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Estimation of morphological traits and mechanical properties of grasspea seeds (*Lathyrus sativus* L.) originating from EU countries

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A b s t r a c t. The material for the study comprised 30 accession forms of grasspea (Gene Bank in Gatersleben, Germany) originating from four European countries, and two Polish cultivars – Derek and Krab. Estimation of variability of the morphological traits and yield structure was performed on the basis of a field experiment and the obtained seeds were analysed under laboratory conditions, taking into account the geometric features of the seeds and their physical (mechanical) properties as defined by values of static loads.

Apart from differences in the dates of start of blooming, plant height, height of positioning of the lowest pod on the plant, and pod morphology (length and width), the plants under study differed with respect to their yield-forming traits, such as the number of pods per plant, number and weight of seeds in pod, and number and weight of seeds per plant. Seeds under analysis, taken for static load tests, were characterised by fairly uniform moisture content within the range from 7.9 to 9.8%. In terms of weight of 100 seeds, the experimental objects displayed a broad range of variability, representing forms typically small-seeded (from 5 to 15 g), medium-seeded (from 15 to 25 g), and coarse-seeded (over 25 g). The coarse-seeded forms originated mainly from Italy and Spain, while those with smaller seeds came from France, Germany and Poland. The above trait was related to the geometric features of the seeds, expressed in terms of their thickness, width and length. The ranges of variability of those features were, respectively, 4.61-6.13, 7.13-12.98 and 7.88-14.43 mm. The most extensive ranges of variation were recorded for static loading parameters concerning maximum force and elasticity (N), maximum and elastic strain (mm) and energy (mJ), and apparent modulus of elasticity (MPa). On the basis of the results obtained, forms with the highest and the lowest values of static load were identified. The above traits were related not only with the geometric features of the seeds, but likely also with genetically determined changes in the microstructure of the seeds. Analysis of the microstructure in further research would surely permit demonstration of the relevant relationships with respect to the results obtained from analysis of static loading. The results obtained from the field trial and from estimation of the mechanical properties of the seeds indicate a broad range of variability of the parameters under analysis. This permits to isolate the most valuable foreign genotypes and their further utilisation as parent material for hybridisation aimed at improvement of local forms of grasspea.

K e y w o r d s: grasspea, accession lines, plant morphology, yield structure, seed geometry, static loading of seeds

INTRODUCTION

The genus *Lathyrus* is highly numerous and comprises 187 species and subspecies, spreading over the territory of the Old as well as the New World (Allkin *et al.*, 1983). Among those, the most common as food in the form of seeds, is grasspea (*Lathyrus satvus* L.). Other species, like *L. cicera*, *L. clymenum* and *L. ochrus,* are used both for the production of seeds and for green fodder (hay). The remaining, less known species, such as *L. tingitanus*, *L. latifolius* and *L. sylvestris,* are used solely for green fodder production. For decorative purposes, also in Poland, sweet pea (*L. odoratus)* is grown. Overall, under the climatic conditions of Poland, there are 15 species (Dziamba, 1997), only two of which have an economic significance: African everlasting pea (*Lathyrus tingitanus* L.) and, in particular, grasspea (*Lathyrus sativus* L.).

The problem of protein fodder deficiency in Poland is related both to its quantity and quality. The basic fodders in this respect are seeds of leguminous plants, extraction meals, and – until recently – waste products of animal origin. Due to the appearance of the threat of BSE, as of the 1st of November, 2003, the use of mean-and-bone meals in animal feeding (that had constituted 6-8% of fodders before that) is

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totally prohibited in Poland. In feeding chickens, for example, such feeds have been substituted with cereals and soybean meal. The final effect is growth of feed and fodder prices, and animals grow more slowly and need to consume more to obtain the required body mass. The effect of elimination of high-protein fodders of animal origin, and the controversies around the use of genetically modified soybean (GMO), may additionally aggravate the current deficit in animal feeding, indicating at the same time the role of local sources of protein from leguminous plants. Apart from the traditional leguminous crops (pea, faba bean, lupine), the palette of such species in human and animal nutrition may be complemented with high-protein grasspea (up to 30% of protein content and above) which, even though it has been grown for decades in the region of Podlasie, still has an undeservedly marginal importance in the Polish agriculture (Milczak *et al.*, 2001). In recent years, thanks to ongoing breeding work and increased interest on grasspea growing, two Polish crop cultivars of grasspea have been registered – Derek and Krab.

In Poland lighter and sandy soils dominate, constituting 60% of all arable lands. Traditionally, rye and potatoes are grown on such soils, occasionally serradella, yellow lupine or oats, but not high-protein leguminous plants like pea of faba bean that require better sites (Dziamba, 1997). Grasspea has low habitat requirements and there may be competitive (alternative) relative to those crops. Grasspea can be successfully grown on light soils of classes IV, V and even VI, with yields reaching 3 500 ha^{-1} on better soils (Cichy and Rybiński, 2007; Grela and Skórnicki, 1997). This capability of the plant results, among other things, from its exceptional resistance to drought, and according to literature data it can be grown even at rainfall level of 380 mm. These features makes grasspea unique among all other crop plants cultivated in Poland. This is especially important in view of the global climatic change and the cyclic period of drought observed in recent years. Grasspea resistance to drought is due to its strongly developed, deep root system (Campbell *et al.*, 1994) which, additionally, activates insoluble nutrients and transports them from deeper layers of soil, with simultaneous improvement of its hydraulic capacity. Also important is its high protein content (Rybiński and Starzycki, 2004), often higher than that of pea, faba bean and vetch (Hanbury *et al.,* 2000), and due to its capacity to absorb nitrogen from the atmosphere grasspea is a valuable element of crop rotation. Taking into account th notable resistance of grasspea to abiotic stress *eg* diseases, pest infestation and drought, grasspea has been accepted as a model crop plant for sustainable agriculture (Vaz Patto *et al.*, 2006). An undesirable element is the presence of ODAP, an anti-nutritional neuro-toxic substance, in the seeds, though cultivars have already been developed that have only a trace content of that component (Hanbury *et. al.*, 2000; Vaz Patto *et al.*, 2006; Rybiński and Grela, 2007; Siddique *et al.,* 1996; Tiwari and Campbell, 1996).

In spite of the positive breeding achievements and unquestionable fodder value of the crop, its role in agricultural practice is still marginal. One of the reasons of that is not only the shortage of exhaustive information on the benefits of grasspea growing, but also the fact that it requires improvement of a number of traits that may have a limiting effect on more expansive introduction of grasspea in the Polish agriculture. Hence the need of extending the existing pool of genetic variability of traits, which determines the possibility of selection of the most desirable genotypes. This may be achieved, among other things, through induced mutation (Kozak *et al.,* 2008; Rybiński, 2003; Rybiński *et al.*, 2004; Smulikowska *et al.*, 2008), but also by trying to make use of recombination variability in both intra- and inter-species breeding of forms genetically varied to the greatest extent available, originating from the world accession gene bank resources (Tiwari and Campbell, 1996; Yunus and Jackson, 1991). To enrich the gene pool of the Polish forms of grasspea, work has been initiated on the estimation of genetic variability of traits of European accessions of grasspea. The study presented herein is a part of that project, and its objective is estimation of variability of morphological traits, yield-forming features and mechanical properties of seeds, and at a later stage – selection of the most favourable genotypes that may be used for cross-breeding with the Polish cultivars of grasspea.

