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Geometric properties of grasspea seeds and their mechanical loads

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A b s t r a c t. The objective of the study was an attempt at the application of multivariate statistical analysis for the determination of variability, dependence and similarity of phenotypic and field-forming properties of grasspea on the basis of a field experiment, and of the geometry of its seeds and their resistance to mechanical loads in laboratory tests. The research material comprised Polish grasspea cultivars and collection materials representing various geographical regions of Central and South Europe.

The results obtained indicated a broad range of variation of the features and traits under analysis, with a distinct division and separateness of forms originating from South Europe with relation to those from Central-Eastern Europe. Based on multivariate statistical analysis the similarity between particular lines and cultivars was determined, pertaining to their phenotypic and yield-forming features and to the geometry of their seeds and their resistance to mechanical loads.

K e y w o r d s: grasspea, geometry of seeds, mechanical loads, multivariate statistical analysis

INTRODUCTION

In recent years, in countries with higher living standard one can observe a trend in food preferences towards total elimination or limitation of the amount of meat in the diet. Therefore, it appears to be right to comply with the observed trends and to provide a sufficient supply of high-protein plant products on the market, including products of legume crops that should be characterized, among other things, by a short time of culinary preparation (Lisewska *et al*., 2003). The crop species that comply with the current food and fodder requirements include grasspea (*Lathyrus sativus* L.), a high-protein species that so far has been undervalued and of only marginal importance.

Grasspea is one of the oldest species of crop plants and it was cultivated in the Balkans as far back as about 8 000 years before Christ (Lambein and Kuo, 1997). It has low habitat requirements and tolerates both light and heavier soils, therefore it can be competitive (alternative) with relation to other legume crop species. The exceptional drought resistance of grasspea is facilitated by its strongly developed and deep root system that additionally mobilizes nutrients and transports them from deeper layers of soil with simultaneous improvement of its hydraulic capacity. Also important is its notable content of high-value protein, varying from 18.2 to 34.6%, its tolerance to cold, (Robertson e*t al*., 1996), lack of significant pests (Tiwari and Campbell, 1996), resistance to various diseases (Robertson *et al*., 1996), and binding of atmospheric nitrogen (McCuthan, 2003). In that last respect grasspea is a valuable component of crop rotation, enriching the soil with nitrogen for the successive crops (Skiba *et al*., 2007). Taking into account the unique resistance of grasspea to biotic and abiotic stresses, and to drought in particular, *Lathyrus sativus* can be classified as a proecological species, and in the opinion of Vaz Patto *et al*. (2006) as a model crop for sustainable agriculture. This is especially important in the context of the global climate change in which cyclic droughts appear to be a key factor limiting the yielding of crops on the world scale.

As mentioned above, grasspea is the most drought tolerant commercial legume and also an outstanding fixer of atmospheric nitrogen, adaptable to marginal soils and the source of the cheapest dietary protein. However, the neuro-excitatory amino acid beta-ODAP is present in the seeds in variable amounts, making this survival food during drought

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and famine a mixed blessing (Lambein and Kuo, 1997). Seeds of grasspea have long been known for their toxic properties if used as the main component in human and animal feeding. The effects related with paralysis of the lower limbs were called neurolathirism, generally manifested by stiffness of skeleton muscles in the lower limbs, overall muscular weakness, and also by spastic paralysis of leg muscles ending in patient demise in advanced stages of the disease (Tivari and Campbell 1996). Ever since the identification of the neurotoxin, extensive research has been done to eliminate this toxin by selection, by breeding and somaclonal variation, or by induced mutations (Smulikowska *et al*., 2008).

It turns out that the processes of technological processing of seeds are also a significant element of reducing the level of neurotoxins. In the simplest case, boiling would be a significant condition for the reduction or even elimination of seed toxicity, though the available data on the subject are not equivocal (Tekle Haimanot *et al*., 1997). According to Padmajaprasad *et al*. (1997), boiling and straining of the water reduces the neurotoxin ODAP in 90%. Applying somewhat more advanced technologies, it turns out that the process of seed extrusion significantly reduced the content of neurotoxins, tannins, and limited the activity of trypsin inhibitors (Grela *et al*., 1999). Apart from the observed advances in genetics related to the enhancement of the utility value of grasspea or the application of more and more effective methods for the processing of seed, the resistance of seeds to mechanical loads, in the context of the technology of their harvest and processing, is an element of reducing the content of anti-nutritional components that is undervalued and frequently treated as one of only marginal importance (Rybiński *et al*., 2004). Knowledge of the physical parameters of seeds is of special importance for the optimization of harvest, drying and storage technologies, which is related with minimization of quantitative losses and mechanical damage.

The aim of the study presented ere was estimation of the variability, relations and similarities of the phenotypic and yield-forming features of plants, geometric parameters and mechanical properties of seeds of European collection forms of grasspea.

