Bulgarian Journal of Agricultural Science, 28 (No 3) 2022, 401–407

Dependencies between quantitative traits, determining the seed productivity in white lupine accessions

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Abstract

Kosev, V. & Georgieva, N. (2022). Dependencies between quantitative traits, determining the seed productivity in white lupine accessions. *Bulg. J. Agric. Sci., 28 (3)*, 401–407

The experiment was conducted during the period 2016-2018 at the Institute of Forage Crops (Pleven, Bulgaria) to establish the phenotypic and genotypic correlations between the main quantitative traits in 15 accessions of white lupine. Correlation and regression analyzes were applied. The results showed that the values of the positive genotypic correlations in the studied white lupine accessions were higher than the ones of phenotypic correlations for all traits, whereas in negative coefficients the trend was reversed. The genotypic correlation of seeds number with seed weight (r=0.974; r=0.901; r=0.832) and pods number per plant (r = 0.980; r = 0.881) was strong and positive. Positive were the genotypic relationships of plant height with 1st pod height (r = 0.632; r = 0.635; r = 0.895), and pod length with 1000 seeds mass (r = 0.655; r = 0.559; r = 0.382). The values of the correlation coefficients for plant height with 1st pod height, pods with seeds number, 1000 seeds mass with seed weight and pod length, and seeds number with seed weight remained relatively constant during the three years of the study. Positive share for the formation of seed productivity had the traits of seeds number of per plant (R = 0.200; R = 0.253; R = 0.240) and 1000 seeds mass (R = 0.080; R = 0.044; R = 0.018). Seeds number and 1000 seeds mass had direct positive effect on the seeds weight per plant, and seeds and pods number and plant height had the highest total effect.

Keywords: dependence; accessions; correlations; productivity; trait; white lupine

Introduction

Even though in the past the white lupine was widespread in Europe, nowadays it is unvalued culture. Nevertheless, during the past few years, work on creating new varieties and improving the agronomic characteristics of lupine has intensified. The white lupine (*Lupinus albus* L.) is an important source of protein, carbohydrates, and fats, but there is a necessity for genetic improvement to reaching its agronomic potential (Pospišil & Pospišil, 2015; Książkiewicz et al., 2017). According to Bulgakova & Syukov (2015), the characteristic of new lines, hybrids, and forms should be performed not on individual traits, but in their totality. Therefore, it is necessary to apply different methods for an integrated evaluation of the initial breeding material. These methods include evaluation of materials using correlation and Path analysis.

The plant traits are considerably influenced by the changing environmental conditions. The latter can cause variability not only in the traits but also in the connections between them (Dadерkina, 2007). In this regard, a question arises with the search for regularity in the variability of the relations between the traits in case of changing environmental conditions, as well as in the nature of the manifestation of correlations in the specific conditions over the years (Korobeynikov, 2002).

Yield increment is not an immediate result only from mutagenesis, but it is also determined by interrelated traits, which means that direct yield selection can be misleading. In this sense, knowing the relations between crucial yield components and seed yield can help the researcher to identify appropriate donors for a successful breeding program (Singh et al., 2017). In other words, associations between yield components may be used as the best guide for successful yield increase through indirect selection. Phenotypic and genotypic correlation values provide information about the relationship between two or more than two independent variables. In breeding and genetics, different traits can be assessed by correlation analysis. The knowledge about the relation between the various traits and seed productivity would be of great assistance in preparing an effective selection and screening program. A number of researchers have reported established correlations between yield and its components in different legumes (Kumar & Lavanya, 2014; Sharifi, 2014; Kamadi et al., 2015; Kour & Agarwal, 2016).

Based on the evaluations from correlation and regression analysis, it is possible to conduct indirect selection on main traits, which leads to faster progress in the breeding process, compared to direct selection on a given trait. Phenotypic and genotypic correlations do not determine the relative importance of direct and indirect influences of traits on crop productivity. The causal link between them can be determined by path-analysis, which allows the distribution of correlation coefficients of direct and indirect effects (Gonçalves et al., 2017).

