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RESEARCH ARTICLE

Estimation of mechanical properties of seeds of common vetch accessions (*Vicia sativa* L.) and their chemical composition

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Abstract The attempt was made to estimate the mechanical loads on seeds, taking into account their geometric properties and chemical composition. Material chosen for the study comprised 46 samples of common vetch representing collection accessions originated from Europe. Additionally, accessions of other legume species were involved. The study included determinations of seed thickness and weight of 1,000 seeds (TSW) followed by static loading tests. Moisture content of the seeds did not exceed 10 %, and TSW of vetch determined at that moisture was from 19.7 g for small seeded Polish lines VSAT 42 to 73 g for VSAT 24 obtained from Slovakia. Seed thickness value ranged for common vetch accessions from 2.5 to 4.4 mm and for the rest of species from 2.6 mm for lentil to 7.2 mm for chickpea. Apart from the obvious accessions-related differences among various seeds in terms of TSW and seed thickness, the study revealed a wide range of differentiation in the resistance of seeds to static loading expressed by: maximum load, deflation at max. load stress at max. load and work to max. load. Obtained result allowed to select vetch accessions with a high resistance of seed to static loading. Fat content is low at the level of pea, grass pea and lentil as compared with high values of Andean lupin species and white lupin. Fatty acids composition of vetch is different in comparison with remaining species characterized by lowest content of monounsaturated oleic acid (29 %) and relatively high content of polyunsaturated linoleic and linolenic acids (respectively 44 and 11.7 %).

Keywords Common vetch · Chemical composition of seeds · Geometry of seeds · Mechanical loads · Multivariate statistical analysis · *Vicia sativa*

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Introduction

According to the European Union, ensuring high-protein and high-quality protein in human and animal feeding is of great importance. At present the EU countries import 70 % of plant protein, mainly in the form of soybean extraction meal and seed. In Poland, meeting the fodder needs requires ca. 1 mln t of protein per annum, with 80 % of the fodder requirement being covered by import of soybean meal. Meanwhile, a greater part of that requirements could be covered from own cultivation of grain legumes to the moderate climate (Pahl 2002; Święcicki et al. 2007). Unfortunately, the area of cultivation of such crop in Poland (only 1 % in the crop structure), is not in any way commensurable with the undoubted advantages of grain legume. Among others, to improve this unfavourable situation it is necessary to include in greater scale grain legumes production underutilized or neglected species like common vetch (*Vicia sativa* L.), the main research object of presented paper. The growing area of vetch in Poland constitutes only 1 % of all area (0.12 million ha) under grain legume production; in EU countries—4 % of 2.2 million ha (FAOSTAT 2007). Progress in common vetch breeding in terms of grain yield and yield-quality improvement, included among others: increase of protein content (with enhanced amino acids composition), reduction of the content of anti-nutritive components and limitation of susceptibility of plants to lodging and abiotic stresses (drought, diseases and pest), should be related with ultimate goal of the breeder to make vetch more competitive as compared to other main species of grain legumes.

Among the above mentioned traits affecting the level of attractiveness of vetch and other grain legume species, the mechanical properties of seeds are underestimated and still little known about them. Knowledge of the physical parameters of seeds has a particular importance for the optimization technologies of harvest, drying and storage, which relates to minimization of quantitative losses and mechanical damage caused among others decrease of seeds germination ability (Szot and Tarkowski 1997). Variability of physical properties of seeds depends on vast range of external factors, as well as on species—cultivar-relates traits.

Accessions collected in the Gene Bank, in a world scale and representing genotypes of different geographical origin, constitute a very important source of variability of many traits, including mechanical properties of seeds and their chemical composition. This creates a possibility of appropriate selection of components for cross-breeding and direct breeding. In this paper we are trying to determine the resistance of seeds to mechanical loads and their chemical composition using vetch accessions obtained from gene banks originating from the East and Middle-East European countries as well as to compare goals with selected cultivars and lines of vetch, other grain legume species of Polish origin.

Materials and methods

For the performed studies material included seeds of 59 cultivars and lines representing selected species of grain legumes. The main objects were 44 accessions of common vetch (*Vicia sativa* L.) obtained from Gene Banks in Germany (Gatersleben), Slovak Republic (Piescany) and Poland (Lublin) and representing countries of East and Middle-East Europe. Among above mentioned accessions four originated from Germany (VSAT 1–VSAT 4), four from Russia and Ukraine (VSAT 5–VSAT 8 and VSAT 9–VSAT 12). Three accessions came from the Czech Republic (VSAT 13–

Table 1 Mean squares from one-way analysis of variance (ANOVA) and coefficient of variability for investigated traits of studied accessions

Source of variation	Accessions	Residual	Coefficient of variability (%)
Maximum load			
Degree of freedom	58	118	55.92
Mean square	70294***	4975	
Deflection at max. load			
Degree of freedom	58	118	47.79
Mean square	0.26391***	0.0183	
Stress at max. load			
Degree of freedom	58	118	48.76
Mean square	400.45***	43.01	
Work to max. load			
Degree of freedom	58	118	121.3
Mean square	0.040209***	0.001883	
Weight of 1,000 seeds			
Degree of freedom	58	118	95.91
Mean square	23172.11***	41.06	
Seed thickness			
Degree of freedom	57	1681	27.32
Mean square	29.9653***	0.1154	