MATERIALS AND METHODS

The research material comprised 32 forms of grasspea (1-LAT 4050/99, 2-LAT 4051/99, 3-LAT 4052/99, 4-LAT 4053/99, 5-LAT 4054/99, 6-LAT 4055/99, 7-LAT 4056/99, 8-LAT 4061/99, 9-LAT 4063/01, 10-LAT 4064/01, 11-LAT 4065/01, 12-LAT 4068/01, 13-LAT 4069/01, 14-LAT 4070/01, 15-LAT 4071/01, 16-LAT 4074/01, 17-LAT 4075/00, 18-LAT 4078/00, 19-LAT 4079/00, 20-LAT 4081/00, 21-LAT 4082/00 – Italy; 22-LAT456/75, 23-B 1706/92, 24-LAT 4006/84, 25-LAT 4007/84, 26-LAT 4085/00 – Spain; 27-LAT 444/73, 28-LAT 462/82 – Germany; 29-B 1702/80, 30-B 1705/87 – France; 31-cv. Derek, 32-cv. Krab – Poland) from the Gene Bank in Gatersleben (Germany) and from the Hodowla Roślin Spójnia plant breeding company in Nochowo (Poland).

Estimation of the variability of phenotypic features and yield structure was performed on the basis of results obtained in a field experiment. The experiment was conducted on an experimental field of the Institute of Plant Genetics, PAS, in Cerekwica, sowing seed on plots of 4.5 m^2 in area, with 30 x 15 cm spacing, in random blocks with three replications. The day after the sowing the Afalon weed control preparation was applied. Due to the good level of nutrients in the soil and to the low requirements of grasspea in this respect no mineral fertilization was applied. With relation to the phenological phases, only the time of start of blooming was determined, as the number of days from sowing to the moment when 50% of the plants began flowering. Other traits (Table 1) concerning plant height, height of first pod, pod morphology and yield-forming traits were estimated for plants harvested in the phase of full seed ripeness, analysing 15 plants from each replication. Geometric measurements of seeds of the collections studied (thickness, width, length) were taken with accuracy of 0.01 mm. The measurements were made on seeds with conditional moisture, with 300 replications for every sample. Mechanical quasistatic tests were made on a strength-testing apparatus in accordance with a method developed earlier, with 60 replications. The result of the tests was determination of the maximum force (N), elastic force (N), maximum deformation (mm), energy (mJ) and modulus of elasticity (MPa).

The results obtained from the field experiment and from the laboratory analysis of seeds with respect to their geometric features and resistance to mechanical loads were processed statistically by means of multivariate statistical analysis. Analysis of variance was performed for the individual traits under study, giving mean square values. Estimations were made of the mean values, maximum and minimum values, variance, and coefficient of variation for the traits studied. Estimation of correlations among the traits studied was performed based on the relevant coefficients of correlation estimated on the basis of mean values for the individual objects. Similarity between all pairs of collection objects estimated in terms of the traits analyzed, treated jointly, was expressed by means of suitable Mahalnobis distances. Graphic distribution of cultivars and lines on a plane relative to all traits combined was possible through the application of canonical variables analysis (Rencher, 1992). Stepwise reverse multiple regression was applied to identify those factors that had a significant ($\alpha = 0.05$) effect on the traits under analysis.

RESULTS AND DISCUSSION

The results obtained from the field experiment were processed statistically, giving the mean values, range of variation, variance and coefficient of variation for each trait

T a b l e 1. Statistic characteristics of morphological traits and yield structure parameters of grasspea plants

Traits	Mean	Variation range		Variance	Coefficient of variation (%)
		Min	Max		
Time of flowering (days)	62.19	58.00	67.00	5.46	3.76
Plant height (cm)	50.79	31.40	67.40	5.74	14.93
Height of the lowest pod (cm)	17.88	11.00	27.00	1.13	18.83
Number of branches/plant	5.13	3.00	7.40	7.31	16.66
Number of pods/plant	29.56	17.80	69.40	6.90	28.09
Pod length (cm)	3.99	3.20	4.70	9.49	7.70
Pod width (cm)	1.56	1.33	1.92	1.74	8.48
Seeds number/pod	2.31	1.08	3.74	3.32	24.93
Seeds mass /pod (g)	0.60	0.31	0.91	1.25	18.59
Seeds number/plant	58.24	15.50	148.40	6.45	43.62
Seeds mass/plant (g)	13.85	7.20	21.19	9.53	22.29
Mass of 100 seeds (g)	27.10	8.70	51.00	9.17	35.33

and for the objects combined (Table 1). The mean values provide general information on the values of the individual traits for the whole group of objects, while more information on the range of variation of the traits under analysis is obtained from the minimum and maximum values. Those values indicate that the objects, for every trait, are characterized by a broad range of intra-species variation within grasspea. Notable differentiation of the collection materials studied is also indicated by variance, and especially by the value of the coefficient of variation. The value of the coefficient was the highest for the number of seeds per plant, mass of 100 seeds, and the lower for the number of bifurcations per plant, number of seeds per pod, and mass of seeds per plant. The lowest variation was observed for the feature of the time of start of blooming, and of the length and width of pod (Table 1). A high degree of differentiation of grasspea forms with relation to the geographic origin, in terms of the morphological features, times of phenophases, yield structure and seed quality was also observed by Hanbury *et al.* (1999).

Estimation of mean squares from the analysis of variance for the geometric parameters of the seeds and their resistance to mechanical loads indicates significant differentiation of the objects in terms of the traits under analysis. For all the traits significant mean square values were obtained. Significant values at the level of $\alpha = 0.05$ were obtained for the modulus, at the level of $\alpha = 0.01$ for the energy, and highly significant values ($\alpha = 0.001$) for the remaining parameters of mechanical loads and for all geometric features of seeds under analysis.