One component is the path-coefficient (or standardized partial regression coefficient), which measures the direct effect of the predictor variable on its response. The other component is the indirect effect of the predictor variable on the response of the variable through the predictive variables (Dewey & Lu, 1959).

Path analysis allows the breeder to understand better the association between different traits by presenting the correlation coefficients as direct and indirect effects, using basic and explanatory variables.

The present study aimed to establish the coefficients of phenotypic and genotypic correlations between the main quantitative traits in white lupine accessions.

Materials and Methods

The field experiments were conducted out during the period 2016 – 2018 at the Institute of Forage Crops (Pleven, Bulgaria). Plant material from 15 white lupine (*Lupinus albus* L.) accessions was analyzed: Lp 1, Lp 4, Lp 6, Lp 10, Lp 21, Lp 23, Lp 25, Lp 27, Lp 28, Lp 29, Lp 27\1, Lp 27\3, Lp 27\7, Lp 27\10, Lp 28\1. The variants were arranged randomly, by block method (Barov, 1982) with a plot size of 4 m^2 and three replications. Sowing was carried out in optimal time (at the end of March), with a rate of 50 seeds per m^2, row spacing of 50 cm and depth of 2-3 cm. The plants were cultivated in organic farming conditions, without use of fertilizers and pesticides. The following traits of plants were recorded: 1st pod height (cm), plant height (cm), pods number per plant, pod length (cm), pod width (cm), seeds number per plant, 1000 seeds mass (g), seed weight per plant (g).

Correlation and regression analysis were applied for statistical data processing (Dimova & Marinkov, 1999). Genetic and phenotypic correlations were calculated by two-factor analysis of variance (ANOVA) and path analysis (Williams et al., 1990). The phenotypic correlation is conditioned by the relationship among individual characters and the influence of environmental factors. The genotypic correlation is a function of the pleiotropic action of the genes involved and their related inheritance. Linked genes have additive, dominant and epistatic actions. It is generally regarded that the additive genes are of greatest value in breeding (Zhelyazkov & Tsvetanova, 2002). Coefficient of correlation was partitioned into path coefficient using the technique outlined by Dewey & Lu (1959). The software products MS Excel (2003) and GENES 2009.7.0 (Cruz, 2009) were used in the processing of the experimental data.

Results

The correlations between the traits allow determination of the degree of interrelation between the individual indicators, which makes it possible to control the change of the traits and to predict their manifestation in cases when a purposeful selection is led by them (Daderkina, 2007). In terms of direction, correlations can be positive, which shows a tendency to increase one variable when increasing another. And conversely, when they are negative, it suggests the possibility of increasing the value of one variable while the other one decreases (Nogueira et al., 2012).

Correlation analysis

The performed correlation analysis of the traits for 2016 shows that a considerable part of the dependencies is statistically significant (Table 1). The values of the genotypic correlation coefficients with a positive sign were slightly higher than the phenotypic ones, which is an indication that the environmental factors have a less pronounced effect on the manifestation of the studied traits. The trend was reversed in terms of negative coefficients, as in phenotypic dependences, the values were higher.

Significant positive genotypic relations were established regarding the pods number with seeds number ($r = 0.986$) and seed weight per plant ($r = 0.954$), seeds number with seed weight ($r = 0.974$), pod length with pod weight ($r = 0.959$), and 1^{st} pod height with 1000 seeds mass ($r = 0.829$). The obtained results suggest that these traits would contribute to increasing grain production and should be taken into account in the selection of genotypes.