*** Significance at $\alpha = 0.001$ level

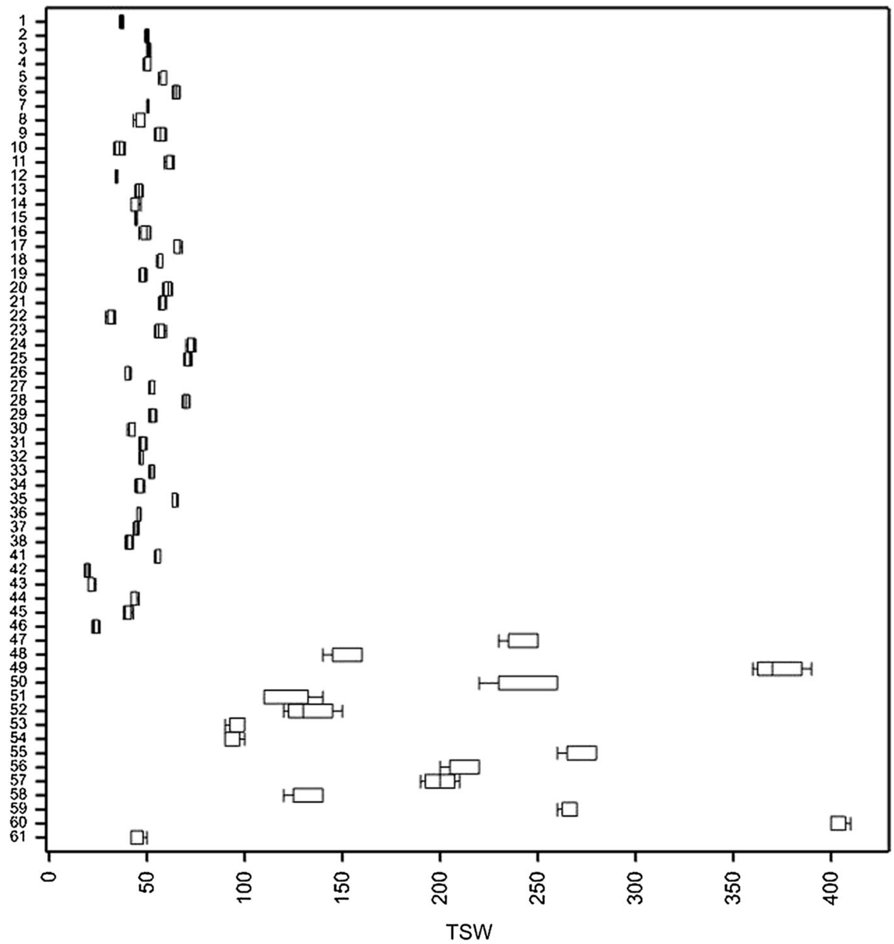


Fig. 1 Box-and-whisker diagram of values of thousand seed weight (g) for analyzed of common vetch accessions (*Vicia sativa* L.). Nos. 1–46—accessions of *Vicia sativa*, 47–48—*Lupinus angustifoloius*; 49–50—*Lupinus albus*, 51–52—*Lupinus luteus*, 53–54—*Lupinus mutabilis*, 55–56—*Pisum sativum*, 57–58—*Lathyrus sativus*, 59–60—*Cicer arietinum*, 61—*Lens culinaris* (particular accessions are also listed in chapter "Materials and methods" section)

VSAT 15), four Hungary (VSAT 16–VSAT 19) and 19 the Slovak Republic (VSAT 21–VSAT 38). Remaining six accessions stemmed from Poland (University of Life Sciences in Lublin)–VSAT 41–VSAT 46. To compare obtained results with common vetch, additional seeds of other grain legume species were examined. Seeds of lupins represented four species, among which there were two cultivars of narrow-leafed lupin (*Lupinus angustifolius* L.)—Neptun and Zeus (Nos. 47 and 48), two cultivars of white lupin (*Lupinus albus* L.)—Boros and Butan (Nos. 49 and 50) and two yellow lupin (*Lupinus luteus* L.)—cv. Parys and Lord (Nos. 51–52). Andean lupin (*Lupinus mutabilis* Sweet) was represented by two Polish lines of mutation origin: traditional type (No. 53) and determinate type (No. 54). Seeds of the above mentioned cultivars and lines were obtained from lupin breeding companies located in Przebędowo and Wiatrowo (Wielkopolska Province). Representative of field pea (*Pisum sativum* L.) included seeds of two cultivars: Milwa and Muza (Nos. 55 and 56), grass pea (*Lathyrus sativus* L.) cultivars: Krab and Derek (Nos. 57 and 58), chickpea (*Cicer arietinum* L.)—accessions CAR 15 and CAR 17 (Nos. 59 and 60) and one lines of lentil (*Lens culinaris* L.) originated from Turkey (No. 61).

The collected seeds were analyzed in terms of their physical properties including seed thickness. This parameter was measured using an adapted dial gauge and an electronic slide caliper with the accuracy of 0.01 mm. To obtain detailed distribution of this property in air-dry seed samples, 30 replications were made on the same seeds selected at random. For 1,000 seeds weight estimation—three

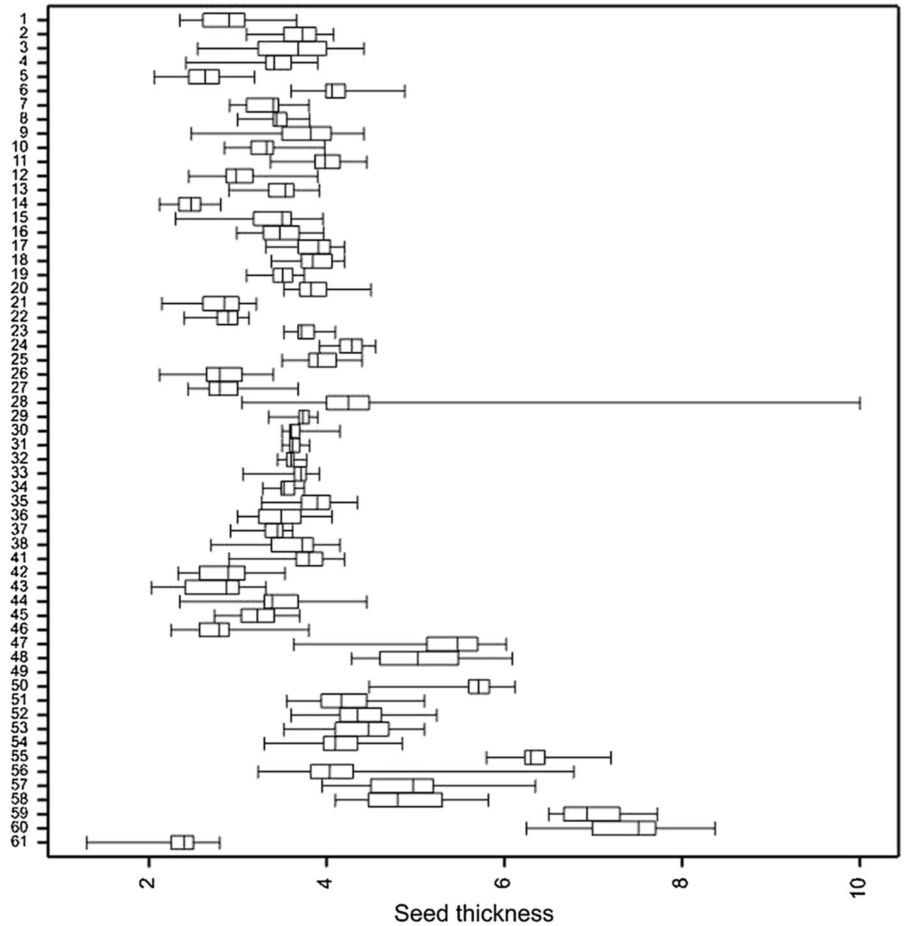


Fig. 2 Box-and-whisker diagram of values of seed thickness (mm) for analyzed of common vetch accessions (*Vicia sativa* L.). See explanation in Fig. 1