Knowledge of the physical parameters of seeds has special importance for the optimization of the technology of harvest, drying and storage, which is related with maximum limitation of quantitative losses and mechanical damage to the seeds (Bagherpour *et al.*, 2010). Micro- and macro-damage to seeds may have a negative effect on the quality of sowing material, and ultimately also on the yields, and literature reports indicate the occurrence of notable inter-variety differences in the resistance of seeds to mechanical deformations, even at identical geometric features of seeds. Statistical characterisation of the geometric parameters of the seeds and their resistance to mechanical loads is presented in Table 2. In terms of the mechanical loads similar mean values were obtained for the maximum force and the elastic force, with notable variation of those traits among the particular objects, which is illustrated by the minimum and maximum values. For the maximum force the mean value was 264.8 N with the range of variability of that trait for the objects from 131.2 to 407.6 N. In a study on grasspea mutants obtained from the cultivars Krab and Derek the extreme values fell within broad ranges and varied from 82.6 to 633.6 N and from 65.1 to 393.5 N, respectively (Rybiński *et al.*, 2004). In another study on mutants of spring barley originating from line 1N/86 the values of maximum force were from 28.3 to 492 N, indicating extensive variation of that trait as a result of application of chemomutagens (Rybiński and Szot, 2006). The broad range of variation of the extreme values for the remaining mechanical load traits indicates strong differentiation among the collection objects, which permits effective selection of form with the highest seed resistance to mechanical damage. The values of the coefficient of variation of that trait were similar (above 20%), and only in the case of modulus that value was lower (16.7%). A particularly broad range of variation among the objects was observed for the geometric features of the seeds

T a b l e 2. Statistic characteristics of geometrical properties of seeds and their resistance on mechanical loads

Traits	Mean	Variation range		Variance	Coefficient of variation (%)
		Min	Max		
Force maximum (N)	264.81	131.21	407.62	3 346.41	21.85
Force of elasticity (N)	216.30	92.28	382.69	3 783.50	28.42
Deformation maximum (mm)	0.42	0.23	0.81	0.01	27.02
Elastic deformation (mm)	0.13	0.09	0.29	0.01	20.65
Energy (mJ)	29.42	13.50	47.20	56.33	25.51
Modulus (MPa)	888.24	557.63	1 273.70	22 131.41	16.75
Seed thickness (mm)	5.35	4.42	8.34	0.29	10.00
Seed width (mm)	9.50	5.70	13.00	2.41	16.34
Seed length (mm)	10.46	6.30	14.55	3.05	16.70

(Table 2). Mean thickness, width and length of seeds of the particular objects was 5.3, 9.5 and 10.5 mm, respectively, with a broad range of minimum and maximum values. This indicates that apart from the small-seeded forms characteristic of the local materials and those from Germany and Northern France, there were also large-seeded forms typical of the area of South Europe – Italy and Spain. The lowest values of variance and of the coefficient of variation were obtained for seed thickness, and higher values for seed width and length. In the study by Rybiński *et al*. (2004) the thickness of seeds of mutants originating from the Polish cultivars Krab and Derek was from 4.2 to 5.3 mm and from 4.7 to 5.0 mm, respectively, while the range of variability for the collection objects analyzed in this study the range was from 4.4 to 8.3 mm and the mean value was 5.3 mm. This indicates a separateness of the Polish materials from the foreign ones, which is related with their origin and habitation in other geographic regions of Europe. Confirmation of the notable differentiation of the objects in terms of seed geometry is provided by the results of mass of 100 seeds (Table 1) ranging from 8.7 to 51 g while the values of that trait in the Polish mutants of grasspea range from 9.5 to 22.8 g (Rybiński *et al*., 2004). Some of the Italian and Spanish forms were characterised by very broad and long seeds, with maximum values of 13.0 and 14.5 mm, respectively. The lowest variation as expressed by the values of the coefficient of variation was that of seed thickness (10.0%), and the highest – seed width and length (16.3 and 16.7%).

The degree of correlation among the values of the particular traits in the forms under analysis was expressed by the values of coefficient of correlation (Table 3). As concerns the estimation of seed geometry, one of the significant traits was the mass of 100 seeds and the relations of that trait with the other morphological and yield-forming parameters estimated on the basis of the field experiment (traits 1-12). The mass of 100 seeds was negatively and significantly correlated with the time of start of blooming, plant height, number of pods per plant, number of seeds in pod and per plant, and positively with pod width and mass of seeds per pod. In the study on the Polish mutants of grasspea the mass of 100 seeds was also negatively and statistically significantly correlated with the number of seeds per pod and per plant, and positively with pod width and length and with the mass of seeds per pod (Rybiński *et al*., 2004, 2009). Also noteworthy is an important yield-forming trait – the number of seeds per plant – that was positively and significantly correlated with the time of blooming, plant height and height of the lowest pod, number of bifurcations per plant, number of seeds per pod, and negatively with pod width, mass of seeds per pod, and mass of 100 seeds. Comparing the particular morphological and yield-forming traits (Nos 1-12) with each of the mechanical load parameters (Nos 13-18) no significant relationships were observed. Whereas, strong and significant correlations were observed among the individual mechanical parameters (Nos 13-18). Non-significant values of the coefficient of correlation were obtained only for the correlations between maximum deformation and energy and the modulus of elasticity, and between the modulus and elastic deformation. For the remaining comparisons of pairs of traits positive and statistically significant values of the coefficient of correlation were obtained (Table 3). With the exception of significant and positive correlation between elastic deformation and seed thickness, and negative correlation between the modulus of elasticity and seed thickness, no other statistically significant correlations between the mechanical properties and the geometric features of the seeds were observed. These results indicate a weak (or non-existent) significant relation between the geometry of the seeds and their resistance to mechanical loads. In turn, all three features of seed geometry were positively and statistically highly significantly correlated with one another. Moreover, each of the seed geometry features was positively and significantly correlated with pod width, mass of seeds per pod, and mass of 100 seeds, and

