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Effects of genotype and environment on seed quality traits variability in interspecific cross-derived *Brassica* lines

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Abstract Genotype (G), environment [i.e. year (Y) and location (L)] and their interaction (GYL) play an important role in the final expression of quality attributes. A multi-environment trial in selected interspecific cross-derived *Brassica* lines was conducted to evaluate the magnitude of G, Y, L and GYL effects on seed quality traits of *Brassica* genotypes under three locations in Poland, during the 2011–2013 cropping season. The oil, protein, fiber (Acid Detergent Fiber and Neutral Detergent Fiber) as well as glucosinolate contents was determined by near-infrared reflectance spectroscopy (NIRS) and significant differences were observed between tested *Brassica* genotypes and across harvesting years and growing locations. Generally, all tested hybrid lines displayed wider genetic variability for studied quality traits than control genotypes. Analysis of variance indicated that the main effects of genotypes, years and locations as well as all interactions were significant for all traits of study (except year × location interaction for glucosinolates). However, location had the most significant effect on oil, protein and fiber content while genotype had significant impact on glucosinolates content in *Brassica* seeds. Moreover, the individual lines having combination of desirable traits were also identified from F_5 to F_7 generations of tested hybrids.

Keywords *Brassica* lines · Seed quality traits · Genotype–environment interaction · Variability

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Introduction

Brassica is the most economically important genus in the *Brassicaceae* family. Due to substantial progress in breeding and cultivation practice, two major members of the *Brassica* genus commonly known as rapeseed (*Brassica napus* L.) and mustards have become one of the worldwide most principal source of vegetable oil (Rani et al. 2013). Especially in several European countries with cool-temperate climates oilseed rape (*B. napus*) with 'double-low' seed quality (Canola) dominates field crop production. Poland and Great Britain have been ranked interchangeably in sixth place in the production of winter oilseed rape (*Brassica napus* L.) in the world, after China, Canada, India, Germany and France (Ratajczak et al. 2017). In Poland, winter oilseed rape is the most important oil–protein plant. It provides edible vegetable oil for human consumption and proteins for the feed industry, and has recently gained increasing interest as a source of biodiesel (Huang et al. 2016). Traditional breeding, as well as, modern biotechnological tools has led to the improvement of various quantitative and qualitative traits in *Brassica*. At the same time, modern crop breeding has resulted in the reduction of genetic variability in most of the crop species (Tanksley and Nelson 1996). From our previous work it was found that one of the most effective methods for increasing the variability of traits that impacts the quality of rapeseed products is interspecific hybridization (Niemann et al. 2012). In order to combine desirable genes found in two or more different varieties, planned hybridization between carefully selected parents is practiced within or among species. The plant breeder usually keeps such ideal plants in mind that combines a majority of desirable characteristics. These may be general and/or specific traits that could contribute to the improved adaptation of plants to the environment and could enhance yield with better quality seed. Generally, in *Brassica napus* breeding, traits related to commercial success are of highest importance (Friedt and Snowdon 2010). For this reason rapeseed breeding strategies are oriented on developnig new cultivars with high oil, protein as well as low erucic acid, glucosinolate and fiber content (Möllers 2004; Abbadi and Leckband 2011; Zou et al. 2016; Körber et al. 2016). For this purpose knowledge of genetic diversity is indispensible in the development of commercial cultivars (Ahmad et al. 2013; Liu et al. 2016).

The content of oil, protein and anti-nutritive substances like glucosinolates and fiber in rapeseeds decide on their utility value (Bell 1984; Vageeshbabu and Chopra 1997; Liu et al. 2012). *Brassica napus* is planted for oil production and, therefore, an maximization of oil content in the seeds is a major goal in the breeding process (Zhao et al. 2007; Würschum et al. 2012). In general, the oil content in the *Brassica* seeds varies from 30 to 45% depending on the species, the variety and climatic conditions and is mainly driven by the composition of fatty acid components of erucic acid (C22:1), stearic acid (C18:0), oleic acid (C18:1), linoleic acid (C18:2), and linolenic acid (C18:3) (Velasco and Becker 1998; Möllers 2004). In addition, the oil content of *Brassica* oilseed meal contains about 40% protein with a well-balanced amino acid composition (Khan et al. 2008), but lower than would be desired. Moreover, plant breeders have strongly reduced the levels of the unhealthy and uneatable glucosinolates in the seeds (< 30 uM/g) to be able to use the protein-rich seed cake as an animal feed supplement (Halkier and Gershenzon 2006). Besides, the presence of high fibre fraction in oilseed rape meal, which is mostly located in seed hull, is the major obstacle for its use in animal feeding. The fibre fraction is poorly digestible and essentially dilutes the available energy and protein. Consequently, oilseed rape meal has less metabolizable energy and reduces the value of the meal relatively to soybean meal. Fibre contents are related to plant cell walls components, namely cellulose, hemicellulose and lignin. The proportion of hemicellulose, cellulose and lignin can be quantified as neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL). The NDF fraction consists (predominantly) of hemicellulose, cellulose and lignin content, while the ADF fraction comprises cellulose and lignin. ADL represents the non-digestible lignin fraction. To improve the quality of oilseed rape meal, breeding research has been undertaken to select genetic material with lower fibre content.

It is known that all of these seed quality traits are influenced by genetic and environmental factors, as well as agricultural technology (Feng et al. 2012; Ratajczak et al. 2017), so their precise estimation requires phenotyping in replicated multi-environmental field trials. It is important to determine and quantify the extent to which factors like the environment and genotype × environment interaction contribute to variations in each *Brassica* quality parameter.

The objectives of this research were (1) to determine the relative contributions of G, Y, L and GYL to the variation in seed quality traits of twenty-five *Brassica* genotypes tested across three locations, (2) to analyze which factor has the most significant effect on tested traits, and (3) to find the best *Brassica* genotypes based on quality traits.

Materials and methods

Plant material for field trials consisted of 25 winter rapeseed genotypes i.e.: *B. napus* cv. Californium (open pollinated variety), twenty-three interspecific cross-derived *Brassica* lines and male sterile line of F_8 generation of *B. napus* (MS8). MS8 line was selected from resynthesized oilseed rape (*B. rapa* ssp.

chinensis × *B. oleracea* var. *gemmifera*) using in vitro cultures of isolated embryos in Department of Genetics and Plant Breeding, Poznan University of Life Sciences (PULS) (Table 1). Seeds of *B. napus* cv. Californium and MS8 line originated from the resources of the Department of Genetics and Plant Breeding of PULS, while seeds of paternal genotypes i.e. *Brassica rapa* ssp. *pekinensis*, *Brassica rapa* ssp. *trilocularis, Brassica carinata and Brassica juncea* came from the Warwick HRI Genetic Resources Unit. In order to obtain interspecific cross-derived *Brassica* lines, interspecific hybridizations were carried out in the glasshouse and performed with the application of in vitro culture of isolated embryos according to the method described by Niemann et al. (2012). All interspecific cross-derived lines were sister-pollinated (five plants were enclosed in one paper bag during flowering) for four generations in order to stabilize the fertility. F_5–F_7 generation of tested lines and control genotypes were selected from the rapeseed breeding program of Department of the Genetics and Plant Breeding of PULS. During seasons 2010/2011, 2011/2012 and 2012/2013 twenty-five *Brassica* genotypes were grown in three different locations i.e. in the PULS experimental station Dłoń located 100 km south of Poznań and in Złotniki located 15 km west from Poznań as well as in the experimental fields in Poznań-Sołacz. These locations have different types of soil and weather conditions (Tables 2, 3). The field trials at all locations were arranged in a randomized complete block design with three replicates. Each genotype was grown in a 3 row plot of 9.0 m^2 with a 0.30 row distance and a sawing density of 60 seeds/m^2.

Quality analysis

The seed samples for the analysis of fiber, protein, oil and glucosinolates content were collected from five

Table 1 Code and origin of the genotypes tested

Code	Genotype
1	*B. napus* cv. Californium
2	*B. napus* line MS8 × *B. rapa* ssp. *pekinensis*
3	*B. napus* line MS8 × *B. rapa* ssp. *pekinensis*
4	*B. napus* line MS8 × *B. rapa* ssp. *pekinensis*
5	*B. napus* line MS8 × *B. carinata*
6	*B. napus* line MS8 × *B. rapa* ssp. *pekinensis*
7	*B. napus* line MS8 × *B. carinata*
8	*B. napus* line MS8 × *B. carinata*
9	*B. napus* line MS8 × *B. carinata*
10	*B. napus* line MS8 × *B. rapa* ssp. *trilocularis cv.* Yellow Sarson
11	*B. napus* line MS8 × *B. rapa* ssp. *trilocularis cv.* Yellow Sarson
12	*B. napus* line MS8 × *B. rapa* ssp. *trilocularis cv.* Yellow Sarson
13	*B. napus* line MS8 × *B. rapa* ssp. *pekinensis*
14	*B. napus* line MS8 × *B. rapa* ssp. *pekinensis*
15	*B. napus* line MS8 × *B. rapa* ssp. *pekinensis*
16	*B. napus* line MS8 × *B. rapa* ssp. *pekinensis*
17	*B. napus* line MS8 × *B. rapa* ssp. *pekinensis*
18	*B. napus* line MS8 × *B. rapa* ssp. *pekinensis*
19	*B. napus* line MS8 × *B. juncea*
20	*B. napus* line MS8 × *B. rapa* ssp. *trilocularis cv.* Yellow Sarson
21	*B. napus* line MS8 × *B. rapa* ssp. *trilocularis cv.* Yellow Sarson
22	*B. napus* line MS8 × *B. rapa* ssp. *pekinensis*
23	*B. napus* line MS8 × *B. carinata*
24	*B. napus* line MS8 × *B. juncea*
25	*B. napus* line MS8

Table 2 Environments used in the study and their main characteristics

Environment	Longitude (E)	Latitude (N)	Soil quality class	Soil type	Complex of agricultural usefulness
Dłoń	17°04′10″	51°41′23″	III	Heavy	Good rye
Poznań-Sołacz	16°54′26″	52°25′18″	IV	Light, sandy	Good wheat
Złotniki	16°50′41″	52°29′35″	IVa	Luvisols	Very good rye

Table 3 Meteorological conditions in Dłoń, Poznań-Sołacz and Złotniki during the vegetation season of winter oilseed rape in 2011, 2012 and 2013

Basic weather parameters	Dłoń			Poznań-Sołacz			Złotniki		
	2011	2012	2013	2011	2012	2013	2011	2012	2013
Mean annual temperature (°C)	10	10.1	9.7	9.6	9.4	9.2	15.2	9.1	9.8
Sum of precipitation (mm) in whole year	465	631	565	477	514	607	402	678	581

self-pollinated plants from each tested line. The fiber content in the *Brassica* lines and control seeds was expressed as the average value of the neutral detergent fiber (NDF) and the acid detergent fiber (ADF) as a subfraction of the NDF. The seed quality traits content was determined by near-infrared reflectance spectroscopy (NIRS) (Velasco et al. 1999). These analyses were performed at the Małyszyn Laboratory that belongs to Plant Breeding Strzelce in triplicate. For NIRS analysis minimum 3 g of intact seeds were used. Every seed probe was scanned on the NIRS Systems monochromator model 6500 (NIR Systems, Inc. Silver Springers, MD, USA).

