp
root mass fresh weight, g						
LA5108 x BGE027129	3.55	0.10	0.15	-0.18	0.914	0.49
BGE027129 x LA5108	1.27	7.37	2.71	-2.47	0.933	0.16
LA5108 x BGE025277	2.53	0.42	0.4	-0.39	0.91	0.47
BGE025277 x LA5108	2.10	0.03	-0.17	0.09	0.987	0.47
leaf fresh weight						
LA5108 x BGE027129	6.27	0.01	0.68	-0.02	0.987	0.40
BGE027129 x LA5108	8.17	0.07	0.08	0.16	0.914	0.49
LA5108 x BGE025277	11.45	2.59	-2.12	1.20	0.929	0.14
BGE025277 x LA5108	14.64	0.17	-0.31	-0.23	0.98	0.50
aboveground fresh weight						
LA5108 x BGE027129	9.10	11.45	-4.49	3.55	0.983	-0.19
BGE027129 x LA5108	12.16	6.62	-2.69	2.30	0.93	0.12
LA5108 x BGE025277	10.79	1.05	0.21	-0.69	0.931	0.61
BGE025277 x LA5108	21.81	0.03	-0.26	-0.07	0.975	0.46
nodule number						
LA5108 x BGE027129	3.84	34.59	6.10	-8.03	0.41	-0.03
BGE027129 x LA5108	22.02	36.95	9.32	-9.14	0.98	-1.27
LA5108 x BGE025277	0.68	101.1	3.53	15.81	0.1	-3.73
BGE025277 x LA5108	28.05	1.71	-0.9	0.91	0.94	0.29
nodule weight per plant						
LA5108 x BGE027129	6.65	0.00	-0.03	0.01	0.925	0.49
BGE027129 x LA5108	0.01	49.80	11.41	-11.78	0.79	-1.52
LA5108 x BGE025277	5.19	0.00	0.03	-0.03	0.91	0.50
BGE025277 x LA5108	4.24	0.01	-0.08	0.06	0.945	0.49

Tn - manifestations of transgression; N - number of genes by which the parental forms differ; D - manifestations of dominance; E - epistatic gene effects; H2 - coefficient of heritability in a broad sense; Pp - coefficient of effectiveness of the mass team;

When the crop is thickened, the parental forms differ insignificantly in terms of the number of genes determining the expression of the trait. Positive values of epistatic interactions (E) predominated in the cross LA5108 x BGE025277. As a result, a high proportion of individuals from successive generations of collapsing populations with enhanced phenotypic expression of the trait can be expected. In LA5108 x BGE027129, the type of gene interactions is also preserved.

Negative epistatic interactions imply a reduction in the degree of phenotypic manifestation of that trait compared to full additive inheritance. The genetic share in the total phenotypic expression is high especially in dense cropping, which is evident from the relatively high values of heritability coefficients (from 0.15 to 0.983).

These data, as well as the relatively high values of team efficiency coefficients (Pp) - for BGE027129 x LA5108 (0.49-0.67) and BGE025277 x LA5108 (0.50-0.48) indicate that the team on leaf fresh weight will be effective and can to take place in the earlier hybrid generations (F2 - F3).

The number of genes (N) by which the parental forms differ in terms of the productivity of the fresh aboveground biomass is not large (1 – 2). An exception is LA5108 x BGE027129 and the reciprocal and in dense sowing (6-11).

In the present study, negative D values indicate that dominant alleles determine lower aboveground biomass per plant. Positive values for epistatic gene interactions (E) were observed only when crossing cultivar LA5108 with BGE027129, reinforcing the action of dominant alleles and leading to stronger phenotypic expression.

The high coefficients for heritability of the trait (H2>0.90) and that of team effectiveness (Pp) for LA5108 x BGE025277 and BGE025277 x LA5108 from 0.46 to 0.61, give reason to predict that for this trait, the team will be effective in -early hybrid generations.

Participating crosses differed significantly among themselves in the number of genes (N) determining the trait, from 2 in BGE025277 x LA5108 to 26 in LA5108 x BGE027129.

The data on the number of tubers per plant show that the number of genes that differentiate the original parental forms varies widely (N from 1 to 11 in thin seeding and from 1.7 to 101 in dense seeding). Dominant alleles of the indicated genes (D) act in the direction of determining a greater number of tubers per plant (except BGE025277 x LA5108).

The highest transgression indicators (Tp) were found in the hybrid plants of the combination between LA5108 x BGE027129 grown under conditions of a larger food area. In the decaying hybrid generations of the two crosses, genotypes with greater probability of gene combinations leading to an increase in the number of tubers per plant can be expected. Predominantly negative values for epistatic interactions (E) indicate the potential for lower phenotypic expression of the trait in subsequent generations. In the present study, heritability coefficients (H2) were high in all crosses except LA5108 x

BGE025277 (0.10).Based on the values of the selection efficiency parameter (Pp), we can predict that the selection of plants with increased number of tubers will be more efficient in later generations (F5 – F6).

Таблица 29. Values of the gene parameters of the quantitative traits of the studied crosses grass pea in the F2 hybrid generation in a thin crop

Crosses/ Parameters	T_n	N	D	E	H^2	Pp
root mass fresh weight, g						
LA5108 x BGE027129	-5.12	33.01	-14.14	9.23	0.94	-1.89
BGE027129 x LA5108	-4.70	20.07	-9.68	5.99	0.977	-1.21
LA5108 x BGE025277	1.25	0.07	-0.51	0.11	0.982	0.41
BGE025277 x LA5108	2.42	1.25	0.71	-0.75	0.97	0.45
leaf fresh weight						
LA5108 x BGE027129	-2.99	26.08	7.39	-6.84	0.71	-0.85
BGE027129 x LA5108	-3.49	6.18	0.65	-2.00	0.31	0.67
LA5108 x BGE025277	-0.37	2.66	-2.09	1.22	0.929	0.21
BGE025277 x LA5108	-0.79	2.30	0.06	1.09	0.15	0.48
aboveground fresh weight						
LA5108 x BGE027129	12.86	0.49	-0.65	0.41	0.98	0.41
BGE027129 x LA5108	1.54	0.49	-0.70	0.41	0.979	0.50
LA5108 x BGE025277	19.42	0.18	-0.28	0.25	0.983	0.47
BGE025277 x LA5108	2.32	0.62	-0.66	0.48	0.913	0.59
nodule number						
LA5108 x BGE027129	42.36	0.05	0.14	-0.13	0.99	0.62
BGE027129 x LA5108	163.95	0.20	0.33	-0.25	0.99	0.65
LA5108 x BGE025277	4.49	8.67	3.20	-2.81	0.76	0.08
BGE025277 x LA5108	17.38	11.21	5.92	-3.65	0.98	-0.99
nodule weight per plant						
LA5108 x BGE027129	2.12	0.01	-0.23	0.03	0.952	0.46
BGE027129 x LA5108	0.08	30.56	6.63	-7.48	0.51	-0.28
LA5108 x BGE025277	2.61	0.00	0.00	-0.01	9.06	0.50
BGE025277 x LA5108	4.06	0.01	0.10	-0.03	0.915	0.48

Tn - manifestations of transgression; N - number of genes by which the parental forms differ; D - manifestations of dominance; E - epistatic gene effects; H2 - coefficient of heritability in a broad sense; Pp - coefficient of effectiveness of the mass team;

The transgression index (Tp) values show that in the resulting F2 populations from the LA5108 x BGE027129 and BGE025277 x LA5108 crosses, individuals possessing a significantly higher tuber mass per plant can be successfully selected compared to the parental forms . The estimated number of genes that differed parental forms in tuber weight was too small, except for BGE027129 x LA5108 in both growing environments (30.56-49.80).

Interallelic interactions (E) were positive, albeit low, in the LA5108 x BGE027129 combination. Heritability coefficients (H2) are relatively high and it can be assumed that the genetic share in the phenotypic expression of the trait is greater. Selection efficiency (Pp) values suggested that selection of forms with higher tuber weight would be effective in earlier generations especially for LA5108 x BGE025277 and BGE025277 x LA5108.

5.2. Studies on the white lupine (Lupinus albus L.)

5.2.1. Genetic distance of white lupine cultivars according to morphological characters

The study of the regularities of the variation of the quantitative signs makes it possible to objectively select more material for crossing, taking into account the influence of their modification variability. They are also the factor with the largest share on the variation of the indicators. An exception is tuber-forming ability, where the share of the genotype is almost twice that of the environment (Table 34).

From the analysis of variance in the present study, the statistically reliable influence of the years on the manifestation of the signs was established. Although significantly lower, the influence of the genotype in the general variation of the signs was also proven, which shows that there are significant genotypic differences between the varieties of white lupine. These facts allowed to calculate the reliability of the differences between the arithmetic means of the varieties participating in the sample. According to the individual characteristics analyzed, the genotypes are divided into a different number of groups, statistically reliably different from each other.

Genotypes with tall plants are prone to lodging especially under conditions of intensive farming, which leads to disruption of the grain pouring process and to incorrect information about their qualities. During the study period, plant height (Table 35) ranged from 46.27 cm (PI368911) to 57.30 cm (Lucky801).

Among the studied samples, the varieties Zuter (56.33 cm), PI457923 (54.20 cm) and PI533704 (52.47 cm) can be attributed to the group of high-growing ones.

Table 34. Analysis of the variance of the studied characters in the white lupine samples

Source of variation	df	MS						
		Nodule number	nodule weight	specific nodulating ability	root length	root fresh weight	leaf dry weight	leaf number
Environments (E)	2	607.2245**	0.4774**	0.0343*	364.3278**	133.6580**	19.5890**	13,970.7154**
Genotypes (G)	6	317.5450**	0.2001**	0.0588**	22.2653**	7.1864**	0.7727**	647.2919**
Остатък	12	25.1351	0.0254	0.0080	3.9155	1.8915	0.2007	79.5857
Source of variation	df	leaf fresh weight	leaf dry weight	stem fresh weight	stem dry weight	Plant height, cm	aboveground fresh weight	aboveground dry weight
Environments (E)	2	1,076.06**	26.79**	674.74**	986.62**	16,202.4**	6,921.8**	1,316.6019**
Genotypes (G)	6	51.905**	2.28**	153.73**	26.08**	302.63**	110.3798*	20.0620**
Остатък	12	9.951	0.341	20.70	5.45	47.23	44.16	6.3371

*/ ** significant at $p < 0.05$ / 0.01

Table 35. Characteristic features of the investigated white lupine samples

	Aboveground mass						Root mass	Nodules	
Cultivar	plant height	number of pods	number of seeds	seeds weight (g)	number of leaves	fresh weight (g)	fresh weight (g)	nubmer	weigt (g)
PI457923	54.20	9.74	27.23	7.69	18.26	15.47	1.92	10.20	0.40
PI368911	46.27	8.92	24.62	5.73	21.44	18.05	2.03	8.00	0.23
PI533704	52.47	11.70	32.54	7.80	16.48	19.40	1.59	5.20	0.16
PI457938	47.60	9.33	25.67	6.42	24.97	23.20	1.97	8.00	0.42
KALI	47.57	10.54	24.64	5.92	20.43	17.67	1.12	3.40	0.11
Zuter	56.33	10.30	28.79	8.77	19.35	15.12	1.30	6.78	0.39
Lucky801	57.30	9.23	28.27	8.63	22.15	17.66	2.22	15.93	0.35
$LSD_{0.05}$	9.47	4.78	12.06	3.30	7.17	10.80	1.22	9.58	0.25
$LSD_{0.01}$	13.27	6.70	16.91	4.63	10.05	15.14	1.71	13.4	0.35
$LSD_{0.001}$	18.77	9.48	23.91	6.54	14.21	21.41	2.43	18.9	0.50

The reproductive capacity determined by the number of seeds of a plant is a main feature ensuring the selection advantage of the genotype. On average, during the study period, the varieties PI533704 and Zuter managed to form about 10-11 beans with 28-32 number of seeds per plant. KALI also produces a large number of pods (10-11) but with fewer seeds (24) per plant.

Zuter and Lucky801 are distinguished by the highest productive capabilities in terms of seed weight per plant, where the seed mass reaches 8.63-8.77 g. Under the specific test conditions, the least productive were PI368911 and KALI (5.73-5.92 g).

The varietal characteristics of PI368911, PI533704 and especially PI457938 (23.20 g.) allow them, under the specific weather conditions, to form a quantitatively significant productivity of above-ground mass in a fresh state compared to the other samples. In the conducted studies, the lowest fresh weight per plant (15.12-15.47 g) was characterized by the varieties Zuter and PI457923.

According to the weight of the root system, the varieties Lucky801 and PI368911 with a fresh weight of the roots above 2 grams per plant are of interest, followed by PI457938 (1.97 g) and PI457923 (1.92 g). The varieties KALI and Zuter are distinguished by the lowest weight of the roots (1.12-1.30 g).

The number of tubers varies from 15.93 to 3.40. On average over the period, Lucky801 has a great advantage over the other varieties and has formed the most tubers. PI457923, PI368911 and PI457938 managed to form 8-10 tubers and the rest between 3 and 6-7. Regarding the tuber weight trait, considerable diversity was observed between cultivars. Tuber weights ranged from 0.11-0.16 in KALI and PI533704 to 0.40-0.42 in PI457923 and PI457938.

The necessary phenological observations were carried out during the comparative assessment of white lupine varieties according to early maturity.

The studied samples of white lupine show varietal characteristics in terms of the duration of the period of sowing - beginning of flowering. PI533704 and Zuter were the earliest to flower (59 days), followed by PI368911, PI457938 and KALI

(60 days). This period is slightly longer in the varieties Lucky801 and PI457923 (62-63 days). Lucky801 and PI457923 ripen later and reach technical maturity in an average of 107 - 109 days. To the group of ultra-early varieties can be attributed PI533704 and Zuter with an early maturity coefficient of 1.00, to early PI368911, PI457938 and KALI with a coefficient of 1.25 and late Lucky801 and PI457923 with a coefficient greater than 1.66.

According to the indicators related to the above-ground biomass traits, the weakest variation in the sample of studied cultivars was observed in relation to the dry weight of the leaves (PCV – 17.48%; GCV – 4.37%) with the lowest phenotypic and genotypic coefficient of variation calculated respectively (Table 37).

Table 37. Genetic components of quantitative trait variation in white lupine samples

Trait/Parameter	Min	Max	Vg	Ve	GCV (%)	PCV (%)	GA	GG	H2 (%)
Nodule number	1.90	15.90	10.52	25.14	16.75	20.18	2.97	178.39	49.70
Nodule weight	0.10	0.40	0.01	0.03	12.50	15.24	0.24	166.27	50.09
Specific nodulating ability	0.10	0.20	0.001	0.01	8.71	24.89	0.09	145.64	80.81
Root length	8.10	12.10	0.11	3.92	10.62	20.82	0.23	49.14	44.10
Root fresh weight	1.60	3.60	0.46	1.89	7.61	25.37	0.41	102.79	21.61
Leaf dry weight	0.40	1,00	0.01	0.2	-	-	0.11	113.99	14.79
Leaf number	25.90	44.50	29.16	79.59	20.45	30.07	3.56	54.14	67.58
Leaf fresh weight	6.70	12,00	1.09	9.95	17.35	27.98	0.41	72.03	31.47
Leaf dry weight	0.80	2.10	0.09	0.34	4.37	17.48	0.01	51.77	59.23
Stem fresh weight	7.60	17.80	6.99	20.7	20.07	31.36	2.81	99.39	68.24
Stem dry weight	4.40	8.20	1.09	5.46	22.61	34.78	0.31	89.99	62.60
Plant height, cm	51.20	65.10	1.84	47.23	42.84	48.68	7.37	71.97	9.12
Aboveground fresh weight	15.10	23.20	0.02	44.16	51.22	32.62	1.25	71.52	88.05
Aboveground dry weight	5.80	9,00	0.71	6.34	42.07	33.66	0.31	63.88	53.31

Vg: - genetic variance; Ve: - phenotypic variance PCV (%) - phenotypic coefficient of variation GCV (%) - genotypic coefficient of variation; ; GA - genetic progress; GG - genetic gain; H2 (%) - heritability in a broad sense

Significant variation was recorded for the other characters, especially plant height (PCV – 48.68%; GCV – 42.84%), dry stem weight (PCV – 34.78%; GCV – 22.61%), dry and fresh biomass weight (PCV – 33.66% ; GCV – 42.07%; PCV – 32.62%; GCV – 51.22%). The small difference in PCV and GCV values by plant height suggests that the observed variation is due to genetic factors. The variation in the signs related to the root system is within smaller limits.