T a b l e 3. Coefficients of correlation for morphological traits of plants, yuiled structure and mechanical loads of seeds

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1																			
2	0.50**	1																		
3	0.42*	0.86***	1																	
4	0.25	0.47**	0.42*	1																
5	0.26	0.43*	0.07	0.4*	1															
6	0.13	0.22	0.32	0.33	-0.29	1														
7	-0.31	-0.23	-0.01	-0.03	-0.44*	0.57***	1													
8	0.51**	0.63***	0.40*	0.43*	0.51**	0.04	-0.68***	1												
9	-0.38*	-0.08	0.12	0.04	-0.50**	0.56***	0.67***	-0.29	1											
10	0.55***	0.66***	0.39*	0.49**	0.761***	-0.07	-0.65***	0.90***	-0.46**	1										
11	0.00	0.42*	0.34	0.38*	0.19	0.25	0.17	0.21	0.55***	0.24	1									
12	-0.35*	-0.41*	-0.16	-0.28	-0.53**	0.24	0.86***	-0.86***	0.62***	-0.81***	0.15	1								
13	-0.12	-0.11	-0.10	0.02	-0.01	0.18	0.21	-0.03	0.10	0.00	0.06	0.08	1							
14	-0.13	-0.15	-0.11	-0.02	-0.03	0.20	0.27	-0.12	0.15	-0.06	0.05	0.19	0.96***	1						
15	0.08	-0.03	-0.01	-0.14	-0.02	0.15	0.01	0.15	-0.03	0.15	-0.15	-0.10	0.26	0.31	1					
16	-0.32	-0.23	-0.20	-0.11	-0.04	0.12	0.16	-0.14	0.20	-0.11	0.02	0.15	0.58***	0.71***	0.46**	1				
17	-0.27	-0.11	-0.07	-0.02	-0.01	0.18	0.24	-0.06	0.15	-0.04	0.05	0.09	0.95***	0.91***	0.32	0.62***	1			
18	0.24	0.03	0.00	0.09	0.00	0.06	-0.14	0.19	-0.27	0.18	-0.11	-0.25	0.58***	0.46**	-0.04	-0.09	0.36*	1		
19	-0.63***	-0.44*	-0.22	-0.19	-0.43*	0.01	0.45**	-0.62***	0.54**	-0.61***	0.08	0.59***	0.05	0.16	-0.01	0.52**	0.16	-0.48**	1	
20	-0.43*	-0.44*	-0.18	-0.20	-0.61***	0.40*	0.90***	-0.84***	0.61***	-0.82***	0.04	0.9***	0.20	0.27	-0.08	0.19	0.22	-0.10	0.60***	1
21	-0.39*	-0.47**	-0.23	-0.25	-0.58***	0.28	0.81***	-0.87***	0.51**	-0.81***	-0.01	0.88***	0.21	0.31	-0.12	0.21	0.19	-0.01	0.59***	0.96***
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Significant at: * $\alpha = 0.05$; ** $\alpha = 0.01$; *** $\alpha = 0.001$.
1 – time of flowering (days); 2 – plant height (cm); 3 – height of the lowest pod; 4 – number of branches/plant; 5 – number of pods/plant; 6 – pod length (cm); 7– pod width (cm); 8 – seeds number/pod; 9 – seeds mass /pod; 10 – seeds number/plant; 11 – seeds mass/plant (g), 12 – mass of 100 seeds (g); 13 – force maximum (N); 14 – force of elasticity (N), 15 – deformation maximum (mm); 16 – elastic deformation (mm); 17 – energy (mJ); 18 - modulus (MPa); 19 – seed thickness (mm); 20 – seed width (mm); 21 – seed length (mm).

negatively with the time of start of blooming, plan height, number of pods per plant, number of seeds per pod, and number of seeds per plant. In the comparisons of the number of bifurcations per plant with seed thickness, width and length negative though insignificant values of the coefficient of correlation were obtained.

Based on regression analysis of the relations of the particular traits it was found that plant height was statistically significantly and in inverse proportion affected by seed thickness and length (Table 4). Those two variables accounted for a total of 16.9% of the overall variability in plant height. Seed thickness and width significantly affected pod length, accounting for 14.1% of the variation in that trait. The number of seeds per pod was determined by seed thickness, width and length. That relation was inversely proportional *ie* increase in the value of any of those traits caused a decrease in the number of seeds per pod. Those traits accounted for 65.2% of the total variation in the number of seeds per pod. The mass of seeds per pod was directly proportionally determined by seed thickness and width (32% accountability for the total variation). The number of seeds per plant was statistically significantly affected by the elastic force and by seed thickness and width. Those traits accounted for a total of 64.8% of the overall variation in the number of seeds per plant. The mass of 100 seeds was determined by the modulus and by seed width in 73.8%.