Statistical analysis

Firstly, the normality of the distributions of the studied traits (neutral detergent fiber—NDF, acid detergent fiber—ADF, as a subfraction of the NDF, protein, oil content and glucosinolates) were tested using Shapiro–Wilk's normality test (Shapiro and Wilk 1965). Multivariate analysis of variance (MANOVA) was performed on the basis of following model using a procedure MANOVA in GenStat 17th edition: $\mathbf{Y} = \mathbf{XT} + \mathbf{E}$, where: $\mathbf{Y}$ is $(n \times p)$—dimensional matrix of observations, n is number of all observations, p is number of traits ($p = 5$), $\mathbf{X}$ is $(n \times k)$—dimensional matrix of design, k is number of genotypes ($k = 25$), $\mathbf{T}$ is $(k \times p)$—dimensional matrix of unknown effects, $\mathbf{E}$—is $(n \times p)$—dimensional matrix of residuals. Nextly, three-way analysis of variance (ANOVA) was carried out to determine the effects of genotypes, years and locations and the interactions: genotypes × years, genotypes × locations, years × locations and genotypes × years × locations—on the variability of studied traits. The minimal and maximal values of traits as well as arithmetical means and standard deviations were calculated. Moreover, the Fisher's least significant differences (LSDs) were also estimated at the significance level $\alpha = 0.05$. The relationships between observed traits were assessed on the basis of Pearson's correlation coefficients using FCORRELATION procedure in GenStat 17th edition for each environment independent. Results were also analysed using multivariate methods. The canonical variate analysis was applied in order to present multitrait assessment of similarity of tested genotypes in a lower number of dimensions with the least possible loss of information (Rencher 1992). This makes it possible to illustrate variation in genotypes in terms of all observed traits in the graphic form. Mahalanobis' distance was suggested as a measure of "polytrait" genotypes similarity (Seidler-Łożykowska and Bocianowski 2012), whose significance was verified by means of critical value D_α called "the least significant distance" (Mahalanobis 1936). Mahalanobis' distances were calculated for genotypes in each environment independent as well as for all environments data jointly. All the analyses were conducted using the GenStat v. 17 statistical software package (Payne et al. 2012).

Results

All studied traits have a normal distribution as well as a multivariate normality. Results of MANOVA indicate that the genotypes (Wilk's $\lambda = 0.0448$; $F_{24,3148} = 113.51$; $P < 0.0001$), years (Wilk's $\lambda = 0.7618$; $F_{2,3148} = 91.63$; $P < 0.0001$) and locations (Wilk's $\lambda = 0.1305$; $F_{2,3148} = 1112$; $P < 0.0001$) were significant different for all five traits. Moreover, interactions: genotype × years (Wilk's $\lambda = 0.7047$; $F_{48,3148} = 4.75$; $P < 0.0001$), genotype × location (Wilk's $\lambda = 0.1480$; $F_{48,3148} = 30.52$; $P < 0.0001$), years × locations (Wilk's $\lambda = 0.6796$; $F_{4,3148} = 64.39$; $P < 0.0001$) and genotype × years × locations (Wilk's $\lambda = 0.2344$; $F_{96,3148} = 11.03$; $P < 0.0001$) were significant. Analysis of variance indicated that the main effects of genotypes, years and locations as well as all interactions were significat for all the traits of study (except year × location interaction for glucosinolates) (Table 4). However, the obtained data showed that the most significant effect on oil, protein and fiber content in the *Brassica* seeds had environment i.e. location, while genotype had the biggest impact on glucosinolates content.

Minimal, maximal and mean values as well as standard deviations for NDF, ADF, protein, oil and glucosinolates content were presented in Tables 5, 6, 7, 8 and 9, respectively.

Generally, all tested cross-derived *Brassica* lines displayed a great increase in the range of variability for the studied quality traits when compared to the control genotypes. Moreover, the highest mean values of fiber, oil and glucosinolates were observed in Dłoń, although protein content in tested lines in total was slightly higher in Złotniki, where mainly the lowest values of all studied traits were noticed (Tables 5, 6, 7, 8, 9). Both, the highest and the lowest NDF mean values were observed in lines harvested in Dłoń (29.89 and 18.61% respectively), however the differences occured between tested genotypes i.e. in MS8 × *B. rapa* ssp. *trilocularis* and MS8 × *B. rapa* ssp. *pekinensis* adequately (Table 5). Similarly, the highest ADF mean values were observed in the lines harvested in Dłoń from MS8 × *B. rapa* ssp. *pekinensis* seeds (26.68%) but the lowest content was noticed in Złotniki from MS8 × *B. juncea*—17.1% (Table 6). The highest protein mean value was observed in Złotniki (23.80%), while the lowest in Poznań-Sołacz (16.65%) in MS8 × *B. rapa* ssp. *pekinensis* lines in 2012 (lines number 3 and 11, respectively) (Table 7). The highest oil mean value was observed in Dłoń in line number 16 (46.96%), ranged from 44.52 to 49.89%, but the minimum value was noticed in Złotniki (35.35%) in line number 17 (Table 8). The minimal glucosinolates content was observed in

Table 4 Mean squares from three-way analysis of variance for five observed traits

Source of variation	d.f.	NDF	ADF	Protein content	Oil content	Glucosinolate content
Repl	2	3.99	21.45	6.81	0.87	0.4
Genotyp (G)	24	345.30***	70.60***	65.63***	108.25***	18,469.81***
Year (Y)	2	551.38***	70.81***	154.85***	85.55***	137.83*
Location (L)	2	1552.08***	2540.92***	3584.18***	2088.25***	2874.3***
G × Y	48	13.86***	3.87***	2.80***	9.34***	54.89**
G × L	48	62.74***	37.30***	46.91***	88.27***	288.89***
Y × L	4	370.33***	66.86***	96.03***	27.54***	22.68^{ns}
G × Y × L	96	17.05***	19.78***	12.84***	22.69***	53.07***
Residual	3148	1.75	0.63	0.84	4.06	31.76

ns Not significant

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

Table 5 Neutral detergent fiber content (%) in twenty-five *Brassica* genotypes tested in nine environments

Location	Year	Dlon				Poznań-Sołacz				Złotniki			
Genotyp		Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD
1	2011	28.82	28.53	29.21	0.17	27.7	26.25	30.21	1.03	26.87	26.09	28.45	0.53
	2012	27.87	25.54	29.33	1.39	27.61	25.55	33.87	2.16	26.42	25.67	28.45	0.74
	2013	28.89	27.44	30.23	0.95	29.14	26.94	31.95	1.52	26.22	25.45	28.41	0.85
2	2011	22.66	18.9	23.99	1.50	26.54	26.23	27.07	0.22	23.31	22.95	23.79	0.22
	2012	23.22	22.8	23.79	0.27	26.72	26.14	27.75	0.52	24.74	21.25	27.23	1.65
	2013	25.49	22.26	29.2	2.09	26.81	25.16	28.68	1.02	23.19	22.16	25.56	0.85
3	2011	23.43	22.23	25.56	0.74	27.19	26.73	27.62	0.28	22.77	19.61	25.84	2.18
	2012	24.74	21.25	27.23	1.65	27.18	26.55	27.69	0.33	22.78	21.79	25.56	1.06
	2013	22.09	20.55	25.39	1.12	27.14	25.61	28.82	1.10	26.36	23.06	28.96	2.00
4	2011	24.37	20.58	27.76	2.86	28.17	27.66	29.03	0.29	26.83	26.38	28.27	0.45
	2012	21.21	20.13	28.23	1.97	28.11	27.51	29.03	0.35	26.67	26.15	28.27	0.53
	2013	28.76	25.99	31.31	1.47	28.15	25.71	30.75	1.24	26.94	25.84	28.74	1.02
5	2011	20.96	20.49	21.36	0.24	26.11	23.76	27.79	0.97	22.08	21.3	23.55	0.59
	2012	21.9	21.15	23.55	0.65	26.15	23.33	28.56	1.48	22.28	20.38	26.95	2.18
	2013	23.39	21.23	26.97	2.17	26.98	23.38	28.43	1.38	22.15	20.77	23.8	1.02
6	2011	21.18	19	23.96	2.31	20.9	20.23	21.61	0.42	23.7	23.04	25.77	0.64
	2012	20.68	19.19	23.95	1.37	21.07	20.08	23.98	1.15	23.67	23	25.77	0.65
	2013	21.87	19.23	23.92	1.63	23.66	20.05	27	2.35	23.47	21.13	25.52	1.05
7	2011	27.7	20.36	28.92	2.08	23.02	22.51	23.45	0.28	23.71	23.18	25.67	0.58
	2012	20.37	19.16	27.09	2.08	22.87	22.14	23.8	0.45	24.16	23.13	25.67	0.85
	2013	27.98	25.26	30.48	1.42	23.31	21.33	29.05	1.74	23.94	22.16	25.88	1.13
8	2011	29	27.21	29.95	0.59	28.45	28	29.18	0.33	23.91	23.19	25.95	0.71
	2012	27.73	23.51	29.95	1.92	28.19	27.17	29.18	0.52	23.88	23.01	25.95	0.72
	2013	29.08	26.48	31	1.19	28.44	26.71	30.18	0.85	23.84	23.12	25.92	0.87
9	2011	26.21	23.13	26.87	1.23	26.78	26	28.45	0.64	27.24	26.93	27.54	0.19
	2012	26.55	23.58	29.6	1.71	26.71	25.84	28.45	0.65	26.25	23.13	26.91	1.25
	2013	25.08	22.46	26.98	1.76	26.72	23.83	28.82	1.47	27.42	25.56	29.24	1.13
10	2011	29.8	29.63	30.55	0.22	28.69	28.29	29.04	0.23	26.64	26.44	26.96	0.14
	2012	26.97	21.22	30.55	4.10	28.85	28.29	29.38	0.32	26.61	26.25	26.96	0.18
	2013	29.61	27	31.63	1.27	27.87	23.42	29.66	1.97	26.65	25.79	27.36	0.49
11	2011	29.43	28.9	30.44	0.42	29.89	29.04	30.5	0.35	26.64	25.3	29.8	1.83
	2012	24.21	20.92	30.14	3.70	29.9	28.2	30.87	0.63	26.62	25.2	29.61	1.82
	2013	29.54	27.82	31.6	1.02	29.81	28.45	31.61	0.78	27.04	25.24	29.88	1.61
12	2011	29.09	28.86	29.23	0.10	28.41	27.78	28.64	0.23	27.84	27.5	28.55	0.27
	2012	27.76	27.23	28.55	0.33	28.27	27.65	28.9	0.38	25.9	20.07	29.3	4.15
	2013	29.17	27.08	30.33	0.83	28.66	27.58	30.21	0.97	27.72	23.89	28.99	1.18
13	2011	27.81	27.43	28.11	0.20	26.63	25.87	27.8	0.51	24.92	23.17	28.77	2.06
	2012	26.43	22.77	27.95	2.02	26.64	25.86	27.8	0.49	24.68	23.09	27.45	1.73
	2013	27.8	26.01	29.56	1.07	26.81	25.01	28.33	1.08	24.63	23.02	27.51	1.45
14	2011	25.63	18.35	26.54	2.04	26.52	25.2	27.8	0.62	23.64	23.07	23.85	0.18
	2012	18.61	15.31	26.71	2.46	25.25	23.31	26.57	0.65	23.49	23	23.84	0.30
	2013	23.64	23.02	27.5	1.12	25.11	23.4	26.94	1.08	25.47	23.19	27.34	1.38
15	2011	26.49	20.1	27.36	1.78	26.72	25.89	27.01	0.25	23.61	23.08	23.93	0.21