MATERIAL AND METHODS

The experimental material comprised thirty accessions obtained from the Gene Bank in Getersleben (Germany) and originating from four European countries – Italy, Spain, Germany and France. Twenty one objects originated from Italy (Nos 1-21), five from Spain (Nos 22-26), and two each from Germany (Nos 27-28) and France (Nos 29-30). The Polish gene resources were represented by two cultivars: Derek (No. 31) and Krab (No. 32) – Table 1. For comparison of grasspea with other representatives of leguminous crop plants, static load testing of seeds was additionally performed for white lupine cv. Butan (nr 33), field pea cv. Marych (No. 34), and lentil cv. Anita (No. 35). Seeds of those cultivars were obtained from Polish crop plant breeding stations (Table 2).

Estimation of morphological traits and yield-forming features was performed on the basis of results obtained from a field trial. The field trial was arranged in randomised complete block design with three replications, conducted on the Experimental Field of the Institute of Plant Genetics in Cerekwica, Poland (51°55’N, 17°21’E) in 2006. The seeds were sown in experimental plots on the surface of 4.5 m^2 and with seed spacing was 300 x 150 mm. Immediately after sowing, Afalon, a herbicide, was applied on the plots. No mineral fertilization was applied during the growth and development of plants. During plant development, the time to flowering (TK), flower colour and pod shape were

T a b l e 1. Means of traits of grasspea accessions from field trial

No.	Accessions	TK* (days)	WS (cm)	WOS (cm)	LIR	LSR	DS (cm)	SZS (cm)	LNS	MNS (g)	LNR	MNR (g)	MSN (g)
1	LAT 4050/99	58.7	43.2	15.4	4.93	24.8	4.01	1.75	2.03	0.65	48.9	13.62	27.7
2	LAT 4051/99	63.6	44.2	17.4	4.33	20.3	3.82	1.67	1.31	0.53	21.7	8.32	38.5
3	LAT 4052/99	63.0	37.2	13.8	5.06	20.5	4.33	1.87	1.10	0.60	18.3	10.03	49.2
4	LAT 4053/99	60.6	37.6	12.3	4.00	27.	3.31	1.41	1.69	0.48	41.9	12.43	29.6
5	LAT 4054/99	62.3	43.5	16.5	5.93	30.2	4.10	1.56	2.65	0.69	60.9	14.71	24.1
6	LAT 4055/99	60.3	50.3	20.0	5.53	23.8	4.08	1.72	1.64	0.76	31.3	14.52	46.3
7	LAT 4056/99	60.7	50.8	18.4	5.93	33.7	3.74	1.56	2.03	0.59	53.5	15.51	29.0
8	LAT 4061/99	59.0	47.6	16.3	4.73	32.8	3.70	1.54	2.12	0.61	56.8	15.65	27.6
9	LAT 4063/01	59.0	50.7	16.1	5.26	30.5	4.36	1.68	2.28	0.67	51.4	14.04	27.3
10	LAT 4064/01	62.6	57.0	20.8	4.00	21.3	3.88	1.50	2.04	0.60	40.3	11.78	29.4
11	LAT 4065/01	61.3	50.3	17.3	4.80	37.5	3.78	1.51	2.08	0.52	44.7	10.82	24.1
12	LAT 4068/01	62.7	46.0	15.4	4.46	21.8	4.27	1.50	2.15	0.55	41.6	10.25	24.6
13	LAT 4069/01	61.6	44.2	15.7	3.86	22.7	3.94	1.58	2.11	0.62	40.1	10.84	27.3
14	LAT 4070/01	59.7	52.9	18.2	4.70	29.9	4.10	1.55	2.47	0.69	63.3	18.07	28.6
15	LAT 4071/01	60.0	48.1	17.2	4.46	24.5	3.81	1.45	2.58	0.54	53.7	10.44	19.4
16	LAT 4074/01	58.7	51.3	17.1	4.86	32.7	3.88	1.61	2.20	0.65	56.5	15.97	28.3
17	LAT 4075/00	62.0	47.7	16.7	4.46	23.1	4.15	1.62	2.56	0.86	48.7	16.15	33.5
18	LAT 4078/00	62.6	58.3	22.4	4.93	29.8	4.33	1.90	1.65	0.74	41.3	19.65	46.9
19	LAT 4079/00	63.0	54.3	20.0	4.53	25.1	4.32	1.72	1.87	0.70	38.8	15.48	39.8
20	LAT 4081/00	63.3	42.1	13.5	4.33	29.8	3.67	1.41	2.10	0.47	52.6	11.27	23.0
21	LAT 4082/00	59.0	47.1	16.1	5.13	28.0	3.60	1.47	2.20	0.52	47.1	11.62	24.7
22	LAT456/75	64.0	52.9	18.3	5.80	28.6	4.28	1.58	2.34	0.67	63.7	18.47	29.1
23	B 1706/92	60.7	50.7	15.5	6.06	37.7	3.77	1.62	1.78	0.59	45.1	13.80	30.7
24	LAT 4006/84	62.6	52.5	18.9	6.20	28.5	4.27	1.55	2.68	0.73	69.1	18.21	26.4
25	LAT 4007/84	62.6	52.5	17.5	6.06	28.3	4.25	1.60	2.52	0.68	60.9	17.52	28.8
26	LAT 4085/00	62.0	59.2	23.5	6.46	30.4	4.93	1.60	2.73	0.57	81.9	10.28	14.6
27	LAT 444/73	66.0	59.8	22.3	5.60	28.2	4.19	1.42	3.05	0.53	77.0	12.77	16.7
28	LAT 462/82	64.3	49.3	14.4	5.20	27.3	4.11	1.52	2.95	0.52	71.1	11.76	16.6
29	B 1702/80	66.0	63.3	23.7	5.60	32.3	3.86	1.42	3.35	0.52	102.5	15.37	15.0
30	B 1705/87	66.0	59.7	24.3	5.73	29.7	3.95	1.44	3.22	0.57	90.4	15.46	17.0
31	Derek	66.0	56.9	16.1	5.46	60.3	3.80	1.35	3.47	0.35	137.7	12.48	9.1
32	Krab	66.0	63.6	21.0	5.80	44.9	3.71	1.34	3.00	0.42	110.9	15.85	14.2

*TK – time of flowering, WS – plant height, WOS – height of the lowest pod, LIR – number of branches per plant, LSR – number of pods/plant; DS – pod length, SZS – pod width, LNS – number of seeds/pod, MNS – weight of seeds/pod, LNR – number of seeds/plant, MNR – weight of seeds/plant, MSN – weight of 100 seeds.