It is most significant in relation to the fresh weight of the roots (PCV – 25.37%; GCV – 7.61%) and the specific tuber-forming ability (PCV – 24.89%; GCV – 8.71%). Weaker variation was recorded for the indicator of tuber weight per plant (PCV – 15.24%; GCV – 12.50%). The genetic variance (Vg) values ranged from 0.001 for specific tuber-forming ability to 29.16 for number of leaves per plant, while the phenotypic variance (Vp) values ranged from 0.001 for specific tuber-forming ability to 43.15 again for number of leaves per plant.

The genetic variance value of almost all traits is less than the corresponding phenotypic variance value. Exceptions are tuber weight per plant and specific tuber-forming ability, where genetic and phenotypic variance are equal, which is an indication of the significant magnitude of their genetic variability.

Higher environmental variance (Ve) for number of leaves per plant (79.59), plant height (47.23), aboveground biomass fresh weight (44.16) and number of tubers per plant (25.14) indicated that they were strongly influenced by environment in which the plants develop, while for the other signs this influence is weaker. The genetic variance (Vg) values ranged from 0.001 for specific tuber-forming ability to 29.16 for number of leaves per plant, while the phenotypic variance (Vp) values ranged from 0.001 for specific tuber-forming ability to 43.15 again for number of leaves per plant.

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In the present study, the traits specific tuber bearing ability (H2 – 80.81%) and aboveground fresh biomass weight (H2 – 88.05%) showed relatively higher heritability coefficient values in a broad sense (Table 36) followed by stem fresh weight (H2 – 68.24%), number of leaves per plant (H2 – 67.58%) and weight of dry stems (H2 – 62.60%).

Genetic progress (GA) in selection refers to the improvement of traits in the future new population compared to the starting population. High genetic advancement (GA) combined with high heritability was obtained for number of leaves per plant (3.56), stem fresh weight (2.81) and fresh biomass weight (1.25), suggesting the additive type of their inheritance and that they are more -weakly dependent on the conditions of the external environment. High heritability combined with low genetic progress was found for specific tuber-forming ability and dry stem weight, indicating the involvement of non-additive gene actions (dominance and epistasis).

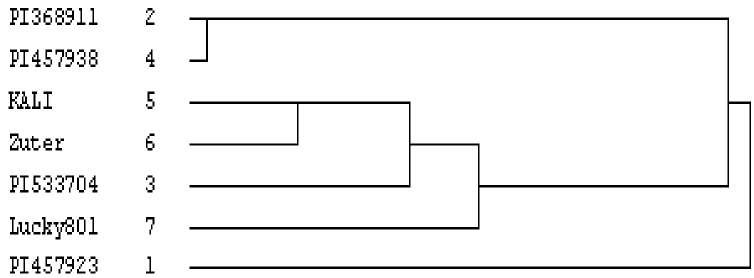


Figure 21. Dendrogram of the white lupine samples (2014-2016)

Based on the data for the investigated characteristics, a cluster analysis was made, according to which the samples are divided into two main clusters. From the dendrogram in Figure 21, it can be seen that the first cluster is represented by only one variety PI457923. The second cluster is covered by the remaining varieties, formed in two subclusters. The first group within the cluster was the most numerous and included Lucky801, PI533704, KALI and Zuter, with the last two cultivars being the most closely related. The second group of the same cluster is smaller and is represented by PI368911 and PI457938, which are genetically most distant from PI457923. The 38 factors listed in the table determine about 89.27% of the total variation.

The first factor explains (Table 38) 42.16%, the second 20.73%, the third 19.21% and 7.17%. The first principal component was related to dry leaf weight and dry aboveground biomass, number and weight of fresh leaves, and root length.

Table 38. Eigenvalues and vectors of the correlation matrix for 14 characters in white lupine varieties

Trait	PC1	PC2	PC3	PC4
Nodule number	-0.1395	0.5054	-0.0351	0.3001
Nodule weight	-0.2723	0.0923	-0.4128	-0.0892
Specific nodulating ability	-0.226	-0.2289	-0.3638	-0.3146
Root length	0.1461	-0.3828	-0.2096	0.5731
Root fresh weight	-0.0927	0.2798	-0.3662	0.004
Leaf dry weight	-0.3779	-0.1111	-0.1755	0.0261
Leaf number	0.195	0.4349	-0.2547	-0.1618
Leaf fresh weight	0.1153	-0.4464	-0.2626	-0.0719
Leaf dry weight	0.2263	0.1376	-0.3941	0.2737
Stem fresh weight	-0.3356	-0.0862	0.0511	-0.3834
Stem dry weight	-0.3937	-0.0753	0.0054	0.2346
Plant height, cm	-0.3614	0.1538	0.1197	0.0359
Aboveground fresh weight	0.2107	-0.0078	-0.4055	-0.2244
Aboveground dry weight	-0.3707	-0.0484	-0.1293	0.3376
Parameters				
Eigen value	5.90	2.90	2.68	1.004
Cumulative (%)	42.16	62.89	82.09	89.26
Variability (%)	42.16	20.73	19.21	7.17
Standard deviation	2.43	1.70	1.64	1.002

PC1; PC2; PC3; PC4 = principle components 1, 2 and 3 respectively

With most of the signs affecting the first main, the second has a negative or slightly positive relationship. To a greater extent, the second principal component was influenced by number of tubers per plant, number of leaves, fresh weight of roots, plant height, and weight of tubers per plant. Of the studied traits, only three stem fresh weight, stem dry weight and plant height positively influenced the three main components. The fourth principal component is primarily related to root length and dry aboveground biomass weight. The number of tubers per plant, the weight of dry leaves and stems also have a less positive influence.

Figure 22 shows sample values for the first three principal components. PI457923, Zuter, and Lucky801 have positive values on all three components, and the remaining cultivars have positive values on the first and second third principal components.

The cultivars PI457923 and PI533704 were more strongly affected by the first principal component. The second principal component has a more significant impact on PI368911, PI457938 and Lucky801. There is no significant difference in the influence of the first two principal components on KALI and Zuter.

Figure 23 plots the samples according to their values for the first (PC1) and second factor (PC2). Samples PI457923 and Lucky801 have negative values on PC1 and positive values on PC2. Their location on PC1 is determined by the indicators related to the formation of the number of leaves, the weight of dry leaves and the weight of aboveground fresh biomass, and on PC2 by the low values of fresh weight of leaves, length of roots and the specific tuber-forming ability.

The samples KALI and PI533704 are located in the sector with positive values on PC1 and with negative values on PC2. Their location relative to the first principle component is determined by root length and fresh leaf weight, and their negative PC2 values are related to the elements dry weight of root mass and weight of fresh and dry stems.

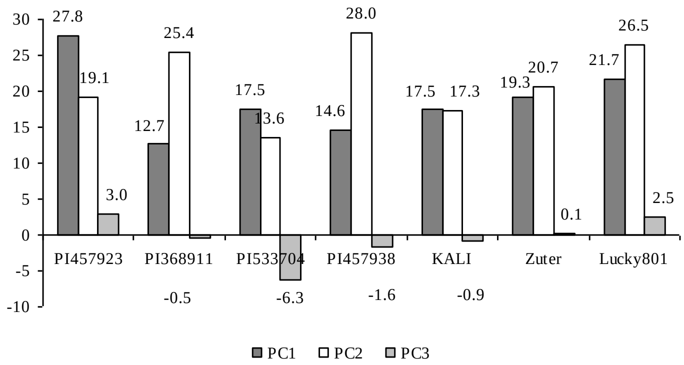
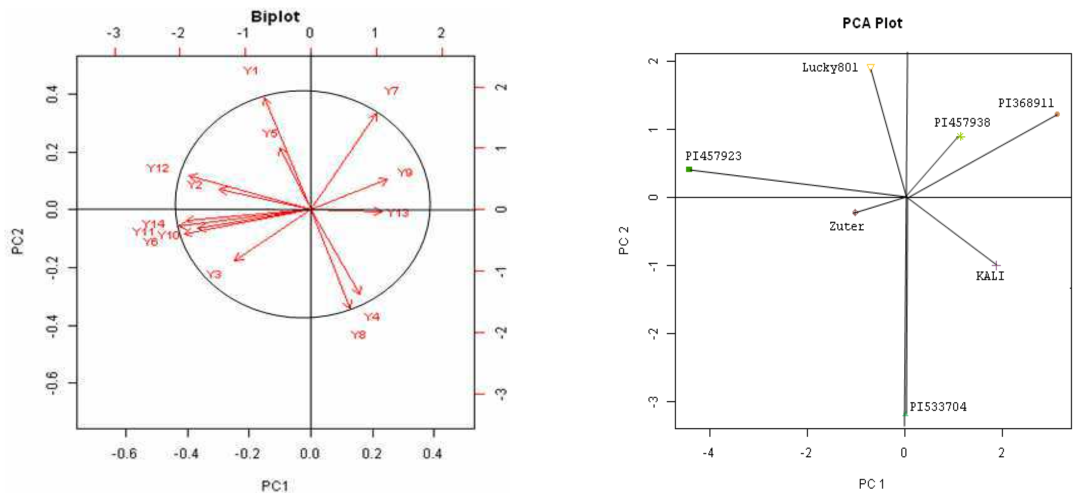


Figure 22. Values of the white lupine varieties according to the components PC1; PC2; PC3; PC3 = principal components 1, 2 and 3;

The varieties PI368911 and PI457938 are located in the plane with positive values for both principle components. Determining their position in this quadrant are number of leaves per plant, weight of fresh and dry aboveground biomass, number of tubers and fresh weight of root mass.



A B

Figure 23. Projection of varieties and traits on the vector plane.
A - for the quantitative signs: Y1 - number of tubers; Y2 - tuber weight; Y3 - specific tuber-forming ability; Y4 - length of roots; Y5 - fresh weight of roots; Y6 - dry weight of roots; Y7 - leaf number; Y8 -leaf fresh weight; Y9 -leaf dry weight; Y10 - stems fresh weight; Y11 - stems dry weight; Y12 - plant height; Y13 - aboveground mass fresh weight; Y14 - aboveground mass dry weight; B - for the white lupine samples;

The Zuter variety appears as independent of the coordinate system in the negative part of both principle components. Its localization there is due to the signs specific tuber-forming ability, weight of dry above-ground biomass, dry weight of roots, weight of dry and fresh stems.

The vectors of root dry weight, stem fresh and dry weight, and aboveground dry weight signs form sharp angles, indicating a strong positive relationship between them. The relationship between the number of tubers and the fresh weight of the roots is of the same sign; tuber weight and plant height; root length and leaf fresh weight. The correlation coefficients between the studied signs were established.

5.2.2. Evaluation of traits of white lupine cultivars for ecological stability

According to the data from the dispersion analysis (Table 40), the studied varieties differ reliably in their genetic essence, with the exception of the trait weight of seeds in beans, where the influence of none of the sources of variation was statistically proven .

The values of mean sum of squares for plant height, number of seeds per plant and weight of seeds per plant show that the influence of the growing environment is many times stronger than the influence of the other two factors genotype (variety) and the interaction «genotype-environment» . The significant variation of these signs by year shows that their formation depends to a large extent on the changing growing conditions. The cultivar factor had a greater share of influence than the total variation in plant height and seed weight relative to the genotype-environment interaction. In the number of seeds and beans per plant, the latter factor has a larger share.

Table 40. Analysis of variance for plant seed weight stability and grain yield elements of white lupine cultivars

Source of variation	Df	MS				
		plant height, cm	Number of pods per plant	Number of seeds per plant	Seeds weight per plant	Seeds weight per pod
Environments (E)	2	19852.47**	8.95*	2266.74**	163.15**	2.43
Genotypes (G)	6	307.69**	13.81**	118.61**	23.76**	0.41
G x E nteractions	12	141.73**	36.17**	230.05**	17.24**	0.11
E/G	14	2957.55**	32.28**	521.01**	38.08**	0.44
E/ PI457923	2	4041.60**	67.84**	860.68*	68.70**	0.07
E/ PI368911	2	1501.07**	5.93*	9.31**	0.50	0.32
E/ PI533704	2	2844.87**	34.27**	975.77**	56.01**	0.24
E/ PI457938	2	2071.40**	60.68**	678.90**	42.43**	0.51
E/ KALI	2	2133.32**	17.15**	160.35**	9.25*	0.21
E/ Zuter	2	3943.47**	7.39*	137.22**	12.73**	0.99
E/ Lucky801	2	4167.15**	32.68**	824.82**	76.95**	0.74
Total	20					

*/ ** significant at $p < 0.05$ / 0.01

The calculated parameters of the phenotypic stability of each variety according to the studied traits are presented in table 410. The Lucky801 variety is characterized by a marginal value of the trait plant height, but also with a maximum value of the "bi" parameter (bi=1.21).

It can be referred to the genotypes with well-expressed ecological plasticity. Zuter (bi=1.18) and PI457923 (bi=1.18), whose plants are also tall, belong to the same group responsive to improvement of growing conditions. The varieties PI368911, PI457938, KALI are lower, and with a coefficient of "bi"<1, which testifies to their stability under deteriorating conditions.

Table 41. Assessment of adaptability and stability parameters for the traits of the studied white lupine varieties

Variety	Eberhart and Russell (1966)		Tai (1979)		Theil (1950)	Plaisted and Peterson (1979)	Wricke (1965)	Annicchiarico (1992)
	bi	Si^2	ai	λi	T	PP	W^2	W_i
plant height, cm								
PI457923	1.18**	47.569**	1.18	139.282	96.54	38.15	414.53	95.02
PI368911	0.71**	23.167**	0.71	68.267	95.44	48.00	583.33	84.60
PI533704	1.00	1.826**	1.00	5.910	99.79	14.56	10.13	99.92
PI457938	0.85**	0.937*	0.85	3.344	99.84	21.35	126.53	90.46
KALI	0.87**	2.565**	0.87	8.060	99.62	20.73	115.83	90.37
Zuter	1.18**	1.283*	1.18	4.320	99.89	24.96	188.40	105.27
Lucky801	1.21**	1.427**	1.21	4.690	99.89	29.26	262.03	105.83
Number of pods per plant								
PI457923	5.59**	10.988**	6.16	28.687	58.66	9.815	109.69	73.70
PI368911	-2.15*	-0.200	-2.55	-1.867	100.00	4.901	25.44	79.65
PI533704	3.07*	8.690**	3.33	25.127	34.97	6.649	55.40	101.66
PI457938	4.11	15.440**	4.50	43.801	35.39	9.420	102.91	70.59
KALI	-0.58	6.486**	-0.78	19.031	2.26	5.740	39.83	92.15
Zuter	-0.99	2.254**	-1.24	6.412	16.77	4.724	22.41	93.72
Lucky801	-2.04*	10.754**	-2.42	30.222	15.98	7.986	78.33	73.78

*/ ** significant at $p < 0.05$ / 0.01

Variety PI533704 has a statistically insignificant regression coefficient with a value of 1.00, which defines it as close as possible to the "ideal" genotype for this trait. The values of the other stability parameters, combined with the numerical expression of the feature, also determine it as the most preferred. The criteria (PP) of Plaisted and Peterson (1959) and ecovalence (W2) of Wricke (1965) determined the cultivars PI368911 and Zuter as the most stable for the trait number of beans per plant. These two varieties managed to form an average of about 9 - 10 beans per plant over the years of testing, second only to variety PI533704 forming 10 - 11 beans. PI457923 and PI457938 are characterized by high variability and medium high biological potential in terms of number of beans.

