ISSN: 1314-6246 Kosev & Georgieva *J. BioSci. Biotech.* **2018**, 7(2): 143-150.

RESEARCH ARTICLE

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Relationship of quantitative traits in different morphotypes of pea (*Pisum sativum* L.)

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Article info:
Received: 2018
Accepted: 2018

ABSTRACT

Studying the relationships between main quantitative traits gives an opportunity the results of selection on certain traits to be predicted and the breeding process to be improved. In the present investigation, it was made an assessment of correlation dependencies in pea lines with a different morphology of the compound leaf: ordinary ("AFAFTLTLSTST"); afila (semi-leafless -"afafTLTLSTST"); pleiofila (tendril acacia - "afaftltlSTST"). The results showed a positive significant correlation of the plant height with 1st pod height (r=0.701, 0.390, 0.386) in the three pea morphotypes, and with the pods number per plant (r=0.560, 0.558) in afila and pleiofila type. Positive, statistically significant relationships were found between seed weight per plant with the number of pods (r = 0.516) and seeds (r = 0.567) only in ordinary leaf morphotype, and with the 1000 seeds weight (r = 0.448) in pleiofila type. The number of pods per plant and number of seeds in a pod had the maximum positive direct effect on seed productivity in afila and pleiofila types of leaves. In genotypes with the ordinary type of leaves, selection criteria can be the number of seeds per plant (0.890) and plant height (0.420), and in pleiofila type - 1000 seeds weight (0.596). In the genotypes of the three morphotypes, the traits of number seeds per plant (0.850, 0.042, 0.075) and number of seeds in a pod (0.070, 0.421, 0.373) positively influenced the seed productivity.

Key words: pea, correlation coefficient, quantitative trait, relationship

Introduction

Worldwide, pea is one of the most widely used crops in agricultural production because of its valuable nutritional and flavor qualities. Pea seeds are used in both food and vegetable canning industry (Georgieva & Pachev, 2009; Pachev et al., 2011; Lukashevich & Kovaleva, 2012; Suhenko, 2013).

The breeding success in this crop depends to a large extent on the richness and diversity of the source material, which has to possess valuable and useful characteristics and traits. In the selection practice, it is important to know the nature of dependence between these characteristics and traits in order to enhance the effect of desired traits and to reduce or exclude the performance of inappropriate ones. The correlation dependencies between main traits allow predicting the results of using the parental forms and help in selecting parent pairs for hybridization (Vitko, 2014; Maximenya, 2016).

In the pea gene pool, genotypes with new mutant traits have appeared, changing the plant habitus. It has led to a substantial change in the parameters of the morphostructure of the new varieties and increasing the limit of the variability of the quantitative traits. Many researchers differently assess the role of the individual characteristics in plant productivity formation. The data from these studies provide an opportunity to combine appropriate traits in one genotype and increase the efficiency of the breeding activity (Shuhraeva & Fadeeva, 2011; Lihacheva et al., 2016).

Studying relationships gives an opportunity to be predicted the results of the selection of certain traits and improved the breeding process. It also allows determining by which structural elements of the yield it is possible to increase more efficiently the total productivity of seeds per plant. Since all these elements are interconnected, the productivity increase can be achieved by recombining genes determining the quantitative expression of individual elements of the yield structure (Kurkina & Tkachenko, 2003; Semenov, 2005).

The introduction of new, more productive pea varieties is one of the main means of increasing the production in this crop. For raising the effectiveness of the breeding process, the right choices of hybridization scheme, and also knowing the potential of the source material, have a crucial role. This particularly applies to the breeding of quantitative signs, where the lack of such information leads to a decrease in the work efficiency (Pivovarova & Tsiganka, 2001; Kalapchieva, 2013; Zotikov, 2017).

The aim of the study was to determine the relationship between the most important and main traits in peas (*Pisum sativum* L.) in the breeding of high-productive genotypes.

Materials and Methods

The field trial was conducted during the period 2015-2017 at the Institute for Forage Crops (Pleven). The study included five hybrid lines of winter forage pea with a different morphology of the compound leaf: L12, L13, L14 – ordinary type (“AFAFTLTLSTST”); L6 – afila type (semi-leafless - "afafTLTLSTST"); L9 – double recessive type "pleiofila" (tendril acacia). The selection material was sown randomly in plots, in six replications, with a size of 2 m2 for each plot. The sowing was performed in October at a rate of 120 seeds m-2.