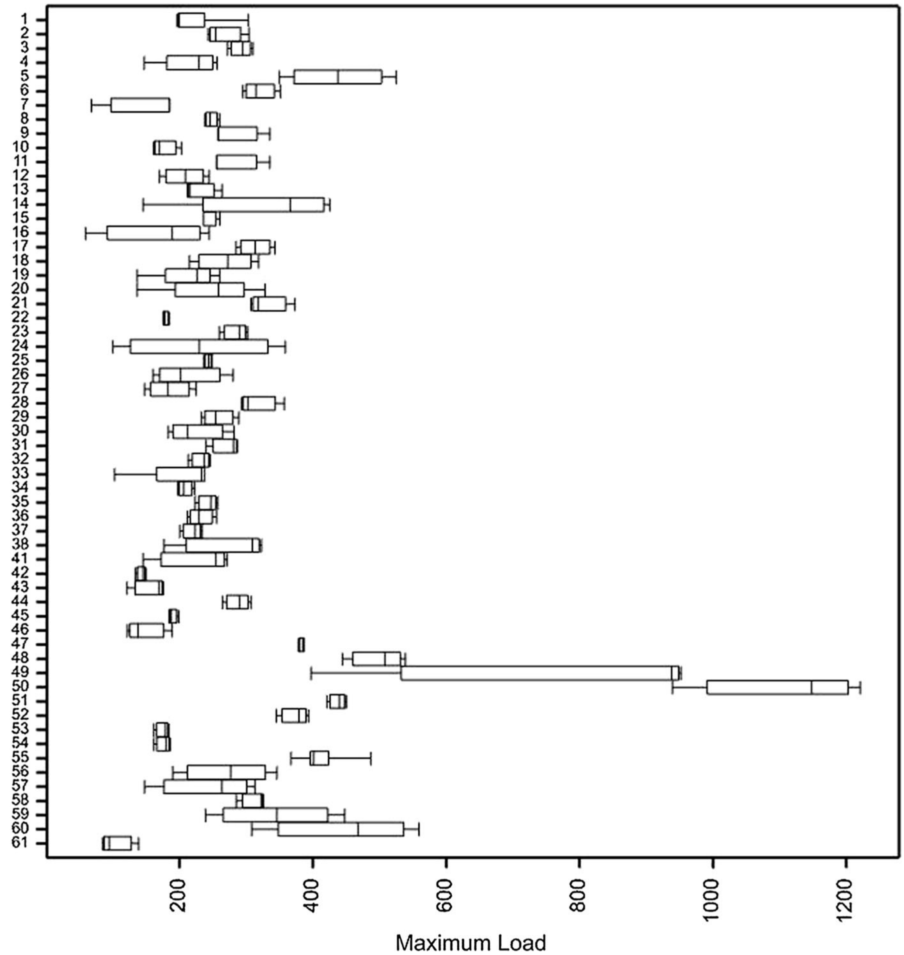
replications × 1,000 seeds (TSW) electronic seed counter was used.

The resistance of individual seeds to static loading was determined using strength installation—Lloyd LRX and Nexygen program for registration of measurements and calculation of mechanical parameters. Basic test for the measurement of seed to compression—was performed in line with the following parameters: reading head 2.5 kN, speed of head motion—5 mm/min and deepness of compressions—1.5 mm. Registration of measurements started when the strength exceeded 0.5 N. The results of the determination were expressed in values of: maximum load (N)—compressive force caused failure of seed; deflation at max. load (mm)—maximum of seed deformation in the moment of failure; stress at max. load (MPa)—intensity of stress in the moment of seed failure and work to max load (J)—needed energy for seed crushing.

Harvested seeds of each object were used to estimate protein and fat content as well as fatty acids composition. Protein content was examined with the use of Kjeldahl method (N × 6.25) and percentage fat content by weight method with fat extraction in Soxlet appliance. To estimate fatty acids composition the chromatography (Hewlett Packard, Gas Chromatograph 5890) and capilar column (30 m, RTX-225) were used. Chromatography allowed to estimate the following fatty acids: palmitic ($C_{16:0}$), stearic ($C_{18:0}$), oleic ($C_{18:1}$), linoleic ($C_{18:2}$), linolenic ($C_{18:3}$), eicosenoic ($C_{20:1}$) and erucic ($C_{22:1}$).

Obtained results were analyzed statistically. The normality of the distribution of the traits was tested with the Shapiro–Wilk's normality test (Shapiro and Wilk 1965). The one-way fixed model analysis of variance (ANOVA) was carried out to determine the effect of analyzed accessions on the variability of maximum load, deflation at max. load, stress at max.

Fig. 3 Box-and-whisker diagram of values of maximum load (N) for analyzed of common vetch accessions (*Vicia sativa* L.). See explanation in Fig. 1



load, work to max. load, seed thickness and weight of thousand seeds. Estimations were also made by mean values, maximum and minimum values, and coefficient of variation (Kozak et al. 2013) for the traits studied. Positions characteristics of every accessions for static load parameters, seed thickness and thousand seeds weight were presented in form of boxplots. The relationships between all traits were estimated on the basis of correlation coefficients (Kozak et al. 2010). A possibility of graphic distribution of accessions described by seed thickness, thousand seed weight and mechanical loads traits together was obtained with the use of the analysis of canonical varieties (Morrison 1976). A possibility of graphic distribution of accessions described by static loads parameters, seed thickness, thousand seed weight and chemical compositions of seed combined was obtained with the use of the principal components analysis. Principal component analysis (PCA) is a mathematical procedure that uses orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components.

Results and discussion

The results of analysis of variance have shown that parameters of mechanical loading of seeds, their thickness and thousand seed weight (TSW) the accessions under estimation combined different significantly with relation to each features at the level of 0.001 (Table 1). This was supported by the characteristics of variables expressed by mean values. Part of them calculated TSW, seed thickness and four parameters of mechanical loading and expressed graphical in form of boxplot for each accession presents Figs. 1, 2, 3, 4, 5, 6. Prior to the estimation

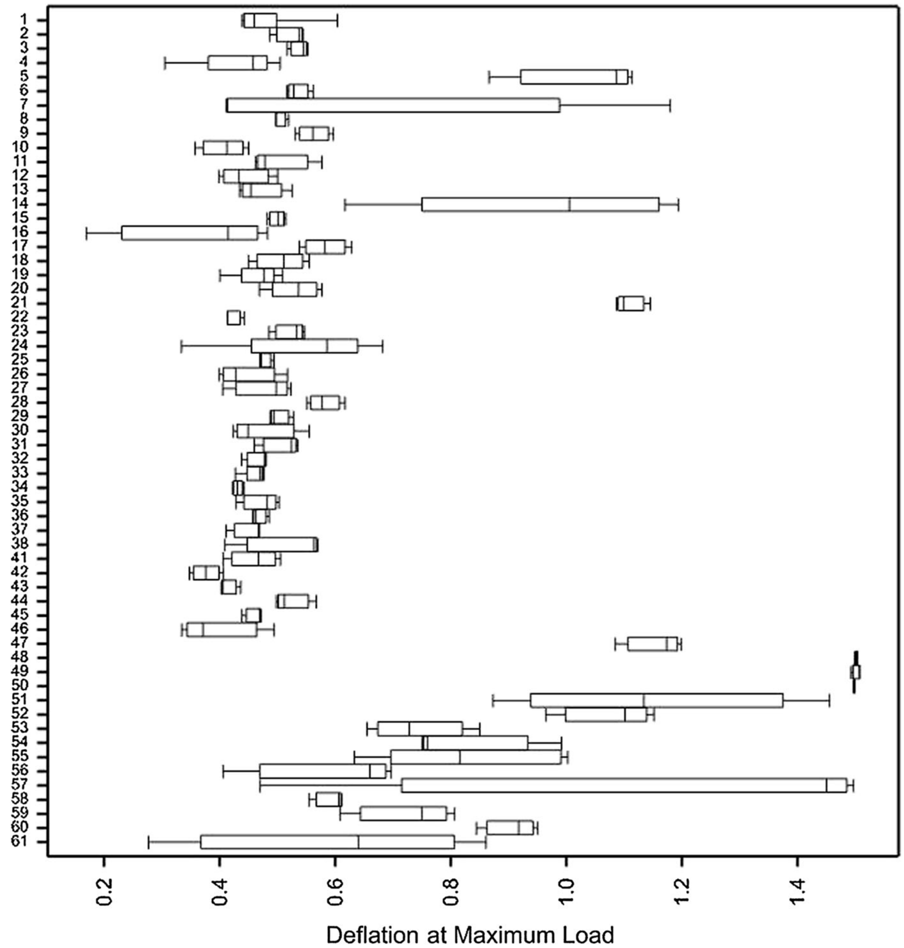


Fig. 4 Box-and-whisker diagram of values of deflation at maximum load (mm) for analyzed of common vetch accessions (*Vicia sativa* L.). See explanation in Fig. 1