Table 5 continued

Location	Year	Dlon				Poznań-Sołacz				Złotniki			
Genotyp		Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD
	2012	20.46	19.04	27.41	1.99	26.63	25.89	26.85	0.25	23.6	23.08	25	0.46
	2013	27.01	25.52	28.24	0.83	26.74	25.39	28.32	0.74	23.16	22.04	25.49	0.83
16	2011	25.22	21.02	25.85	1.18	26.53	25.53	27.62	0.59	22.33	21.69	22.62	0.24
	2012	21.24	20.35	25.31	1.21	25.55	23.75	26.82	1.20	22.12	21.51	22.58	0.36
	2013	25.71	23.04	28.6	1.79	26.03	23.67	27.91	1.30	22.17	21.15	23.65	0.87
17	2011	26.29	21.3	26.93	1.42	25.61	25.39	25.81	0.12	22.29	21.52	23.23	0.50
	2012	20.42	19.15	22.17	0.99	25.54	25.11	26.17	0.31	22.03	21.11	23.23	0.67
	2013	26.67	23.18	29.07	1.67	25.45	23.12	27.62	1.20	22.3	20.5	23.31	0.83
18	2011	23.51	23.01	23.98	0.40	23.64	23.16	26.89	0.93	22.88	22.07	23.67	0.50
	2012	21.88	18.67	23.72	2.23	23.63	23.13	26.89	0.94	22.79	21.63	23.8	0.64
	2013	24.18	22.69	27.17	1.50	23.99	22.18	28.9	1.66	22.68	21.54	23.54	0.68
19	2011	26.22	23.94	27.1	0.68	26.46	25.95	26.8	0.21	23.81	22.02	27.45	1.74
	2012	23.98	19.58	27.32	3.22	26.41	25.77	26.96	0.32	23.53	22.26	26.45	1.40
	2013	25.74	23.05	30.23	2.42	25.65	23.46	27.65	1.42	23.19	21.31	25.92	1.19
20	2011	26.89	26.26	27.18	0.29	26.58	26.23	26.95	0.19	23.4	23.11	23.79	0.23
	2012	23.9	19.11	27.43	3.67	26.46	25.84	26.8	0.29	23.32	23	23.79	0.26
	2013	26.93	23.12	29.14	1.81	26.46	25.13	27.88	0.76	23.6	22.63	25.1	0.68
21	2011	27.63	26.18	29.77	0.79	26.51	26.18	26.96	0.22	22.19	21.48	22.55	0.26
	2012	25.03	19.32	29.77	4.10	26.4	25.89	26.96	0.29	22.02	21.48	22.55	0.29
	2013	27.8	23.2	30.36	1.76	26.5	25.16	27.8	0.79	22.18	20.78	23.29	0.70
22	2011	26.79	19.23	28.52	2.13	26.2	25.37	26.68	0.42	22.91	22.08	24.99	0.90
	2012	20.66	18.77	26.29	2.22	25.53	23.26	26.68	1.29	23.18	22.16	24.97	1.11
	2013	27.44	25.86	29.14	1.16	25.73	22.59	28.08	1.55	23.11	22.01	24.68	0.87
23	2011	26.12	21.43	26.93	1.33	25.33	23.43	25.97	0.74	23.29	22.75	23.5	0.23
	2012	22.14	20.65	27.92	2.10	24.83	23.6	25.97	0.92	22.99	22.04	23.5	0.53
	2013	26.24	23.6	28.76	1.57	25.45	23.24	27.52	1.52	22.99	21.87	23.72	0.62
24	2011	26.5	19.9	27.44	1.85	26.11	25.43	27.18	0.46	21.98	21.27	23.47	0.58
	2012	20.45	19.19	26.65	1.96	25.72	23.52	27.18	0.97	21.77	20.99	23.47	0.71
	2013	26.65	23.07	29.67	1.91	25.82	23.35	28.16	1.33	22.05	20.48	24	1.18
25	2011	27.53	22.03	28.43	1.55	27.05	26.11	27.94	0.59	22.54	22.1	23.51	0.40
	2012	21.96	21.12	27.56	1.59	26.59	25.46	27.71	0.59	22.86	22.08	23.69	0.62
	2013	27.76	25.42	30.17	1.48	26.31	23.98	27.98	1.06	23.14	20.72	23.88	0.88
$LSD_{0.05}$	G: 0.32, Y: 0.11, L: 0.11, GY: 0.55, GL: 0.55, YL: 0.19, GYL: 0.95												

Złotniki in MS8 × *B. rapa* lines and ranged from 6.1 to 69.37 umol/g seeds (Table 9).

NDF was positive correlated with ADF in all nine environments, except in Dłoń 2012 (Table 10). Protein content was negative correlated with NDF (except Dłoń 2012 and Złotniki 2012) and ADF (except Dłoń 2012). Oil content was positive correlated with NDF and ADF in six environments; and negative correlated with protein content in eight environment (only in Złotniki 2012 these two traits were not correlated). Glucosinolates content and NDF were negative correlated in all nine environments.

Table 6 Acid detergent fiber content (%) in twenty-five *Brassica* genotypes tested in nine environments

Location	Year	Dłon				Poznań-Sołacz				Złotniki			
Genotyp		Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD
1	2011	22.51	22.3	22.59	0.09	21.94	20.57	23.64	0.82	20.59	19.89	22.03	0.47
	2012	24.27	21.97	28.4	2.59	21.37	19.68	23.64	1.17	20.23	19.68	22.03	0.63
	2013	22.57	21.36	23.6	0.66	22.53	20.02	23.81	0.97	20.49	19.49	22.08	1.13
2	2011	22.05	19.54	23.41	1.09	21.86	21.62	22.06	0.12	18.9	18.37	20.57	0.57
	2012	18.7	18.07	20.57	0.69	22.02	21.76	22.58	0.23	23.97	19.14	26.95	1.87
	2013	20.63	18.49	22.78	1.41	21.92	21.04	22.82	0.60	18.91	17.68	21.1	1.24
3	2011	18.82	17.99	20.31	0.52	21.96	21.28	22.49	0.35	22.55	20.75	23.99	0.93
	2012	23.97	19.14	26.95	1.87	21.67	20.79	22.49	0.49	18.34	17.58	20.31	0.75
	2013	18.65	17.47	20.58	1.24	21.92	20.41	23.77	1.05	21.54	19.31	23.07	1.02
4	2011	24.18	21.13	26.95	2.00	22.7	22.3	22.96	0.14	20.5	20.2	21.7	0.37
	2012	26.68	22.57	28.31	1.44	22.8	22.3	23.19	0.21	20.4	20.04	21.7	0.42
	2013	22.24	19.02	23.91	1.29	22.59	21.08	23.52	0.64	20.56	19.72	21.94	0.85
5	2011	21.53	20.95	22.33	0.33	21.35	20.87	22.5	0.41	19.86	18.42	21.83	0.96
	2012	19.59	16.8	21.42	1.00	21.2	20.71	22.5	0.46	22.26	19.34	24	1.29
	2013	21.75	20.33	22.9	0.80	21.56	20.38	22.96	0.91	19.94	19.09	20.89	0.49
6	2011	20.87	20.41	21.41	0.24	21.69	21.26	22.17	0.27	19.39	19.22	20.18	0.24
	2012	22.13	20.8	23.26	0.77	21.41	20.19	22.17	0.50	19.49	19.18	20.19	0.33
	2013	21.38	20.01	23.86	0.90	21.67	20.41	22.83	0.67	19.5	18.84	20.35	0.47
7	2011	22.35	21.84	22.96	0.35	22.39	22.01	22.9	0.26	19.3	18.9	20.39	0.36
	2012	23.49	22.47	25.16	0.78	22.28	21.48	23.02	0.42	19.31	18.89	20.39	0.36
	2013	22.21	20.31	23.65	1.15	22.32	19.93	23.19	0.83	19.32	18.43	20.35	0.58
8	2011	22.98	22.83	23.22	0.12	23.15	22.99	23.52	0.13	19.24	18.74	20.47	0.42
	2012	24.38	22.91	27.09	1.78	23.14	22.76	23.52	0.17	19.18	18.72	20.47	0.45
	2013	22.75	21.16	23.97	0.74	23.05	21.85	24	0.62	19.02	18.36	20.78	0.66
9	2011	18.57	18.22	19.19	0.27	21.75	21.21	23.2	0.53	21.72	21.28	21.97	0.16
	2012	22.57	20.46	25.46	1.60	21.63	20.48	23.2	0.70	18.53	18.19	19.19	0.30
	2013	18.69	17.95	19.74	0.52	21.61	18.26	23.49	1.30	21.88	20.72	22.91	0.62
10	2011	23.02	22.72	23.46	0.22	23.15	22.84	23.46	0.16	20.27	20.14	20.7	0.16
	2012	24.77	22.83	28.24	2.39	23.33	22.84	23.78	0.29	20.23	20.04	20.7	0.18
	2013	22.9	21.59	23.96	0.65	23.1	22.13	23.94	0.59	20.28	19.84	20.94	0.37
11	2011	22.47	22.28	22.84	0.17	23.29	22.43	23.7	0.29	19.14	18.77	19.92	0.28
	2012	21.96	20.63	22.86	0.79	23.37	22.43	23.92	0.34	19.1	18.78	19.92	0.30
	2013	22.57	21.56	23.59	0.57	23.29	22.35	23.97	0.46	19.21	18.5	20.52	0.59
12	2011	22.23	21.91	22.42	0.13	22.59	21.97	22.81	0.21	18.69	18.27	19.33	0.29
	2012	18.56	18.05	19.33	0.39	22.56	21.97	23.35	0.34	22.99	21.91	25.61	1.14
	2013	22.24	21.3	23.14	0.53	22.53	21.23	23.78	0.76	18.69	17.93	19.49	0.53
13	2011	21.47	21.02	21.9	0.25	21.28	20.86	21.84	0.26	18.6	18.23	18.87	0.17
	2012	21.58	20.17	23.84	0.81	21.35	20.92	21.84	0.26	18.47	17.93	18.87	0.31
	2013	21.36	19.7	23.14	1.03	21.44	20.07	22.58	0.78	18.57	17.62	19	0.43
14	2011	20.86	20.19	21.12	0.21	21.22	20.54	21.84	0.32	18.24	18.09	18.76	0.18
	2012	20.97	20.19	22.48	0.55	20.7	19.96	22.11	0.45	18.21	18.02	18.76	0.19
	2013	18.29	17.66	18.92	0.39	20.69	19.58	21.45	0.61	20.73	19	22.52	1.07
15	2011	21.67	20.86	27.1	1.53	21.7	21.11	21.9	0.18	18.67	17.72	18.95	0.28