Biometric measurements included plant height (cm), 1st pod height (cm), pods number and seeds number per plant, seeds number per pod, seeds weight per plant and 1000 seeds weight (g). The experimental data were processed by using Path coefficient analysis (Singh & Chaudhary, 1979), correlation and regression analysis (Dimova & Marinkov, 1999), software products MS Excel (2003) and GENES 2009.7.0 (Cruz, 2009).

Results

An increased seed productivity in the process of continuous breeding activity is achieved as a consequence of a very good distribution of the assimilates in favor of the seeds but at unchanged total biomass of the plant. As a result, the potential of modern pea varieties has achieved to its maximum. Therefore, one of the ways to solve this problem was the breeding of new morphotypes possessing a higher biological potential (Urievich, 2008).

Correlation analysis

In the conditions of the experiment conducted, the plant height correlated statistically significant with the 1st pod height in the three morphotypes leaves (r=0.701, 0.390, 0.386), and also with the pods numbers (r=0.046, 0.560, 0.558), but in pea forms with the ordinary type of leaves, this correlation was very low and insignificant (Table 1). Plant height interacted negatively with seeds number in a pod (r=-0.099, -0.244, -0.240) and seeds weight per plant (r=-0.271, -0.177, -0.023). Compared to the other traits (1000 seeds weight and seeds number per pod), the correlations were also weak and non-significant. Exceptions were the plants "pleiofila" regarding the mass of 1000 seeds (r=0.089) and seed numbers per plant (r=0.330), and the plants "afila" regarding the last trait (r=0.333), where the correlation coefficient had a positive sign.

A similar analogy was also observed for the dependencies between the 1st pod height and the other traits determining the plant productivity. In pea with ordinary type of leaves, the correlation with pod number per plant, seeds number per pod, seeds number per plant and 1000 seeds weight was slightly negative and insignificant, whereas in the other types it was positive, considerably higher and significant. The 1st pod height was to a lesser extent related to the seeds weight per plant. An expression of this dependence was the strong negative correlation, especially in afila and pleiofila leaf types (r=-0.860, -0.850).

It was established a narrow correlation between pods number and seeds number per plant (r=0.939, 0.670, 0.674) in the three types leaves, and also negative one between pods number and seeds number per pod (r=-0.210, -0.460, -0.463). The pod number was in negative relation with the 1000 seeds weight and seeds weight per plant in afila and pleiofila type. For plants with ordinary leaf type, this dependence was significant, with a positive sign.

The seeds number in a pod was in a weak to medium positive correlation with 1000 seeds weight (r=0.066, 0.421, 0.373) and seeds weight per plant (r=0.023, 0.325, 0.338), as the correlation coefficients had lower values in pea forms with ordinary leaf type.

Between 1000 seeds weight and seeds weight per plant were recorded slight negative dependencies in the afila forms (r=-0.097), and positive ones in the ordinary (r=0.365) and pleiofila type (r=0.448).

The interdependence between plant productivity (weight of the seeds per plant) and structural elements of the yield has been shown to be more closely related in peas with ordinary type and pleiofila type of leaves. In afila type, the dependence of the plant productivity with all traits (except seeds number in a pod) was inversely proportionate.

Path coefficient analysis

Pat coefficient analysis (Table 2) showed that in afila and pleiofila types, the pod number (4.667, 5.560) and seeds numbers in a pod (3.763, 4.004) were the components with maximum positive direct effect on the plant productivity. In the ordinary type, the podsnumber had a very slight effect (0.08), and the seeds number in a pod even had a negative effect (-0.021). In pea forms with the ordinary type of leaves, a selection criterion for the genetic improvement of this morphotype can be the seeds number per plant (0.890) and plant height (0.420).

In pea genotypes of afila and pleiofila type, the strongest positive indirect effect showed the trait of pod number per plant through plant height (2.604, 3.103), 1st pod height (2.875, 3.425) and seeds number of plant (3.146, 3.748), as well as 1st pod height (1.100, 0.488), seeds number in a pod (1.223, 1.353) and seeds number per plant (0.795, 0.718) through the 1000 seeds weight.