of the resistance of seed static loads, determination was made of the TSW as well as their geometric properties expressed by seed thickness. One of the most important traits which characterized genetic variation of seeds in terms their inter-species diversity is TSW (Fig. 1). Although that average TSW value of vetch amounted 49 g, estimated accessions represent broad range of variability on a large from 19.7 g for accession no. 42 of Polish origin to 73 g for Slovak vetch no. 24. Polish vetches with the lowest TSW below 24 g (Nos. 42, 43 and 46) are similar to small-seeded accessions of Asian origin (Sharma and Kalia 2003) with TSW not exceeding 27 g. According to Styk and Przybysz (1967) TSW of Polish vetch cultivars amounted 42.3 g and is near to TSW of Polish large-seeded cultivar Kamiko (No. 41) amounted 56 g by relatively high seed thickness on the level of 3.7 mm. Next, investigation of Silezin and Szwed-Urbaś (2004) on Polish vetches Kamiko and Alba (Nos. 41 and 43 in our paper) brought similar TSW results to ours—52 and 15 g, respectively and according to Rybiński et al. (2009)—73.6 and 20.2 g, respectively.

TSW values are related to the second analyzed trait—seed thickness (Fig. 2). The legume species group with average value of this trait below 4 mm comprises: accessions of lentil and vetch (2.3 and 3.4 mm, respectively), in a range from 4 to 6 mm accessions of Andean and yellow lupin (4.2 and 4.4 mm), grass pea (4.9 mm), field pea (5.2 mm), white lupin 5.6 mm and above 6 mm—only seeds of chickpea (7.2 mm). In terms of vetch accessions, average value was 3.4 mm and the variability of this trait ranged from 2.47 mm for the Czech accession (No. 14) to 4.4 mm for large-seeded form from Slovakia (No. 28). Approaching average value of

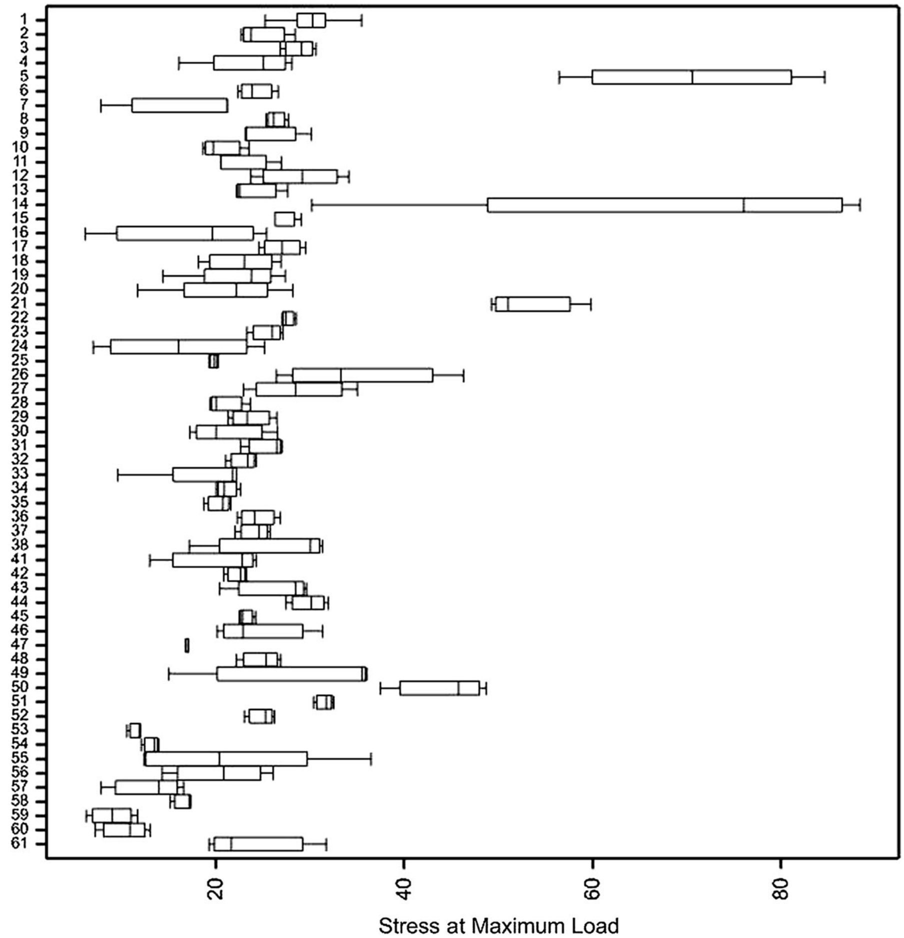


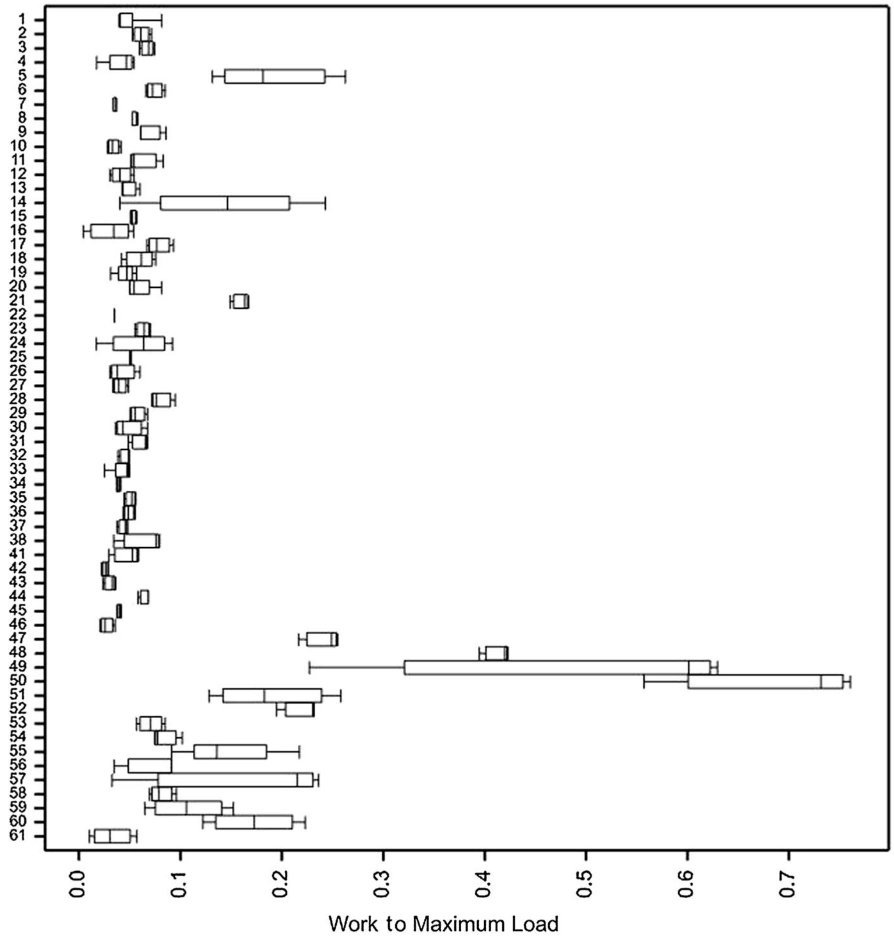
Fig. 5 Box-and-whisker diagram of values of stress at maximum load (MPa) for analyzed of common vetch accessions (*Vicia sativa* L.). See explanation in Fig. 1

collected vetches accessions on the level of 3.2 mm obtained Sharma and Kalia (2003). Notable differences in the value of seed thickness obtained by Rybiński et al. (2004) for grass pea mutants and Szot et al. (2005) for lentil. No clear-cut link was observed between seed thickness and geographical origin of analyzed accessions.