Table 1. Correlation dependencies in white lupine accessions, 2016

Traits	Plant height	1st pod height	Pods number	Seeds number	Seed weight	Pod length	Pod width	1000 seeds mass
Plant height		0.632**	0.137	0.188	0.336**	0.279	0.146	0.398*
1st pod height	0.630**		-0.615**	-0.554**	-0.454**	0.581**	0.493**	0.829**
Pods number	0.139	-0.603**		0.986**	0.954**	-0.710**	-0.678**	-0.793**
Seeds number	0.187	-0.552**	0.980**		0.974**	-0.701**	-0.709**	-0.743**
Seed weight	0.335*	-0.445**	0.950**	0.970**		-0.620**	-0.656**	-0.588**
Pod length	0.271	0.553**	-0.661**	-0.668**	-0.585**		0.959**	0.655**
Pod width	0.142	0.483**	-0.644**	-0.690**	-0.628**	0.939**		0.586**
1000 seeds mass	0.389**	0.810**	-0.747**	-0.718**	-0.553**	0.623**	0.562**	

Phenotypic correlations – below the diagonal, genotypic ones – above the diagonal; * / ** significant at the 0.05 / 0.01 level

Table 2. Correlation dependencies in white lupine accessions, 2017

Traits	Plant height	1st pod height	Pods number	Seeds number	Seed weight	Pod length	Pod width	1000 seeds mass
Plant height		0.635**	0.398**	0.510**	0.642**	0.304	0.032	0.406**
1st pod height	0.628**		-0.075	0.037	0.069	-0.259	-0.208	0.104
Pods number	0.397**	-0.074		0.886**	0.743**	0.256	-0.123	-0.096
Seeds number	0.507**	0.033	0.881**		0.901**	0.257	-0.215	-0.001
Seed weight	0.636**	0.065	0.740**	0.897**		0.431*	0.015	0.418**
Pod length	0.279	-0.219	0.234	0.237	0.396*		0.732**	0.559**
Pod width	0.034	-0.181	-0.111	-0.197	0.025	0.737**		0.585**
1000 seeds mass	0.405**	0.103	-0.095	0.001	0.416**	0.506**	0.554**	

Phenotypic correlations – below the diagonal, genotypic ones – above the diagonal; * / ** significant at the 0.05/0.01 level

At average level was the dependence between the 1st pod height with the plant height (r = 0.632), the pod length (r = 0.581) and the pod width (r = 0.493); the pod length and the 1000 seeds mass (r = 0.655). The genotype relationships of plant height with seed weight (r = 0.336) and 1000 seeds mass (r = 0.398) can be mentioned as weaker.

There was a strong negative phenotypic correlation between seeds number per plant and 1000 seeds mass (r = -0.718), pod width (r = -0.690) and pod length (r = -0.668), as well as regarding pods number with the same characteristics. The phenotypic dependence with the same sign between 1st pod height and pods number (r = -0.603) and seeds number per plant (r = -0.552) was average.

The average negative genotypic and phenotypic relationship between seed weight and pod length (r = -0.620; r = -0.585), pod width (r = -0.656; r = -0.628) and 1000 seeds mass (r = -0.588; r = -0.553) shows that increasing the pod size, as well as the mass of the seeds, leads to a productivity decrease. A negative but relatively weaker correlation was found between the seeds mass per plant and the 1st pod height (r = -0.454; r = -0.445).

The correlation analysis for the year 2017 shows that in a considerable part of the traits, the environment influence is so strongly expressed that it substantially changes the expression of both the phenotypic and genotypic correlation coefficient compared to the year 2016 (Table 2). This fact was observed in the dependences of plant height with pods number (r = 0.398; r = 0.397), seeds number (r = 0.187; r = 0.188), seed weight (r = 0.642; r = 0.636) and 1000 seeds mass (r = 0.406; r = 0.405). In the traits, directly related to the productivity, such a difference was also found but the correlation coefficient changed its sign regarding pod length with pods number (r = 0.256; r = 0.234) and seeds number (r = 0.237; r = 0.257). There was a similar dependence between seeds weight per plant and 1000 seeds mass (r = 0.416; r = 0.418).