T a b l e 2. Moisture and geometric features of grasspea, pea, lupine and lentil seeds

No.	Accessions	Moisture (%)	Thickness (mm)	SD (mm)	Width (mm)	SD (mm)	Length (mm)	SD (mm)
1	LAT 4050/99	8.8	5.81	0.60	10.48	1.17	12.37	1.16
2	LAT 4051/99	9.3	5.64	0.62	11.35	0.90	12.50	0.95
3	LAT 4052/99	8.4	5.76	0.61	12.98	1.30	14.43	1.37
4	LAT 4053/99	8.4	5.49	0.52	9.10	0.68	10.62	1.06
5	LAT 4054/99	8.1	5.38	0.60	9.02	1.03	9.72	0.88
6	LAT 4055/99	7.8	6.03	0.72	11.52	1.28	13.02	1.35
7	LAT 4056/99	8.2	6.01	0.49	9.02	0.70	10.02	0.81
8	LAT 4061/99	7.9	5.80	0.54	9.57	0.59	9.95	0.57
9	LAT 4063/01	9.2	5.31	0.56	9.58	0.81	10.20	0.81
10	LAT 4064/01	9.3	6.13	0.51	9.50	0.72	10.50	0.89
11	LAT 4065/01	8.3	5.30	0.56	9.27	0.66	10.27	0.78
12	LAT 4068/01	9.1	5.19	0.67	9.67	0.54	10.33	0.73
13	LAT 4069/01	8.8	5.33	0.58	9.73	0.73	10.45	0.79
14	LAT 4070/01	8.1	5.71	0.51	9.53	0.75	10.33	0.91
15	LAT 4071/01	8.0	4.89	0.51	8.23	0.98	9.03	0.66
16	LAT 4074/01	8.0	5.54	0.71	10.12	1.19	11.05	1.31
17	LAT 4075/00	8.1	5.66	0.59	9.98	0.87	10.73	1.02
18	LAT 4078/00	8.4	5.23	0.63	12.43	1.00	12.73	1.18
19	LAT 4079/00	8.1	5.13	0.59	11.27	0.92	13.32	1.14
20	LAT 4081/00	8.9	4.82	0.44	8.77	0.72	11.25	0.96
21	LAT 4082/00	8.6	5.16	0.53	9.45	0.72	10.40	0.98
22	LAT456/75	8.3	5.30	0.55	10.15	0.66	11.00	0.88
23	B 1706/92	7.9	5.57	0.56	10.12	0.64	11.52	1.00
24	LAT 4006/84	8.5	5.62	0.48	10.13	0.54	11.00	0.84
25	LAT 4007/84	9.3	5.12	0.58	9.10	0.68	9.83	0.67
26	LAT 4085/00	9.8	5.09	0.40	9.93	0.71	10.72	0.83
27	LAT 444/73	9.2	4.71	0.40	7.13	0.70	7.88	0.67
28	LAT 462/82	8.6	4.80	0.45	9.20	0.82	10.08	0.84
29	B 1702/80	8.1	4.61	0.44	7.15	0.76	7.97	0.66
30	B 1705/87	8.9	5.05	0.48	7.53	0.95	8.38	0.72
31	cv. Derek	8.5	4.62	0.43	7.15	0.84	9.27	-
32	cv. Krab	8.5	5.05	0.48	7.53	0.95	8.38	0.72
33	White lupin	8.2	4.45	0.41	9.28	0.85	-	-
34	Field pea	9.3	6.61	0.37	-	-	-	-
35	Lentil	9.7	2.43	0.20	5.88	0.59	-	-

estimated. At harvest, plant height (WS), height of lowest-located pod per plant (WOS), number of branches and pods/plant (LIR, LSR), pod length and width (DS, SZS), seed number and weight per pod and plant (LNS, MNR and LNR, MNR) as well as weight of 100 seeds (MSN) were analysed. The traits were measured on 15 plants randomly chosen from replicate plots. Additionally, seed shape and seed coat colour were described. These two morphological traits, as well as flower colour and pod shape, were estimated according to data given in Descriptors for *Lathyrus* (IPGRI, 2000). Obtained results were processed statistically with the use of multivariate statistical method. The results were complemented with meteorological data (rainfall and air temperature) for the year 2006 in which the field trial was conducted and, for comparison, data were also given for the years immediately preceding and following the trial year *ie* for the years 2005 and 2007 (Table 3).

The collected seeds were also analysed in terms of their physical properties. The first stage of the determination included seed thickness, seed length and seed width. Those parameters were measured using an adapted dial gauge and an electronic slide caliper with the accuracy of 0.01 mm. To obtain detailed distributions of this property in air dry seed samples, 300 replications were made on the same seeds selected at random.

The resistance of individual seeds to static loading was determined by means of the INSTRON model 6022 strength tester, according to a method developed earlier, in 30 replications (Szot *et al.*, 1994). The results obtained were used to determine the compressive strength of the seeds. The results of the determination were expressed in values of force (mm), force of elasticity (N), maximal deformation (mm), elastic deformation (mm), energy (mJ) and apparent modulus of elasticity (MPa).

RESULTS AND DISCUSSION

Grasspea is one of the oldest crop plants in the world, and it most probably arrived in Europe as a result of agricultural expansion from the Middle East (Kislev, 1986, 1989). Its presence is dated back to the Neolithic age (Lambein and Kuo, 1997), and according to Milczak *et al*. (2001) it appeared in Poland, in the region of Podlasie, more than 200 years ago with the Tartar settlers. It is still grown there, though its spread is limited to a few isolated local populations representing a narrow pool of genes. In order to expand and enhance the effectiveness of selection of desirable genotypes for breeding purposes, it is necessary to expand the variability of traits in parent forms through an influx of genes originating from genetically varied forms from other geographic regions of Europe, taking advantage of the resources of the Gene Bank, as was the case in this study.

T a b l e 3. Rainfall level and average temperature during field trial in 2006 as compared with the years 2005 and 2007

Months	Rainfall (mm)						Temperature (°C)		
	2005		2006		2007		2005	2006	2007
	Sum	Decade	Sum	Decade	Sum	Decade			
March (III)	24.7	2.1 21.7 0.9	16.6	3.1 0 13.5	52.8	12.6 12.6 27.6	1.4	0.7	5.8
April (IV)	14.2	4.4 3.4 6.4	39.8	6.1 13.5 20.2	5.4	2.0 1.4 2.0	9.6	9.2	9.6
May (V)	68.0	27.5 24.2 16.3	33.3	11.3 7.1 14.9	98.8	21.0 65.4 12.4	14.3	14.4	14.2
June (IV)	11.5	11.5 0 0	17.4	5.8 3.0 8.6	85.6	11.4 11.8 62.4	17.4	19.5	18.1
July (VII)	96.6	25.2 6.9 64.5	23.8	0.8 21.2 1.8	94.8	41.4 3.4 50.0	20.3	22.9	17.7
August (VIII)	56.7	41.5 8.1 7.1	162.0	102.4 16.0 43.6	34.8	26.4 3.4 5.0	17.6	16.7	18.2
Sum III-VII	215.0	-	130.9	-	337.4	-	-	-	-