Estimation of the quality of a given agricultural material requires knowledge of the range of variability of its physical, particularly mechanical properties expressed among others by compressive strength of seeds (Grundas 2004), with reference to various species of the crop plants (Szot et al. 2005). For example seed damage my occur even prior to harvest, when under certain unfavourable environmental conditions internal damages are observed in the course of seed filling process, especially due to a high gradient of moisture in the seed (Grundas et al. 1990; Godecki and Grundas 2003). Mechanical damage my occur at any stage of further treatment of seeds, beginning with harvest (cracking, breaking of seed fragments), through transport and storage, up to final processing (grinding of fragmentation).

The average values of individual seeds in resistance to static loading in form of box plots presents Figs. 3, 4, 5, 6. In terms of seeds resistance to mechanical loads expressed by maximum loads (Fig. 3) the mean value for all accessions combined was 282 N with the coefficient of variation on the level 51.03 %. Average values of maximum load indicate on broad variability not only among legumes but also among accessions in limits of each species. In terms of vetch average values of this parameter was 240 N, higher than in lentil (106 N) and Andean lupin seeds (175 N) but lower in comparison to: grass pea (276 N), narrow-leafed and yellow lupin (440 and 404 N), field pea and chickpea

Fig. 6 Box-and-whisker diagram of values of work to maximum load (J) for analyzed of common vetch accessions (*Vicia sativa* L.). See explanation in Fig. 1



(440 and 404 N) and white lupin at the level of 932 N. Among vetch accessions the lowest values of maximum load were observed for small-seeded Polish genotypes nos. 42 and 46 (142.9 and 149.5 N, respectively) and the highest for the accession no. 5 (437.5 N) originated from Russia. The same vetch accession as well as no. 21 from Slovakia showed the highest seed deformation in the moment of failure (above 1.01 mm) expressed by second used parameter—deflation on maximum load (Fig. 4). In terms of vetch the lowest values were noticed for Polish small-seeded accession no. 42 and Slovak accession no. 16—0.376 and 0.355 mm, respectively. Among remaining species the highest values were obtained for seeds of white lupin cultivars Boros and Butan (nos. 49 and 50) and narrow-leafed lupin cultivar Zeus (no. 48) on the similar level—1.5 mm. The values of third parameter of mechanical loading static loading expressed by stress at maximum load (Fig. 5) inform about intensity of stress in the moment of seed failure. Mean value of this parameter for accessions combined was 24.2 MPa. The broad range of obtained values from 8.9 MPa for chickpea (no. 59) originated from Turkey to 70.5 MPa for vetch accession no. 5 of Russian origin. Among remaining vetch accessions the lowest value (below 20 MPa) characterized four accessions nos. 7 and 16 originated, respectively, from Russia and Hungary and genotypes nos. 24 and 33 from the Slovak Republic.

The last estimated mechanical loading parameter (work to maximum load) informs about energy needed for seed crushing (Fig. 6). Mean value of this parameter for all objects was 0.097 J and ranged from 0.025 J for small-seeded Polish vetch no. 42 to 0.682 J for white lupin cultivar Butan (no. 50) originated also from Poland. By high values are also characterized both narrow-leafed lupin cultivar Neptun and Zeus (nos. 47 and 48). In terms of vetch accessions three of

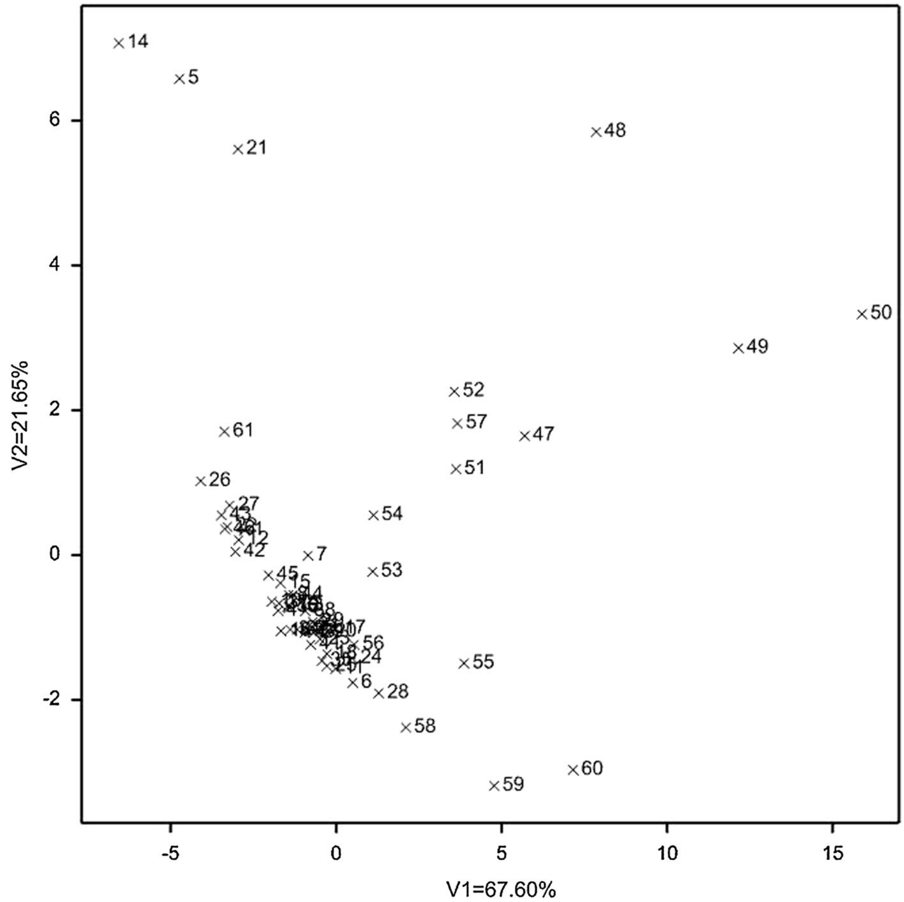


Fig. 7 Distribution of common vetch accessions (*Vicia sativa* L.) in the space of two first canonical variables for four static loads parameters combined. See explanation in Fig. 1

them, namely objects no. 5 from Russia, 21 from Slovakia and no. 14 from the Czech Republic, varied noticeably from the rest (Fig. 6).

As mentioned above vetch accessions present a great variation in terms of mechanical loads parameters but particularly interesting is Russian accession no. 5. The seeds of this form are characterized by the highest values of each used parameter. It indicates a unique reaction of this genotype to mechanical loading and specific level of resistance to squashing. This trait may be controlled genetically (inside seed structure) and from the genetic point of view this Russian accession can be an interesting initial material for breeding purposes to create new improved vetch cultivars.