The indicated genotypic and phenotypic correlation coefficients for the year 2018 have certain specificity and a discrepancy with the previous two years, which is obviously due not only to the genetics white lupine accessions, but also to the environment influence on the trait manifestation (Table 3). In contrast to years 2016 and 2017, in 2018, opposite in sign, but statistically insignificant correlations were found between seeds number of plant height (r = -0.037; r = -0.038), pods number and 1st pod height (r = 0. 0.040; r = 0.037); 1000 seed mass with seed number (r = 0. 124; r = 0.129) and pods width (r = -0.285; r = -0.239).

The greatest contribution to increasing seed weight per plant have the seeds number (r = 0.832; r = 0.801) and 1000 seeds mass (r = 0.442; r = 0.425), while the pod width (r = -0.760; r = -0.709) affects negatively.

For some of the traits, the values of the correlation coefficients remained relatively constant regardless of climate change, such as the dependence of plant height with 1st pod height and the seeds number with seed weight per plant (Table 4). Regarding seeds number with pods number and in pods

Table 3. Correlation dependencies in white lupine accessions, 2018

Traits	Plant height	1st pod height	Pods number	Seeds number	Seed weight	Pod length	Pod width	1000 seeds mass
Plant height		0.895**	0.125	-0.037	0.045	0.285	0.071	0.119
1st pod height	0.890**		0.040	-0.196	-0.067	0.366*	0.284	0.053
Pods number	0.121	0.037		0.368*	0.193	-0.616**	-0.186	-0.481**
Seeds number	-0.038	-0.193	0.362*		0.832**	-0.310	-0.514**	0.124
Seed weight	0.045	-0.066	0.184	0.801**		-0.091	-0.760**	0.442**
Pod length	0.275	0.345*	-0.576**	-0.265	-0.107		0.147	0.382*
Pod width	0.078	0.247	-0.177	-0.459**	-0.709**	0.171		-0.285
1000 seeds mass	0.118	0.050	-0.464**	0.129	0.425**	0.368*	-0.239	

Phenotypic correlations – below the diagonal, genotypic ones – above the diagonal; * / ** significant at the 0.05/0.01 level

Table 4. Correlation dependencies in white lupine accessions (2016-2018)

Traits	Years	Plant height	1st pod height	Pods number	Seeds number	Seed weight	Pod length	Pod width	1000 seeds mass
Plant height	2016		0.632**	0.137	0.188	0.336**	0.279	0.146	0.398*
	2017		0.635**	0.398**	0.510**	0.642**	0.304	0.032	0.406**
	2018		0.895**	0.125	-0.037	0.045	0.285	0.071	0.119
1st pod height	2016	0.630**		-0.615**	-0.554**	-0.454**	0.581**	0.493**	0.829**
	2017	0.628**		-0.075	0.037	0.069	-0.259	-0.208	0.104
	2018	0.890**		0.040	-0.196	-0.067	0.366*	0.284	0.053
Pods number	2016	0.139	-0.603**		0.986**	0.954**	-0.710**	-0.678**	-0.793**
	2017	0.397**	-0.074		0.886**	0.743**	0.256	-0.123	-0.096
	2018	0.121	0.037		0.368*	0.193	-0.616**	-0.186	-0.481**
Seeds number	2016	0.187	-0.552**	0.980**		0.974**	-0.701**	-0.709**	-0.743**
	2017	0.507**	0.033	0.881**		0.901**	0.257	-0.215	-0.001
	2018	-0.038	-0.193	0.362*		0.832**	-0.310	-0.514**	0.124
Seed weight	2016	0.335*	-0.445**	0.950**	0.970**		-0.620**	-0.656**	-0.588**
	2017	0.636**	0.065	0.740**	0.897**		0.431*	0.015	0.418**
	2018	0.045	-0.066	0.184	0.801**		-0.091	-0.760**	0.442**
Pod length	2016	0.271	0.553**	-0.661**	-0.668**	-0.585**		0.959**	0.655**
	2017	0.279	-0.219	0.234	0.237	0.396*		0.732**	0.559**
	2018	0.275	0.345*	-0.576**	-0.265	-0.107		0.147	0.382*
Pod width	2016	0.142	0.483**	-0.644**	-0.690**	-0.628**	0.939**		0.586**
	2017	0.034	-0.181	-0.111	-0.197	0.025	0.737**		0.585**
	2018	0.078	0.247	-0.177	-0.459**	-0.709**	0.171		-0.285
1000 seeds mass	2016	0.389**	0.810**	-0.747**	-0.718**	-0.553**	0.623**	0.562**	
	2017	0.405**	0.103	-0.095	0.001	0.416**	0.506**	0.554**	
	2018	0.118	0.050	-0.464**	0.129	0.425**	0.368*	-0.239	