For estimation of genetic variability of the studied grasspea accessions in the context of selection of the most promising lines for crossbreeding with local forms, the experimental material was analysed in 2006 under conditions of a field trial. The year 2006 was characterised by a strong drought during the vegetation period of grasspea (March-July). The sum of rainfalls during that period was only 130 mm, with corresponding values of 215 and 337.4 mm in the years 2005 and 2007, respectively (Table 3). The low level of rainfall observed in March (16.6 mm) already indicated lower availability of water for the next months of vegetation, and low level of rainfall in subsequent months (with a minimum in June – 17.4 mm) caused an aggravation of water deficit until the end of July. The drought was interrupted after 5th August (102.4 mm), when grasspea practically enters the stage of full ripeness and could not utilise the available water for the growth and development of plants. In spite of those unfavourable conditions caused by water stress, compared to other plants in the neighbourhood no significant drought-related damage was observed, which supports the unique resistance of grasspea to water deficit, pointed out by numerous authors (Abd El-Moneim *et al*., 2000; Campbell *et al*., 1994; Hanbury *et al*., 2000; McCuthan, 2003; Rybiński, 2003; Rybiński and Bocianowski, 2006; Tiwari and Campbell 1996).

Mean values of traits of grasspea accessions from the field trial are given in Table 1. On average, the plants flowered after 62 days from the date of sowing, the earliest blooming – within the range of 58 to 64 days - being characteristic of accession from Italy (Nos 1-21) and Spain (Nos 22-26), and later, above 64 days, of accessions from Germany (Nos 27-28), France (Nos 29-30) and Poland (Nos 31-32). The relatively short blooming period difference between the earliest and latest blooming (eight days) may result from the intensifying drought (Table 3) conducive to faster and more uniform times of start of blooming. A broader range of variability of that trait is indicated by data obtained by Hanbury *et al*. (1995), where for 451 accession lines of grasspea differences in the time of start of blooming varied within the range from 43 to 123 days, and for 1072 accessions the range of variation was from 43 to 88 days (Sarwar *et al*., 1995), and for plants obtained after irradiation with gamma rays (generation M_2 and M_3) - from 53 to 94 days (Waghmare and Mehra, 2000). The range of variation in plant height was from 37.2 cm in the Italian form LAT 4052/99 to 63.6 cm in the Polish cultivar Krab. Earlier measurements of grasspea plant height indicated that in a year with normal level of rainfall (516 mm in 2002) the plant height was from 67.8 to 94.3 cm, but in a drier year 2003 (331 mm) the range of variability of that trait was only from 25.6 to 42.7 cm (Kozak *et al*., 2008). Moreover, in this study the forms from Italy and Spain were lower than those from Germany or Poland. A significant feature permitting more effective mechanised harvest is the height of the lowest pod. The range of variability of that trait was from 12.3 cm for the low Italian accession LAT 4053/99 to 24.3 cm for the tall French accession B 1705/87. In a study by Tavoletti and Capitani (2000) the range of variation of that trait for Italian accession was from 11.2 to 16.1 cm, and for accessions from Slovakia – from 19.2 to 30.3 cm (Benkova and Żakowa, 2001). The Italian accessions usually produced less than five first-order branches per plant, while in those from the other countries that number was higher. According to Mehra *et al*. (1995), accessions from France developed 5.2 branches (in this study – 5.6 and 5.7), and those form Germany – 5.0 (in our study – 5.6 and 5.2). In turn, in 60 accessions from Spain (De La Rosa and Martin, 2001) the maximum number of branches did not exceed 4.5, with variability from 5.2 to 6.5 in the Spanish accessions analysed in this study.

The fewest pods per plant were produced by accessions from Italy (20.3 in LAT 4051/99), as well as by those from Spain, France and Germany (maximum up to 37.7 pods in B 1706/92 from Spain), with 60.3 and 44.9 pods for the Polish cultivars Derek and Krab. Local accessions from various regions of Spain formed, on average, 29.3 pods per plant, with variation from 17.4 to 46.8 (De La Rosa and Martin, 2001), and in this study the Spanish accessions produced an average of 30.7 with variability within the range from 28.3 to 37.7. According to Yadov (1995), for 72 local accessions from Nepal the mean number of pods per plant was 36, with variability from 13 to 59, and according to Pandey *et al*. (1995), in 1187 accessions studied in India the mean number was 19.3 pods and the range of variation was from 2.4 to 59. Pod length varied within the range from 4.93 cm for the Spanish accession LAT 4085/00 to 3.6 cm for the Italian accession LAT 4082. In accession studied in Canada, the values of that trait varied from 1.7 to 5.6 cm (Campbell, 1997), in India from 1.88 to 5.18 cm (Pandey *et al*., 1995) and from 3.05 to 3.62 (Sarkar *et al*., 2003). In Spanish accessions, pod length varied from 3.45 to 5.24 cm, and pod width from 1.2 to 1.7 cm (De La Rosa and Martin, 2001). In the study presented here, the values of both traits for the Spanish accessions were from 3.7 to 4.93 cm and from 1.55 to 1.62 cm, respectively. Compared to the Polish cultivars, very broad pods were characteristic of the Italian accessions, LAT 4052/99 and LAT 4078/00, with pod width values of 1.87 and 1.90 cm (Table 1).

The range of the number of seeds per pod was from 1.1 for the broad-pod Italian accession LAT 4052/99 to 3.47 for the Polish cultivar Derek. Seeds-per-pod number above three was characteristic only of accessions from Germany, France and Poland (Table 1). In a study by Campbell (1997), the number of seeds per pod was from 1.4 to 4.6, and according to Yadov (1995) – from 2 to 5 seeds. Although for the Italian accessions the number of seeds per pod was low, due to their producing large seeds the weight of seeds in a pod often exceeded 0.6 g (even up to 0.86 g in the Italian accession LAT 4075/00), as against a greater number of

T a b l e 4. Statistical characteristics of grasspea accessions

Traits	Mean	Variation range		Range of confidence		Variance	SD	SV (%)
		Min	Max	Min	Max			
Time of flowering (days)	62.19	58.0	67.0	61.7	62.7	0.546	2.337	3.76
Plant height (cm)	50.79	31.4	67.4	49.	52.3	0.574	7.585	14.93
Height of the lowest pod	17.88	11.0	27.0	17.2	18.6	0.113	3.368	18.83
Number of branches/plant	5.13	3.0	7.4	4.9	5.3	0.731	0.855	16.66
Number of pods/plant	29.56	17.8	69.4	27.8	31.2	0.690	8.309	28.09
Pod length (cm)	3.99	3.2	4.7	3.9	4.1	0.949	0.308	7.70
Pod width (cm)	1.56	1.33	1.92	1.53	1.58	0.174	0.132	8.48
Number of seeds/pod	2.31	1.08	3.74	2.19	2.43	0.332	0.577	24.93
Seeds weight /pod	0.60	0.31	0.91	0.58	0.62	0.125	0.112	18.59
Number of seeds/plant	58.24	15.50	148.4	53.1	63.4	0.645	25.406	43.62
Seeds weight/plant (g)	13.85	7.20	21.19	13.2	14.5	0.953	3.087	22.29
Weight of 100 seeds (g)	27.10	8.70	51.0	25.1	29.0	0.917	9.576	35.33