Estimation of similarity of all accessions in terms of mechanical loads parameters on seeds, approached jointly, in spatial form and in the system of the first two canonical variables, is present in Fig. 7; for mechanical loads parameters and TSW in Fig. 8 and for mechanical loads parameters and seed thickness in Fig. 9. In terms of Fig. 7 the most remote spatial position (left-hand side of figures) is characteristics of the densely located vetch accessions (nos. 1–46) except separate position (left-top part of figure) of three accessions: nos. 14, 5 and 21 originated respectively from the Czech republic, Russia and Slovakia. Two first canonical varieties elucidated 89.25 % of multivariate variability. The most extreme position of this three accessions indicates their low degree of similarity in the response of their seeds to mechanical loads as compared to remaining genotypes of vetch. A middle- and right-hand side of the figure is occupied by accessions of remaining species with extreme position (right side) of white lupin cv. Boros and Butan (nos. 49 and 50) and narrow-leaf lupin cv. Zeus (no. 48). Taking in account additional included parameter (TSW) only partially changed position of accessions (Fig. 8). Two first canonical varieties elucidated 96.79 % of multivariate variability. Genotypes of

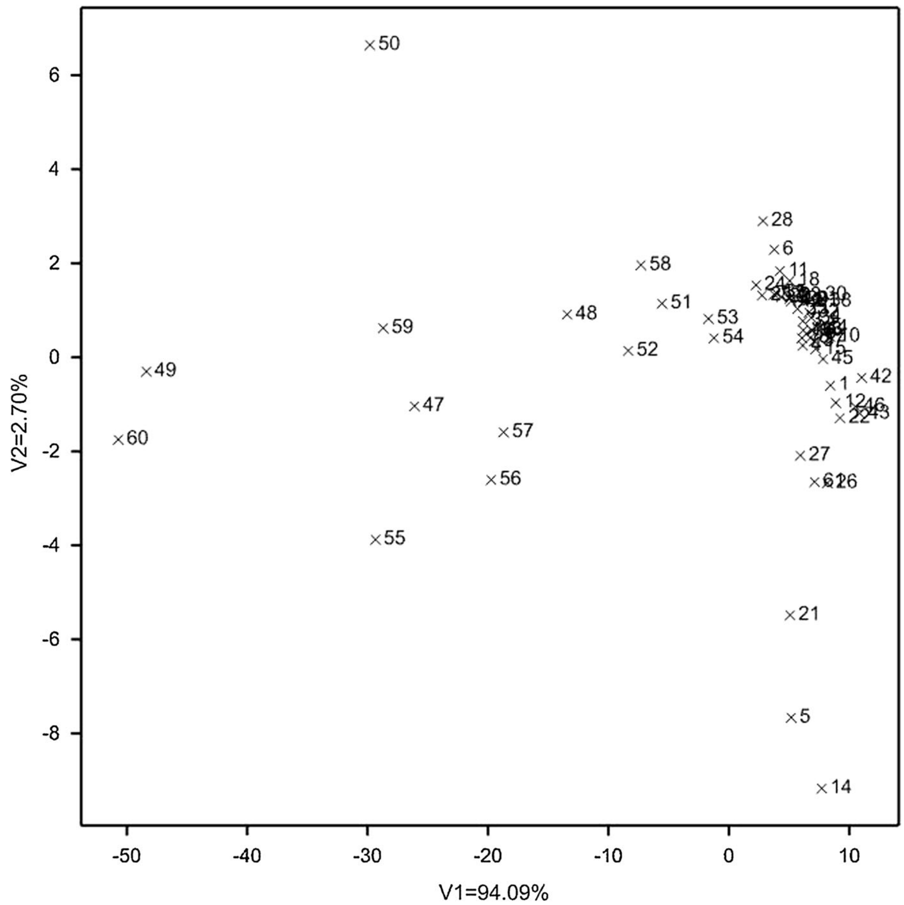


Fig. 8 Distribution of common vetch accessions (*Vicia sativa* L.) in the space of two first canonical variables for four static loads parameters and thousand seed weight (TSW) combined. See explanation in Fig. 1

vetch are more concentrated as in Fig. 7 with similar separate position of above mentioned accessions nos. 21, 5 and 14 (right side of figures). As compared to Fig. 7 the most extreme position (left side) occupied accessions of white lupin cv. Boros (no. 49) and chickpea from Canada (no. 60) characterized by the highest TSW value (373 and 403 g, respectively) among all analyzed accessions. Due to very high degree of correlation between TSW and seed thickness ($r = 0.905$) (Table 2), this last parameter haven't changed significantly the position of accessions presented in Fig. 9 as compared with Fig. 8. However, separate position of vetch accession nos. 14, 5 and 21 is not such visible like this in the Fig. 8. Two first canonical variates elucidated 95.47 % of multivariate variability.

The relationships between the traits analyzed are characterized by a coefficient of correlation (Table 2). With the exception of one pair of traits (TSW and stress at maximum loads, $r = -0.247$) the remaining were obtained exclusively significant coefficients of correlation ($P < 0.05$). A negative correlation was observed only for pair: seed thickness and stress at maximum load ($r = -0.449$). Four parameters of mechanical load were reciprocally significantly positive correlated what indicate on dependence among them (Table 2). Similar connection among mechanical load parameters was observed for grain legume crops (Rybiński et al. 2009). The highest coefficient of correlation was noticed for pairs: work to maximum load and maximum load (0.930), deflation at maximum load and work to maximum load (0.876) as well as between maximum load and deflation at maximum load (0.735). The pair of traits which have significant effect on the mechanical load parameters are TSW and seed thickness (Table 2). These traits showed the highest value of correlation coefficient (0.905) as compared with other pairs of traits. Seed thickness was positively and significantly correlated with maximum load (0.534), deflation at maximum load (0.476) and