Table 6 continued

Location	Year	Dłon				Poznań-Sołacz				Złotniki			
Genotyp		Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD
	2012	26.27	22.27	27.61	1.35	21.81	21.11	22.58	0.34	18.57	17.72	18.96	0.30
	2013	21.35	19.74	23.11	0.87	21.7	20.9	22.45	0.45	18.83	17.86	19.8	0.63
16	2011	20.51	20.07	20.85	0.18	21.41	21.21	21.85	0.16	17.69	16.97	17.91	0.24
	2012	22.99	20.07	27.75	3.28	21.29	21.04	21.85	0.19	17.52	16.97	17.9	0.31
	2013	20.83	18.81	22.79	1.09	21.27	20.13	22.57	0.73	17.52	16.81	18.51	0.68
17	2011	20.47	19.75	25.96	1.53	20.6	20.4	20.77	0.09	17.43	17.04	17.91	0.24
	2012	24.8	16.62	28.23	2.64	20.64	20.29	21.19	0.24	17.29	16.79	17.91	0.34
	2013	20.13	16.69	21.69	1.32	20.63	19.75	21.9	0.60	17.43	16.39	18.13	0.49
18	2011	20	19.49	20.55	0.28	20.31	20.14	20.73	0.17	19.29	18	19.99	0.93
	2012	20.51	18.84	22.51	1.23	20.6	20.11	21.57	0.49	19.35	18	19.98	0.83
	2013	20	18.54	21.55	0.96	20.33	19.67	21.48	0.53	19.36	18.03	19.95	0.73
19	2011	21.17	19.78	21.53	0.42	21.83	21.5	22.01	0.11	18.82	18.5	20.39	0.54
	2012	21.98	19.78	23.9	1.27	21.84	21.21	22.27	0.25	18.81	18.39	19.96	0.51
	2013	20.89	19.04	22.97	1.20	21.77	20.14	22.47	0.62	18.67	17.89	19.85	0.56
20	2011	21.28	20.77	21.42	0.19	21.98	21.71	22.12	0.10	17.96	17.75	18.33	0.15
	2012	21.73	18.6	23.84	1.42	22.01	21.71	22.33	0.14	17.9	17.65	18.33	0.18
	2013	21.42	19.43	22.71	1.01	21.94	21.41	22.56	0.45	17.92	17.47	18.51	0.29
21	2011	21.99	21.22	22.86	0.43	21.53	21.38	21.76	0.10	17.37	17.17	17.46	0.08
	2012	22.46	20.89	23.99	1.03	21.56	21.29	22.04	0.17	17.31	17.13	17.45	0.10
	2013	22.16	19.25	23.66	1.04	21.59	20.35	22.6	0.63	17.32	16.64	17.72	0.30
22	2011	21.96	21.79	22.29	0.12	21.87	21.38	22.28	0.26	19.54	18.02	19.83	0.43
	2012	21.93	20.66	23.03	0.49	21.64	21	22.28	0.43	19.58	18.02	19.92	0.45
	2013	22.11	21.17	23.17	0.55	21.62	20.42	22.6	0.76	19.47	18.03	19.97	0.57
23	2011	21.81	20.59	22.38	0.43	21.27	20.49	21.72	0.34	18.37	18.11	18.53	0.11
	2012	22.55	20.59	25.68	1.55	20.9	19.91	21.72	0.64	18.24	17.84	18.53	0.24
	2013	21.66	19.66	23.33	1.17	21.14	19.2	22.59	0.94	18.3	17.81	18.82	0.33
24	2011	21.43	20.94	22.33	0.32	21.37	20.86	22.45	0.41	17.26	16.81	17.94	0.33
	2012	22.28	20.94	23.7	0.81	21.19	20.28	22.45	0.56	17.1	16.54	17.94	0.43
	2013	21.33	19.58	23.27	1.13	21.22	19.79	22.61	0.71	17.37	16.35	18.13	0.57
25	2011	22.07	21.47	25.8	1.05	21.78	21.25	22.47	0.28	19.37	17.5	19.68	0.54
	2012	25.26	21.57	26.91	1.47	21.54	20.8	22.47	0.46	19.44	19.04	19.68	0.18
	2013	21.72	19.47	23.5	1.04	21.65	20.17	22.73	0.78	19.02	16.83	20	0.97
$LSD_{0.05}$	G: 0.19, Y: 0.07, L: 0.07, GY: 0.33, GL: 0.33, YL: 0.11, GYL: 0.57												

Glucosinolates content was positive correlated with protein only in Sołacz (all 3 years) and negative correlated with ADF in Dłoń 2011 and Sołacz—all 3 years of study. Glucosinolates and oil content were negative correlate only in two environments—Sołacz 2013 and Złotniki 2012 (Table 10).

Particular traits have a different degree of significance and a different extent of contribution to the overall multi-trait variability. The multi-trait variability analysis includes identification of the most important traits in the objects' multi-trait variability. A statistical tool which helps solve this problem is

Table 7 Protein content (%) in twenty-five *Brassica* genotypes tested in nine environments

Location	Year	Dłon				Poznań-Sołacz				Złotniki			
Genotyp		Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD
1	2011	18.81	18.46	19.4	0.30	19.02	16.83	20.6	0.98	21.79	19.81	22.73	0.65
	2012	19.73	18.4	21.25	1.08	19.83	16.83	21.87	1.50	22.28	19.81	23.02	0.86
	2013	18.94	17.32	21.23	1.11	18.79	16.11	21.45	1.89	21.92	19.57	23.25	1.55
2	2011	20.73	18.93	23.55	1.59	20.67	19.12	21.54	0.56	22.30	19.67	23.46	0.92
	2012	22.74	19.67	23.8	1.17	20.64	19.62	21.79	0.58	23.45	22.12	25.62	1.05
	2013	18.98	16.54	21.71	1.67	20.59	18.03	22.00	1.06	22.34	19.06	23.88	1.99
3	2011	23.49	22.24	23.87	0.40	18.59	18.15	19.12	0.24	21.09	19.33	25.51	1.61
	2012	23.45	22.12	25.62	1.05	18.88	18.3	19.59	0.37	23.80	23.10	25.63	0.69
	2013	23.05	22.01	23.56	0.61	18.97	17.11	21.64	1.36	20.79	18.82	23.27	1.20
4	2011	20.33	19.19	22.03	1.01	18.46	18.33	18.57	0.07	22.90	21.21	23.29	0.52
	2012	21.23	18.03	22.15	1.02	18.54	18.33	18.85	0.16	23.01	21.21	23.46	0.57
	2013	18.51	16.2	22.09	1.55	18.51	17.21	19.99	0.77	22.73	20.94	23.98	1.15
5	2011	18.47	17.76	20.89	0.77	19.36	18.09	20.23	0.56	20.55	19.04	23.57	1.17
	2012	20.40	19.01	23.57	1.18	19.73	18.09	20.70	0.77	21.41	20.36	22.99	0.76
	2013	18.20	16.36	20.18	1.15	19.23	17.58	21.17	1.12	21.16	19.09	25.5	1.95
6	2011	19.85	19.32	21.72	0.56	20.07	19.52	20.37	0.20	23.33	22.49	23.52	0.25
	2012	21.87	19.89	23.58	1.30	20.18	19.52	21.03	0.33	23.31	22.49	23.56	0.25
	2013	20.23	17.8	22.75	1.30	20.04	18.83	22.24	0.91	23.16	22.37	23.85	0.53
7	2011	17.89	16.87	21.5	1.07	19.10	18.17	19.53	0.36	23.33	22.51	23.56	0.26
	2012	22.64	16.12	23.63	1.89	19.10	18.17	19.88	0.45	23.34	22.51	23.55	0.27
	2013	18.03	16.5	20.42	1.30	19.60	17.81	21.45	0.97	22.63	20.51	23.84	0.96
8	2011	17.81	17.37	18.24	0.25	18.84	18.07	19.21	0.29	23.19	22.71	23.3	0.14
	2012	19.57	16.72	23.56	2.83	18.82	18.07	19.56	0.37	23.13	22.71	23.26	0.13
	2013	17.69	15.19	19.12	1.01	18.71	17.37	20.64	1.02	23.08	22.49	23.72	0.37
9	2011	19.51	17.54	20.57	0.71	19.17	17.91	19.67	0.44	17.86	17.64	18.19	0.16
	2012	18.70	17.52	23.08	1.39	18.81	17.91	19.68	0.57	19.87	19.41	23.55	1.05
	2013	20.05	17.38	23.8	1.70	18.82	16.77	21.40	1.13	17.88	16.94	20.42	0.83
10	2011	18.60	17.76	19.39	0.45	19.30	18.55	20.11	0.36	23.38	23.33	23.47	0.03
	2012	19.40	17.76	21.65	1.57	18.87	17.75	20.11	0.76	23.4	23.33	23.51	0.04
	2013	18.35	17.29	21.21	1.11	19.12	17.58	21.59	1.14	23.4	23.08	23.54	0.12
11	2011	16.99	16.26	17.30	0.27	16.88	16.17	17.92	0.43	22.26	22.16	22.45	0.06
	2012	18.06	15.87	20.20	1.52	16.65	15.73	17.92	0.55	22.27	22.16	22.45	0.07
	2013	16.86	14.96	18.52	1.00	16.92	15.5	19.53	1.00	22.24	22.00	22.4	0.13
12	2011	18.19	17.75	18.45	0.21	18.84	18.42	20.21	0.42	23.23	23.15	23.41	0.07
	2012	23.31	23.15	23.57	0.15	18.86	18.12	20.21	0.46	19.22	17.46	21.60	1.62
	2013	17.98	16.54	19.57	0.85	18.79	17.02	21.84	1.28	23.27	22.87	23.68	0.25
13	2011	17.95	17.21	18.26	0.28	19.91	19.07	20.26	0.32	23.17	23.05	23.35	0.08
	2012	18.12	17.02	19.39	0.62	19.76	19.07	20.25	0.37	23.24	23.05	23.53	0.16
	2013	18.05	16.57	19.16	0.72	19.58	18.00	20.97	0.86	23.21	22.85	23.66	0.23
14	2011	18.29	17.76	20.17	0.61	19.95	19.07	20.42	0.35	23.52	23.37	23.66	0.09
	2012	20.10	18.45	22.88	1.14	20.06	18.44	21.17	0.57	23.47	23.15	23.66	0.15
	2013	23.50	23.15	23.84	0.22	20.26	19.23	21.77	0.63	18.38	15.66	20.45	1.25
15	2011	18.79	17.82	20.35	0.66	19.55	19.14	20.52	0.33	23.11	22.90	23.71	0.20