A high regression coefficient (bi) of 1.23 to 1.67 defines the varieties PI457938, Lucky801, PI457923 and PI533704 as ecologically unstable in number of seeds per plant, but with some responsiveness. The varieties PI533704 and Lucky801 under favorable development conditions can provide a relatively large number of seeds per plant.

The variety PI368911 is low productive with respect to this trait. From the values of bi (bi=0.13), as well as other parameters, it is clear that this variety is ecologically stable and low adaptive. Its low biological potential does not allow it to have an advantage over other varieties.

According to the information provided by all stability parameters (tables 41), Zuter is close to the ideal type combining high productivity (large number of seeds per plant) with ecological stability. This variety is suitable for growing in a wide range of environmental conditions. The study of cultivars by seed mass of a plant shows that its numerical expression depends on both the growing environment and the genotype. The variety Zuter is distinguished by the highest seed mass, followed by Lucky801, PI533704 and PI457923.

The values of the stability parameters show that variety PI533704 under certain favorable environmental conditions can develop its potential and form an even greater number of beans per plant. From the evaluation of the varieties for ecological stability, it is evident that the variety PI368911 has the lowest value of the regression coefficient (bi=0.11), which testifies to its stability and low adaptability.

Lucky801, PI533704 and PI457923 are highly productive but ecologically unstable (bi >1). They are suitable for growing at a high level of agrotechnics. Of selective interest is the Zuter variety, which has a high seed mass per plant and good environmental stability according to the stability evaluation criteria used. The KALI cultivar is also low variable, but with an unsatisfactory level of the trait compared to almost all other cultivars.

In terms of plant height, the varieties Lucky801 and Zuter are distinguished by the tallest plants, and the variety PI368911, occupying the extreme left position of the coordinate system, is characterized by the lowest plants. According to this indicator, PI457923 turns out to be the most variable. The high yielding cultivars Lucky801 and Zuter exhibited lower stability than the lower growing cultivars PI533704 and PI457938.

Table 41. Assessment of adaptability and stability parameters for the traits of the studied white lupine varieties

Variety	Eberhartand Russell (1966)		Tai (1979)		Theil (1950)	Plaisted and Peterson (1979)	Wricke (1965)	Annicchia-rico (1992)
	bi	Si^2	ai	λi	T	PP	W^2	W_i
Number of seeds per plant								
PI457923	1.36**	105.558**	1.36	308.429	59.92	58.47	611.32	75.18
PI368911	0.13**	1.369*	0.13	4.494	45.01	51.93	499.23	79.93
PI533704	1.67**	27.609**	1.67	81.017	90.70	48.02	432.30	102.06
PI457938	1.23*	76.676**	1.23	224.205	63.07	47.16	417.45	73.26
KALI	0.63**	13.187**	0.63	39.040	72.77	31.99	157.54	82.34
Zuter	0.65**	0.679*	0.65	2.552	97.91	27.80	85.68	99.65
Lucky801	1.34**	95.931**	1.34	280.346	61.98	55.30	557.07	80.12
Seeds weight per plant								
PI457923	1.43	8.298**	1.43	24.755	59.75	4.498	50.98	79.94
PI368911	0.11**	-0.115	0.11	0.115	45.31	3.693	37.18	69.91
PI533704	1.49	1.371*	1.50	4.540	90.87	2.648	19.27	92.19
PI457938	1.14	4.636**	1.14	14.102	62.91	2.988	25.11	68.95
KALI	0.56	0.566	0.56	2.201	73.06	2.271	12.81	74.41
Zuter	0.73	-0.116	0.73	0.234	97.84	1.742	3.75	114.11
Lucky801	1.53	8.711**	1.53	25.942	62.32	4.891	57.73	92.18

*/ ** significant at $p < 0.05 / 0.01$

The "ideal" genotype is the one that has both a high mean expression of the studied trait and a high stability in different environments. In reality, such a genotype may not exist, but it can be used as a benchmark when evaluating genotypes. In terms of number of beans per plant, the length of the vectors defined the cultivars PI457923 and PI457938 as highly variable.

The short vector at PI368911 characterizes the variety as stable, but it forms few beans per plant. The cultivar PI533704 is in a more favorable position due to the higher expression of the trait. The most desirable variety is KALI, which exhibits an average level of trait stability and manages to form relatively many beans per plant. The absolute favorite in number of seeds per plant is variety PI533704, followed by Lucky801, which is highly unstable as can be seen from the figure itself.

The variety Zuter is less productive than PI533704, but forms a very short vector with the axis characterizing the stability of the genotypes, which gives it a certain advantage when grown in different growing environments. The cultivars PI368911, KALI and PI457938 are low yielding and highly variable. With regard to the trait of plant seed weight, the distribution of varieties on the coordinate system shows that growing environments have a different influence on the manifestation of the trait in individual genotypes.

The varieties PI368911 and KALI can be defined as stable and low productive with the lowest seed weight. Variety PI457923 is relatively high yielding and highly variable. Of breeding interest is Zuter, which is stable and highly productive.

Lucky801 is ecologically unstable, but is also highly productive and could be included in future breeding programs to obtain new forms with increased seed weight from a plant. Correlation analysis of ecological stability parameters showed that seed mass per plant was closely related to the Wi index of Annicchiarico (1992) (r=0.87).

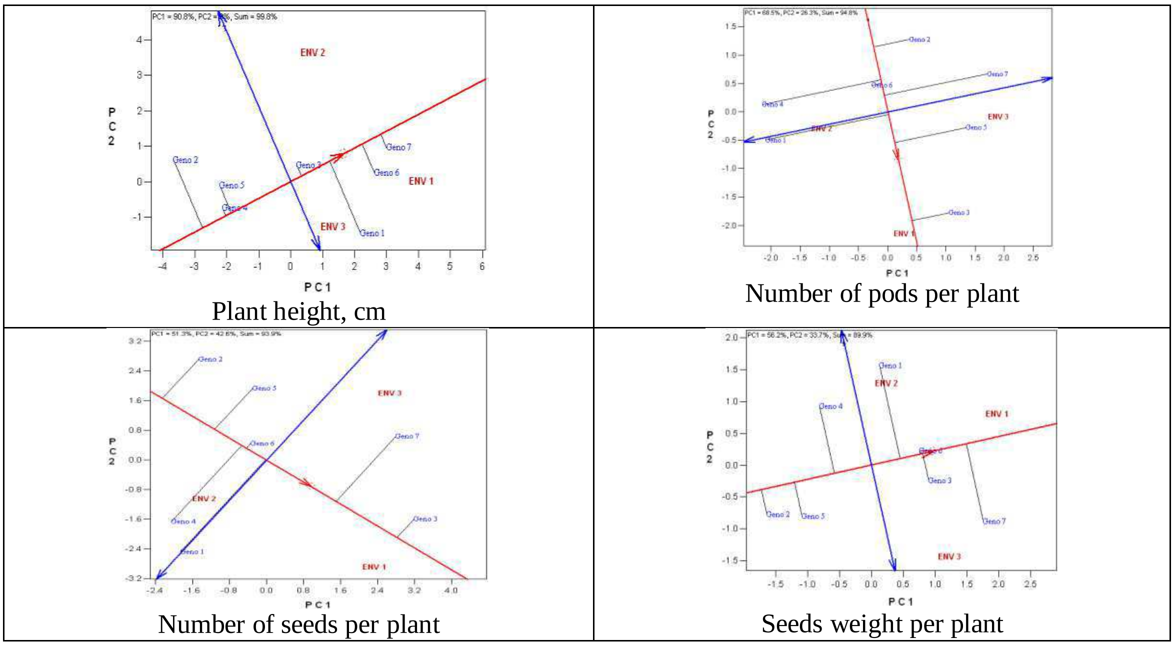


Figure 25. GGE biplot analysis for the traits - plant height, number of pods per plant, number of seeds per plant, seed weight per plant

Geno 1 - PI457923; Geno 2 - PI368911; Geno 3 - PI533704; Geno 4 - PI457938; Geno 5 - KALI; Geno 6 - Zuter; Geno 7 - Lucky801;

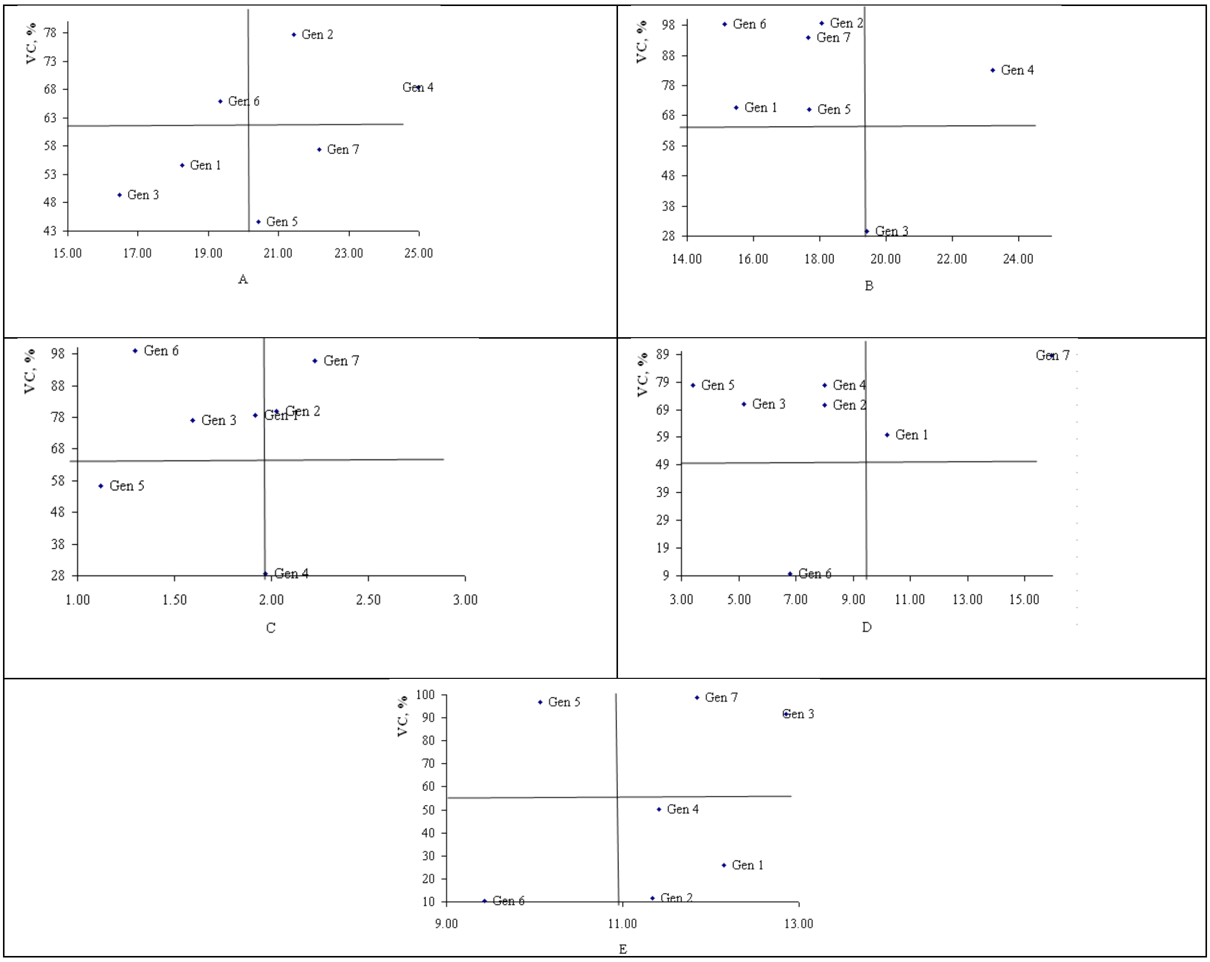


Figure 27. Stability (VC%) of cultivar traits according to Francis and Kannenberg (1978)

A - aboveground mass - number of leaves, B - aboveground mass, weight of whole plant, fresh, C - root mass - fresh weight, gram, D - root mass of tubers - number, E - length of roots; Gen1 - PI457923; Gen2 - PI368911; Gen3 - PI533704; Gen4 - PI457938; Gen5 - KALI; Gen6 - Zuter; Gen7 - Lucky801;

The mean value of the trait and its coefficient of variation (Figure 27) for each variety divide the coordinate system into four quadrants. Varieties with high ecological stability and high productivity fall into the lower right quadrant of the coordinate system. For the trait number of leaves per plant, these are the varieties Lucky801 and KALI. The last variety is further away from the abscissa axis, which speaks of its greater variability. These cultivars are most favored in selection to create leafier genotypes.

The cultivars (PI368911 and PI533704) located above this quadrant are also tall plants, but are more variable and responsive only to favorable environmental conditions. The location of the cultivars at the bottom left of the coordinate system PI457923 and PI533704 reveals their stability, but also a lower potential in terms of the trait.

In terms of fresh biomass weight of the whole plant, variety PI457938 maintains its position. As the most preferred from a selection point of view, only the PI533704 variety remains, which is highly productive and has the lowest variability compared to the other varieties. From the presentation of the cultivars according to the fresh weight of the root mass, it is clear that a selection compromise can be made on the cultivar PI457938, which is characterized by the lowest variability of the trait and with a root weight around the average for the studied group of cultivars. The cultivars PI368911 and Lucky801 have higher trait values, but also very highly dependent on changing environmental conditions.

In terms of root length, the low variable varieties PI457923, PI368911 and PI457938 make an impression. The lowest is PI368911, not inferior in magnitude to the sign of the more unstable PI457938. In this quadrant, the most preferred is PI457923, whose plants form long roots very little affected by the adverse impact but the factors of the growing environment.

Zuter can be defined as a genotype with a relatively good adaptability, both by this trait and by the fresh weight of the whole plant; variety KALI by weight of fresh biomass, number of tubers and length of roots per plant; PI457923 by fresh weight of root mass and PI457938 by number of tubers per plant.

5.2.4. Application of the eco-genetic model in the selection of white lupine

In the present study, the limiting factor of the environment is the year. The analysis of the elements of productivity (Table 47) shows significant variation by year and average values of the studied signs. With regard to the module number of seeds per plant, varietal differences were established both in terms of the component characters and the resulting one. The number of seeds formed per plant in 2014 and 2016 was greater than in 2014. The exception was the variety Lucky801, the plants of which managed to form 40 seeds per plant in 2014.