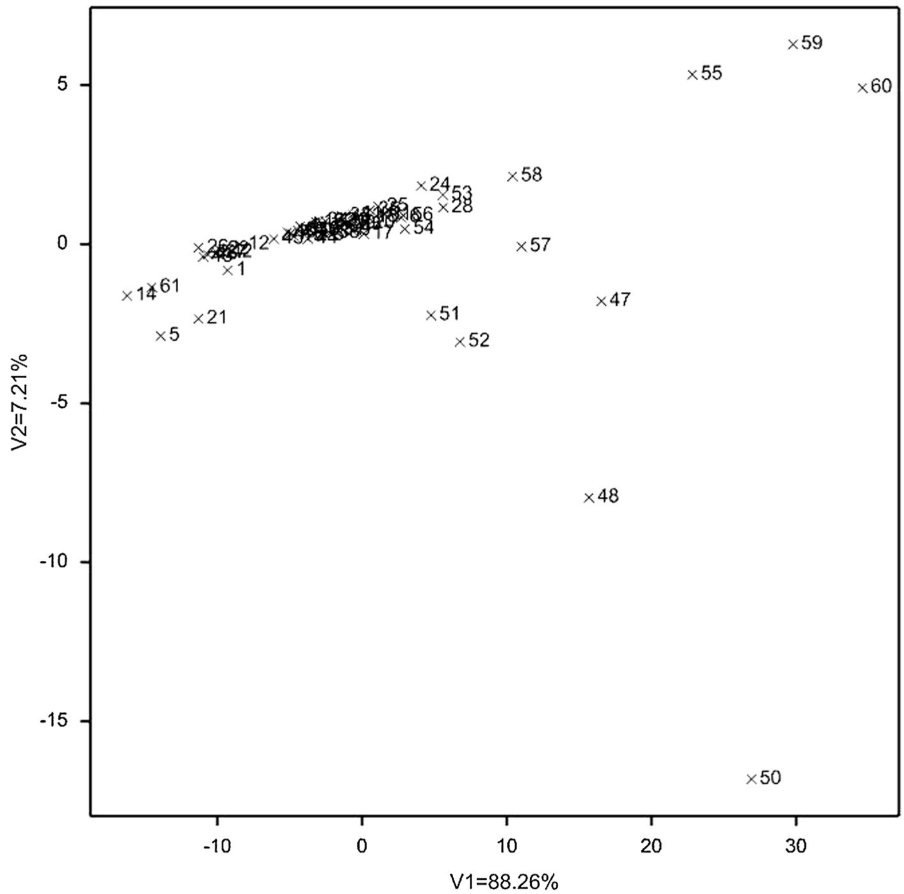


Fig. 9 Distribution of common vetch accessions (*Vicia sativa* L.) in the space of two first canonical variables for four static loads parameters and seed thickness combined. See explanation in Fig. 1

Table 2 Coefficient of correlations for seed traits of investigated accessions

Parameters	Maximum load	Deflection at maximum load	Stress at maximum load	Work to maximum load	Weight of 1,000 seeds	Seed thickness
Maximum load	1					
Deflection at maximum load	0.735***	1				
Stress at maximum load	0.338**	0.3*	1			
Work to maximum load	0.93***	0.876***	0.3*	1		
Weight of 1,000 seeds	0.577***	0.612***	−0.247	0.572***	1	
Seed thickness	0.534***	0.476***	−0.449***	0.483***	0.905***	1

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

work to maximum load (0.483) and negatively with stress at maximum load (−0.449). TSW was insignificantly and negatively connected only with stress at maximum load (Table 2).

Common vetch belongs to grain legume crops with high protein content in seeds (Samarah and Ereifej 2009). In presented studies protein content in seeds of analyzed accessions ranged from 23.8–32.2 % in Russian form no. 5, with average value at the level of 27.2 % (Table 3). According to Sharma and Kalia (2003) the seeds of common vetch contain 22.9 % protein, seeds of five accessions from 25.1 to 28.2 % (Abdouli et al. 1994) and 23.5 % (Hector et al. 1990). Compared to vetch the highest protein contains the seeds of Andean, yellow and white lupin (41.1; 39.6 and 31.8 %, respectively) and the lowest the seeds of

Table 3 Chemical composition of seeds of investigated species and accessions for protein and fat content and composition of fatty acids

	Common vetch	Narrow-leafed lupine	White lupine	Yellow lupine	Andean lupine	Field pea	Grass pea	Chick pea	Lentil	Coefficient of variability
Protein (%)										
Mean	27.2	27.4	31.8	39.6	41.1	22.7	26.8	18.7	24.9	15.89
Range	23.8–32.3	24.07–30.7	30.94–32.61	36.41–42.84	38.08–44.2	21.92–23.52	24.96–28.57	18.23–19.09	24.9	
Fat (%)										
Mean	2.2	6.8	10.9	6.8	14.8	1.5	1.3	6.9	2.6	91.79
Range	1.3–5.0	5.99–7.62	9.76–12.09	4.86–8.76	14.12–15.56	1.43–1.59	1.05–1.5	6.7–7.2	2.6	
*Fatty acids**										
$C_{16\text{-}0}$										
Mean	9.8	10.3	6.2	4.7	11.9	6.9	7.1	41.6	11.2	70.03
Range	8.4–11.7	8.8–11.7	5.9–6.5	4.6–4.8	1.8–11.9	6.6–7.2	6.7–7.6	18.5–64.7	11.2	
$C_{18\text{-}0}$										
Mean	2.80	6.05	2.0	2.4	6.0	2.95	3.55	6.90	1.9	42.74
Range	2.1–3.3	5.3–6.8	1.6–2.4	2.3–2.5	5.7–6.3	2.5–3.4	3.4–37	3.1–10.7	1.9	
$C_{18\text{-}1}$										
Mean	29.41	39.4	61.65	29.4	44.85	39.7	34.8	35.5	27.2	30.92
Range	19.9–35.4	37.3–41.5	60.9–62.4	28.1–30.7	43.4–46.3	38.2–41.3	28.6–41.0	0–71	27.2	
$C_{18\text{-}2}$										
Mean	44.04	38.6	15.6	52.35	34.2	38.0	42.5	0	43.6	32.4
Range	38.7–51.8	38.5–38.7	14.5–16.7	51.9–52.8	33.2–35.2	36.3–39.7	39.7–45.3	0	43.6	
$C_{18\text{-}3}$										
Mean	11.68	5.55	8.15	8.5	2.85	12.35	10.2	12.2	14.7	23.13
Range	9.6–13.3	5.4–5.7	8.0–8.3	7.6–9.4	2.8–2.9	11.8–12.9	9.2–11.2	5.7–18.7	14.7	
$C_{20\text{-}1}$										
Mean	1.71	0.2	4.65	1.95	0.2	0	1.0	3.2	1.5	57.0
Range	0.8–2.9	0–0.4	4.3–5.0	1.9–2.0	0.2–0.2	0	0–2	1.5–4.9	1.5	
$C_{22\text{-}1}$										
Mean	0.48	0	1.75	0.7	0	0	0.8	0.7	0	98.24
Range	0–1.3	0	1.7–1.8	0.6–08	0	0	0–1.6	1.0	0	

* palmitic acid ($C_{16:0}$), stearic acid ($C_{18:0}$), oleic acid ($C_{18:1}$), linoleic acid ($C_{18:2}$), linolenic acid ($C_{18:3}$), eicosenoic ($C_{20:1}$) and erucic ($C_{22:1}$)

Table 4 Coefficient of correlations for traits of chemical composition of seeds

Trait	Protein	Fat	Palmitic acid	Stearic acid	Oleic acid	Linoleic acid	Linolenic acid	Eicosenoic acid
Protein	1							
Fat	0.474***	1						
Palmitic acid	−0.338**	0.192	1					
Stearic acid	−0.012	0.496***	0.768***	1				
Oleic acid	0.145	0.41**	−0.393**	−0.2	1			
Linoleic acid	0.074	−0.153	−0.165	−0.04	−0.117	1		
Linolenic acid	−0.533***	−0.662***	0.35**	−0.14	−0.711***	0.031	1	
Eicosenoic acid	−0.098	−0.031	0.421***	0.008	−0.146	−0.021	0.372**	1
Erucic acid	0.077	−0.035	0.088	−0.1	−0.023	0.287*	0.145	0.62***