Apart from the determination of the correlations between the traits under study and regression analysis of the individual traits, the Mahalanobis intervals from the multivariate statistical analysis were used as basis for the estimation of similarity between the individual collection forms in terms of all analyzed traits combined (Table 5). Analysing the similarity between the particular forms one can distinguish two basic groups. The first group, with the highest mutual similarity (lowest intervals), can include objects originating from Italy and Spain (Nos 1-26), among which a lower similarity with other objects included in that group is characteristic of the Italian forms 3, 8 and 16 (LAT 4052/99; LAT 4078/00 and LAT 4055/99). The second group with notable mutual similarity (lower intervals) is constituted by the objects from Germany, Northern France and Poland (Nos 27-32), among which the most divergent is cv. Derek. The longest intervals (lowest similarity) were obtained in the comparisons of objects from the first group with objects from the second group, which indicates their notable mutual separateness in terms of the whole complex of traits under study. This is undoubtedly related with their geographical origin and the distinct morphological (phenotypic) character of Mediterranean grasspea from all other forms (Campbell, 1997; Hanbury *et al*., 1999). In the comparisons of objects from the first and the second groups the longest intervals were obtained in comparisons of cv. Derek (No. 31) with the forms from Italy and Spain (Nos 1-26). This indicates the greatest separateness of the Derek genotype, in terms of the analyzed traits, from the Mediterranean forms, but also – though to a lower degree – from the forms of Northern France and Germany.

Confirmation of the notable separateness of the forms relative to their geographical origin is provided by the positioning of the objects on the plane in the system of the first two canonical variables in terms of all analyzed traits combined (Fig. 1). The most divergent of all the forms is the Polish cultivar Derek, followed by cv. Krab and the objects from Northern France and Germany (Nos 27-30). Considerably distinct nup of forms from Italy and Spain is characterist3c an objects 3, 18 and 6 (LAT 4052/99; LAT 4078/00 and LAT 4055/99). The positioning of the objects with relation to their mechanical properties combined is presented in Fig. 2. With the exception of cv. Krab, the central area of the graph is occupied, among others, by a cluster of forms from Central-Eastern Europe, and namely by cv. Derek and objects from France (Nos 29 and 30) and Germany (Nos 27 and 28). This indicates considerable similarity of those forms in terms of their resistance to mechanical loads, and separateness in that respect of the Polish cultivar Krab which is closer to some of the Italian forms. The positioning of the remaining objects, especially the most extreme forms (to the left and right of the graph), indicates their notable differentiation in terms of values of static loads, permitting effective selection of the most

Table 4. Regression analysis for the dependence of individual traits

Model	% variation explained by model	Standard error of observations
x_2=81.29-3.55x_{19}-1.099x_{21}	16.9	6.91
x_6=3.841-0.13x_{19}+0.09x_{20}	14.1	0.286
x_8=5.84-0.18x_{19}-0.15x_{20}-0.11x_{21}	65.2	0.341
x_9=0.0554+0.0475x_{19}+0.031x_{20}	32	0.0924
x_{10}=198.4+0.063x_{14}-9.73x_{19}-11.59x_{20}	64.8	15.4
x_{12}=-15.93-0.0074x_{18}+5.222x_{20}	73.8	4.9

x_2 – plant height (cm); x_6 – pod length (cm); x_8 – seeds number/pod; x_9 – seeds mass /pod; x_{10} – seeds number/plant; x_{12} – mass of 100 seeds (g); x_{14} – force of elasticity (N), x_{18} – modulus (MPa); x_{19} – seed thickness (mm); x_{20} – seed width (mm); x_{21} – seed length (mm).

T a b l e 5. Estimation of similarity between accessions for the analyzed traits calculated on the basis of Mahalanobis distance