Table 1. *Correlation coefficients (r) between quantitative traits in pea genotypes with different type of leaves*

Traits	Plant height	1st pod height	Pods number per plant	Seeds number per plant	Seeds number per pod	1000 seeds weight
1st pod height	**0.701**** 0.390* 0.386*					
Pod number per plant	**0.046** 0.560** 0.558**	**-0.088** 0.616** 0.620**				
Seeds number per plant	**-0.093** 0.333 0.330	**-0.221** 0.367* 0.370	**0.939**** 0.670* 0.674*			
Seeds number per pod	**-0.099** -0.244 -0.240	**-0.153** -0.205 -0.210	**-0.21** -0.460* -0.463*	**0.059** 0.318 0.320		
1000 seeds weight	**-0.017** -0.094 0.089	**-0.377** -0.084 -0.256	**0.797**** -0.201 -0.162	**0.851**** 0.042 0.075	**0.066** 0.421* 0.373*	
Seeds weight per plant	**-0.271** -0.177 -0.023	**-0.489*** -0.860** -0.850**	**0.516*** -0.55** -0.488	**0.567**** -0.202 -0.158	**0.023** 0.325 0.338	**0.365** -0.097 0.448*

According to the analysis results, in morphotypes with ordinary leaves, the seeds number per plant (0.840) through pods number per plant had indirectly the greatest impact on the seed productivity. But the 1st pod height and number of seeds per plant through 1000 seeds have higher values – 0.320 and 0.510.

Traits as pods number per plant and seeds number in a pod (for all pea morphotypes) had the most pronounced total effect on the productivity expressed by seed weight per plant. In genotypes with ordinary type of leaves, the impact of seeds number per plant was much more noticeable (0.850), and in afila and pleiofila forms, this was expressed by seeds number in a pod (0.421, 0.373).

Regression analysis

The strength and direction of change in seed productivity of genotypes with different types of leaves, depending on the traits studied, were expressed by the following linear regression equations:

In ordinary type of leaves

(1)

$$Y = 11.82+0.06*X1-0.12*X2+0.11*X3+0.11*X4-0.14*X5-0.07*X6$$

In afila type of leaves

(2)

$$Y = 14.43+0.03*X1-0.12*X2-0.28*X3+0.05*X4+0.03*X5-0.02*X6$$

In pleiofila type of leaves

(3)

$$Y = 8.69+0.05*X1-0.09*X2-0.66*X3+0.1*X4-0.27*X5+0.01*X6$$

where: У – seed productivity per plant; X1 – plant height; X2 – 1st pod height; X3 – pod number per plant; X4 – seed number per plant; X5 – seed number in a pod; X6 – 1000 seedweight

Table 3 presents the dispersion analysis for the different pea morphotypes and shows the adequacy of the regression model. The share of dispersion of factor components (plant height, 1st pod height, pods number per plant, seeds number per plant, seeds number in a pod, 1000 seeds weight) in the seed productivity formation was statistically significant and considerably greater than that of the residual.

Table 2. *Path analysis for seed productivity in pea genotypes.*

Traits	Direct effect	Indirect effects						Total effect
		Plants height	1st pod height	Pods number per plant	Seeds number per plant	Seeds number per pod	1000 seeds weight	
Plants height	**0.420**		**-0.462**	**0.020**	**-0.083**	**0.030**	**0.110**	**-0.017**
	-0.094		-0.494	2.604	-1.310	-0.918	0.118	-0.094
	-0.288		-0.221	3.103	-1.514	-0.977	-0.014	0.089
1st pod height	**-0.659**	**0.290**		**-0.007**	**-0.198**	**0.020**	**0.190**	**-0.377**
	-1.279	-0.036		2.875	-1.444	-0.771	0.571	-0.084
	-0.574	-0.111		3.425	-1.668	-0.821	-0.507	-0.256
Pods number per plant	**0.080**	**0.020**	**0.060**		**0.840**	**0.040**	**-0.202**	**0.800**
	4.667	-0.052	-0.788		-2.651	-1.742	0.365	-0.201
	5.560	-0.161	-0.353		-3.064	-1.854	-0.291	-0.162
Seeds number per plant	**0.890**	**-0.039**	**0.150**	**0.070**		**-0.001**	**-0.222**	**0.850**
	-3.934	-0.031	-0.469	3.146		1.197	0.134	0.042
	-4.545	-0.096	-0.211	3.748		1.273	-0.094	0.075
Seeds number per pod	**-0.021**	**-0.041**	**0.100**	**-0.016**	**0.050**		**-0.009**	**0.070**
	3.763	0.023	0.262	-2.161	-1.251		-0.216	0.421
	4.004	0.070	0.118	-2.574	-1.445		0.201	0.373
1000 seeds weight	**-0.391**	**-0.113**	**0.320**	**0.040**	**0.510**	**0.000**		**0.370**
	-0.664	0.017	1.100	-2.567	0.795	1.223		-0.097
	0.596	0.007	0.488	-2.713	0.718	1.353		0.448