** $P < 0.01$; *** $P < 0.001$

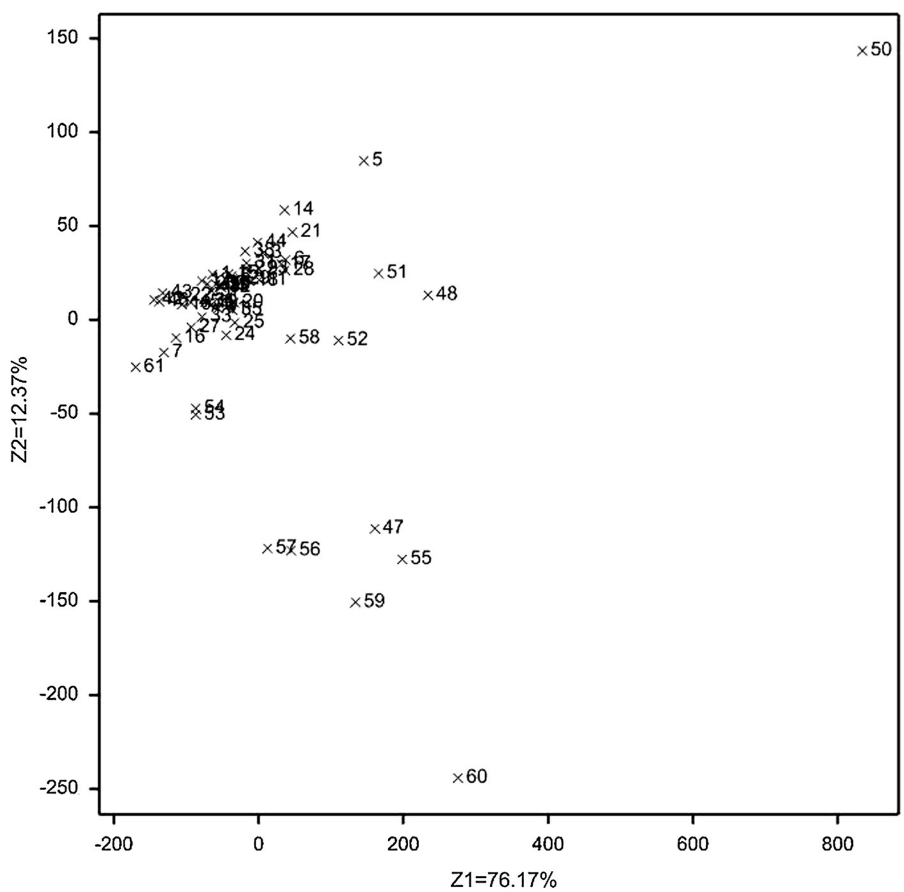


Fig. 10 Distribution of common vetch accessions (*Vicia sativa* L.) in the space of two first principal components for static loads parameters, seed thickness, thousand seed weight and chemical compositions of seed combined. See explanation in Fig. 1

chickpea (18.7 %). In comparison to Andean—and white lupin characterized by high fat content (14.8 and 10.9 %), vetch accessions (2.2 %), similar like field pea, grass pea and lentil (1.5; 1.3 and 2.2 %, respectively) belongs to grain legume species with low fat content. Fat content in seeds of vetch varied in broad range from 1.3 to 5 % in seeds of Czech accession no. 15. The fat content was observed as 1.05, 1.03 and 1.26 % for different seeds vetch samples (Sharma and Kalia 2003), 1.1 % as described by Round (1989) and from 1.3 to 1.6 % in researches of Mao et al. (2012). Regardless of the species, oleic ($C_{18\text{-}1}$) and linoleic acid ($C_{18\text{-}2}$) dominated in the fatty acid profiles with the exception of chickpea characterized by absent of linoleic acid and very high content of palmitic acid. In comparison to other analyzed species the seeds of common vetch showed the lowest content of monounsaturated oleic acid and relatively high content of valuable polyunsaturated linoleic acid at the level of lentil, but lower as compared to seeds of yellow lupin (Table 3). The seeds of vetch contain also high portion of another polyunsaturated acid—linolenic acid ($C_{18:3}$) at the level of field pea and chickpea and markedly higher as seeds of lupin. High level of polyunsaturated fatty acids (PUFA) in vetch was also observed by Chu et al. (2011) and Mao et al. (2012). Both authors indicate a valuable, from nutritional point of view, acid profile of common vetch.

Table 4 presents the values of correlation coefficient for protein, fat and fatty acids content. The protein content was positively and statistically significantly correlated with fat content (0.474) and significantly but negatively with either palmitic (−0.338) or linolenic acid (−0.533). The fat was significantly and positively correlated with stearic (0.496) acid and negatively with linolenic acid (−0.662). The highest negative and significant coefficient of correlations among fatty acids was observed between linolenic and oleic acids (−0.711) and positive between palmitic and stearic acid (0.768). High level of correlation was noticed also for the next pair: eicosenoic and palmitic acid (0.421). Trace amounts of erucic acid were significantly and positively correlated with eicosenoic and linoleic acid (Table 4).

To summarize the diversity of all the traits (static loads parameters, seed thickness, TSW and chemical compositions of seed combined) of the analyzed accessions, spatial distribution of the results obtained is shown in Fig. 10. Apart from one main cluster on the left of the plane, a few extreme position of accessions can be distinguished, e.q white lupin cv. Butan from Poland (No. 50) and chickpea from Canada (No. 60). In investigation of Rybiński et al. (2009) also white lupin was distinguished as compared to other grain legume species. Small separate group below main cluster create: narrow-leafed lupin cv. Neptun (No. 47), field pea cv. Milva and Muza (nos. 55 and 56), grass pea cv. Krab (No. 57) and chickpea originated from Turkey (No. 59). Among vetches, only accession no. 5 originated from Russia noticeably differed from remaining. It indicates genetic separateness of this unique genotype.

Conclusions

1. Mean square values from the analysis of variance indicate statistically differentiation among estimated grain legume accessions in terms of mechanical load parameters under analysis, seed thickness and TSW.
2. The seeds of common vetch are characterized by markedly lower values of TSW and seed thickness. However, a great segregation among all vetches accessions was observed with the lowest TSW for three Polish low toxin accessions and the highest for three accessions at the level above 70 g originated from the Slovak Republic. Wide-ranging differentiation among vetch accessions was also observed for seed thickness with the lowest values for Polish low toxin accessions. TSW and seed thickness were significantly positive correlated at the level 0.001.
3. In terms of response to the effect of external mechanical loads the seeds were characterized by wide range of variation. The obtained variability was connected primarily with inter-species differentiation, as well as with difference among accessions within single species. Obtained results allowed to select genotypes with the greatest and the lowest seed resistance in respect of static load.
4. Regardless of the interspecies variation common vetch accessions exhibiting extreme values of the particular parameters of mechanical loads were distinguished. The analysis of distribution of the vetch accessions in the system of the first two canonical variables of mechanical load parameters combined demonstrated not only broad range of variability but also markedly visible separateness of few accessions as compared to remaining. It is particularly true for the accession no. 5 originated from Russia characterized by extreme values of mechanical loads parameters. In terms

of above mentioned vetch accession and few others the differences in the reaction to mechanical loading may be related to genetic changes in the internal structure of seeds. To support this opinion the analysis of the seeds microstructure is necessary.

5. Compared with analyzed grain legume species vetch accessions are characterized by relatively high protein content (higher than chickpea and lentil but lower than lupin species) and low fat content at the level of field pea, grass pea and lentil. In spite of low fat content fatty acid profile of vetch is well balanced and in comparison with other analyzed species is characterized by high level of polyunsaturated linoleic and linolenic fatty acid (PUFA) as well as lower content of monounsaturated oleic acid (MUFA). Obtained results allowed to select the vetch accession with desirable chemical composition of seeds, particularly with high protein content. Positive and statistically high significant correlation between protein and fat content indicates that increase of protein content in the seeds of new released cultivars may be obtained without fat content decrease.

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