seeds per pod but with smaller seeds in the case of the Polish cultivars Derek and Krab (0.35 and 0.42 g). Generally, one of the features that distinguished the Polish cultivars from the accessions from Italy or Spain was seed size. Mean weight of 100 seeds for accessions from Italy, Spain, Germany, France and Poland was 30.9, 25.9, 16.6, 16.0 and 11.6 g, respectively. This indicates the difference of accessions from the first two of those countries relative to the smaller-seeded accessions from the other countries, and especially from Poland. The highest weight of 100 seeds was characteristic of accession LAT 4052/99 – 49.2 g, and the lowest – the Polish small-seed cultivar Derek, with 100 seeds weight of 9.1 g (Table 1). In a study conducted in Australia, (Hanbury *et al*., 1995), the range of variation of the weight of 1000 seeds under study, for 451 accessions, was from 190 to 220 g, the smallest of the seeds originating from Bangladesh, and the largest – from Greece and Cyprus, among others (Campbell, 1997). In seed material from Bangladesh, the weight of 1000 seeds was only from 29.5 to 67.7 g (Sarwar *et al*., 1995), while in studies by other authors the values of that trait varied from 34.5 to 225.9 g (Robertson and Abd El Moneim, 1995), from 56 to 288 g (Campbell, 1997), and from 232 to 354 g in accessions from Slovakia (Benkova and akova, 2001). In a study on accessions from Spain, the range of variability of the weight of 100 seeds was from 13.8 to 36.8 g (De La Rosa and Martin, 2001), and for the Spanish accessions included in our study – from 14.6 to 30.7 g. Large-seed forms are typical for grasspeas grown in Chile, where the mean weight of a single seed of some accessions reached 455 mg (Mehra *et al*., 2003) *ie* a value similar to that attained by some of the Italian large-seeded accessions analysed by us. The high value of weight of 100 seeds of Italian accessions is confirmed by reports of Hammer *et al*. (1995), informing of the existence, in the south of Italy, of accessions with exceptionally large seeds, compared to the small seeds typical for the Indian subcontinent, frequently prone to shedding during ripening and harvest (Campbell, 1997).

In spite of the greater number of branches and pods per plant and greater number of seeds per pod and plant, typical of the Polish cultivars, compared to the accessions from Italy or Spain, the large seed size typical of the accessions from those two countries caused that the weight of seeds per plant, that for the small-seed cultivars Derek and Krab was 12.48 and 15.85 g, respectively, proved to be – in several cases – lower than for the large-seed accessions from Italy (19.65 g for LAT 4078/00 and 18.07 g for LAT 4070/01) or Spain (18.47 g for LAT 456/75 and 18.21 for LAT 4006/84) (Table 1). Seed yield per plant in accessions from Germany or France was similar to that of the Polish cultivars Derek and Krab. This indicates that in spite of reduction of significant parameters of yield structure in accessions from the Mediterranean area the seed yield per plant was frequently determined by the concurrent greater weight of 1000 seeds. Hence of introduction of the trait of large seed size in Polish genotypes through crossbreeding appears to be a significant element for improving their yielding capacity.

The notable differentiation of the above traits was reflected in the statistical characteristics of the results of examinations of the accessions, presented in Table 4. The observed variability is confirmed by the minimum and maximum values, variance, and especially by the coefficient of variation. The least variability, as expressed by the coefficient of variation for all the accessions jointly, was that relating to the dates of blooming and to the pod length and width; greater variability was found in the number of branches per plant, number of seeds per pod and weight of seeds per plant, and the greatest - for the weight of 100 seeds and for the number of seeds per plant.

Apart from traits typical for estimations of yield structure, the accessions under study differed also from one another in terms of morphological features concerning the growth habit of the plants, colour of flowers, shape of pod and seed, and seed colour (Table 5). Among the accessions under study, plants with spreading growing habit were dominant. Noteworthy are the semi-erect forms, in view of the necessity of improving the lodging resistance, one of the most unfavourable utility features of grasspea.

Among the accessions studied, white flowers dominated, the colour being typical of accessions from France and Poland. Certain accessions from Italy and Spain were characterised by blue or pale blue flowers, and only one accession from Germany, LAT 462/82, had light pink flowers. Pods with broad-elliptical shape were observed only in some accessions from Italy, while both Polish cultivars, Derek and Krab, were characterised by oblong-linear pod shape. A number of other accessions had pods elliptical or linear to a varying degree. Seed shape was wedge-shaped, rhomboid/ triangular, rhomboid, and rhomboid/angled, some of the large seeds from Italy being more or less rhomboid slightly flattened. Seeds had uniform light colour (creamy, white), light coloured with brown lining, or uniformly coloured with more or less visible mottling or pigmentation. As a rule, accessions with white flowers (like *eg* the Polish cultivars) produced uniformly light-coloured seeds, accessions with coloured flowers (white-blue) – light-coloured seeds but with brown edge, and accessions with totally blue or pink flowers – seeds wholly coloured (Table 5). Notable correlation between the colour of flowers and of the seed coat is pointed out by Desphande and Campbell (1992) who demonstrated that white-blooming plants produced light-coloured seeds, while plants with coloured flowers had also coloured seeds. Grasspea accessions with white or creamy seeds were most frequently encountered among the European ones, while accession lines producing coloured seeds are more typical of material from Ethiopia or the Indian subcontinent. Notable differences among the accessions were in seed size. According to Dziamba's classification (1997), the limit values of weight of 1000 seeds for their division into small, medium and large are 50-150; 150-250 and above 250 g, respectively. Large seeds were produced only by accessions originating from Italy and Spain, medium seeds – by accessions from Italy, Spain, Germany and France, and small-seed accessions were typical of the Polish cultivars (Krab, Derek).