Phenotypic correlations – below the diagonal, genotypic ones – above the diagonal; * / ** significant at the 0.05/0.01 level

length with a 1000 seeds mass, the correlation was positive and significant, but for 2018 it was significantly weaker. For seeds weight with 1000 seeds mass, the dependence for 2016 was average and negative ($r = -0.553$; $r = -0.588$).

The low positive, but insignificant genotypic and phenotypic relation between plant height and pod length/width in all three experimental years indicates that only some of the selected accessions with longer stems will form broad pods with longer length. The observed deviation in the values of the correlation coefficients during the three years in the traits considered in this study will contribute to better efficiency of the selection in the breeding of highly productive lupine genotypes.

Coefficient of determination (r^2)

The analysis of the r^2 values for 2016 shows that the seed weight per plant w as determined by pods (90.25%) and seeds number (94.09%), followed by pod width (39.44%), pod length (34.22%) and 1000 seeds mass (30.58%) (Figure 1). The seed weight was much less affected by the plant height (11.22%).

In 2017, the variation in seed weight depends up to 80.46% on the variation in seeds number, 54.76% on pods number, 40.45% on plant height and 17.31% on 1000 seeds mass. It practically does not depend on pod width (0.06%) and 1st pod height (0.42%).

The coefficients of determination for 2018 show that in the present study no essential relation was found between the magnitude of seed productivity and plant height (0.203%), 1st pod height (0.44%) and pods length (1.14%). It actually varies greatly from the manifestations of the seeds number (up to 64.16%), pod width and 1000 seeds mass (50.27% and 18.06%, respectively).

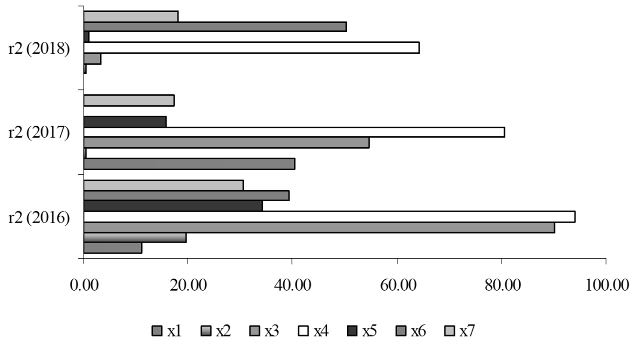
Path analysis

The direct and indirect effect of the yield structural elements on the seeds weight per plant was traced by the path-analysis (Table 5).

In this study, seed weight per plant was accepted as the main variable. It is directly positively affected by seeds number (0.835), pods number (0.169), 1000 seeds mass (0.223) and plant height (0.159). The increase in these indicators led to productivity increase in white lupine accessions. The direct effect of the 1st pod height (-0.048), the pod length (-0.009) and width (-0.031) was negative and with a very low value.