The bold values are pea forms with ordinary type of leaves; underlined values are afila type; with normal font are pleiofila type

Table 3. *ANOVA analysis of variance for seed productivity in investigated pea genotypes.*

Source of variation	df	SS	MS	F	Significance F
		pea forms with ordinary type of leaves			
Factor regression	6	458.5091	76.41818	52.92967	$2.57E^{-12}$
Residual regression	23	33.20667	1.443768		
Total	29	491.7158			
		pea forms with afila type of leaves			
Factor regression	6	61.74854	10.29142	26.02712	$3.67E^{-09}$
Residual regression	23	9.094465	0.395412		
Total	29	70.843			
		pea forms with pleiofila type of leaves			
Factor regression	6	95.59539	15.93256	33.30864	$3.14E^{-10}$
Residual regression	23	11.00162	0.478331		
Total	29	106.597			

The results, regarding dependencies, obtained for seed weight per plant vs. the other traits (Table 4), showed that traits as plant height and seeds number per plant positively influenced the change of seed productivity in the three pea

Table 4. *Regression coefficients for seed productivity in different pea forms.*

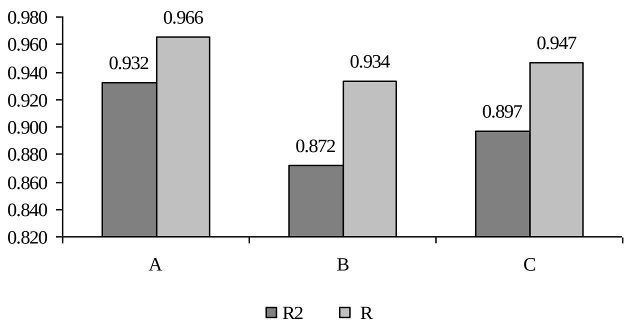
	Coefficients	Standard Error	t Stat	P-value
		pea forms with ordinary type of leaves		
Intercept	11.82	2.91	4.068853	0.000474
Plants height	0.06	0.01	5.189163	$2.92E^{-05}$
1st pod height	-0.12	0.02	-7.70842	$8.06E^{-08}$
Pods number per plant	0.11	0.20	0.581433	0.566604
Seeds number per plant	0.11	0.04	3.190901	0.004066
Seeds number per pod	-0.14	0.36	-0.39307	0.697886
1000 seeds weight	-0.07	0.01	-4.57679	0.000134
		pea forms with afila type of leaves		
Intercept	14.43	6.65	6.00873	$3.97E^{-06}$
Plants height	0.03	0.04	2.574348	0.016954
1st pod height	-0.12	0.06	-5.03712	$4.25E^{-05}$
Pods number per plant	-0.28	1.61	-0.48669	0.631083
Seeds number per plant	0.05	0.34	0.414192	0.682571
Seeds number per pod	0.03	2.16	0.042711	0.966301
1000 seeds weight	-0.02	0.02	-2.27325	0.032667
		pea forms with pleiofila type of leaves		
Intercept	8.69	2.97	2.921386	0.00768
Plants height	0.05	0.01	4.636466	0.000115
1st pod height	-0.09	0.02	-5.0244	4.39E-05
Pods number per plant	-0.66	0.85	-0.77214	0.447891
Seeds number per plant	0.10	0.14	0.730174	0.472656
Seeds number per pod	-0.27	0.72	-0.38207	0.705917
1000 seeds weight	0.01	0.00	1.50644	0.145567

morphotypes. In genotypes with the ordinary type of leaves, increasing the pods number will also result in an increase in the total seed mass per plant. In affila type, the seeds number in a pod also had a favourable effect, and in pleiofila, the 1000 seeds weight had a slight positive effect.

A considerable raising of the 1st pod height resulted in a decrease in seed mass per plant in all types, especially in pea forms with ordinary leaves (-0.12) and afila type (-0.12), where the regression coefficients were statistically significant. For pleiofila and afila types, the seed productivity would decrease sharply after an essential increase in the pod number per plant (-0.66, -0.28).

The multiple correlation coefficient (R) (Figure 1) reflects the complex influence of factors included in the regression model. Its high values (0.966, 0.934, 0.947) were indicators of the existence of a strong correlation between the seed productivity and observed traits.

The determination coefficients (Figure 1) between productivity elements show how much one trait depends on another trait. The values of determination coefficient in genotypes with ordinary, afila and pleiofila leaf type (0.932, 0.872 and 0.897, respectively) indicated that over 87% of the total dispersion of the resultant trait can be explained by factor dispersion (the studied traits). The remaining less than 13% were due to factors which were not included in the model.