Table 7 continued

Location	Year	Dłon				Poznań-Sołacz				Złotniki			
Genotyp		Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD
	2012	21.03	17.44	22.77	1.54	19.30	18.22	20.52	0.51	23.25	22.91	23.71	0.26
	2013	18.26	16.20	19.56	1.06	19.56	18.20	20.79	0.81	23.25	22.34	23.91	0.57
16	2011	19.62	18.98	20.42	0.43	19.90	19.28	20.12	0.21	23.21	23.01	23.96	0.32
	2012	19.63	18.22	20.75	0.86	19.99	19.28	20.27	0.24	23.30	23.03	23.99	0.30
	2013	18.93	17.06	20.92	1.17	20.05	18.51	21.30	0.89	23.50	23.14	23.83	0.19
17	2011	19.74	18.53	22.57	0.91	20.39	20.15	20.51	0.10	23.45	23.01	23.99	0.38
	2012	21.66	20.53	22.32	0.54	20.32	19.76	20.87	0.32	23.46	23.00	23.98	0.32
	2013	19.29	17.92	21.64	1.27	20.36	19.27	21.90	0.70	23.62	23.05	23.87	0.25
18	2011	21.69	21.06	22.15	0.31	21.51	20.78	21.82	0.29	22.09	18.21	23.28	1.65
	2012	22.09	19.76	23.6	1.13	21.03	19.96	21.89	0.69	22.31	18.12	23.55	1.73
	2013	21.46	17.96	23.27	1.67	21.38	19.26	22.89	1.05	22.35	18.97	23.83	1.55
19	2011	19.17	18.61	21.16	0.61	19.29	18.79	19.92	0.29	21.32	18.90	21.97	1.13
	2012	20.50	18.36	23.45	2.04	19.06	18.43	19.92	0.44	21.25	18.91	21.97	0.98
	2013	19.41	16.82	22.06	1.97	19.41	17.99	21.79	1.03	21.12	19.06	21.97	0.87
20	2011	18.84	18.60	19.59	0.31	18.96	18.64	19.57	0.21	23.61	23.35	23.78	0.10
	2012	20.39	18.43	23.00	1.90	18.95	18.69	19.57	0.22	23.64	23.35	23.86	0.13
	2013	18.73	17.48	20.51	1.02	18.97	17.90	20.30	0.65	23.64	23.19	23.97	0.20
21	2011	18.28	17.06	19.49	0.60	19.75	19.61	19.96	0.10	23.12	23.01	23.23	0.05
	2012	19.91	17.06	23.46	2.52	19.65	18.94	19.96	0.27	23.18	23.01	23.35	0.09
	2013	18.01	16.45	22.71	1.50	19.69	18.58	21.58	0.87	23.39	23.04	23.99	0.35
22	2011	18.22	17.64	18.74	0.37	19.23	18.69	19.92	0.36	23.55	23.17	23.92	0.21
	2012	20.03	17.26	23.8	2.67	19.56	18.69	20.48	0.63	23.44	23.08	23.89	0.27
	2013	17.88	15.66	20.17	1.25	19.60	18.06	22.29	1.22	23.34	23.10	23.94	0.21
23	2011	18.63	18.35	18.91	0.16	20.11	19.52	20.93	0.38	23.29	22.97	23.84	0.25
	2012	19.52	18.16	21.20	1.13	20.47	19.52	21.73	0.74	23.27	22.97	23.70	0.20
	2013	18.57	17.02	20.78	1.04	20.13	18.46	22.34	1.04	23.06	22.82	23.46	0.17
24	2011	18.84	18.43	21.60	0.79	19.97	19.14	20.40	0.36	23.55	23.01	23.97	0.32
	2012	21.76	17.34	22.89	1.34	20.14	19.14	20.99	0.49	23.58	23.09	23.99	0.29
	2013	18.65	16.54	21.03	1.10	20.09	18.53	21.61	0.88	23.41	22.97	23.99	0.36
25	2011	17.67	17.11	20.48	0.80	19.13	18.10	19.93	0.43	23.58	23.04	23.91	0.19
	2012	20.83	17.74	22.07	1.06	19.48	18.10	20.69	0.69	23.58	23.30	23.88	0.19
	2013	17.69	16.10	20.24	0.98	19.14	17.93	20.69	0.98	23.24	22.24	23.85	0.44
$LSD_{0.05}$	G: 0.22, Y: 0.08, L: 0.08, GY: 0.38, GL: 0.38, YL: 0.13, GYL: 0.65												

canonical variable analysis. The results of the analysis for analyzed objects are presented in Table 11. The multidimensional analysis of the tested traits compared 25 genotypes in respect of five traits simultaneously in all nine environments data observations (Fig. 1). The first and second canonical varieties elucidated 87.98% and 5.81%, respectively, of multivariate variability of genotypes (Fig. 1). Figure 1 shows the variability of analyzed traits in the configuration of the first two canonical variables. On the graph the coordinates of the point for particular genotypes are values of the first and second canonical variables, respectively. The most significant linear relation with the first canonical variable was observed for: NDF, ADF, oil content (positive correlation), protein and glucosinolates (negative correlations)

Table 8 Oil content (%) in twenty-five *Brassica* genotypes tested in nine environments

Location	Year	Dłon				Poznań-Sołacz				Złotniki			
Genotyp		Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD
1	2011	45.16	43.1	45.86	0.70	43.43	42.4	45.28	0.75	39.89	38.55	42.14	0.80
	2012	43.85	40.68	45.48	1.59	42.86	41.56	45.28	0.96	39.48	37.8	43.84	1.66
	2013	43.68	41.48	46.59	1.46	45.11	41.76	47.46	1.98	42.05	39.05	44	1.44
2	2011	42.84	38.82	46.18	2.41	43.33	43.02	43.76	0.23	41.28	39.98	43.49	0.89
	2012	40.53	39.47	42.49	0.79	43.51	43.04	44.16	0.31	41.86	40.15	43.66	1.04
	2013	43.38	41.68	45.72	1.52	43.45	41.02	45.07	1.05	42.37	40.84	43.49	0.78
3	2011	41.18	40	43.98	1.07	43.78	43.16	44.08	0.21	42.15	39.99	44.05	1.39
	2012	41.86	40.15	43.66	1.04	43.91	43.16	44.74	0.46	40.66	36.03	44.77	2.10
	2013	41.15	39.13	44.17	1.71	43.72	41.14	45.58	1.20	44.48	42.23	46.93	1.37
4	2011	43.17	41.26	44.72	1.10	43.04	42.5	44.69	0.61	41.14	38.51	43.94	1.60
	2012	41.96	40.45	47.26	1.58	42.64	42.01	43.73	0.39	40.87	37.65	43.65	2.03
	2013	43	39.27	47.76	2.72	42.85	40.97	45.19	1.34	40.35	39.11	42.4	0.98
5	2011	45.78	44.92	46.2	0.44	42.56	41.36	43.92	0.61	41.6	40.48	44.22	0.90
	2012	41.47	38.29	45.57	1.96	41.86	40.03	43.92	1.18	44.14	40.1	45.81	1.84
	2013	42.67	40.11	46.73	1.84	43.16	40.61	45.29	1.23	41.5	39.51	44.51	1.25
6	2011	43.83	41.02	44.98	1.53	41.74	41.02	42.94	0.86	39.08	38.56	40.19	0.54
	2012	41.55	40.62	43.44	0.95	41.84	41.02	42.99	0.86	38.94	38.41	40.19	0.43
	2013	43.73	41.29	47.22	2.18	42	41.15	43.17	0.60	38.42	37.28	39.95	0.83
7	2011	46.22	41.21	47.26	1.42	42.23	41.81	43.58	0.45	42.05	38.76	43.13	1.11
	2012	41.27	39.96	48.29	2.05	42.36	41.56	44.18	0.72	42.5	40.88	44.04	0.65
	2013	46.59	44.31	48.68	1.20	41.71	39.6	43.82	1.29	42.91	40.85	44.62	1.06
8	2011	45.47	44.43	46.05	0.39	43.85	41.44	44.99	1.29	42.57	36.7	45.9	2.21
	2012	45.39	43.79	46.94	0.88	43.39	42	44.94	1.23	40.9	36.5	42.74	2.01
	2013	46.06	44.94	48.69	0.98	43.12	39.14	44.94	1.48	41.07	36.99	42.17	1.35
9	2011	41.71	40.26	45.42	1.44	42.16	41.67	43.65	0.54	47.04	46.46	47.45	0.29
	2012	46.48	44.37	48.48	1.05	42.44	41.14	43.66	0.84	40.33	36.8	43.12	1.92
	2013	41.88	39.98	43.72	1.23	42.35	39.5	45.52	1.61	46.88	44.02	48.31	1.19
10	2011	43.8	42.82	44.7	0.50	40.55	39.06	41.58	0.58	42.28	40.29	46.75	2.04
	2012	43.76	40.64	45.68	1.33	41.19	39.06	42.69	1.07	42.2	40.05	46.52	2.23
	2013	44.39	39.84	47.39	1.83	41.4	37.59	43.49	1.55	41.36	35.62	46.05	2.89
11	2011	45.95	43.9	46.46	0.60	43.25	42.23	44.03	0.51	47.51	36.37	96.93	20.21
	2012	44.92	41.75	47.88	1.63	43.75	42.23	45.65	0.90	40.08	36.42	45.54	2.92
	2013	46.27	43.95	47.88	1.28	43.35	40.15	44.68	1.20	39.73	35.69	46.38	3.58
12	2011	43.06	42.77	43.44	0.18	42.78	41.35	43.5	0.49	42.5	41.99	43.01	0.30
	2012	42.34	41.69	43.01	0.41	42.76	41.33	43.83	0.54	43.47	42.77	44.64	0.50
	2013	43.71	42.02	45.77	0.97	42.65	39.36	45.45	1.43	42.5	41.5	43.18	0.58
13	2011	43.07	40.45	47.75	1.87	41.75	41.14	43.05	0.56	43.81	42.18	44.43	0.51
	2012	41.71	39.76	43.95	1.56	41.79	41.23	43.05	0.56	43.79	42.18	44.43	0.53
	2013	44.9	42.12	48.7	2.30	41.67	39.23	45.07	1.60	43.53	42.27	44.93	0.85
14	2011	41.01	40.08	44.22	1.20	41.65	40.41	43.05	0.66	39.21	39.04	39.71	0.17
	2012	42.96	40.1	45.49	1.78	42.09	39.61	44.73	1.61	39.28	39	39.71	0.20
	2013	39.34	38.28	40.12	0.62	42.7	41.47	44.27	0.92	43.64	40.6	50.45	3.23
15	2011	42.8	41.78	43.56	0.55	42.58	41.65	42.98	0.31	44.57	42.35	45.77	1.23