Table 47. Influence of the environmental conditions on the productivity modules seeds per plant and number of seeds per plant in white lupine varieties (by reported value)

Variety	Year								
	2014	2015	2016	2014	2015	2016	2014	2015	2016
Module I – Seeds weight per plant									
	Component trait 1			Component trait 12			Resultant trait		
	Number of seeds per plant			Seeds weight (g)			Seeds weight per plant,		
PI457923	20.00	16.00	13.80	0.282	0.248	0.282	5.63	3.97	3.89
PI368911	12.90	1.20	24.90	0.234	1.650	0.233	3.02	1.98	5.80
PI533704	24.00	26.00	28.80	0.239	0.215	0.240	5.73	5.60	6.90
PI457938	18.60	7.00	13.90	0.251	0.211	0.250	4.66	1.48	3.47
KALI	15.20	4.00	24.40	0.239	0.120	0.241	3.64	0.48	5.87
Zuter	17.40	22.00	25.20	0.305	0.205	0.305	5.30	4.51	7.68
Lucky801	20.30	40.00	29.20	0.306	0.248	0.306	6.21	9.90	8.93
Module II: Number of seeds per plant									
	Number pods per plant			Number of seeds per pod			Number of seeds per plant		
PI457923	5.70	5.00	5.50	3.51	3.20	2.51	20.00	16.00	13.80
PI368911	3.90	7.00	10.00	3.31	2.31	2.49	12.90	16.20	24.90
PI533704	7.20	10.00	11.50	3.33	2.60	2.50	24.00	26.00	28.80
PI457938	5.00	5.00	5.60	3.72	1.40	2.48	18.60	7.00	13.90
KALI	5.60	2.00	12.00	2.71	2.00	2.03	15.20	4.00	24.40
Zuter	4.60	12.00	10.10	3.78	1.83	2.50	17.40	22.00	25.20
Lucky801	4.70	14.00	11.70	4.32	2.86	2.50	20.30	40.00	29.20

The lower values of the productivity of the seeds have a negative impact on the total weight of the seeds of a plant, although a compensatory reaction on the part of the plant organism is also possible through the second component trait.

When forming the green biomass productivity module per plant (table 49), two component characteristics leaf weight and stem weight were used. The variety PI368911 (17.959 g) distinguished itself with the highest above-ground biomass in 2014, and PI533704 (12.60-11.00 g) in 2015-2016. According to the second component trait, fluctuations in varieties and their dependence on growing conditions were also established.

The module mass of tubers per plant directly depends on the weight of one tuber and the number of tubers on the plant. According to the first sign, the varieties Lucky801 and PI457923 are of breeding interest, although they do not retain their productive capabilities when growing conditions change, as well as PI457938, which is characterized by an average level but also with good stability of the sign.

Average tuber weight per plant was 0.138 g for 2014, 0.030 g for 2015 and 0.022 g for 2016. In most of the studied varieties, the increased number of tubers is at the expense of their weight. A good combination between number and weight of tubers was found in variety PI457938, which has the highest complex score.

Table 47. Influence of the environmental conditions on the productivity modules seeds per plant and number of seeds per plant in white lupine varieties (by reported value)

Variety	Year								
	2014	2015	2016	2014	2015	2016	2014	2015	2016
Module III: aboveground fresh weight									
	Component trait 1			Component trait 12			Resultant trait		
	leaf fresh weight			stem fresh weight			aboveground fresh weight		
PI457923	13.128	5.282	1.89	12.859	10.989	2.27	25.987	16.271	4.16
PI368911	17.959	3.942	2.33	22.57	5.382	1.98	40.529	9.324	4.31
PI533704	13.068	12.600	11.00	12.78	5.046	3.72	25.848	17.646	14.72
PI457938	15.279	7.101	3.44	29.23	11.138	3.41	44.509	18.239	6.85
KALI	13.335	6.368	3.00	17.36	9.832	3.13	30.695	16.200	6.12
Zuter	15.543	2.570	2.55	18.5	3.031	3.16	34.043	5.601	5.71
Lucky801	12.87	2.788	4.57	23.77	3.270	5.71	36.64	6.058	10.28
Module IV: nodule weight per plant									
	nodule number			nodule weight;			nodule weight per plant		
PI457923	3.60	16.00	11.00	0.147	0.026	0.022	0.53	0.412	0.240
PI368911	3.80	11.60	8.60	0.087	0.016	0.020	0.33	0.186	0.170
PI533704	1.60	3.00	11.00	0.094	0.053	0.015	0.15	0.16	0.167
PI457938	4.20	7.80	12.00	0.171	0.036	0.023	0.72	0.277	0.272
KALI	1.20	2.20	6.80	0.075	0.028	0.024	0.09	0.062	0.160
Zuter	1.75	8.60	10.00	0.354	0.030	0.030	0.62	0.261	0.298
Lucky801	8.40	6.60	32.80	0.038	0.022	0.018	0.32	0.146	0.582

Table 47. Influence of the environmental conditions on the productivity modules seeds per plant and number of seeds per plant in white lupine varieties (by reported value)

Variety	Year								
	2014	2015	2016	2014	2015	2016	2014	2015	2016
Module V: root fresh weight per plant									
	Component trait 1			Component trait 12			Resultant trait		
	Supply of root mass of one plant in nodules			nodule weight per plant			root fresh weight per plant		
PI457923	5.587	4.760	3.438	0.53	0.412	0.240	2.961	1.961	0.825
PI368911	13.867	4.220	4.224	0.33	0.186	0.170	4.576	0.785	0.718
PI533704	17.947	4.656	8.030	0.15	0.16	0.167	2.692	0.745	1.341
PI457938	4.822	5.617	3.246	0.72	0.277	0.272	3.472	1.556	0.883
KALI	16.589	16.081	5.475	0.09	0.062	0.160	1.493	0.997	0.876
Zuter	3.692	3.287	2.520	0.62	0.261	0.298	2.289	0.858	0.751
Lucky801	12.581	6.342	2.945	0.32	0.146	0.582	4.026	0.926	1.714

The root mass module of a plant is the result of the multiplicative inheritance of the two component traits saturation of the root mass of a plant with tubers and weight of the tubers of a plant, the product of which gives the already mentioned resulting trait.

The effects of growing environment on grain yield and aboveground biomass are presented in Table 48. The final selection was made on the highest average ranks. From the selected sample collection, the highest seed yield was reported for Lucky801 (155.25 kg da-1, 247.5 kg da-1, 223.25 kg da-1) and PI533704 (143.25 kg da1, 140.00 kg da-1, 172.50 kg da-1 1) during all three years of research. These varieties occupy the stable first and second positions according to the ranking analysis. PI368911; PI457938 and KALI are distinguished by high variability and grain yield below the average (90.00 kg da-1, 80.08 kg da-1, 83.25 kg da-1) for the studied group of cultivars. Therefore, the ranking analysis assigns them the last 6th position.

The highest yields in terms of fresh above-ground biomass (table 49) are the varieties PI457938 and PI533704 with an average yield for the period 597.98 – 485.12 kg da-1. The second variety is impressive, which has a relatively high grain yield, and in terms of green biomass yield is highly variable, as in 2014 it took the last place with rank 7. With values close to the average yield of green mass are PI368911 (451.36 kg da- 1), KALI (441.79 kg da-1) and Lucky801 (441.48 kg da1).

Table 48. Influence of environmental conditions on seed yield and green mass modules, for white lupine varieties (by reported value and by rank)

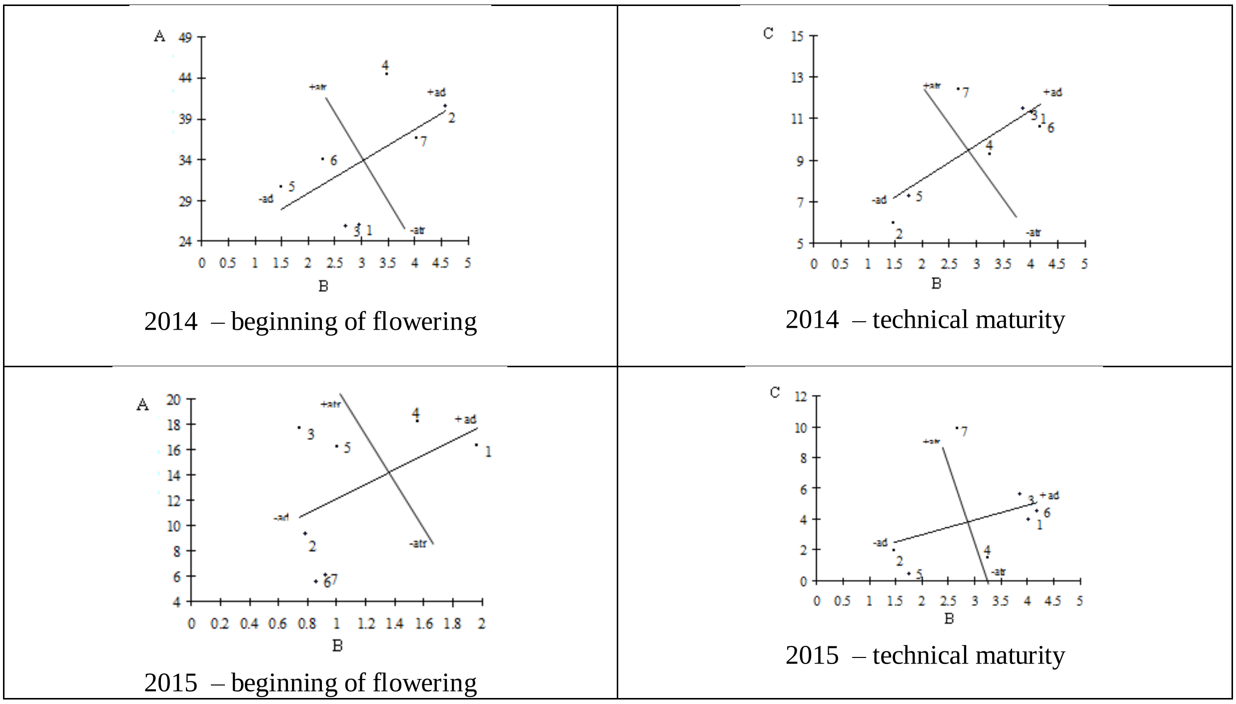
Variety	Year			Yield (kg da^{-1})	Ranks			
	2014	2015	2016	2014-2016	2014	2015	2016	Average
	Module Grain yield							
PI457923	140.75	99.25	97.25	112.42^{ab}	3	4	6	4
PI368911	75.50	49.50	145,00	90.00^{ab}	7	5	5	6
PI533704	143.25	140.00	172.50	151.92^{bc}	2	2	3	2
PI457938	116.50	37.00	86.75	80.08^{a}	5	6	7	6
KALI	91,00	12.00	146.75	83.25^{a}	6	7	4	6
Zuter	132.50	112.75	192,00	145.75^{abc}	4	3	2	3
Lucky801	155.25	247.50	223.25	208.67^{c}	1	1	1	1
	Module Green mass yield							
PI457923	649.68	406.78	104.00	386.82^{a}	6	3	7	5
PI368911	1013.23	233.10	107.75	451.36^{a}	2	5	6	4
PI533704	646.20	441.15	368.00	485.12^{a}	7	2	1	3
PI457938	1112.73	455.98	171.25	579.98^{a}	1	1	3	2
KALI	767.38	405.00	153.00	441.79^{a}	5	4	4	4
Zuter	851.08	140.03	142.75	377.95^{a}	4	7	5	5
Lucky801	916.00	151.45	257.00	441.48^{a}	3	6	2	4

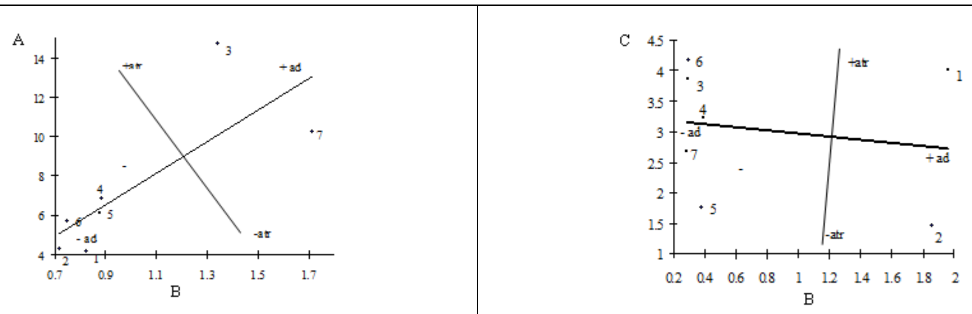
Different letters (a, b, c. . .) in the same column indicate a significant difference between treatments at $p < 0.05$

5.2.4.2. Method of orthogonal regressions. Genotype identification by phenotype

In the graph presented in figure 28, so-called orthogonal regressions are used, from where the method is called the orthogonal regression method.

When the coenotic situation worsened (in 2015), the most adaptively valuable variety was PI457938, which is located in the quadrant bounded by the positive part of attractiveness and adaptability (figure 26). It exhibits a good combination of genes for adaptability and attraction (rapid transition of plastic substances when conditions deteriorate). Plants of this variety form aerial and root mass of high weight.





2016 – beginning of flowering | 2016 – technical maturity

Figure 28. Distribution of mean values of white lupine varieties
A - green biomass weight per plant (g), B - root mass weight per plant (g), C - seed weight per plant (g), 1- PI457923; 2 - PI368911; 3 - PI533704; 4 - PI457938; 5 - KALI, 6 - Zuter; 7 -Lucky801

The varieties PI533704, KALI and Zuter represented in the graph in the negative part of the adaptation line are the least adaptable. They do not respond positively to being placed in a favorable growing environment. Variety PI368911, as can be seen from the graph in 2014, has the highest adaptability, although it is placed very close to the regression line. When growing conditions worsened (2015), it moved to the negative part of the adaptability line and occupied an almost terminal position, which testifies that the genetic control of adaptability in terms of the traits fresh aboveground biomass weight and root weight is redefined to negative at these environment limits.

At technological maturity, the Lucky801 variety is characterized by positive manifestations of genes for adaptability and attraction. The greater distance to the adaptability line in 2015 compared to 2014 indicates that this variety has strong attraction genes. Variety PI533704 is in the same quadrant (bounded by the positive part of the adaptability and attraction lines), but occupies a far right position at both environmental limits, which is determined by its having stronger genes for adaptability (showing good environmental stability).

The positive shift of these two varieties on the physiological systems of attraction (Lucky801) and adaptability (PI533704) defines them as the most interesting in breeding work as parents to obtain hybrids combining favorable genes for plant seed weight and root mass weight.

The varieties PI457923 and Zuter are also of interest for combinatory selection; which are also well adapted to changes in the environment. They are characterized by negative attractiveness, but are quite close to the line of adaptability.

5.2.5. Genetic analysis of quantitative traits in white lupine hybrids

From the biometric data presented in Tables 50 and 51, it can be seen that stocking density the number of tubers per plant is inherited negatively superdominantly with a greater influence of epistatic gene actions.

Table 50. Characteristics of the studied genotypes

Trait\Variety	PI533704	Zuter	Lucky801
Dense sowing			
nodule number per plant	11.00a	10.00a	32.80b
nodule weight per plant (g)	0.17a	0.30a	0.58b
root fresh weight (g)	0.17a	0.38b	0.69c
aboveground fresh weight (g)	4.68a	6.44b	7.15c
seeds weight per plant, g	6.90a	7.68b	8.93c
Rare sowing			
nodule number per plant	11.65a	10.59a	34.75b
nodule weight per plant (g)	0.18a	0.33a	0.64b
root fresh weight (g)	0.20a	0.37b	0.71c
aboveground fresh weight (g)	5.38a	7.41b	8.22c
seeds weight per plant, g	8.62a	9.60b	11.17c

Different letters (a, b, c. . .) in the same column indicate a significant difference between treatments at $p < 0.05$

An exception is PI533704 x Lucky801 characterized by positive trait dominance. In the same cross, a negative true heterosis was found (-11.86%), and in the reciprocal the heterosis was the highest, reaching 259.45%. In the second hybrid generation, plants derived from PI533704 and Zuter were the least depressed, regardless of the direction of crossing (62.20-62.21%).

In the first generation, PI533704 x Lucky801 and its reciprocal stand out with the highest tuber weight, while in the second generation, no statistically significant differences were found between individual hybrids and a relatively high level of depression was observed. On this basis, all four combinations show positive heterosis, while the reciprocal hypothetical heterosis has a significantly higher value (205.88% - 276.47%). In the hybrid combination PI533704 x Lucky801 dominant gene effects predominate, while in all others epistasis plays a greater role in the inheritance of the trait (51 and 52).