The indirect indicator influencing the seed productivity was the seeds number per plant, expressed by pods number (0.806) and plant height (0.258). Other indirect indicators affecting productivity were the pods number per plant by seeds number (0.163) and 1000 seeds mass by pod width (0.111).

From the obtained results, for the study period, it can be assumed that the white lupine specimens with a larger number of pods and seeds per plant, and a higher 1000 seeds mass, were characterized by a higher seed weight per plant.



X1 – plant height; X2 – 1st pod height; X3 – pods number; X4 – seeds number;
X5 – pod length; X6 – pod width; X7 – 1000 seeds mass

Fig. 1. Coefficients of determination between seed productivity and studied traits in white lupine accessions (2016-2018)

Regression analysis

From the conducted multiple regression analysis (Tables 6 and 7), equations of the productivity model for each of the study years were compiled. The significance and adequacy of the derived models were evaluated.

The linear model of the plant, characterizing the seed weight of a plant, was expressed by the following regression equations:

(2016) $Y = -18.188 + 0.068*X1 - 0.130*X2 + 0.138*X3 + 0.200*X4 - 0.781*X5 – 4.172*X6 + 0.080*X7$;

(2017) $Y = -10.048 + 0.018*X1 - 0.024*X2 - 0.032*X3 - 0.253*X4 - 0.220*X5 + 0.293*X6 + 0.044*X7$;

(2018) $Y = 6.854 - 0.033*X1 + 0.076*X2 - 0.037*X3 + 0.240*X4 - 0.257*X5 - 7.926*X6 + 0.018*X7$,

where Y is the seed weight per plant; X1 – plant height; X2 – 1st pod height; X3 – pods number; X4 – seeds number; X5 – pod length; X6 – pod width; X7 – 1000 seeds mass

Model (1) shows that the seed weight per plant increases with increasing plant height, number of seeds and pods, pod width, and 1000 seeds mass, whereas it decreases with increasing pod length and 1st pod height. According to model (2), an increase in white lupine productivity can be achieved by reducing the pod length and lowering the emplacement of the 1st pods, while increasing the seeds number and 1000 seeds mass. Model (3) confirms the importance of the traits of pods number and 1000 seeds mass, the increase of which leads to an increase in seed productivity. Weak positive deviations of plant height would also lead to an increase in individual plant productivity.

Discussion

When evaluating pea accessions, Bashir et al. (2017) found statistically significant differences in almost all studied traits except for the seed weight of the plant. The authors indicated that the applied path analysis shows that the 1000 seeds mass, the pod length, and the seeds number in one pod have the maximum direct effect on the seed productivity per plant. To a consider-

Table 5. Direct and indirect influence of the studied traits on seed weight per plant in white lupine accessions

Traits	Direct effect	Indirect effect							Total effect
		plant height	1st pod height	pods number	seeds number	pod length	pod width	1000 seeds mass	
Plant height	0.159		-0.028	0.048	0.258	-0.002	0.009	-0.025	0.420
1st pod height	-0.048	0.092		-0.054	-0.253	-0.003	-0.004	0.056	-0.213
Pods number	0.169	0.045	0.015		0.806	0.004	0.017	-0.136	0.921
Seeds number	0.835	0.049	0.014	0.163		0.004	0.019	-0.126	0.959
Pod length	-0.009	0.036	-0.016	0.074	-0.356		-0.018	0.098	-0.338
Pod width	-0.031	-0.047	-0.006	-0.094	-0.508	-0.005		0.111	-0.580
1000 seeds mass	0.223	-0.018	-0.012	-0.103	-0.472	-0.004	-0.016		-0.402

Table 6. Regression analysis in white lupine accessions

Regression	2016				
	df	SS	MS	F	Significance of F
	7	1396.684	199.5263	246.1505	4.92E-29
Residual	37	29.99172	0.810587		
Total	44	1426.676			
2017					
Regression	7	325.3706	46.48151	126.3537	7.42E-24
Residual	37	13.61113	0.367868		
Total	44	338.9817			
2018					
Regression	7	89.8757	12.83939	19.44665	1.26E-10
Residual	37	24.4287	0.660236		
Total	44	114.3044			