Table 8 continued

Location	Year	Dłon				Poznań-Sołacz				Złotniki			
Genotyp		Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD
	2012	42.77	40.08	47.19	1.84	42.79	41.65	43.65	0.43	43.96	42.12	45.84	1.36
	2013	42.44	40.04	47.16	1.78	42.56	40.63	44.75	1.01	43.35	42.17	46.19	1.25
16	2011	46.18	44.96	47.49	0.61	43.06	41.77	46.29	1.51	43.44	41.96	46.11	1.32
	2012	46.18	42.8	48.97	1.53	43.35	41.43	46.14	1.72	42.84	41.94	45.48	1.02
	2013	46.96	44.52	49.89	1.65	43.11	41.23	45.64	1.24	42.71	41.44	44.41	0.88
17	2011	45.02	42.43	46.17	0.94	41.59	41.16	42.42	0.33	40.91	40.16	42	0.51
	2012	44.48	42.07	47.2	1.70	41.91	40.88	43.33	0.87	39.6	35.35	42	2.48
	2013	45.6	40.44	48.38	2.14	41.52	38.9	43.4	1.30	41.16	35.91	45.64	1.99
18	2011	41.66	40.63	43.07	0.73	38.47	36.51	43.44	1.90	39.05	37.19	43.54	2.09
	2012	41.92	40.39	46.35	1.75	39.72	36.72	42.54	2.05	38.26	36.73	41.44	1.36
	2013	41.91	37.6	45.58	2.74	39.72	31.22	43.95	2.94	38.53	36.29	43.65	2.05
19	2011	44.64	43.15	45.58	0.63	42.68	42.18	43	0.24	43.04	39.74	44.9	1.94
	2012	43.87	39.3	45.67	2.01	42.68	42.09	43.4	0.41	42.42	37	47.93	3.30
	2013	44.12	41.15	47.64	2.26	42.03	36.51	44.49	2.12	41.8	37.05	47.57	3.68
20	2011	45.85	45.15	46.17	0.30	42.81	42.5	43.23	0.18	41.45	38	41.9	0.97
	2012	45.28	43.11	46.97	1.20	42.88	42.5	43.23	0.23	40.73	36.95	41.93	1.81
	2013	45.92	43.14	47.68	1.42	42.76	41.45	43.62	0.65	39.51	36.3	41.84	1.96
21	2011	46.25	45.12	47.71	0.57	41.96	41.07	42.55	0.41	40.26	36.02	41.99	2.32
	2012	45.93	42.49	48.46	1.66	42.21	41.66	43.17	0.35	40.85	36.29	41.92	1.84
	2013	46.63	41.63	49.69	1.78	42.16	39.86	44.78	1.45	39.56	36.17	45.36	2.79
22	2011	46.19	45.49	47.1	0.44	42.35	41.71	43.36	0.41	41.09	36.43	43.58	3.16
	2012	45.87	40.49	47.1	1.69	42.04	40.64	43.36	0.76	38.81	35.99	43.58	3.33
	2013	46.82	42.01	49.65	1.88	41.92	38.37	44.21	1.48	40.45	35.9	43.9	3.50
23	2011	45.14	44.58	45.87	0.30	40.63	39.63	41.37	0.43	40.12	36.1	42.83	2.83
	2012	44.94	41.07	46.91	1.32	40.17	38.88	41.37	0.80	38.54	35.2	42.75	3.06
	2013	45.49	42.99	48.96	1.61	40.44	38.08	43.05	1.53	39.48	35.56	42.99	2.21
24	2011	46.94	43.19	47.45	1.06	42.64	42.11	43.73	0.42	40.83	37.69	41.51	1.18
	2012	45.16	41.2	49.18	2.19	42.49	41.6	43.73	0.56	41.01	38.22	41.69	0.82
	2013	46.97	44.7	49.12	1.33	41.69	39.89	43.61	1.22	40.66	38.41	41.84	1.13
25	2011	46.77	41	48.18	1.65	42.41	41.66	43.52	0.44	39.97	39.06	43.52	1.54
	2012	44.76	41	47.75	2.06	42.08	40.89	43.52	0.71	40.11	39.06	43.98	1.83
	2013	46.85	44.82	49.66	1.53	41.81	40	43.96	1.29	40.94	39.07	43.74	1.78
$LSD_{0.05}$	G: 0.48, Y: 0.17, L: 0.17, GY: 0.83, GL: 0.83, YL: 0.29, GYL: 1.44												

(Table 11). The largest differences with regard to all five traits (measured in Mahalanobis distances) were recorded for genotypes 6 and 11 (the Mahalanobis distance between them was 7.62). The largest similarities were recorded for 15 and 25 (1.50) (Table 12).

Mahalanobis distances between all pairs of genotypes across nine environments were presented in Table 13. The smallest average value of Mahalanobis distance from nine environmental we observed for genotypes 16 and 24 (1.61). However, the largest for lines 6 and 11 (11.71). The most stable pair (the smallest range of Mahalanobis distance) was 16 and 24 (1.96). However, the least stable pair (range equal to 23.93) was 6 and 11 (Table 13).

For Mahalanobis distances values in particular environments we observed large range in Sołacz 2011

Table 9 Glucosinolate content (umol/g) in twenty-five *Brassica* genotypes tested in nine environments

Location	Year	Dłon				Poznań-Sołacz				Złotniki			
Genotyp		Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD
1	2011	12.38	11.63	13.12	0.45	14.43	11.00	16.81	1.50	12.54	9.62	15.67	1.47
	2012	13.78	11.65	16.74	1.75	14.61	11	16.68	1.61	12.07	9.51	14.33	1.55
	2013	12.32	10.45	16.54	1.88	11.71	8.74	14.82	1.76	10.03	9.15	11.67	0.81
2	2011	35.55	29.3	45.49	4.80	30.86	27.82	32.55	1.27	31.31	28.89	32.92	1.24
	2012	30.1	27.1	32.92	2.09	30.29	20.41	45.2	5.51	30.88	23.81	37.67	3.76
	2013	35.6	11.84	45.31	9.72	28.62	13.2	36.91	5.48	30.16	25.96	45.4	4.67
3	2011	27.48	17.05	43.92	5.44	26.45	23.95	28.12	0.89	28.12	23.13	31.97	2.73
	2012	30.88	23.81	37.67	3.76	26.02	23.33	28.47	1.46	28.94	17.05	41.52	5.16
	2013	31.39	26.88	33.8	1.82	28.16	17.72	35.27	4.83	29.37	19.01	49.1	8.27
4	2011	13.79	11.28	16.38	1.39	13.82	12.96	15.75	0.64	11.72	9.14	13.31	1.01
	2012	14.57	12.58	21.74	2.16	14.27	12.61	19.29	1.62	12.41	9.14	14.27	1.42
	2013	15.35	8.75	27.77	4.37	14.34	11.07	26.17	3.70	12.11	8.64	18.9	2.71
5	2011	31.64	28.51	45.55	4.08	30.93	23.93	40.9	4.55	27.69	15.15	32.97	4.60
	2012	28.45	15.15	32.79	4.66	32.28	20.5	53.81	10.31	31.44	14.15	42.31	8.66
	2013	29.22	14.45	45.93	9.65	25.56	14.13	33.41	5.35	32.13	27.06	45.24	4.09
6	2011	60.87	53.99	74.36	5.48	55.74	53.8	57.37	1.09	45.62	41.35	51.77	3.91
	2012	62.98	58.38	69.79	3.61	55.36	47.51	60.06	3.40	47.06	41.01	51.82	3.52
	2013	57.72	27.44	75.56	12.88	51.31	26.8	59.87	8.12	46.92	41.22	53.88	4.05
7	2011	16.66	11.29	22.28	3.62	15.1	13.12	16.76	0.88	14.29	12.1	15.41	0.94
	2012	15.88	12.5	17.42	1.50	15.29	13.12	18.43	1.30	13.45	11.03	15.52	1.59
	2013	15.09	10.91	23.93	4.34	17.02	12.42	56.13	10.89	12.19	10.37	14.35	1.24
8	2011	13.84	12.28	14.84	0.67	13.77	12.04	15.76	1.48	13.79	10.26	14.69	1.09
	2012	13.67	10.11	16.81	1.96	15.2	12.04	21.09	2.69	13.37	10.26	14.88	1.23
	2013	14.19	9.21	27.13	4.68	13.74	11.98	15.97	1.16	12.34	9.07	14.47	1.46
9	2011	30.18	29.54	30.62	0.30	31.39	23.44	33.6	2.78	35.9	23.05	45.47	6.65
	2012	35.12	23.05	45.69	6.04	31.37	23.44	45.43	4.62	29.73	28.66	30.52	0.58
	2013	25.75	17.8	30.78	4.65	29.25	14.85	47.49	7.94	30.51	13.37	45.32	10.49
10	2011	11.72	10.02	14.12	1.08	13.54	11.55	16.25	1.42	9.91	8.69	10.69	0.54
	2012	12.76	9.67	19.84	2.46	12.87	11.31	16.25	1.66	9.47	7.8	10.69	1.00
	2013	12.86	8.57	22.86	3.94	14.51	10.57	31	5.18	9.78	6.7	12.59	1.65
11	2011	12.71	7.59	17.54	2.70	9.55	8.51	11.46	0.71	10.37	6.1	19.11	2.71
	2012	11.26	6.21	16.16	2.99	8.86	6.83	11.35	1.11	10.08	9.1	12.88	0.88
	2013	10.87	7.02	16.61	3.38	10.59	7.36	18.15	3.31	9.96	7.1	16.78	2.05
12	2011	17.25	13.13	23.42	2.35	16.53	14.29	18.55	1.27	17.85	10.56	31.53	6.54
	2012	14.94	9.85	23.87	4.81	16.61	14.36	23.29	2.17	17.4	11.13	32.39	4.86
	2013	14.81	6.7	32.44	6.43	15.56	10.41	23.98	4.25	15.13	10.2	23.22	4.62
13	2011	10.02	8.21	12.49	1.05	11.91	10.52	12.75	0.71	13.78	6.66	29.4	7.45
	2012	11.11	6.23	16.78	2.82	11.15	8.5	12.95	1.32	11.57	6.66	26.86	5.89
	2013	9.95	7.12	17.82	2.65	11.38	6.99	18.55	2.62	12.59	6.42	19.95	4.74
14	2011	38.62	33.12	42.63	2.66	32.99	30.52	37.02	1.55	33.85	27.64	45.89	4.48
	2012	38.64	29.86	44.99	4.89	36.98	33.86	45.9	2.93	35.14	23.97	45.89	5.98
	2013	36.27	31.26	41.96	4.00	36.63	30.76	45.46	3.63	34.38	19.85	45.94	7.55
15	2011	30.75	19.67	33.1	3.36	21.79	18.68	27.9	2.00	22.76	15	23.91	2.17