Table 51. Biometric data of the quantitative characteristics of the investigated white lupine crosses in dense planting

Hybrids	F_1	F_2	Heterosis F_1 (%)		Depression F_2 (%)	Degrees of dominance	
	x	x	hypothetical	true		in F_1 (h_{p1})	in F_2 (h_{p2})
nodule number							
PI533704 x Zuter	17.41a	6.58ab	65.81	74.1	62.21	-13.82	15.68
Zuter x PI533704	23.81ab	9.00c	126.76	138.1	62.2	-26.62	6
PI533704 x Lucky801	28.91bc	5.41a	32.01	-11.86	81.29	0.64	-3.03
Lucky801 x PI533704	39.54c	7.40b	80.55	259.45	81.28	-1.62	2.66
nodule weight							
PI533704 x Zuter	0.54a	0.26a	129.79	80	51.85	4.69	0.77
Zuter x PI533704	0.52b	0.25a	121.28	205.88	51.92	4.38	0.46
PI533704 x Lucky801	0.67b	0.20a	78.67	15.52	70.15	1.44	-1.71
Lucky801 x PI533704	0.64b	0.19a	70.67	276.47	70.31	-1.29	1.8

Different letters (a, b, c. . .) in the same column indicate a significant difference between treatments at $p < 0.05$

Regarding the fresh weight of the root mass in F1, the hybrids PI533704 x Lucky801 and Lucky801 x PI533704 again prevailed, and statistically proven differences were found between them. The values of both the hypothetical (147.27-285.45%) and the true (78.95-752.94%) heterosis effect are positive for Zuter x PI533704 and Lucky801 x PI533704, respectively, i.e. when PI533704 is used in the paternal form.

Judging from the obtained values for the depression of F2 plants, we can assume that when crossing the varieties PI533704 and Zuter, the resulting hybrids will be slightly depressed (10.29 — 11.32%). The degrees of gene dominance in F1 and F2 characterize heterosis from the standpoint of genetic balance theory. They show that heterosis in F1 is due to overdominance, with only Lucky801 x PI533704 having a negative sign. In the second hybrid generation, in most of the hybrids, the effect of epistatic gene interactions (hp2 >hp1) on the manifestation of the trait is significantly greater.

In terms of aboveground biomass fresh weight, Zuter x PI533704 impresses with its high performance in both hybrid generations. However, none of the hybrids exceeded any of the parental forms, so the negative values of heterosis show. In accordance with these manifestations, PI533704 x Lucky801 and its reciprocal can be indicated as the least depressed (≈ -35..-36%).

From the presented biometric data on productivity expressed as seed mass per plant, it can be seen that the inheritance of the trait is from positive over dominant in Zuter x PI533704 (2.18) and PI533704 x Lucky801 (1.03), dominant in PI533704 x Zuter (0.85) and negative dominant in Lucky801 x PI533704 (-0.53). In reciprocal crosses, a stronger true heterosis effect was found, ranging from -0.78% for PI533704 x Zuter to 22.46% for Lucky801 x PI533704.

The plants obtained by crossing PI533704 with Zuter were relatively less depressed (787 - 8.48%) compared to the combination between Lucky801 and PI533704. With the exception of Lucky801 x PI533704, in the rest of the crosses in the second generation, epistatic gene effects predominated, causing the lower expression of the trait in the hybrid plants.

Table 51. Biometric data of the quantitative characteristics of the investigated white lupine crosses in dense planting

Hybrids	F_1	F_2	Heterosis F_1 (%)		Depression F_2 (%)	Degrees of dominance	
	x	x	hypothetical	true		in F_1 (h_{p1})	in F_2 (h_{p2})
root fresh weight							
PI533704 x Zuter	0.68a	0.61b	147.27	78.95	10.29	3.86	6.38
Zuter x PI533704	1.06b	0.94c	285.45	178.95	11.32	7.48	12.67
PI533704 x Lucky801	1.58d	0.41a	267.44	128.99	74.05	4.42	-0.15
Lucky801 x PI533704	1.45c	0.63b	237.21	752.94	56.55	-3.92	-1.54
aboveground fresh weight							
PI533704 x Zuter	1.97b	1.79a	-64.57	-69.41	9.14	-4.08	-8.57
Zuter x PI533704	3.50c	3.17c	-37.05	-45.65	9.43	-2.34	-5.43
PI533704 x Lucky801	1.08a	1.46a	-81.74	-84.9	-35.19	-3.91	-7.21
Lucky801 x PI533704	1.91b	2.59b	-67.71	-59.19	-35.6	3.24	5.38

Different letters (a, b, c. . .) in the same column indicate a significant difference between treatments at $p < 0.05$

Tables 52 and 53 reflect the average values of the F1 and F2 hybrids and the obtained biometric data for the analyzed parameters under sparse sowing conditions. According to the number of tubers from one plant when thinning the crop, it is found that in all hybrids the heterosis (hypothetical and real) effect is negative and reaches up to 63.58% in Lucky801 x

PI533704 and up to 74.22% in PI533704 x Lucky801, respectively. A certain analogy was observed in the level of depression. At the different limits of the medium, plants from the crosses PI533704 x Zuter and the reciprocal are the least depressed. And also in the type of inheritance in the second generation in which the significant share in the expression of the trait falls on epistatic gene interactions (hp2 >hp1).

Table 51. Biometric data of the quantitative characteristics of the investigated white lupine crosses in dense planting

Hybrids	F_1	F_2	Heterosis F_1 (%)		Depression F_2 (%)	Degrees of dominance	
	x	x	hypothetical	true		in F_1 (h_{p1})	in F_2 (h_{p2})
seeds weight per plant							
PI533704 x Zuter	7.62a	7.02a	4.53	-0.78	7.87	0.85	-1.38
Zuter x PI533704	8.14a	7.45a	11.66	5.99	8.48	2.18	0.82
PI533704 x Lucky801	8.96b	7.36a	13.2	0.34	17.86	1.03	-1.09
Lucky801 x PI533704	8.45b	7.43a	6.76	22.46	12.07	-0.53	0.96

Different letters (a, b, c. . .) in the same column indicate a significant difference between treatments at $p < 0.05$

Changing the environmental conditions affects the manifestations of heterosis and the weight of tubers per plant. The true heterosis effect was most pronounced in PI533704 x Lucky801 (233.33%), followed by PI533704 x Zuter (83.33%). These hybrids show a certain responsiveness to improvement of growing conditions, while in their reciprocal crosses the true heterosis is even negative. For tuber weight per plant in PI533704 x Zuter and the reciprocal inheritance was positive dominant and in the other two crosses it was negative dominant. Under favorable growing conditions, the genetic control changes so that in the second generation, non-allelic gene interactions of the epistasis type already prevail.

Table 52. Biometric data of the quantitative characteristics of the investigated white lupine crosses in thinned sowing

Hybrids	F_1	F_2	Heterosis F_1 (%)		Depression F_2 (%)	Degrees of dominance	
	x	x	hypothetical	true		in F_1 (h_{p1})	in F_2 (h_{p2})
nodule number							
PI533704 x Zuter	11.33a	10.11a	-31.47	-28.05	7.87	6.6	15.47
Zuter x PI533704	15.50ab	41.00b	-26.8	-23.14	8.48	5.62	13.85
PI533704 x Lucky801	25.01bc	7.78a	-61.38	-74.22	17.86	-1.23	-2.74
Lucky801 x PI533704	34.20c	6.40a	-63.58	-27.47	12.07	1.28	2.73
nodule weight							
PI533704 x Zuter	0.33a	0.42b	29.41	83.33	-27.27	1	4.4
Zuter x PI533704	0.32a	0.66c	25.49	-3.03	-106.25	0.87	10.8
PI533704 x Lucky801	0.60b	0.23a	46.34	233.33	61.67	-0.83	1.57
Lucky801 x PI533704	0.58b	0.17a	222.22	-9.38	70.69	-0.74	2.09
root fresh weight							
PI533704 x Zuter	1.17a	0.35a	310.53	216.22	70.09	10.41	1.53
Zuter x PI533704	1.81a	2.03c	670.21	805	-12.15	45	102.57
PI533704 x Lucky801	1.31b	0.78b	187.91	84.51	40.46	3.35	2.55
Lucky801 x PI533704	2.04b	0.52a	348.35	920	74.51	-6.22	-0.51

The fresh weight of the root system is characterized by an even stronger expression of the heterosis effect compared to the restrictive growing conditions, especially in the reciprocal crosses (805.00%, 920.00%). The lowest depression was found in Zuter x PI533704 (-12.15%), and the highest in Lucky801 x PI533704 (74.51%). The nature of inheritance of the trait in the first generation is preserved as in the dense crop, but in the second generation at PI533704 x Zuter and its reciprocal changes Zuter x PI533704, with dominant gene effects playing a significantly more important role in the first.

Reciprocal crosses, falling into a better nutritional environment, show their biological capabilities and exceed the parental forms in terms of the productivity of fresh above-ground biomass. An expression of their hybrid strength is the positive value of both the hypothetical (48.55%, 38.34%) and the true (28.21%, 14.48%) heterosis effect. In these crosses, the inheritance of aboveground biomass weight is positive superdominant. Greater sensitivity to environmental conditions was found in hybrids with parental components PI533704 and Zuter, which lacked depression only under favorable growing conditions. In the second hybrid generation, interallelic interactions predominated in plants from all crosses (hp2 >hp1).

Under favorable environmental conditions, the parents outperformed the first generation hybrids, whose seed mass per plant was lower. Therefore, the heterosis effect, both hypothetical and real, has a negative sign. The highest true heterosis (-15.20%) was observed in the hybrid Lucky801 x PI533704 in the direction of the maternal variety, and the lowest in the reciprocal (-49.78%). The data in Table 51 show that the inheritance of the trait in the first generation is superdominant positive for Lucky801 x PI533704 and superdominant negative for all others.

A shift in the genetic control of trait expression was observed when the rearing environment was changed. In the plants from the reciprocal crosses in the second generation, the manifestations of epistasis prevail (hp2 > hp1).

Table 52 presents the values of the gene parameters for the studied traits in the studied crosses. The results show that in the conditions of the generally accepted density of sowing, positive manifestations of transgression were established for all signs.

As the most significant were in PI533704 x Lucky801 and the reciprocal and the signs number of tubers per plant (11.14 - 11.21), fresh weight of aerial mass (1.24 - 1.54) and weight of seeds per plant (1.71 - 1.87), indicating that in the hybrid generations from these crosses, homozygous genotypes can be expected, in which there will be gene recombinations leading to a quantitative increase of these signs.

The number of genes by which the parents differ in the number of tubers per plant is large. The situation is similar for the other traits, with the exception of seed weight from a plant in which the number of genes controlling the trait by which the parental forms differ is comparatively smaller (12.38 to 25.31).

For most of the signs, unidirectionality is observed in the action of the dominant alleles of the genes determining the corresponding signs. Their negative value indicates that their action leads to a decrease in the phenotypic manifestation of the signs. This is most pronounced in the PI533704 x Lucky801 cross. Only in Zuter x PI533704 in terms of fresh weight of the root mass, the allelic interactions are of the positive overdominance type (32.62) and cause the formation of a heavier root mass.

Table 52. Biometric data of the quantitative characteristics of the investigated white lupine crosses in thinned sowing

Hybrids	F_1	F_2	Heterosis F_1 (%)		Depression F_2 (%)	Degrees of dominance	
	x	x	hypothetical	true		in F_1 (h_{p1})	in F_2 (h_{p2})
aboveground fresh weight							
PI533704 x Zuter	5.36a	6.66a	-16.18	-27.67	-24.25	-1.02	0.52
Zuter x PI533704	9.50b	10.49b	48.55	28.21	-10.42	3.06	8.07
PI533704 x Lucky801	5.31a	15.59c	-21.85	-35.32	-193.6	-1.05	12.43
Lucky801 x PI533704	9.41b	12.74b	38.48	14.48	-35.39	1.9	8.37
seeds weight per plant							
PI533704 x Zuter	7.26b	7.56ab	-20.31	-24.38	-4.13	-3.78	-6.33
Zuter x PI533704	6.62ab	8.76b	-27.33	-31.04	-32.33	-5.08	-1.43
PI533704 x Lucky801	5.61a	6.90a	-43.30	-49.78	-22.99	-3.37	-4.71
Lucky801 x PI533704	7.31b	7.94ab	-26.12	-15.20	-8.62	2.03	3.07

Table 53. Values of the gene parameters of the quantitative traits of the investigated white lupine crosses in the F2 hybrid generation in a dense crop

Crosses/Parameters	T_n	N	D	E	H^2	Pp
nodule number						
PI533704 x Zuter	0.69	120.19	-18.99	24.81	0.63	-1.88
Zuter x PI533704	0.19	257.16	-27.95	47.21	0.47	-0.96
PI533704 x Lucky801	11.14	1576.4	-298.90	327.66	0.51	-48.98
Lucky801 x PI533704	11.21	1490.6	-240.50	296.64	0.75	-38.42
nodule weight						
PI533704 x Zuter	0.55	2.17	-0.41	1.05	0.78	0.54
Zuter x PI533704	0.08	168.06	-12.34	28.71	0.11	0.00
PI533704 x Lucky801	0.08	539.84	-54.05	95.67	0.05	-0.82
Lucky801 x PI533704	0.07	816.72	-85.44	145.63	0.03	-1.75
root fresh weight						
PI533704 x Zuter	0.14	148.69	-18.99	28.91	0.46	-0.85
Zuter x PI533704	0.16	68.80	32.62	-18.97	0.61	-9.47
PI533704 x Lucky801	0.14	457.72	-26.82	71.83	0.34	-2.75
Lucky801 x PI533704	0.14	655.07	-24.23	92.88	0.23	-7.83

Tn - manifestations of transgression; N - number of genes by which the parental forms differ; D - manifestations of dominance; E - epistatic gene effects; H2 - coefficient of heritability in a broad sense; Pp - coefficient of effectiveness of the mass team;

The data from the hybridological analysis show that in the second generation of the last cross, epistatic interactions with a negative sign predominate, and it can be assumed that this will reduce the degree of phenotypic expression of the trait (root fresh weight) compared to full additive inheritance. Positive epistatic interactions occurred in all other hybrids from 1.05 in PI533704 x Zuter for tuber weight to 2532.58 in PI533704 x Lucky801 for aboveground fresh weight.

Stronger inter-allelic interactions prevailed in PI533704 x Lucky801 and its reciprocal in tuber number and weight per plant and aboveground biomass fresh weight. The genetic contribution to the overall phenotypic manifestation of the number of tubers was higher in Lucky801 x PI533704 (0.75), followed by the cross PI533704 x Zuter (0.63), which was also distinguished by a high coefficient of inheritance in the broad sense (0.78) and in weight on the tubers of a plant. On this basis, the hybrids obtained from PI533704 and Lucky801 are more labile, regardless of the crossing direction. A similar analogy can be made in the inheritance of the trait fresh weight of the root mass, as for PI533704 x Zuter and Zuter x PI533704 the value of the inheritance coefficient is in the range 0.46-0.61, and for the other crosses 0.23-0.34.