Seeds from the field trial were used for estimation of their static loads. In the first stage of the examinations, the geometric features of the seeds were estimated (Table 2). Grasspea seeds for the static tests were characterised by uniform moisture within the range from 7.8 to 9.3%. The values of force causing the destruction of the structure of grasspea seeds depend on the seed moisture level, and with increasing moisture there is a rapid drop of seed resistance to static loading (Szot *et al.,* 1998). In the experiment conducted within this study, the seed moisture content of the grasspea accessions under study was nearly identical, which permitted comparison of the results obtained. The mean values of seed thickness, for accessions from Italy, Spain, Germany, France and Poland, were 5.49, 5.37, 4.75, 4.83 and 4.83 mm, respectively, and the greatest seed thickness values, above 6 mm, were recorded only for the Italian accessions LAT 4056/99, LAT 4055/99 and LAT 4064/01. A study by Szot *et al*. (1998) showed that seeds of cv. Krab were thicker than those of cv. Derek (this was also confirmed in this study), which was reflected in greater weight of 1000 seeds for cv. Krab than for cv. Derek. In turn, mean values of seed width, in the same order by country of origin as above, were 10, 9.88, 8.10, 7.34 and 7.34 mm, respectively, the broadest seeds – above 12 mm – being also characteristic of the Italian accessions - LAT 4078/00 and LAT 4052/99. The longest seeds were found for the Italian and Spanish accessions (mean seed length values of 11.05 and 10.81 mm), with only the Italian accession LAT 4052/99 exceeding the value of 14 mm. That accession deserves special attention, as with its notable seed thickness (5.76 mm) it also developed the broadest and longest seeds among all accessions under analysis. That line was also characterised by the greatest weight of 100 seeds (Table 1). Among other leguminous plants, the thickest seeds were characteristic of field pea (6.61 mm), thicker even than those of grasspea, followed by white lupine (4.45 mm) and lentil (2.43 mm). Notable differences in the values of the geometric features of grasspea mutants are also indicated by the results obtained by Rybiński *et al*. (2004), Szot *et al*. (2005) for lentil, and for wheat by Geodecki and Grundas (2003) oraz Grundas (2004) in their studies.

Quality of agricultural crops or, more generally, agricultural materials is usually associated with their utility value, as suitability for food or non-food purposes is essential in their utility value. For the estimation of quality of a given agricultural material it is necessary to know the range of variation of its physical properties (Grundas, 2004) with relation to various species of agricultural crops (Szot *et al*., 2005). In the study presented herein, the authors estimated the variability of static loading for the grasspea accessions and, for comparison, of selected species of leguminous plants. Damage to seeds may occur already at the pre-harvest stage when, under specified unfavourable

T a b l e 5. Origin and estimation of morphological traits of grasspea accessions

Accession number	Country of origin	Plant growth habit	Flower colour	Pod shape	Seed shape	Seed coat colour	Seed size
LAT 4050/99	Italy	Spreading	White	Broad-elliptical	Rhomboid-obtriangular	Cream to brightgreen	Large
LAT 4051/99	Italy	Spreading	White	Broad-elliptical	Rhomboid-obtriangular	Cream to brightgreen	Large
LAT 4052/99	Italy	Semi-erect	White	Oblong-elliptical	Rhomboid-obtriangular	Cream to brightgreen	Large
LAT 4053/99	Italy	Semi-erect	White	Broad-elliptical	Rhomboid-flattened	Cream to brightgreen	Large
LAT 4054/99	Italy	Spreading	Blue	Oblong-elliptical	Rhomboid	Cream, mottled with brown edge	Medium
LAT 4055/99	Italy	Spreading	White	Broad-elliptical	Rhomboid-flattened	Cream, slightly mottled and flattened	Large
LAT 4056/99	Italy	Spreading	White	Oblong-elliptical	Rhomboid-tria ngular	Cream to brightGreen	Large
LAT4061/99	Italy	Spreading	Bright blue	Oblong-elliptical	Rhomboid	Greyed-white with brown edge	Large
LAT 4063/01	Italy	Spreading	White	Oblong-elliptical	Rhomboid, slightly flattened	Cream-white	Large
LAT 4064/01	Italy	Spreading	Blue	Oblong-elliptical	Rhomboid	Brick-red, dark mottled	Large
LAT 4065/01	Italy	Spreading	Bright blue	Oblong-elliptical	Rhomboid	Greyed-white with brown edge	Medium
LAT 4068/01	Italy	Spreading	Bright blue	Oblong-elliptical	Rhomboid	Brick-red, dark mottled	Medium
LAT 4069/01	Italy	Spreading	White-creme	Medium oblong - elliptical	Rhomboid, slightly flattened	Cream	Large
LAT 4070/01	Italy	Spreading	Dark-blue	Oblong-elliptical	Rhomboid	Brick-red, dark mottled	Large
LAT 4071/01	Italy	Spreading	White	Oblong-elliptical	Rhomboid	Cream	Medium
LAT 4074/01	Italy	Spreading	White	Broad-elliptical	Rhomboid	Greye-white with brown edge	Large
LAT 40/75/00	Italy	Semi-erect	White blue	Oblong-elliptical	Rhomboid	Cream with brown edge	Large
LAT 4078/00	Italy	Spreading	White blue	Broad-elliptical	Rhomboid-flattened	Cream to brightgreen with brown edge	Large

T a b l e 5. Continuation

Accession number	Country of origin	Plant growth habit	Flower colour	Pod shape	Seed shape	Seed coat colour	Seed size
LAT 4081/00	Italy	Spreading	White	Oblong-elliptical	Rhomboid	Cream	Medium
LAT 4082/00	Italy	Semi-erect	White- blue	Oblong-elliptical	Rhomboid	Cream with brown edge	Medium
LAT 456/75	Spain	Spreading	White- blue	Oblong-elliptical	Rhomboid	Cream with dark edge	Large
B 1706/92	Spain	Semi-erect	White- cream	Oblong-elliptical	Rhomboid, slightly flattened	Cream with short black edge	Large
LAT 4006/84	Spain	Spreading	Bright- blue to white	Oblong-elliptical	Rhomboid	Cream with brown edge	Large
LAT 4007/84	Spain	Spreading	White	Oblong-elliptical	Rhomboid	Cream	Large
LAT 4085/00	Spain	Spreading	White	Oblong-elliptical	Rhomboid	Cream	Medium
LAT 444/73	Germany	Spreading	White- blue	Mediumoblong - elliptical	Rhomboid	Cream, brown edge, slightly mottled	Medium
LAT 462/82	Germany	Semi-erect	Light pink	Medium oblong-elliptical	Rhomboid	Grey, dark brown edge, slightly mottled	Medium
B 1702/80	France	Spreading	White- creme	Medium oblong-elliptical	Rhomboid	Cream, slightly brick-red	Medium
B 1705/87	France	Semi-erect	White	Medium oblong-elliptical	Rhomboid	Cream	Medium
DEREK	Poland	Semi-erect	White	Oblong -linear	Rhomboid to slightly spherical	Beige-cream	Small
KRAB	Poland	Semi-erect	White	Oblong -linear	Rhomboid, wedge	Cream	Small

conditions, internal seed damage is observed in the process of seed filling, mainly due to a high moisture gradient in the seeds (Geodecki and Grundas, 2003; Grundas *et al.,* 1990). Mechanical damage to seeds is encountered at every stage of further treatment, beginning with harvest (cracking, breaking off of fragments of seeds), transport and storage, until the moment of seed processing (grinding or fragmentation). The mechanical damage to seeds is affected by various factors *eg* their seed coat, and according to Kolasińska and Boros (2003) naked cultivars of barley introduce undesirable problems related with the sowing value of grain, and facilitated damage to germs during threshing may significantly reduce its germination capacity, leading even to the need to reject qualified sowing material. The authors mentioned above suggest that the structure of the kernel, its lack of glumes, causes that naked kernels are more exposed to crushing and compression. Notable differences in the mechanical properties of kernels of naked barley cultivars under various static loads were observed by Woźniak *et al*. (2006).