Table 7. Regression coefficients in white lupine accessions

Traits	2016	2017	2018
Intercept	-18.188	-10.048	6.854
Plant height	0.068*	0.018	-0.033
1st pod height	-0.130*	-0.024	0.076
Pods number	0.138	-0.032	-0.037
Seeds number	0.200**	0.253**	0.240**
Pod length	-0.781	-0.220	-0.257
Pod width	4.172	0.293	-7.926**
1000 seeds mass	0.080**	0.044**	0.018**

*/** significant at the 0.05/0.01 level

able extent our results confirm this statement. The advantage of path-analysis is that it allows dividing the correlation coefficient to its components.

The carried out assessment of the dependencies in white lupine accessions was in line with the studies of Machado et al. (2017) in soybean genotypes showing significant positive phenotype and genotype correlations concerning the pods number and seed production per plant. Similar findings have been reported by other researchers (Tiwari & Lavanya, 2012; Govardhan et al., 2013) in experiments with peas.

Under the conditions of the present study, the values of the positive genotype correlation coefficients were higher than those of the phenotype ones. Such a relation has been established by Almeida et al. (2010) and Sousa et al. (2015) for another annual legume species – soybean. The authors point out that for all traits except plant height, genotype correlations are higher than phenotype ones. This fact suggests a small effect of the environment on the manifestation of the traits. In researches conducted with peas, Abdolla & Tofiq (2019) reported the highest positive direct effect on seed productivity of the trait of seed weight, while the pods number had the highest positive indirect effect.

The results obtained in our study partially support the conclusions made by Adetiloye et al. (2017) in cowpea. The authors established significant positive genotypic correlations between productivity and pods number, pod length and seeds number in one bean. In the present study, increasing the length definitely had a negative effect on the total weight of seeds per plant.

The results of the path-analysis showed that the characteristics of the number of seeds and pods per plant, 1000 seeds mass, and plant height have the maximum direct effect on seed productivity, while the pod length and width have a negative direct effect. Similar conclusions were established by Kumar et al. (2013) and Prasad et al. (2018) in experiments conducted with peas

Cruz et al. (2012) believed that although correlation coefficients are useful for quantifying the magnitude and direction of the relationships between traits, they can lead to misconceptions when choosing a strategy to improve these traits. The authors noted that a high degree of correlation between two indicators may occur due to an indirect effect of a third indicator or a group of indicators. According to Romanato (2013), the high correlation between two traits does not guarantee the successful selection of one trait through another, as the nature of its inheritance must also be taken into account.

Conclusions

In conclusion, for all traits, the values of the positive genotypic correlations in the studied white lupine accessions were higher than the ones of phenotypic correlations whereas in negative coefficients the trend was reversed.

The genotypic correlation of seeds number with seed weight (r=0.974; r=0.901; r=0.832) and pods number per plant (r = 0.980; r = 0.881) was strong and positive. Positive were the genotypic relationships of plant height with 1st pod height (r = 0.632; r = 0.635; r = 0.895), and pod length with 1000 seeds mass (r = 0.655; r = 0.559; r = 0.382).

The values of the correlation coefficients for plant height with 1st pod height, pods number with seeds number, 1000 seeds mass with seed weight and pod length, and seeds number with seed weight remained relatively constant during the three years of the study.

Significant positive share for the formation of seed productivity had the traits of seeds number of per plant (R = 0.200; R = 0.253; R = 0.240) and 1000 seeds mass (R = 0.080; R = 0.044; R = 0.018).

Seeds number and 1000 seeds mass had direct positive effect on the seeds weight per plant, and seeds number, pods number and plant height had the highest total effect. These traits could be used as selection criteria in white lupine breeding programs.

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