Table 53. Values of the gene parameters of the quantitative traits of the investigated white lupine crosses in the F2 hybrid generation in a dense crop

Crosses/Parameters	T_n	N	D	E	H^2	Pp
aboveground fresh weight						
PI533704 x Zuter	0.93	771.15	-278.7	191.61	0.13	-62.80
Zuter x PI533704	1.15	79.41	-27.97	20.27	0.39	-6.37
PI533704 x Lucky801	1.24	9899.30	-4037	2532.6	0.03	-1032
Lucky801 x PI533704	1.54	62.71	-30.72	17.48	0.66	-8.36
seeds weight per plant						
PI533704 x Zuter	0.68	23.93	-4.83	5.97	0.29	0.07
Zuter x PI533704	0.71	13.61	-0.65	3.3	0.14	0.46
PI533704 x Lucky801	1.71	25.31	-4.68	6.17	0.65	0.19
Lucky801 x PI533704	1.87	12.38	-2.91	3.53	0.66	0.4

Tn - manifestations of transgression; N - number of genes by which the parental forms differ; D - manifestations of dominance; E - epistatic gene effects; H2 - coefficient of heritability in a broad sense; Pp - coefficient of effectiveness of the mass team;

A higher heritability coefficient was obtained for the trait fresh weight of aerial mass when cultivar PI533704 was used as pollinator. A higher genetic share is indicated by the heritability coefficient values for the trait plant seed weight in PI533704 x Lucky801 and Lucky801 x PI533704 (0.65-0.66). Crossing direction definitely influences the inheritance of the trait in PI533704 and Zuter. It is preferred that strain PI533704 be used as the parent form.

Selection efficiency data combined with heritability coefficient values show that the probability of mass selection by phenotype in the early hybrid generations of genotypes with increased tuber weight we can allow in the cross PI533704 x Zuter (0.54), and by seed weight per plant at Lucky801 x PI533704 (0.40). By the same token, the mass at Zuter x PI533704 (0.46) actually the probability of effective mass selection of homozygous genotypes will be greater in the late hybrid generations (F5 - F6). The negative value of the efficiency coefficient of the team for the other signs suggests the application of multiple individual teams in the selection process for these crosses.

Placed in a favorable cenotic environment (larger food area), a different reaction was found in some of the hybrids. The values of the transgression indicators allow to determine the samples of the homozygous genotypes with the maximum and minimum for the studied characters, which can be obtained by the combination of the parental components involved in the hybrid combinations. The data from the hybridological analysis (table 54) show that there is almost the same level of transgression (11.62 - 12.38) in PI533704 x Lucky801 and the reciprocal of the number of tubers per plant, while in PI533704 x Zuter the transgression index is higher compared to this under limiting environmental conditions.

The hybrids show a certain similarity in terms of tuber weight per plant, fresh weight of green biomass and seed weight per plant. The negative sign in all hybrids suggests that plants with increased root weight cannot be selected. The number of genes influencing the manifestation of the investigated traits, which differentiate the parental forms, is different, both in relation to the limit of the environment and in relation to the direction of crossing. In the cross PI533704 x Zuter the difference is small (2-3), while in its reciprocal it is significant (4227). A relatively small number of genes differed between PI533704 and Lucky801 in tuber weight per plant (8).

The same cultivars differ significantly in the number of genes determining the manifestation of the signs of fresh weight of the root and aerial mass, and a certain analogy is observed in the dense crop. The situation is similar for the seed weight of a plant in which the number of genes controlling the trait by which the parental forms differ is comparatively smaller (7.79 to 62.55). From the values found for allelic interactions, positive dominance and over-dominance of the dominant alleles determining the expression of all characters in Zuter x PI533704, in the number of tubers per plant and fresh weight of the above-ground mass in PI533704 x Lucky801 were established.

Dominant alleles determine a better numerical expression of these characters in the plants of the indicated hybrids. When analyzing the index of interallelic interactions, it can be seen that epistasis is negative for a significant part of the investigated traits. In the cross between PI533704 and Lucky801, positive epistasis was maintained for tuber weight, root fresh weight and seed weight per plant, indicating a relatively strong influence on the phenotypic expression of the traits. The values for fresh weight of root mass (310.55) and number of tubers (106.95) are especially high for Lucky801 x PI533704.

The genetic share in the general phenotypic manifestation of the investigated indicators, expressed by the coefficient of heritability in a broad sense, is high in the crosses PI533704 x Zuter Lucky801 x PI533704 for number (0.51; 0.92) and weight (0.71; 0.79) of tubers and weight of seeds per plant (0.93; 0.96). In the crosses between PI533704 and Lucky801, a significantly higher coefficient of inheritance of the trait (0.83; 0.79) was found for tuber weight when the plants were grown under more favorable conditions.

From the values showing the effect of selection, which in the crosses PI533704 x Zuter in number of tubers (0.57) and Zuter x PI533704 in weight of seeds per plant (0.70) reflect a positive difference compared to the parent forms and taking into account the coefficient values of heritability, it can be assumed that with these combinations mass selection will be effective in the earlier hybrid offspring.

Table 54. Values of the gene parameters of the quantitative traits of the investigated white lupine crosses in the F2 hybrid generation in a thinned crop

Crosses/Parameters	T_n	N	D	E	H^2	Pp
nodule number						
PI533704 x Zuter	3.02	2.85	-1.20	1.26	0.51	0.57
Zuter x PI533704	-0.41	4227.50	956.90	-920.7	0.13	-224.80
PI533704 x Lucky801	11.62	5673.60	1071.20	-1175	0.07	-219.20
Lucky801 x PI533704	12.38	517.46	-93.75	106.95	0.92	-15.53
nodule weight						
PI533704 x Zuter	0.12	37.99	11.21	-9.70	0.71	-1.95
Zuter x PI533704	0.12	141.45	33.47	-32.07	0.75	-6.64
PI533704 x Lucky801	0.32	50.63	-9.50	11.46	0.83	-0.64
Lucky801 x PI533704	0.33	58.86	-11.58	13.30	0.79	-0.91
root fresh weight						
PI533704 x Zuter	-0.40	470.02	-298.40	135.72	0.05	-89.58
Zuter x PI533704	-0.31	125.14	42.13	-31.15	0.90	-10.92
PI533704 x Lucky801	-0.10	51.75	-8.27	11.30	0.48	-0.27
Lucky801 x PI533704	-0.21	1633.50	-222.50	310.55	0.16	-23.25

Tn - manifestations of transgression; N - number of genes by which the parental forms differ; D - manifestations of dominance; E - epistatic gene effects; H2 - coefficient of heritability in a broad sense; Pp - coefficient of effectiveness of the mass team;

Table 54. Values of the gene parameters of the quantitative traits of the investigated white lupine crosses in the F2 hybrid generation in a thinned crop

Crosses/Parameters	T_n	N	D	E	H^2	Pp
aboveground fresh weight						
PI533704 x Zuter	1.16	644.20	-149.00	141.92	0.15	-18.34
Zuter x PI533704	1.53	78.62	25.74	-19.72	0.31	-5.99
PI533704 x Lucky801	1.60	1017.3	207.68	-216.10	0.59	-46.08
Lucky801 x PI533704	2.33	191.21	40.08	-41.71	0.52	-7.42
seeds weight per plant						
PI533704 x Zuter	1.17	11.10	-6.36	3.66	0.93	-1.18
Zuter x PI533704	2.03	7.79	0.70	-2.32	0.97	0.70
PI533704 x Lucky801	1.45	62.55	-42.54	18.84	0.19	-13.63
Lucky801 x PI533704	2.05	9.9	-6.74	3.40	0.96	-1.38

Tn - manifestations of transgression; N - number of genes by which the parental forms differ; D - manifestations of dominance; E - epistatic gene effects; H2 - coefficient of heritability in a broad sense; Pp - coefficient of effectiveness of the mass team;

Figure 30 shows the results of the test are 16 F1 hybrids at the limit of the medium expressed by two different sowing rates for the traits aboveground biomass weight and seed weight per plant.

It can be seen that the studied hybrids differ in the stability of their genetic systems when the limits of the environment are changed. It is clear from the figure that when the cenotic situation worsens (dense cropping), the most valuable hybrid is additively obtained by crossing the varieties Lucky801 and PI533704 (4). This hybrid exhibits a good combination of genes for adaptability and attraction under adverse conditions. When thinning the crop, such a combination was found only in the hybrids Zuter x PI533704 (3) and PI533704 x Lucky801 (2) with positive attraction and adaptability values.

Hybrid plants from the crosses PI533704 x Zuter and PI533704 x Lucky801 (without PI533704 x Lucky801 (4)) under dense cropping fell into the quadrant defined by negative adaptability and attraction, indicating that the genetic control of adaptability is unfavorably redefined for higher plant density. sowing for these hybrids.

Hybrids from Lucky801 x PI533704 and Zuter x PI533704 are characterized by positive attractiveness, but differ too much in their adaptive capabilities, occupying diametrically opposite places on the orthogonal regression line. When thinning the crop, the scatter around the regression line decreases significantly. The situation is similar in terms of plant seed weight, where a donor combining high values of the parameter weight of root mass and plant seed weight cannot be emitted. Graphical analysis shows that at both limits of the environment, the scope of variability in adaptability and in attraction is substantial.

VI. Characteristics of growth, development and comparative biological characteristics of prospective lines grass pea and white lupina

6.1. Comparative test of hybrid lines grass pea (Lathyrus sativus L.)

The occurrence of the phenological phases of development in the varieties and lines was followed by dates as follows - sowing; beginning of flowering; technical maturity. Table 60 presents data on the main periods of plant development for individual lines and varieties of grass pea.

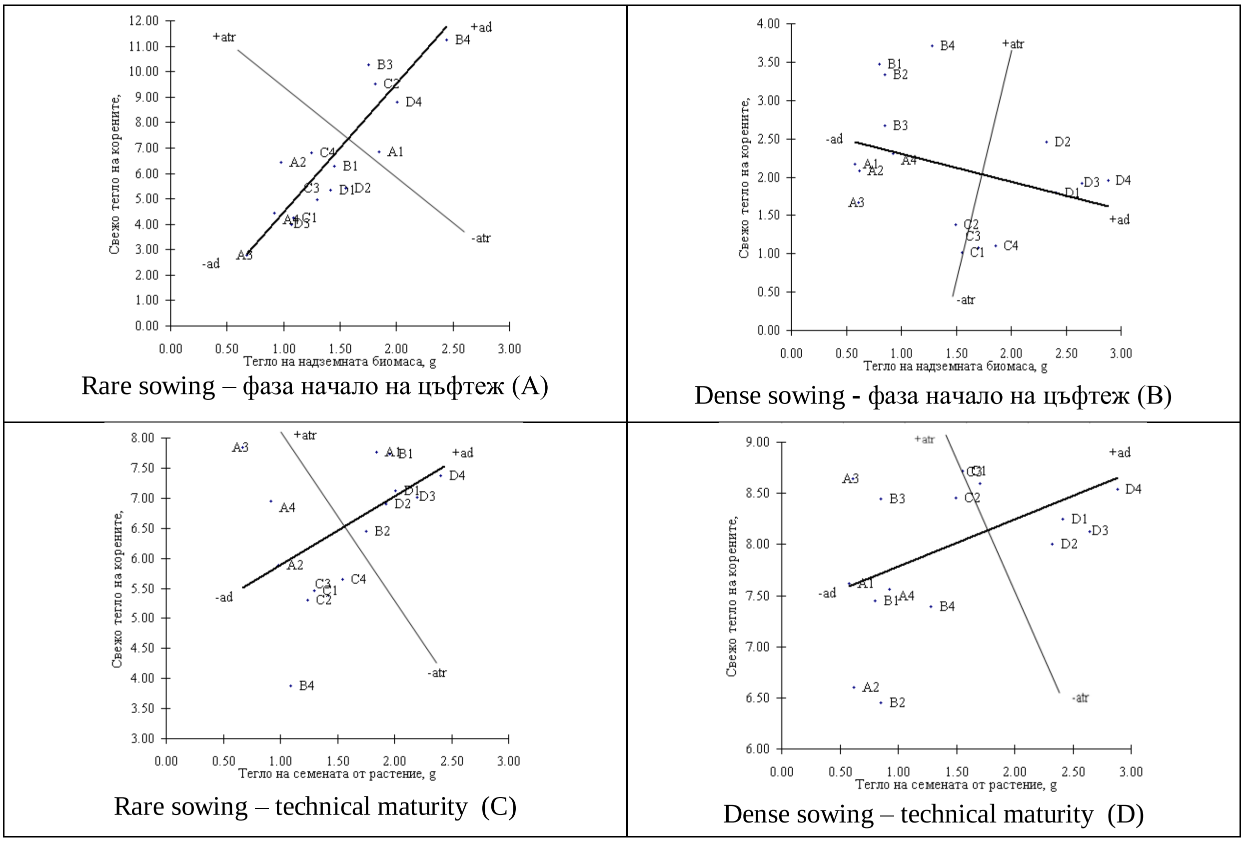


Figure 30. Distribution of mean values of common ax varieties along the orthogonal regression line
A - PI533704 x Zuter; B - Zuter x PI533704; C - PI533704 x Lucky801; D - Lucky801 x PI533704; 1, 2, 3, 4 - individual plants of the respective hybrid

Table 60. Phenological development of lines and varieties grass pea (2019-2021 г.)

Phenophases/ variety (line)	Year	Date of sowing	Date of germination	Beginning of flowering
BGE027129	2019	05.03	05.04	17.05
	2020	20.03	02.04	10.05
	2021	04.03	08.04	18.05
LA5108	2019	05.03	05.04	16.05
	2020	20.03	02.04	08.05
	2021	04.03	08.04	13.05
BGE025277	2019	05.03	05.04	19.05
	2020	20.03	02.04	12.05
	2021	04.03	08.04	20.05
LHL	2019	05.03	05.04	15.05
	2020	20.03	02.04	07.05
	2021	04.03	08.04	11.05
LHL-2	2019	05.03	05.04	17.05
	2020	20.03	02.04	07.05
	2021	04.03	08.04	11.05
LHL-3	2019	05.03	05.04	17.05
	2020	20.03	02.04	10.05
	2021	04.03	08.04	18.05

Certain differences were found in the onset of flowering, as well as in the rates of growth and reaching technical maturity. The main influence on the rate of full emergence and initial development of plants in our conditions of the field experiment was the average daily air temperature, with sufficient amount of moisture in the upper soil layer before sowing.

The earliest flowering phenological phase occurred in cultivar LA5108 and line LHL in all three years of the study (Table 60). Lines LHL-2 and LHL-3 start flowering 2-3 days later than LHL. BGE025277 is the latest blooming variety. At the end of the growing season, differentiation was observed in the early flowering genotypes, with LA5108 reaching technical maturity in 80 to 104 days, and LHL line 77-101 days.

Plants of cultivars BGE025277 and BGE027129 complete their growing season in 81-107 days, depending on sowing date and climatic conditions. Lines LHL-2 and LHL-3 mature slightly later with a difference of 3-5 days compared to LHL due to their slower growth and development.

Table 60. Phenological development of lines and varieties grass pea (2019-2021 г.)

Phenophases/ variety (line)	Year	Full bloom	Technical maturity	Vegetation period, days
BGE027129	2019	27.05	19.06	106
	2020	20.05	09.06	81
	2021	25.05	16.06	104
LA5108	2019	23.05	17.06	104
	2020	17.05	08.06	80
	2021	21.05	14.06	102
BGE025277	2019	26.05	20.06	107
	2020	19.05	09.06	81
	2021	27.05	13.06	101
LHL	2019	22.05	14.06	101
	2020	16.05	05.06	77
	2021	20.05	11.06	99
LHL-2	2019	22.05	17.06	104
	2020	16.05	08.06	80
	2021	18.05	10.06	98
LHL-3	2019	26.05	17.06	104
	2020	18.05	10.06	82
	2021	28.05	13.06	101

In 2021, at an average daily temperature of 5.16 C° for the month of March, the plants germinated for a relatively long period of time, 35 days after sowing. In 2019, at higher daily temperatures (9.50 C°) due to the small and unevenly distributed amounts of precipitation, plants sprouted in about 30 days, and in 2020, at a temperature of 8.18 C°, sprouting occurred after 13 days. In these initial phenological phases of plant development, no differences were found between cultivars and lines.