A – ordinary type of leaves; B – afila type; C – pleiofila type

Figure 1. *Multiple correlation coefficient (R) and coefficient of determination (R2) between the productivity elements in different pea morphotypes.*

From the multifactorial regression dependencies between productivity and other quantitative traits, a more sensitive change was observed in the lines with ordinary type of leaves, where the determination coefficient was higher. The results showed that the seed weight per plant in this morphotype was more than 93% dependent on the traits studied. For the other two morphotypes, the determination coefficients indicated that the quantitative expression of the change of seed productivity, depending on the manifestation of the other traits was below 90%.

Discussion

For a fuller performance of high productive potential, it is crucial to know the complicated relationships between the individual traits and their combination in the plant organism. The results obtained in this study were in accordance with the findings of a number of researchers, although there have also been reports for different values of the correlation coefficients between the traits considered. Gaynullina (2014) reported significant positive correlations obtained between plant productivity and seeds number, and pods number per plant.

Fadeev (2015) found a high positive correlation between the yield and seed weight per plant, and plant height as for the second trait, the correlation was positive only under moderately humid conditions. It was also established that the plant biomass and seed weight of plant positively correlated with seed weight per a fertile node, seed number in a pod and the mass of 1000 seeds, regardless of the environmental conditions.

According to Ashiev (2014), the magnitude of correlation coefficients obtained in the researches of different authors often was different, probably due to both the variety of studied cultivars and the environmental conditions.

Kaygorodova (2014) considered that the correlation coefficient is most suitable for studying the interdependence of quantitative characteristics. The author concluded that in the breeding work an important role had the study of coherence at the genotypic level, which can be used in the selection and creation of desired varieties.

Seliberova & Vitko (2014) indicated that the relationship between the yield components and the seed productivity of plants is always positive and linear. Therefore, the selection regarding seeds number in a pod and pods number had the greatest impact on seed productivity. The authors also found a positive correlation between seed productivity and the number of seeds and pods per plant, and the number of fertile nodes.

Kalapchieva (2012) established that the highest direct effect on grain yield of a plant was due to the number of pods, which also had a positive indirect effect on the mass of seeds.

According to Petkov (2010), the use of the coefficient of multiple regression was not entirely correct because this coefficient increased with the addition of a new factor (trait). This raising is due to the fact that the residual dispersion decreases with each additional factor introduced in the model. The author recommends using the so-called corrected correlation coefficient to obtain a more precise assessment.

Our experimental data obtained from Pat's analysis confirm results from other researchers (Espósito et al., 2009; Nisar & Ghafoor, 2009) who have found that the highest direct effect on yield had the number of seeds and pods per plant, as well as the length of internodes. The highest indirect effect had the plant height.

According to Marchenko & Anohina (2007) and Fadeev & Fadeeva (2018), in new pea genotypes with non-shattering pods, itwas found a different level of genotypic variability of the yield elements, due in large part to the changing environmental conditions. Characteristics such as the number of productive nodules, number of seeds and pods per plant, as well as seed weight of plant were characterized by a weaker reaction to these conditions.

The correlation analysis performed under the present experiment showed relationships between some quantitative traits in different morphotypes of peas. The obtained results suggest the possibility of predicting how new, highly productive genotypes can be received by the way of artificial hybridization between different morphotypes of pea.

Conclusions

The results of the conducted experiment showed a positive significant correlation of the plant height with 1st pod height (r=0.701, 0.390, 0.386) in the three pea morphotypes and with the pods number per plant (r= 0.560, r= 0.558) in afila and pleiofila type.

A positive, statistically significant relationship was found between seed weight per plant with the number of pods (r = 0.516) and seeds (r = 0.567) only in ordinary leaf morphotype, and with the 1000 seeds weight (r = 0.448) in pleiofila type.

The number of pods per plant (4.667; 5.560) and number of seeds in a pod (3.763; 4.004) had the maximum positive direct effect on seed productivity in afila and pleiofila types of leaves and they could be used as a selection criteria. In genotypes with the ordinary type of leaves, selection criteria can be the number of seeds per plant (0.890) and plant height (0.420), and in pleiofila type - 1000 seeds weight (0.596).

In the genotypes of the three morphotypes, the traits of number seeds per plant (0.850, 0.042, 0.075) and the number of seeds in a pod (0.070, 0.421, 0.373) positively influenced the seed productivity.

Correlation dependencies described between different quantitative traits indicate the possibility of using them in the selection process depending on the breeding tasks.

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