	1*	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	16.35														
3	23.88	12.63													
4	10.73	14.87	24.22												
5	12.99	19.01	27.65	10.31											
6	16.14	11.88	12.11	17.96	20.86										
7	10.13	17.99	25.63	9.11	9.34	17.82									
8	8.67	18.35	25.77	8.7	9.34	17.53	5.31								
9	11.07	18.28	25.24	11.16	9.73	18.74	7.79	6.53							
10	11.29	15.52	25.36	9.03	10	18.07	9.01	10.11	12.12						
11	12.67	17.66	27.09	8.05	9.54	21.36	9.27	9.27	8.72	9.52					
12	13.21	17.26	27.32	9.69	8.82	22.11	11.69	12.3	12.06	7.82	8.21				
13	9.71	14.25	24.27	8.2	8.68	17.85	10.16	9.36	10.02	8.17	9.11	7.6			
14	10.53	19.52	26.79	10.46	8.64	18.46	7.69	5.92	7.85	10.38	10.77	12.45	9.75		
15	15.17	22.38	32.7	12.63	10.01	26.09	13.42	12.46	12.18	12.9	9.92	10.14	10.49	13.14	
16	9.13	17.03	24.3	9.89	10.45	16.8	8	4.93	5.29	11.91	9.99	13.45	9.44	6.61	12.95
17	12.32	15.63	22.77	11.65	9.25	15.06	12.03	10.99	12.21	10.65	14.03	12.98	9.64	9.2	16.31
18	21.34	16.03	14.65	21.74	23.16	13.1	20.23	19.98	19.28	21.42	23.06	24.37	21.32	20.59	28.41
19	14.77	9.36	15.64	13.2	15.33	11.35	14.45	14.23	13.65	12.83	14.96	15.27	12.48	14.08	20.16
20	16.09	18.36	28.98	9.13	10.35	24.21	14.03	14.01	14.4	10.95	8.61	7.53	10.23	14.57	9.67
21	11.7	18.85	27.99	9.18	8.86	20.92	7.88	7.46	7.53	11.07	8.03	10.83	9.26	9.56	8.26
22	14.35	16.64	24.81	11.31	7.58	19.07	10.57	11.45	11.71	9.29	11.95	9.6	10.21	9.93	14.67
23	10.24	13.29	20.79	7.94	11.47	14.86	7.3	7.78	7.92	10.47	8.54	11.92	9.9	10.93	15.13
24	13.29	18.52	26.39	12.12	6.14	19.36	11.25	11.16	11.93	10.52	12.67	11.19	10.45	8.01	14.07
25	13.95	18.09	26.28	10.72	5.7	19.93	8.82	9.92	9.46	9.75	10.76	9.26	9.28	8.42	12.21
26	18.91	23.18	31.87	19.82	14.64	26.51	18.8	18.12	16.83	17.92	16.58	16.6	15.68	17.57	13.29
27	24.58	27.39	37.37	20.44	15.05	32.39	21.05	21.98	21.04	18.44	17.62	15.52	18.37	19.62	14.33
28	19.65	22.74	32.19	16.3	10.65	27.89	17.15	17.29	15.72	15.65	13.82	11.85	13.55	15.62	10.96
29	26.85	29.72	38.92	23.88	18.22	33.74	24.25	24.27	23.99	22.32	21.95	20.69	21.25	21.8	17.47
30	23.86	27.39	36.58	20.95	14.68	31.01	20.85	21.16	20.99	18.75	18.73	17.46	18.63	18.53	15.44
31	35.84	37.95	44.96	32.49	28.81	41.33	33.41	33.04	32.79	32.74	30.25	31.09	31.59	31.55	28.2
32	26.37	29.23	38.37	22.11	17.94	33.36	23.14	23.21	23.5	21.17	19.97	19.6	21.17	21.5	17.17

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
17	10.69															
18	18.23	18.47														
19	12.54	10.88	11.02													
20	14.79	15.15	26.29	16.72												
21	7.63	13.4	23.4	16.35	11.66											
22	11.77	8.69	18.94	11.53	11.99	12.36										
23	7.7	12.03	16.78	10.48	13.38	9.63	11.35									
24	11.33	7.36	21.57	13.91	13.43	12.18	6.22	13.08								
25	10.3	9.13	20.39	13.18	11.67	9.96	4.66	10.73	6.71							
26	17.55	19.47	29.22	22.07	17.01	15.58	18.34	19.92	16.06	17.5						
27	22.34	21	33.69	25.1	14.61	18.76	17.3	23.35	16.31	16.19	15.61					
28	16.89	16.5	28.52	20.33	11.38	14.06	13.04	18.26	12.4	11.86	12.72	8.53				
29	24.27	23.04	35.24	27.52	19.04	21.86	20.79	26.62	18.72	19.72	14.98	8.51	11.62			
30	21.56	19.94	32.38	24.56	16.43	19.3	17.18	23.51	14.99	16.42	13.77	6.7	9.78	5.59		
31	33.42	33.22	43.77	36.83	28.31	31.42	32.24	34.9	30.21	31.19	23.93	21.67	23.54	17.46	20.43	
32	23.93	23.41	35.09	27.03	16.62	21.25	20.52	25.16	19.2	19.76	16.03	9.65	12.59	7.45	8.47	14.77

*Notation of accessions are given in Materials and Methods: 1-32 forms of grasspea.