Table 9 continued

Location	Year	Dłon				Poznań-Sołacz				Złotniki			
Genotyp		Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD
	2012	23.5	15.64	36.02	4.99	22.23	19.91	27.9	1.81	22.43	15	23.91	2.29
	2013	28.16	12.04	42.46	7.25	22.53	13.32	32.75	5.34	20.29	15.02	23.99	4.05
16	2011	34.82	27.14	49.01	5.58	38.11	36.05	45.9	3.11	36.15	25.54	39.71	4.12
	2012	32.53	27.03	45.9	5.79	37.15	20.96	45.3	5.00	37.28	32.04	40.83	2.59
	2013	42.87	31.88	60.2	9.64	39.73	21.61	46.97	5.90	36.6	25.75	40.75	4.82
17	2011	23.64	20.3	28.51	2.17	27.7	26.53	32.98	1.53	30.26	22.27	51.67	9.76
	2012	23.11	20.26	27.21	1.94	27.93	25.75	32.98	1.57	32.85	22.27	59.67	11.50
	2013	21.83	11.03	48.45	9.02	29.54	21.54	45.9	7.23	27.73	20.96	61.76	12.57
18	2011	44.9	23.81	55.04	7.72	42.39	40.86	44.56	1.12	42.13	29.71	61.75	8.72
	2012	43.33	18.35	55.5	10.89	42.44	40.32	46.69	1.78	37.12	30.89	55.15	6.07
	2013	41.13	20.53	58.99	11.13	39.51	21.75	50.11	8.52	41.01	30.05	69.37	12.58
19	2011	37.04	21.32	44.77	7.80	32.81	27.58	45.93	5.36	25.96	23.78	29.78	1.41
	2012	36.68	21.29	47.23	8.17	32.3	25.78	45.93	5.67	26.69	23.8	29.78	1.74
	2013	30.08	16.2	51.23	10.67	32.53	19.5	45.17	7.35	28.97	22.19	42.6	4.82
20	2011	32.8	21.58	45.95	5.91	28.54	27.07	30.22	0.80	25.87	18.07	49.93	12.46
	2012	33.46	21.58	48.8	7.38	29.1	26.37	33.03	1.67	28.16	18.14	49.5	12.45
	2013	28.86	13.34	50.05	10.17	30.14	22.12	39.78	4.45	22.4	12.19	42.23	6.59
21	2011	38.88	22.84	45.78	6.27	30.52	29.24	31.74	0.71	24.82	23.01	31.26	1.94
	2012	35.48	22.84	45.62	6.93	30.24	27.59	31.74	1.19	25.5	21.02	31.6	3.35
	2013	32.97	11.14	47.83	11.10	30.2	17.4	43.59	6.42	25.16	17.31	33.28	4.53
22	2011	41.48	32.81	45.73	3.92	38.81	32.59	45.87	4.53	36.88	25.05	47.52	8.98
	2012	39.24	23.38	50.72	6.42	39.79	32.59	45.72	4.86	36.19	25.83	47.72	8.39
	2013	44.07	29.14	60.07	9.54	35.23	21	47.04	8.51	35.64	19.16	47.89	8.28
23	2011	49.6	39.98	53.37	3.15	40.76	39.03	42.9	1.03	43.36	29.18	47.99	7.29
	2012	46.8	26.45	53.44	7.88	41.99	39.03	47.7	2.49	40.19	29.21	47.99	8.50
	2013	48.38	28.66	60.36	8.41	40.66	30.48	49.97	4.80	35.57	23.98	47.87	8.66
24	2011	40.02	20.09	61.41	13.06	40.11	38.71	41.31	0.71	30.07	14.89	49.13	10.05
	2012	41.02	20.09	61.69	15.97	40.76	38.3	48.68	2.64	30.63	15.2	49.1	8.37
	2013	44.87	20.57	66.54	13.28	40.6	27.28	50.12	6.39	33.61	23.38	42.98	8.63
25	2011	23.86	11.32	29.05	5.12	25.18	19	29.12	3.75	22.73	19.64	29.64	3.05
	2012	25.8	20.05	38.64	5.11	25.19	19.02	30.15	3.96	21.65	17.41	25.85	2.36
	2013	23.66	10.84	47.85	9.14	28.14	22.4	37.8	4.99	20.88	16.63	28.45	3.18
$LSD_{0.05}$	G: 1.35, Y: 0.47, L: 0.47, GY: 2.33, GL: 2.33, YL: 0.81, GYL: 4.04												

with the largest mean value (Fig. 2). Generally, in 2011 Mahalanobis distance values were larger than in 2012 and 2013. In 2013 these values were the smallest (Fig. 2).

Discussion

Understanding the genetic basis of seed quality traits and environmental factors that influence their expression is important for efficient rapeseed breeding (Jiang et al. 2014). To utilize genetic diversity present in interspecific cross-derived *Brassica* lines originated from Department of Genetics and Plant Breeding

Table 10 Correlation coefficients between observed traits calculated on the basis of genotypes' means in environments independent

Trait	Year	Location	NDF	ADF	Protein content	Oil content
ADF	2011	Dłoń	0.4028*			
	2012	Dłoń	− 0.0759			
	2013	Dłoń	0.7359***			
	2011	Sołacz	0.5707**			
	2012	Sołacz	0.6278***			
	2013	Sołacz	0.70***			
	2011	Złotniki	0.4375*			
	2012	Złotniki	0.4518*			
	2013	Złotniki	0.6767***			
Protein content	2011	Dłoń	− 0.6268***	− 0.5341**		
	2012	Dłoń	− 0.2771	− 0.1391		
	2013	Dłoń	− 0.7512***	− 0.8506***		
	2011	Sołacz	− 0.6183***	− 0.7951***		
	2012	Sołacz	− 0.6489***	− 0.7947***		
	2013	Sołacz	− 0.7626***	− 0.8077***		
	2011	Złotniki	− 0.2746	− 0.6374***		
	2012	Złotniki	− 0.4056*	− 0.3985*		
	2013	Złotniki	− 0.4032*	− 0.7148***		
Oil content	2011	Dłoń	0.3036	0.4116*	− 0.5677**	
	2012	Dłoń	0.1388	0.2375	− 0.5576**	
	2013	Dłoń	0.5407**	0.6259***	− 0.7439***	
	2011	Sołacz	0.4589*	0.5116**	− 0.6226***	
	2012	Sołacz	0.47*	0.4602*	− 0.5402**	
	2013	Sołacz	0.6287***	0.4997*	− 0.5375**	
	2011	Złotniki	0.4416*	0.2152	− 0.458*	
	2012	Złotniki	0.0848	0.2937	− 0.2472	
	2013	Złotniki	0.406*	0.4714*	− 0.6136**	
Glucosinolates content	2011	Dłoń	− 0.619***	− 0.4405*	0.2911	− 0.0374
	2012	Dłoń	− 0.4853*	− 0.2911	0.1902	0.0985
	2013	Dłoń	− 0.6921***	− 0.3609	0.3868	− 0.0414
	2011	Sołacz	− 0.6939***	− 0.6386***	0.6139**	− 0.3632
	2012	Sołacz	− 0.7339***	− 0.6735***	0.6444***	− 0.3849
	2013	Sołacz	− 0.7236***	− 0.7243***	0.6676***	− 0.4085*
	2011	Złotniki	− 0.5313**	− 0.1574	− 0.117	− 0.3563
	2012	Złotniki	− 0.6487***	− 0.198	0.1246	− 0.4079*
	2013	Złotniki	− 0.5312**	− 0.0947	− 0.1928	− 0.169

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

collection of PULS and improve this genotypes itself, it was crucial to evaluate the extent of genetic diversity and to determine which of the tested factors i.e. genotype, year or location has the most significant effect on studied quality traits. Our results provide evidence for large phenotypic variability within the studied *Brassica* lines for oil, protein, glucosinolates and fiber (ADF and NDF) levels in seeds. The results of the present study are supported by the findings of Marjenovic-Jeromela et al. (2011) and Abideen et al.