Estimation of the resistance of seeds to static loading is presented in Tables 6 and 7. The range of variability of the maximum force causing the destruction of seed structure was from 154.8 N for the Italian accession LAT 4064/01 to 354.3 N for another Italian accession – LAT 4070/01. Mean values of that trait for the Italian and Spanish accessions were similar (262.5 and 265.6 N), that for the German accessions was higher (297.3 N), and the lowest – that for the Polish cultivars (237.8 N). Compared to grasspea, the highest value of force causing the destruction of seeds was

Table 6. Estimation of resistance to mechanical loads of grasspea, pea, lupine and lentil seeds expressed by values of maximal force, force of elasticity and maximal deformation

No.	Accessions	Force max.	SD	Force of elasticity	SD	Deformation max.	SD
		(N)				(mm)	
1	LAT 4050/99	307.50	150.71	279.81	159.93	0.53	0.46
2	LAT 4051/99	295.86	162.52	244.88	165.30	0.46	0.35
3	LAT 4052/99	313.73	170.62	295.73	184.01	0.46	0.39
4	LAT 4053/99	296.87	153.07	261.40	165.39	0.35	0.22
5	LAT 4054/99	214.20	122.37	162.97	95.31	0.36	0.24
6	LAT 4055/99	244.67	135.51	223.03	144.43	0.45	0.32
7	LAT 4056/99	209.96	141.72	141.02	114.66	0.40	0.34
8	LAT 4061/99	231.90	114.33	189.56	124.65	0.40	0.22
9	LAT 4063/01	307.81	149.93	256.56	155.97	0.38	0.18
10	LAT 4064/01	154.86	100.14	110.13	85.17	0.31	0.12
11	LAT 4065/01	290.79	112.63	248.40	131.45	0.34	0.12
12	LAT 4068/01	202.73	110.76	166.62	98.82	0.47	0.42
13	LAT 4069/01	267.82	121.97	222.48	126.90	0.73	0.47
14	LAT 4070/01	354.28	143.27	309.18	157.36	0.51	0.38
15	LAT 4071/01	202.22	93.52	147.31	86.21	0.41	0.25
16	LAT 4074/01	333.95	186.23	284.44	198.54	0.42	0.28
17	LAT 4075/00	252.77	122.71	206.30	117.32	0.40	0.30
18	LAT 4078/00	244.36	135.70	190.90	141.25	0.35	0.23
19	LAT 4079/00	297.00	134.23	254.80	151.75	0.39	0.22
20	LAT 4081/00	238.63	130.11	182.94	129.39	0.30	0.19
21	LAT 4082/00	251.04	119.33	160.32	112.75	0.31	0.07
22	LAT456/75	240.55	130.61	175.71	114.61	0.35	0.23
23	B 1706/92	254.34	121.05	216.60	125.23	0.33	0.12
24	LAT 4006/84	323.37	152.91	286.09	166.57	0.37	0.26
25	LAT 4007/84	225.40	105.32	169.49	91.73	0.44	0.34
26	LAT 4085/00	284.62	179.37	228.84	175.10	0.44	0.36
27	LAT 444/73	292.08	82.57	226.99	114.70	0.43	0.34
28	LAT 462/82	302.06	122.38	230.26	132.67	0.42	0.24
29	B 1702/80	271.77	114.94	222.15	115.08	0.54	0.40
30	B 1705/87	283.67	88.57	237.90	107.42	0.38	0.15
31	cv. Derek	265.87	105.72	217.35	105.72	0.54	0.42
32	cv. Krab	209.72	90.73	170.80	90.73	0.44	0.34
33	White lupin	1765.76	298.99	566.63	318.48	1.30	0.32
34	Field pea	406.29	112.90	256.27	119.06	0.50	0.31
35	Lentil	179.21	30.64	143.90	45.11	0.44	0.24

T a b l e 7. Estimation of resistance to mechanical loads of grasspea, pea, lupine and lentil seeds expressed by values of elastic deformation, energy and apparent modulus of elasticity

No.	Accessions	Elastic deformation (mm)	SD (mm)	Energy (mJ)	SD (mJ)	Apparent modulus of elasticity (MPa)	SD (MPa)
1	LAT 4050/99	0.20	0.29	34.06	22.83	918.81	350.70
2	LAT 4051/99	0.12	0.05	30.64	20.72	1036.82	381.57
3	LAT 4052/99	0.15	0.05	34.74	21.54	869.73	320.38
4	LAT 4053/99	0.14	0.06	33.87	21.56	949.48	361.55
5	LAT 4054/99	0.11	0.03	23.21	16.46	806.50	429.28
6	LAT 4055/99	0.14	0.06	28.25	21.35	749.73	241.58
7	LAT 4056/99	0.13	0.12	25.64	20.59	675.03	305.34
8	LAT 4061/99	0.13	0.05	28.46	18.80	735.14	225.77
9	LAT 4063/01	0.14	0.06	36.60	24.97	894.79	251.56
10	LAT 4064/01	0.11	0.09	17.99	15.87	631.20	276.31
11	LAT 4065/01	0.15	0.06	33.21	17.52	873.15	244.17
12	LAT 4068/01	0.13	0.10	21.66	16.13	779.36	375.06
13	LAT 4069/01	0.14	0.05	33.12	18.37	788.11	244.49
14	LAT 4070/01	0.16	0.06	43.13	20.77	894.58	237.08
15	LAT 4071/01	0.11	0.05	20.69	10.63	951.17	576.36
16	LAT 4074/01	0.14	0.05	37.28	23.22	1001.31	446.52
17	LAT 4075/00	0.14	0.04	27.78	15.62	792.13	307.02
18	LAT 4078/00	0.12	0.04	27.49	17.07	841.89	310.64
19	LAT 4079/00	0.13	0.05	32.01	17.18	978.26	315.62
20	LAT 4081/00	0.10	0.05	23.97	18.33	1052.24	425.43
21	LAT 4082/00	0.10	0.04	28.59	16.71	920.02	369.29
22	LAT456/75	0.11	0.04	24.04	16.07	962.62	350.82
23	B 1706/92	0.14	0.05	27.08	17.07	857.52	266.28
24	LAT 4006/84	0.15	0.05	34.95	18.65	956.05	357.14
25	LAT 4007/84	0.12	0.04	22.61	13.12	876.86	350.39
26	LAT 4085/00	0.12	0.05	34.92	30.30	979.43	327.71
27	LAT 444/73	0.13	0.05	30.17	10.54	1026.56	319.29
28	LAT 462/82	0.13	0.05	33.19	16.93	1005.21	321.81
29	B 1702/80	0.13	0.04	28.74	13.41	967.10	455.85
30	B 1705/87	0.14	0.04	32.76	14.20	909.31	261.00
31	cv. Derek	0.14	0.04	29.49	12.45	853.38	313.17
32	cv. Krab	0.11	0.03	20.69	11.92	857.72	319.66
33	White lupin	0.26	0.14	1147.95	412.30	969.25	292.34
34	Field pea	0.16	0.07	48.04	27.89	873.12	260.15
35	Lentil	0.10	0.03	15.03	3.41	868.53	258.56

characteristic of white lupine (1765.7 N) and pea (406.3 N), lentil having a notably lower value of that parameter (179.2 N). Analysis of grasspea mutants (Rybiński *et al*., 2004) showed that the range of variation of that trait was from 238.1 N to 328.4 N for mutants originating from cv. Krab, and from 234.3 N to 286.1 N for mutants of cv. Derek, with the value of the force, as in the study presented here, being lower for seeds of cv. Krab than for cv. Derek.