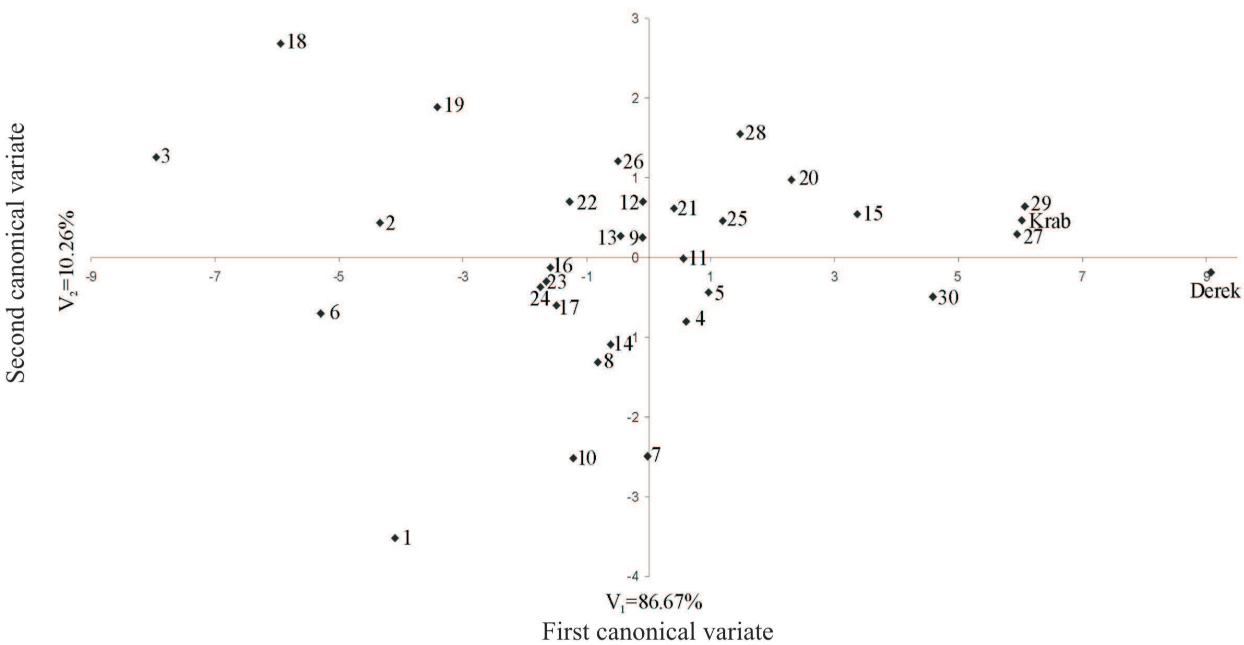

Fig. 1. Distribution of accessions in the space of two first canonical variables for the all analzyed traits together.

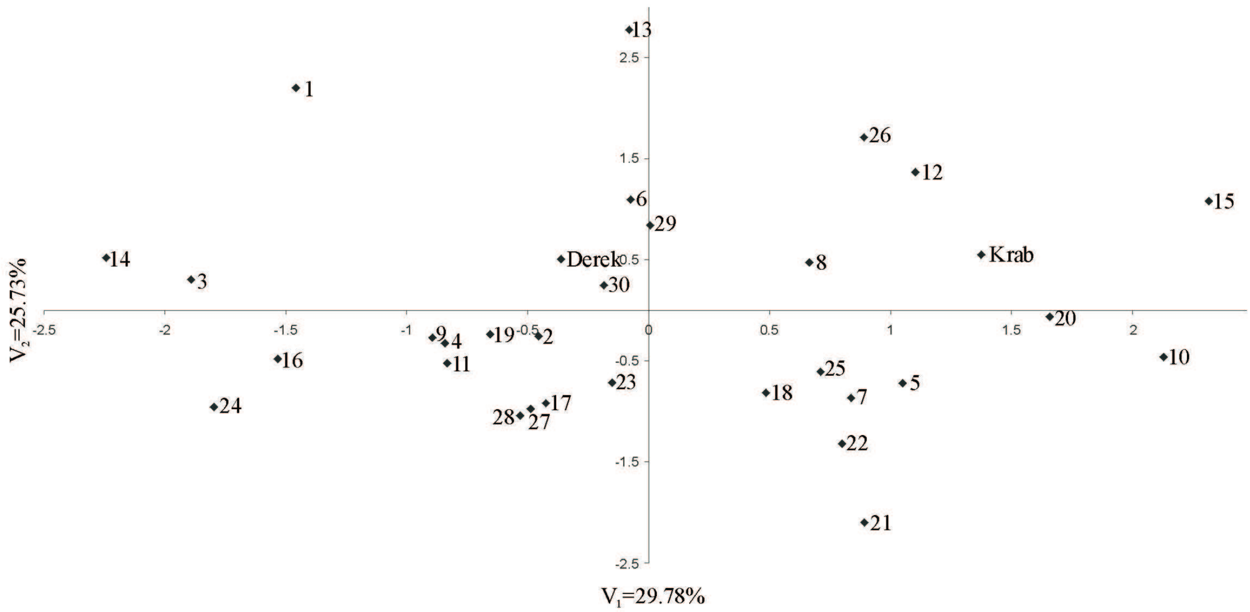

Fig. 2. Distribution of accessions in the space of two first canonical variables for the all analzyed traits of mechanical loads of seeds.