It is noteworthy that for the varieties BGE025277 and BGE027129 the height of the plants is 48-49 cm, while for the other parental component variety LA5108 it does not exceed 44 cm (table 61).

Close to the LA5108 variety are the LHL and LHL-2 lines, which occupy an intermediate position with a plant height of 45-46 cm. According to this trait, LHL-3 lines emerged as the genotype forming plants with the highest stems (53 cm), and the differences with LA5108 and BGE027129 were statistically significant (Figs. 32 and 33).

The productive potential of the genotypes depends on the number of beans per and per seed plant and the number of seeds per bean. BGE027129, LA5108 formed a higher number of pods per plant (14). The situation is similar for line LHL-2, which also has 14 beans, followed by LHL (13). The values of this indicator in line LHL-3 and variety BGE025277 were lower by 9 and 10 beans per plant, respectively.

Figure 32. Line grass pea – LHL (BGE027129 x LA5108)

Figure 33. Line grass pea - LHL-2 (BGE025277 x LA5108)

As a result of the study, significant phenotypic variation was found in another main component affecting productivity - number of seeds per plant. According to this morphological indicator, the genotypes are usually presented in an analogous way as the previous trait. In line LHL-2 and varieties LA5108 and BGE027129, the number of seeds reaches 24-26. The fourth position is occupied by line LHL (22), and BGE025277 and line LHL-3 share the last two places with 15 and 16 seeds per plant, respectively.

Of the tested plant forms, varieties LA5108 and LHL-2 differed from the others in terms of the number of seeds per bean and formed an average of 3 seeds per bean. In beans from the other two cultivars BGE027129 and BGE025277 and lines LHL and LHL-3, up to 2 seeds per bean can be fed.

The mass of seeds per plant is a trait that is highly correlated with grain yield and gives an indirect idea of the magnitude of biological yield. The lowest values of this indicator were found for LA5108 (2.97 g), followed by LHL-2 (3.03 g) below the sample mean (3.98 g) (Figures 30, 31 and 32). Regarding this quantitative trait, variety BGE027129 (4.64 g) and lines LHL (4.41 g) and LHL-3 (4.57 g) are distinguished by the highest seed productivity statistically significant.

Table 61. Biometric analysis of quantitative traits of varieties and lines grass pea (2019-2021 г.)

Variety (lines)	Plant height cm	Number of pods per plant	Number of seeds per pod	Number of seeds per plant	Seeds weight per plant, g	1000 seed mass, g
BGE027129	48c	14d	2a	24c	4.64f	268c
LA5108	44a	14d	3b	26d	2.97a	115a
BGE025277	49d	9a	2a	15a	4.25c	285c
LHL (BGE027129x LA5108)	46b	13c	2a	22b	4.41d	172b
LHL-2 (BGE025277x LA5108)	45b	14d	3b	26d	3.03b	204b
LHL-3 (LA5108x GE027129)	53e	10b	2a	16a	4.57e	246c
Average	48	12	22	2	3.98	215

Different letters (a, b, c. . .) in the same column indicate a significant difference between treatments at $p < 0.05$

Figure 34. Line gpass pea - LHL-3 (LA5108 x BGE027129)

Seed productivity. One of the main characteristics characterizing the economic value of the genotype is its productivity, which depends mainly on the weight of seeds from one plant. The last parameter is determined by several of its components - the number of productive nodes per plant, the number of seeds per bean and the mass of 1000 seeds.

The varieties BGE025277 (285 g) and BGE027129 (268 g) stand out with the highest mass per 1000 seeds, which can be attributed to the large-seeded genotypes. Of the selected hybrid lines, LHL-3 had a slightly lower mass per 1000 seeds (246 g), not significantly different from them. Lines No. LHL (172 g) and LHL-2 (204 g) obtained values for the mass of 1000 seeds, which characterized them as medium-seeded. In the group of small-seeded genotypes with a mass of 1000 seeds below 150 g, variety LA5108 (115 g) can be included.

Differences in weather conditions did not significantly affect the formation of grain yields in common ax genotypes (Table 62). The yields obtained in the individual years of the study do not differ significantly from each other.

Table 62. Grain yield (kg da-1) in varieties - parental components and hybrid line grass pea LHL (2019-2021)

Variety (lines)	2019	2020	2021	Average	%
	Grain yield				
BGE027129	138.85	131.19	131.78	133.94c	126.06
LA5108	80.93	75.10	77.62	77.88a	73.94
LHL	116.33	98.95	111.08	108.79b	107.04
Average (P1+P2)	109.89	103.145	104.7	105.91b	100.00

Different letters (a, b, c. . .) in the same column indicate a significant difference between treatments at $p < 0.05$

Under the conditions of the favorable year 2019, the obtained grain yields varied from 80.93 kg da-1 for LA5108 to 138.85 kg da-1 for BGE027129. Line LHL occupies an intermediate position with a yield of 116.33 kg da-1, surpassing the average yield of parental forms (109.89 kg da-1). In 2020, yields are generally slightly lower compared to the previous year. It is noteworthy that the differences between LA5108 (75.10 kg da-1) and LHL line (98.95 kg da-1) are smaller, and variety

BGE027129 again took the first position (131.19 kg da-1). The year 2021 is characterized by a significant amount of precipitation in the second half of the growing season. From the tested varieties, 131.78 kg da-1 for variety BGE027129, 111.08 kg da-1 for line LHL and 77.62 kg da-1 for LA5108 were obtained, respectively.

The lowest average grain yields during the studied period were recorded for variety LA5108 (77.88 kg da-1). BGE027129 achieved the highest yields (133.94 kg da-1), followed by line LHL (108.79 kg da-1). LHL exceeded by 7.04% the average yield obtained from the parental varieties, although the differences were not statistically proven.

6.1.1. Chemical parameters of a candidate variety grass pea (Lathyrus sativus L.) LHL

To analyze the biochemical composition of the grain of the released candidate varieties common ax and white lupine, the main indicators were determined - dry matter, crude protein (%), crude fiber (%), calcium and phosphorus. The results of the study show (Figure 35) that the dry matter percentage of the established line (LHL) is 89.57. The crude protein content is over 23%. A relatively low crude fiber content (3.96%) was found. The values for phosphorus and calcium content are 0.179% and 0.72%, respectively.

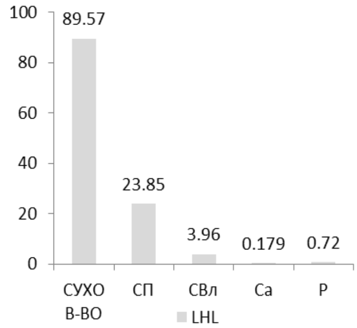


Figure 35. Biochemical evaluation of line LN1-1 grass pea
Dry in-in – dry matter (%); CP - crude protein (%); CBl - raw fibers (%); Ca – Calcium (%); P – phosphorus (%);

6.2. Comparative testing of hybrid lines of white lupine (Lupinus albus L.)

The duration of the vegetation period, calculated as the number of days from the date of sowing to the date of technical maturity in the studied genotypes - prospective lines and parental varieties, varies from 114 days (for PI533704 and LN1-1 for 2020) to 142 days (for Lucky801 for 2021 year). Line LN1-1 is distinguished by the shortest vegetation period from 114 to 135 days (Table 64).

In accordance with the climatic conditions and their genetic endowments, the lines and varieties of white lupine in terms of the occurrence of the individual phenological phases and the duration of the vegetation period can be characterized as follows: PI533704 and PI533704 as early; and Lucky801 and LN5 as later maturing.

Table 64. Phenological development of white lupine lines and varieties (2019-2021 г.)

Variety (lines)	Year	Date of sowing	Date of germination	Beginning of flowering	Full bloom	Technical maturity	Vegetation period, days
Lucky801	2019	05.03	08.04	20.05	27.05	15.07	132
	2020	20.03	04.04	22.05	29.05	18. 07	119
	2021	04.03	26.04	21. 05	26. 05	24. 07	142
PI533704	2019	05.03	08.04	13.05	21.05	11. 07	128
	2020	20.03	04.04	15.05	20.05	13. 07	114
	2021	04.03	26.04	18. 05	22. 05	20. 07	138
LN5	2019	05.03	08.04	16.05	24.05	10. 07	127
	2020	20.03	04.04	17.05	26.05	16. 07	117
	2021	04.03	26.04	21. 05	25. 05	22. 07	140
LN1-1	2019	05.03	08.04	11.05	20.05	14. 07	131
	2020	20.03	04.04	14.05	19.05	13. 07	114
	2021	04.03	26.04	16. 05	21. 05	17. 07	135

Plant height (Table 65) largely determines lodging resistance and suitability for mechanized harvesting. In terms of plant height, variety Lucky801 emerges as the genotype forming plants with the tallest stems (108 cm). Taking into account the climatic conditions during the growing years, the greater responsiveness of the Lucky801 variety to improving growing conditions is evident (Figure 36).

Line LN5 (Lucky801 x PI533704) and variety PI533704 occupy an intermediate position with plant height (Figure 34) in the range of 80 - 87 cm. Data analysis shows that for line #LN1-1 the value of this trait is 68 cm. The situation is similar in terms of height of formation of the first bean. Variety Lucky801 sets its first beans as low as 44 cm. The value of this parameter for variety PI533704 is 36 cm, respectively. The longer-stemmed line LN5 set first beans at a higher height of about 40 cm, and line LN1-1 at 33 cm.

The observed differences in the number of beans per plant are not statistically significant. It was found that the parental variety Lucky801 formed the highest number of beans per plant (33), followed by line LN5 with 28 beans. Line LN1-1 and variety PI533704 fall behind on this indicator, managing to form no more than 23-24 beans per plant.

The results for the number of seeds per plant are similar to the previous trait and show superiority of Lucky801 (130) and line LN5 (114) over PI533704 (103). The last position is occupied by line LN1-1 whose plants managed to feed 92 seeds.

In the biometric analysis, no compensatory mechanisms were established on the part of the trait number of seeds in beans, therefore no change was observed in the arrangement of white lupine genotypes.

Seed weight per plant. Seed productivity is distinguished and is the result of the ratio of many components, of which the influence of the number of seeds per plant and the mass of 1000 seeds is decisive.

Figure 36. Representative plants of Lucky801, PI533704, LN5 and LN1-1 at technological maturity

In the present study, on average for the period 2019-2021, the Lucky801 variety was distinguished by the highest seed productivity (45 g), and the seed mass per plant in line LN5 (37 g) occupied an intermediate position compared to the two parental components. Variety PI533704 and line LN1-1 show a certain similarity in terms of the number of beans and seeds per plant and the number of seeds in a bean, therefore they are statistically reliably close to each other in their productivity (30 g; 26 g).

Table 65. Biometric analysis of quantitative traits of varieties and lines of white lupine (2019-2021 г.)

Variety (lines)	Plant height cm	Height of first pod	Number of pods per plant	Number of seeds per pod	Number of seeds per plant	Seeds weight per plant, g	1000 seed mass, g
Lucky801 (P1)	108c	44b	33a	4a	130a	45b	349b
PI533704 (P2)	80ab	36ab	23a	5a	103a	30a	298a
LN5 (Lucky801 x PI533704)	87b	40ab	28a	4a	114a	37ab	339b
LN1-1 (Lucky801 x PI533704)	68a	33a	24a	4a	92a	26a	305a

Different letters (a, b, c. . .) in the same column indicate a significant difference between treatments at $p < 0.05$

The mass of 1000 seeds depends on the features of the genotype and on environmental factors. Data analysis shows that the productivity of Lucky801 is very well matched with the seed size (349 g). However, the other variety PI533704 was characterized by the lowest average weight per 1000 seeds (298 g) and was overtaken by line LN1-1, whose seeds were slightly heavier (305 g) (Figures 35 and 36). Of interest is line LN5 distinguished by mass per 1000 seeds (339 g) statistically not proven to differ from the better parent (Lucky801).

Grain yield. As a complex quantitative trait, the formation of grain yield is directly dependent on changing climatic conditions. In the conducted field experience, the yield of white lupine varieties and lines varied significantly by year (Table 66).

In the most favorable year 2019, the grain yield of white lupine ranged from 370 kg da-1 to 446 kg da-1. The most productive genotypes were variety Lucky801 and line LN5. Line L1.1 exhibits biological properties close to the second parental component PI533704. Line No. LN5, even in the unfavorable environment, managed to fully express its productive capabilities and accumulate a significant amount of seed production (315 kg da-1), which exceeded the average value of the parents (107.14%). In 2021, fluctuations range from 260 kg da-1 to 392 kg da-1.

On average for the study period, line LN1-1 gave a higher grain yield (263 kg da-1) compared to variety PI533704 (260 kg da-1), although it was not significantly different from it. The last position of this line is due not to the fact that it is less leafy but to the shorter growing season, during which it fails to form a significant seed mass, as well as to the shorter plants.

Differences in grain yields between line LN5 (315 kg.da-1) and variety Lucky801 (339.00 kg.da-1) were not mathematically proven, therefore these genotypes fall into the same statistical group. The numerical expressions of the grain yield of line LN1-1 in the individual years of the study (370 kg.da-1, 111 kg da-1, 308 kg.da-1) give reason to believe that it is significantly influenced by changes in climate conditions.

Table 66. Grain yield (kg.da-1) in varieties - parental components and hybrid lines of white lupine (2019-2021)

Variety (lines)	2019	2020	2021	Average	%
	Grain yield				
Lucky801 (P1)	446	178	392	339c	115.31
PI533704 (P2)	376	112	260	249a	84.69
LN5	419	158	368	315bc	107.14
LN1-1	370	111	308	263a	89.46
Average (P1+P2)	411	145	326	294b	100.00

Different letters (a, b, c. . .) in the same column indicate a significant difference between treatments at $p < 0.05$

Figure 35. White lupine line LN1-1 (Lucky801 x PI533704)

Figure 36. White lupine line LN5 (Lucky801 x PI533704)

The yield obtained from it is lower than the average of the two parent components (294 kg.da-1). Variety PI533704 has a lower average value of grain yield (249 kg.da-1), and the difference compared to line No. LN1-1 is statistically unproven.

6.2.1. Chemical parameters of the candidate varieties of white lupine (Lupinus albus L.) LN1-1 and LN5

The selected white lupine candidate cultivars (LN1-1 and LN5) possessed high grain dry matter values (91.66%; 91.51%) (Figures 39 and 40).

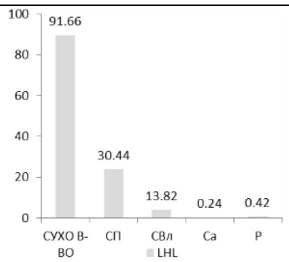


Figure 39. Biochemical evaluation of line LN1-1 white lupine (Lupinus albus L.)

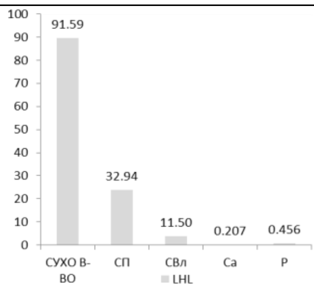


Figure 40. Biochemical evaluation of line LN5 white lupine (*Lupinus albus* L.)

dry matter (%); CP - crude protein (%); CBl - raw fibers (%); Ca – Calcium (%); P – phosphorus (%);

In line LN5, the higher crude protein content (32.94%) was combined with the lower crude fiber content (11.50%). For line LN1-1, a crude protein content of 30.44% and a crude fiber content of 13.82% were found. In terms of calcium content, the white lupine lines do not differ significantly from each other (0.24%; 0.207%). The values showing the phosphorus content are also very close, as for LN1-1 it is 0.42%, and for LN5 it is 0.456%.

VII. CONCLUSIONS

With the grass pea

Strong phenotypic variation was found for number and weight of tubers, fresh weight of leaves and stems, number and weight of seeds per plant and fresh weight of plant, and stronger genotypic variation for number of leaves, fresh and dry weight of roots, weight of dry stems and dry root weight.