The range of force within the limit of elasticity, not causing destruction of seed structure, was from 110.1 to 309.2 N and related to the same Italian accessions as those enumerated above in the case of estimation of the maximum force. The mean values of elastic deformation force for the large-seed accessions from Italy and Spain were also similar (216.6 and 215.4 N), higher elastic force values were recorded for accessions from Germany and France (228.6 and 230.1 N), and the lowest – for the Polish cultivars (194.1 N). The highest elastic force value from among all the objects studied was characteristic of white lupine (566.6 N), and a low value was recorded for lentil (143.9 N). The highest value of maximum deformation was obtained for the Italian accession line LAT 4069 (0.73 mm), and the lowest – for another Italian line, LAT 4081/00 (0.30 mm). Mean values for the medium- and small-seeded accession lines from Germany, France, and Poland (0.42, 0.46 and 0.49 mm) were higher than those for the lines from Italy and Spain (0.41 and 0.38). In a study on grasspea mutants (Rybiński *et al*., 2004) the range of maximum deformation for mutants of cv. Krab was from 0.46 to 0.75 mm, and for mutants of cv. Derek – from 0.44 to 0.47 mm. The highest value of maximum deformation, among all the objects studied, was recorded for seeds of white lupine (1.3 mm).

An important parameter in the study of static loading of seeds is the value of energy corresponding to maximum force that has to be applied to destroy the seed structure. The range of variation of that parameter was from 17.99 mJ for the Italian line LAT 4064/01 to 43.1 mJ for another Italian line – LAT 4070/01. Mean values for the accession lines from Italy and Spain were closely similar (29.6 and 28.7 mJ), those for the lines from Germany and France were higher (31.7 and 30.7 mJ), and the lowest – those for the Polish cultivars (25.1 mJ). The highest value of energy among all the objects studied was that for white lupine (1147.9 mJ), while for field pea and grasspea it was at the level of 48.0 mJ, and the lowest value was recorded for lentil (15.03 mJ). In a study by Rybiński *et al.* (2004), among grasspea mutants a broader range of variability was obtained - from 44.1 up to 110.9 mJ (Rybiński *et al*., 2004).

Values of the apparent modulus of elasticity, related to pressure acting on a specified surface area of seeds (seeming modulus in the case of round seeds), provide information on the properties of plant material. The lowest value of the modulus was observed for the Italian accession line LAT 4064/01 (631.2 MPa, and the highest for the Italian line LAT 4081 (1052.2 MPa), with the highest mean value of the parameter characterising both French accession lines (1015.9 MPa), and the lowest – both Polish cultivars (855.5 MPa). The highest value of apparent modulus of elasticity among the other leguminous species was found for white lupine (969.2 MPa), and the lowest, nearly identical for both – field pea and lentil (837.1 and 868.5 MPa). The values of the apparent modulus for those species fall within the range of variation of that parameter in the lines of grasspea (Table 7).

Differences in resistance to mechanical damage are observed not only between different leguminous species, as discussed above, but also in cereals such as barley, rye, triticale and wheat (Stępniewski and Szot, 1994), also within a single species *eg* mutants of spring barley (Rybiński and Szot, 2006), where the determinant of differences is the structure of the endosperm. For kernels of hard wheat (*Triticum durum*), the maximum force causing damage was significantly higher than for other types of wheat (Szot *et. al.,* 1994). It can be assumed, therefore, that the differences observed among the accession lines of grasspea in their sensitivity to mechanical loading have the character of genetic changes related with the internal structure of the seeds, and that – in turn – is related with their geographic origin concerning various regions of Europe.

CONCLUSIONS

1. Compared to the Polish cultivars of grasspea and the accession lines from France and Germany, the Italian and some of the Spanish lines were characterised by earlier flowering, though compared to literature data the range of variation of that trait was not too broad, which could have been due to accelerated and more uniform times of blooming caused by intensifying drought during the vegetation period.

2. As opposed to the Italian and Spanish accession lines, the Polish cultivars Derek and Krab were characterised by a greater number of branches and of pods per plant, had a different pod shape and a greater number of seeds per pod and per plant, but in some cases also a lower weight of seeds per pod and per plant.

3. The feature that differentiated the accession lines under study the most was seed size. Large-seed forms were typical of the Mediterranean region (Italy and Spain), medium-seed for the lines from northern France and Germany, and the smallest seed was characteristic of the Polish cultivars. The weight of 100 seeds of some of the large-seeded Italian lines exceeded 40 g, and the value of that trait in the Polish cultivars did not exceed 15 g.

4. The trait of the weight of 100 was related to the geometric parameters expressed by the thickness, width and length of the seeds. The broadest range of variation of that trait was observed for the accession lines from Italy, followed by those from Spain, and a more narrow and closer to linear for the accessions from the other countries. The thickest, widest and longest seeds were characteristic of

most of the Italian and Spanish accession lines, and that was true especially of the Italian line LAT 4052/99. With respect to those geometric parameters, the seeds of the Polish cultivars were notably inferior to the accession lines from Italy or Spain and attained values similar to those of the accession lines from France or Germany.

5. The Polish cultivars and those from France were characterised by totally white flowers and uniformly light-coloured seeds. White and blue flowers, with varied presence of the two colours, were observed in the accession lines from the other countries, with a characteristic pink colouring of flowers of one of the lines from Germany. While plants with white flowers had seeds with uniformly light-coloured (white) seed coat, in the case of coloured flowers white or creamy seeds had a brown edge and were spotted or mottled to a varying degree.

6. The broadest range of variation among the accession lines under analysis was that of seed resistance to static loads. Among all of the grasspea accession lines, the highest values of maximum force, elastic force, maximum deformation and energy, and apparent modulus of elasticity were recorded for certain Italian accession lines, and – as a rule – lower values for the Polish cultivars. The broad range of variation in the resistance of the Italian grasspea accession lines to static loads is evidenced by two lines - LAT 4064/01 with the lowest load values among all of the objects studied, and LAT 4070/01 with the highest values.

7. Compared to the grasspea accession lines, with the exception of the apparent modulus of elasticity the highest values of maximum force, elastic force, maximum deformation and energy were obtained for white lupine seeds. Apart from the greater maximum force and energy observed for field pea, the other parameters had values at levels characteristic of grasspea seeds. In comparison with lupine, field pea, and also a large majority of grassspea accession lines, the values of static loads for lentil were very low with relation to the maximum force, elastic force and energy, and on the same level as grasspea as far as maximum deformation and apparent modulus of elasticity are concerned.

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