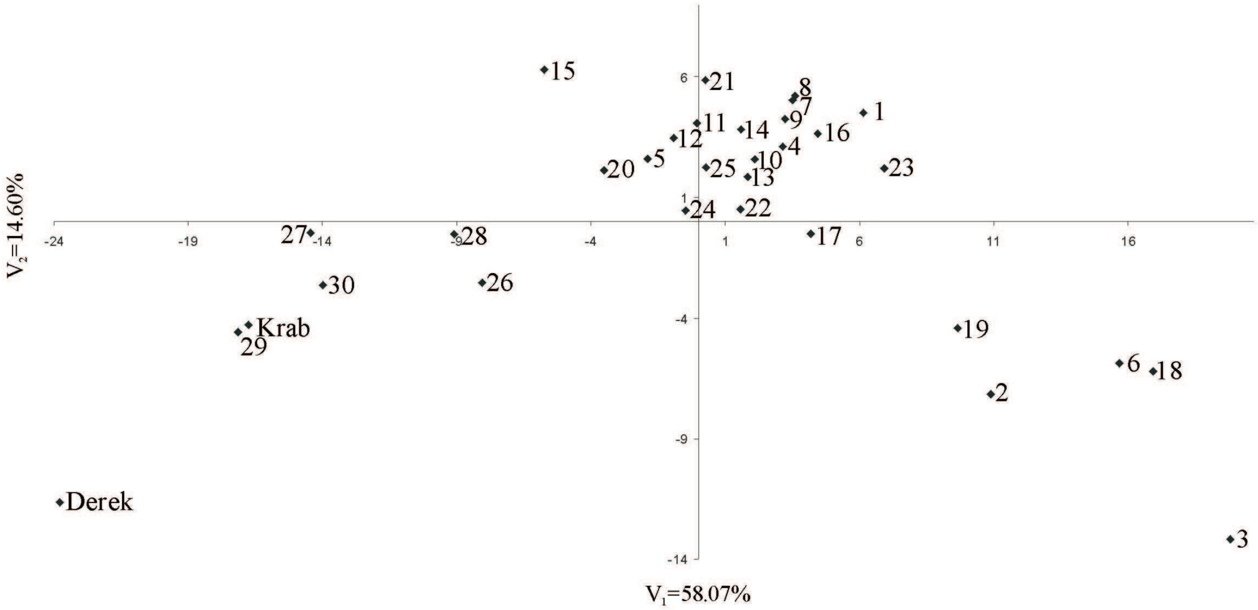

Fig. 3. Distribution of accessions in the space of two first canonical variables for the all analzyed traits of geemetrical properties of seeds.

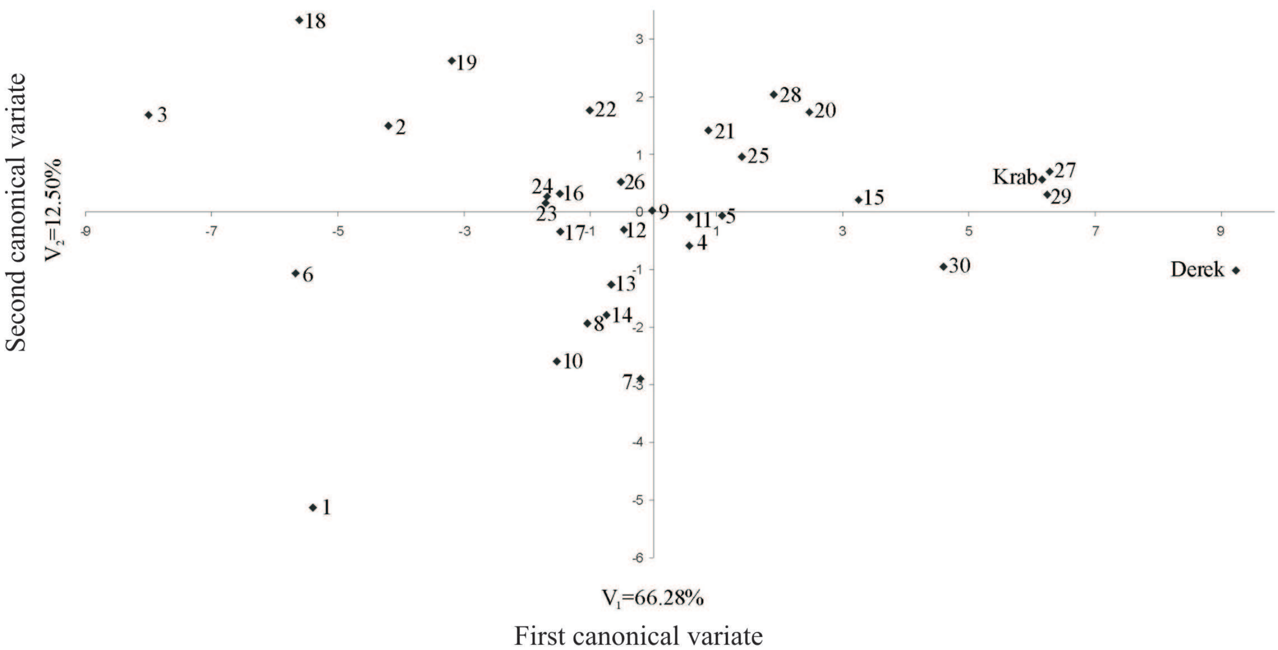

Fig. 4. Distribution of accessions in the space of two first canonical variables for the all analzyed traits of mechanical loads and geometrical properties of seeds together.

desirable genotypes. Figure 3 presents the positioning of the objects in terms of their seed geometry features combined. The outermost part of the left-hand side of the graph is occupied by objects from Central-Eastern Europe, and the Polish forms (Derek and Krab), French (Nos 29 and 30), and one German form (No. 27), with greater distance of the other German form (No. 28). The right-hand part of the graph is occupied by objects from Italy, with lower (Nos 2, 19) or greater (Nos 3, 6, and 18) separateness with relation to the C-E European forms in terms of seed thickness, width and length. Estimation of the similarity of the objects in terms of their seed geometry and resistance to mechanical loads combined (Fig. 4) slightly alters the spatial arrangement of the grass-pea forms compared to Fig. 3. This indicates a dominance of significant differences in seed geometry compared to the differentiation of the objects in terms of their values of the mechanical parameters.

CONCLUSIONS

1. Statistical estimation of variability of phenotypic traits in the field experiment, and of the geometry of the seeds and their resistance to mechanical loads, indicates notable intra-species differentiation of grasspea represented by geographically distant collection objects.

2. The variability demonstrated in the study may constitute a basis for the selection of objects with the most favourable geometric parameters of seeds and the highest seed resistance to mechanical damage that may be utilized in genetic improvement of grasspea in the breeding and technological aspects, in the context of harvest and storage technology for human and animal feeding requirements.

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