Root dry weight, root fresh weight (85.56%), stem dry weight (81.63%), number of leaves per plant (82.00%), number of pods per plant (72.05%) and number of branches are characterized by high heritability. (69.49%).

A strong positive correlation was found between plant seed weight with tuber weight (r=0.712) and dry stem weight (r=0.853) and mean root fresh weight (r=0.499) and specific tuber forming capacity (r =0.520).

The influence of the genotype and the environment was proven on all the investigated characters except for the weight of the fresh root mass. For plant height, plant fresh weight, number of seeds per plant and seed weight per plant, a stronger influence of the environment factor was found, and for the number of tubers per plant, of the genotype factor.

BGE027129 was distinguished as ecologically stable with high values in plant height, stem fresh weight, number of seeds and tubers per plant, and BGE025277 in plant height, seed weight and number of tubers per plant. These cultivars are suitable for growing in a wide range of environmental conditions.

BGE015741 has the best expression of number and weight of grains per plant, has high adaptability and is responsive to improving growing conditions.

BGE027129 has high breeding value and value in number of beans (9.19; 16) and seeds per plant (16.07; 26) and weight of seeds per plant (2.29; 4.65), and BGE015741 in plant height (38.46; 44.13), number (16.43; 29) and weight of seeds per plant (2.09; 21.01).

BGE025277 is of breeding interest for the traits plant height (50.67) and seed weight per plant (4.26), which are combined with good homeostaticity (77.22; 1.65) and relative stability (2.39; 40.18) to the environment.

The highest average seed yield was reported for BGE015741 (158.40 kg da-1), BGE027129 (113.10 kg da-1) and BGE025277 (108.30 kg da-1), and fresh aboveground biomass for BGE015741 (840.40 kg da-1) , LAT4362 (779.3 kg da-1) and BGE027129 (722.80 kg da-1).

LAT4362 and BGE025277 formed heavier fresh shoot and root mass and exhibited a good combination of adaptability and attraction genes. BGE027129, BGE025277 and BGE015741 were breeding valuable in terms of seed weight per plant.

A negative heterosis effect was found in almost all hybrids at both environmental limits. Only in LAT5108 x BGE027129, the heterosis is high and positive in terms of the number of tubers per plant.

Dominant to superdominant negative inheritance was found in F1 at BGE027129 x LAT5108 for root fresh weight, aboveground biomass weight and tuber weight per plant; LAT5108 x BGE027129 by leaf fresh weight and aboveground biomass weight. Non-allelic interactions occurred in the inheritance of tuber number and weight per plant in BGE025277 x LAT5108.

The overall phenotypic expression of fresh weight of roots, aboveground mass and tubers is strongly genotypically determined and mass selection for these traits can begin in the earlier hybrid progeny (F2 - F3).

According to the biochemical composition of the grain, BGE015741 is distinguished by high values of crude protein (28.44%), calcium (1.90%) and phosphorus (0.29%), LAT5038 by crude fiber (46.75%) and LAT4362 by crude ash (14.82%).

At the white lupine

A statistically reliable influence of the environment and the genotype on the manifestation of the studied signs was established. The variation in the tuber-forming ability of plants is determined to the greatest extent by the genotype factor.

High heritability combined with low genetic progress was found for specific tuber-forming ability (80.81%; 0.09) and dry stem weight (62.60%; 0.31), indicating the involvement of non-additive gene actions.

A strong positive correlation was found between the weight of fresh aboveground biomass and the weight of dry and fresh leaves (r=0.881; r=0.897), plant height (r=0.587) and dry weight of roots (r=0.569); of plant height with dry weight of above ground mass (r=0.963).

The calculated parameters of environmental stability by plant height identify PI533704 as the most stable and high growing, by number of beans and seeds per plant and seed weight per plant variety Zuter as the most desirable, near ideal type, combining high productivity with ecological stability.

Lucky801 is by most signs ecologically unstable, but highly productive, and therefore suitable as a parent component in breeding programs for obtaining highly productive varieties.

PI457923 and PI457938 were of high selection value and value of fresh weight of root mass (1.11; 0.95 and 1.92 g; 1.97 g) and number of tubers per plant (5.58; 5.37 and 10.20; 8.00).

The highest average seed yield was reported for Lucky801 (208.67 kg da1) and PI533704 (151.92 kg da-1). PI368911; PI457938 and KALI are distinguished by high variability and grain yield below the average (90.00 kg da-1, 80.08 kg.da-1, 83.25 kg.da-1) for the studied group of cultivars. The highest yields in terms of fresh aboveground biomass are the varieties PI457938 and PI533704 with an average yield of 597.98 - 485.12 kg da-1.

Plants from PI457938 formed high weight fresh shoot and root mass and exhibited a good combination of adaptability and attraction genes.

Strong genes of physiological systems - attraction and adaptability in plant seed weight and root mass weight are possessed by Lucky801 and PI533704 varieties, and PI457923 and Zuter varieties have good adaptation.

Limiting environmental conditions influence the occurrence of heterosis and degrees of dominance. Positive true heterosis was found in PI533704 x Zuter and PI533704 x Lucky801 crosses for tuber weight and root fresh weight per plant at both media limits.

The traits tuber weight per plant and root fresh weight in PI533704 x Zuter were inherited in pronounced positive dominance and overdominance. Manifestations of negative dominance were found in Lucky801 x PI533704 for tuber weight and root mass per plant.

The hybrids PI533704 x Zuter and Lucky801 x PI533704 are characterized by a high coefficient of heritability in both limits of the environment by the number and weight of the tubers, Zuter x PI533704 by the fresh weight of the root and aerial mass, and almost all hybrids by the weight of the seeds per plant.

The overall phenotypic expression of seed weight per plant in Zuter x PI533704 is highly genotypic and a greater effect of mass selection can be expected in the earlier hybrid progeny (F2 - F3).

At full maturity, with maximum values for biochemical parameters, PI368911 and Lucky801 stand out for crude protein (30.14%; 28.88%), Zuter for crude fiber (51.82%), PI457923 and KALI for calcium (0.77%), PI457938 for phosphorus (0.123%) and KALI for raw ash (6.277%).

The correlation coefficient of crude protein content with grain yield (r=0.17) and with the vegetation period (r=0.63) is positive, but statistically insignificant.

VIII. Contributions

8.1. Scientific contributions

8.1.1. Contributions of an original scientific nature

A complex evaluation of a set of genotypes of the species grass pea and white lupine was carried out according to basic quantitative signs and qualitative indicators and according to their reaction to environmental limiting factors.

The genetic diversity of the set of samples of these species was evaluated by a large number of parameters related to the above-ground biomass and the root system, as well as by indicators related to the quality of fresh mass and grains.

The use and joint application of various methods for determining ecological stability and adaptability enables a more complete assessment of selection materials in terms of the complex magnitude of the trait and its stability. Those of the genotypes that realize their productive potential relatively stably, regardless of changing abiotic factors, are indicated.

The method of orthogonal regression has been developed, which makes it possible to evaluate the quantitative polygenic traits in the varieties and hybrids of white lupine and grass pea common ax through the physiological-genetic systems of adaptability and attraction and to identify the best genotypes.

The adaptive capabilities of the varieties and hybrids of grass pea and white lupine have been proven by shifting the mean values of the characters along the coordinate system. The possibility of matching and combining in one genotype genes for attraction and adaptability is shown.

Based on the genetic analysis, high heritability and genetic progress were found for plant, fresh leaf and seed weight and number of branches per plant in grass pea, as well as for number of leaves, fresh stem weight and total plant fresh biomass , which will support the construction of a selection strategy for their improvement.

8.1.2. Scientific contributions of a confirmatory nature

The influence of the main factors - genotype, environment and the genotype-environment interaction, on which the phenotypic expression of individual quantitative and qualitative parameters depends, has been confirmed. In grass pea cultivars, the genotype factor has the strongest influence on the number of tubers per plant, and in white lupine on the tuber-forming ability.

Correlation relations were confirmed both between separate groups of quantitative signs and qualitative indicators, which facilitate the selection of suitable genotypes.

The manifestation of a different type of dominance in the inheritance of most of the studied characters was confirmed in both plant species. The action of dominant alleles is influenced by the direction of crossing as well as environmental conditions.

Genetic control of traits has been confirmed to occur using both additive and non-additive gene effects. Non-allelic interactions were shown in the expression of tuber number and weight in hybrids of the two plant species and in aboveground biomass weight in white lupine Lucky801 and PI533704 (4). This hybrid exhibits a good combination of genes for adaptability and attraction (rapid displacement of plastic substances) when conditions deteriorate. When thinning the crop, such a combination was found only in the hybrids Zuter × PI533704 (3) and PI533704 × Lucky801 (2) with positive values for attraction and adaptability.

8.2. **Contributions of a scientific and applied nature**

For the first time in our country, through a quantitative and complex assessment and with the help of modern mathematical and statistical methods, an in-depth analysis of the main quantitative signs and qualitative indicators of grass pea (Lathyrus sativus L.) and white lupine (Lupinus albus L.) samples was made. The varieties LAT5108, BGE015741 and BGE027129 grass pea and PI533704, Zuter and Lucky801 white lupine were identified as valuable starting material for the selection of new plant forms distinguished by early maturity and increased productive potential.

Promising genotypes were obtained from grass pea (LAT5108 × BGE025277-A1) with a favorable combination of tuber weight and fresh aboveground biomass productivity and from white lupine (Lucky801 and PI533704 (4), Zuter × PI533704 (3) and PI533704 × Lucky801 (2)) by weight of the root system and aboveground biomass, which are suitable for research related to organic agriculture.

Grass pea (BGE027129, BGE025277 and BGE015741) and white lupine (PI533704 and Zuter) cultivars characterized by high trait value and ecological stability were identified and could be included in a breeding program to improve these crops.

The developed ecological-genetic approach will make it possible to reveal new regularities in the team theory and the ecological-genetic organization of the quantitative trait in plants. In light of this approach, progress will be made in the development of new selection models.

A transition was made from selection based on the notions of "gene-trait" to selection of genetic-physiological systems with an emphasis on adaptability (ad) and attraction (atr). The attempt to identify the genotype by phenotype without changing the offspring will increase the efficiency of the selection process many times over.

RESULTS OF THE DISSERTATION DEVELOPMENT

In collaboration with other scientific collaborators, each ax and white lupine varieties have been selected and recognized:

New variety every time Yodai grass pea ax (LHL line). Sorting was obtained by multiple individual selection in the cross BGE027129 × LAT5108. The height of the plants at technological maturity of the grain reaches 46 cm. The vegetation period is an average of 93 days. The new variety ripens 4-5 days before the varieties BGE027129 and LAT5108. On average, one plant produces 13 well-nourished beans with a total of 22 normally developed seeds. The seeds are medium-sized with a white seed coat, with a flat oval shape. Its seed productivity (4.41 g) exceeds the average of the parental varieties (3.80 g). The weight of 1000 seeds is about 172 g. The crude protein content is 23.85%. The variety has good resistance to cracking of the beans. It is drought tolerant. It is weakly attacked by diseases and enemies.

A new variety of Gaia white lupine (line LN1-1). It was obtained by the method of artificial sexual hybridization and between the varieties Lucky801 and PI533704 and followed multiple individual selection. It is adapted to adverse environmental conditions. It exhibits tolerance to economically important diseases and is resistant to lodging. An advantage of the new variety is the shorter growing season - 126 days. Plants of LN1-1 were characterized by a deterministic type of stem development and a plant height of 68 cm. The height of the first rosette of beans develops at 33 cm. The inflorescence is medium in size, blue-white, the seeds are white to medium in size. The formed beans do not crack and the seeds do not spoil, and their number reaches 24. The average number of seeds in one bean is 4-5. The mass of 1000 seeds was 305 g and was higher than the value of PI533704. Ripe grain has a crude protein content of up to 30%. It is characterized by a higher seed yield (263 kg da-1) compared to variety PI533704 (249 kg da-1).

A new variety of white lupine Monica (line LN5). The created variety is intended for seed production. It was obtained by repeated individual selection from the cross Lucky801 × PI533704. It belongs to the medium ripening group with a duration of the growing season of 129 days. It has genetically completed growth. Pods are formed on the main stem and on shortened lateral branches of the first and second order. Plant height is 87 cm. The variety has high lodging resistance and good adaptability to abiotic conditions. The first beans are planted at 40 cm. The pods of the plant are formed on the main stem and on shortened lateral branches of the first and second order.

About 28 uncrackable beans form on one plant. The inflorescence is medium-sized, blue-white, the seeds are white, medium-sized. The number of seeds in one plant is on average 114. The protein content of the grain is 33%. The variety is distinguished by high potential productivity. The variety is distinguished by high potential productivity (37 g is the mass of seeds per plant). The mass of 1000 seeds is 339 g. Its average grain yield (315 kg da-1) in the competitive varietal trials conducted exceeded the average of the parental forms (294 kg da-1).

ABSTRACT: The research was conducted in the period from 2014 to 2021 in the Second Experimental Field of the Institute of Forage Crops-Pleven, Bulgaria. As a result of purposeful scientific activity at the Institute, new varieties of grass pea and white lupine were created, as well as promising lines of these crops in the field of grain production. The aim of this study was to investigate the selection-genetic possibilities for the enrichment of the genetic diversity in grass pea (*Lathyrus sativus* L.) and white lupine (*Lupinus albus* L.) through the methods of combinatorial selection. To achieve this goal, the following tasks were performed: A morphological, ecological and biochemical evaluation of collection samples of grass pea and white lupine was made. Phenotypic correlations between major traits in these species were determined. Selection and genetic studies were carried out and the ways of inheritance of economically valuable quantitative traits in the hybrid generations were studied. Grass pea samples with high heritability were characterized by root dry weight, root fresh weight (85.56%), stem dry weight (81.63%), number of leaves per plant (82.00%), number of pods per plant (72.05%) and number of branches (69.49%). A strong positive correlation was found between plant seed weight with tuber weight (r=0.712) and dry stem weight (r=0.853) and mean root fresh weight (r=0.499) and specific tuber forming capacity (r=0.520). Dominant to overdominant negative inheritance was found in F1 at BGE027129xLA5108 for root fresh weight, aboveground biomass weight and tuber weight per plant; LAT5108 x BGE027129 by leaf fresh weight and aboveground biomass weight. Non-allelic interactions occur in the inheritance of tuber number and weight per plant in BGE025277 x LAT5108. In white lupine, high heritability combined with low genetic progress was found for specific tuber-forming ability (80.81%; 0.09) and dry stem weight (62.60%; 0.31), indicating the involvement of non-additive gene actions. A strong correlation was found between the weight of fresh aboveground biomass with that of dry and fresh leaves (r=0.881; r=0.897), with plant height (r=0.587) and with dry weight of roots (r=0.569); of plant height with dry weight ofove ground mass (r=0.963). Tuber weight per plant and root mass in PI533704xZuter were inherited in pronounced positive dominance and overdominance. The dominance of Lucky801 x PI533704 in tuber weight and root mass is negative. Created and recognized as new are the varieties of grass pea (Yodai) and white lupine (Gaia and Monica).

List of scientific publications on the topic of the dissertation work

of assoc. Prof. Dr. Valentin Ivanov Kosev

in connection with a competition for the acquisition of the scientific degree Doctor of Sciences in the field of higher education 6. Agricultural sciences and veterinary medicine. Direction 6.1 Plant breeding. Scientific specialty "Selection and seed production of cultural plants"

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4 Kosev V., Vasileva V., Popovic V., Pešić V., Nožinić M. 2022. Ecological-genetic model in grass pea (*Lathyrus sativus* L.) breeding. GENETIKA, Vol. 54, No3: 1385-1397.

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