Table 11 Correlation coefficients between the first two principal components and the observed traits

Trait	First canonical variable V_1	Second canonical variable V_2
NDF	0.8477***	0.2385
ADF	0.7038***	0.4038*
Protein content	− 0.5182**	0.3466
Oil content	0.4474*	− 0.417*
Glucosinolates content	− 0.9969***	0.0642
Percentage of elucidated multivariate variability	87.98	5.81

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

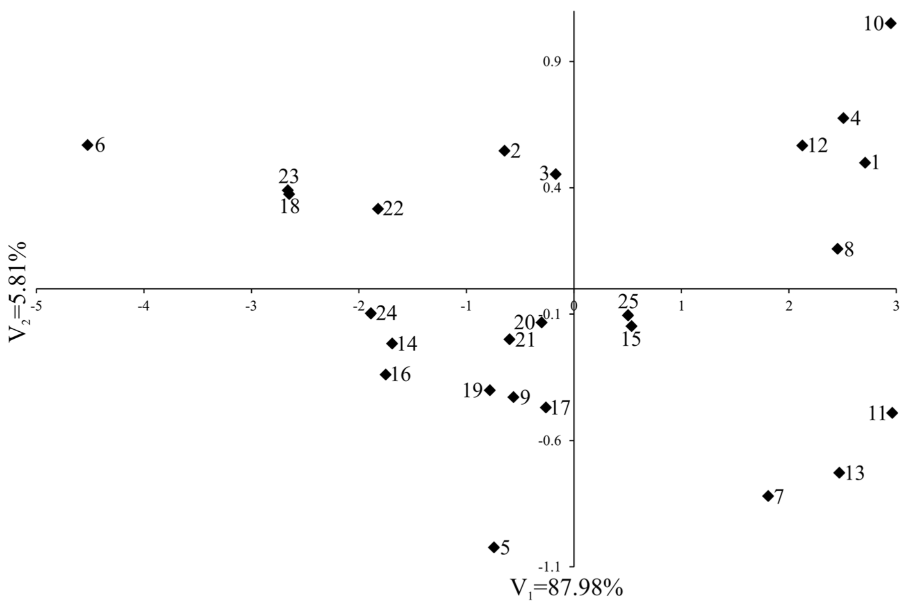

Fig. 1 Distribution of 25 *Brassica* genotypes in the space of two first canonical variables (Genotypes code see in Table 1)

(2013) who recorded significant variability in oil content and other quality traits in oilseed brassicas. Moreover, our results showed that all tested quality traits i.e. fiber, protein, oil and glucosinolate were significantly affected by environments. For example, a higher oil, fiber and glucosinolates content were observed in Dłoń than in Złotniki and Poznań-Sołacz. On the other hand protein content was in analyzed *Brassica* lines slightly higher in Złotniki than in other locations. Our results are in agreement with that of Si et al. (2003) who reported that environment had a much larger impact than genotype on protein content in canola seed, and its genetic variance and genotype × year × location interaction were significant. Similarly, Wu et al. (2005) claimed that since genotype × environment (GE) interaction effects can cause genotype variation in seed quality traits across environments, the estimation of genetic main effect and GE interaction effect can demonstrate the degree of environmental influence on the genotypes and be useful for increasing selection efficiency for quality improvement.

In our study analysis of variance indicated that all interactions were also significant for all the traits of study (except year × location interaction for glucosinolates). Because of the fact that quality parameters are affected by genetic and environment, agronomic conditions, such as soil state, can affect seed quality parameters. In our experiment soil types and weather conditions differs among all locations. The results of

Table 12 Mahalanobis distances between studied genotypes estimated on the basis of data form all environments

	1	2	3	4	5	6	7	8	9	10	11	12
2	3.39											
3	2.93	0.49										
4	0.81	3.23	2.77									
5	3.85	1.78	1.78	3.68								
6	7.26	3.93	4.40	7.04	4.11							
7	1.96	2.93	2.47	1.73	2.66	6.52						
8	0.55	3.14	2.66	0.83	3.48	7.01	1.49					
9	3.50	1.62	1.66	3.58	1.49	4.29	3.07	3.25				
10	0.63	3.66	3.21	0.81	4.28	7.50	2.39	1.06	3.94			
11	1.13	3.88	3.43	1.68	3.88	7.62	1.97	1.11	3.54	1.67		
12	0.77	2.91	2.48	1.32	3.51	6.75	2.15	0.93	2.94	1.18	1.43	
13	1.32	3.42	2.95	1.66	3.36	7.16	1.34	1.08	3.24	1.90	0.97	1.47
14	4.48	1.54	1.86	4.37	1.49	3.05	3.76	4.23	1.52	4.83	4.71	3.96
15	2.33	1.39	0.95	2.20	1.68	5.13	1.59	1.96	1.74	2.72	2.64	1.99
16	4.61	1.55	1.90	4.56	1.82	3.14	3.86	4.29	1.73	4.98	4.83	4.07
17	3.18	1.16	1.00	3.11	1.21	4.47	2.30	2.85	1.42	3.59	3.39	2.74
18	5.42	2.23	2.66	5.22	2.50	2.07	4.74	5.20	2.63	5.68	5.78	4.90
19	3.61	1.13	1.23	3.56	1.00	3.92	2.89	3.30	0.76	4.01	3.76	3.10
20	3.09	0.89	0.79	3.07	1.41	4.36	2.54	2.80	0.99	3.48	3.34	2.56
21	3.39	0.91	0.97	3.36	1.28	4.09	2.79	3.10	0.87	3.78	3.61	2.85
22	4.55	1.29	1.74	4.41	1.87	2.77	3.95	4.28	1.72	4.84	4.89	4.02
23	5.38	2.14	2.60	5.25	2.51	2.00	4.80	5.15	2.36	5.66	5.70	4.81
24	4.66	1.46	1.87	4.59	1.86	2.88	3.97	4.37	1.74	5.01	4.94	4.11
25	2.33	1.37	0.94	2.18	1.62	5.08	1.64	1.98	1.66	2.72	2.64	1.99

	13	14	15	16	17	18	19	20	21	22	23	24
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14	4.21											
15	2.12	2.37										
16	4.35	1.23	2.43									
17	2.77	1.60	1.00	1.73								
18	5.27	1.20	3.36	1.88	2.64							
19	3.31	1.08	1.47	1.27	0.90	2.21						
20	2.87	1.53	1.02	1.58	0.63	2.59	0.65					

Table 12 continued

	13	14	15	16	17	18	19	20	21	22	23	24
21	3.14	1.23	1.29	1.35	0.71	2.31	0.39	0.32				
22	4.48	0.96	2.45	0.96	1.91	1.34	1.30	1.65	1.40			
23	5.27	1.21	3.32	1.52	2.66	0.77	2.05	2.46	2.17	0.97		
24	4.45	0.91	2.50	0.45	1.77	1.46	1.27	1.61	1.34	0.67	1.14	
25	2.16	2.31	0.19	2.44	1.02	3.29	1.42	1.00	1.26	2.40	3.26	2.49
$D_{0.05}$ = 5.73												

field trials conducted in three tested locations (Dłoń, Złotniki, Poznań-Sołacz) confirmed the impact of soils and environmental conditions, especially water regime on particular seeds compound levels. Both, soils rich in fine clay particles, called 'heavy soils', which was available in Dłoń and luvisols, like those in Złotniki contains minerals and organic fractions sufficient to support cropping. This types of soils are used to be potentially very fertile when treated in the right way. On the other hand, in Poznań-Sołacz there are light, sandy soils. Moreover, the highest cumulative precipitation between three tested locations over a 3 year period were observed similarly like better soils in Dłoń and Złotniki. Thoroughly these conditions could be responsible for a higher oil, fiber and glucosinolates contents, observed in Dłoń than in Złotniki and Poznań-Sołacz.

It has been shown that canola protein content is affected by soil nitrogen level; higher nitrogen levels can lead to higher protein and glucosinolate contents and therefore lower oil contents (Aminpanah 2013). Similarly, high sulfur levels in soil, due to fertilizer, are known to increase the glucosinolate and the protein contents of canola seeds.

Furthermore, in canola, it is known that oil and protein contents follow an inverese relationship—the higher the oil and the lower the protein content. Seed protein content like other seed quality traits of rapeseed is a quantitative trait governed by additive gene action, so while many of the QTL for increased oil concentration are linked in coupling phase with QTL for decreased protein concentration (Gül et al. 2003), there are also many independent QTL for oil and protein concentration (Zhao et al. 2006). Therefore, in most cases, protein concentration will decrease when oil concentration is increased; however, there may also be cases where protein concentration is nearly maintained when oil concentration is increased. This literature data are confirmed by our results, since higher oil contents were observed in Dłoń compared to Złotniki, lower protein contents were expected in Dłoń when compared to Złotniki respectively. Besides, detailed analysis of these quality traits showed that in eight environments oil content was negative correlated with protein content and only in Złotniki 2012 these two traits were not correlated. Our results were consistent with those obtained by Khan et al. (2008) and Marjenovic-Jeromela et al. (2011), who reported significant and negative correlation between this two traits. However, this results were contrary to data obtained by Aytaç and Kinaci (2009), because they found significant and positive correlation between protein and oil content in *Brassica* oilseed.

Significant and positive association has been reported between protein content and glucosinolates (Ahmad et al. 2013). Our results exhibited that glucosinolates content was positive correlated with protein only in Sołacz (all 3 years). The differences between the results of the present study and those in previous studies could be due to the differences in the material and environmental conditions in which the studies were conducted.

According to Dimov et al. (2012) negative correlations between protein content of the meal and fibre content found in all *Brassica* DH populations is expected because selection for low fibre content will lead to an increase of protein content in the meal. Our results proved that protein content was exactly negative correlated almost in all analyzed environments with NDF (except Dłoń 2012 and Złotniki 2012) and ADF (except Dłoń 2012).

In the present study, it was found that particular traits have a different degree of significance and a different extent of contribution to overall multi-trait

Table 13 Mahalanobis distances between genotypes across environments

Comp.	Min–Max	Mean	Comp.	Min–Max	Mean	Comp.	Min–Max	Mean
1 versus 2	3.34–10.93	6.26	3 versus 7	3.51–17.47	7.67	5 versus 16	2.47–8.15	4.93
1 versus 3	3.25–11.46	5.60	3 versus 8	3.10–13.25	6.61	5 versus 17	1.55–8.60	4.92
1 versus 4	1.09–4.30	2.54	3 versus 9	1.38–8.18	4.43	5 versus 18	2.58–8.26	4.90
1 versus 5	3.09–9.95	6.19	3 versus 10	3.82–13.21	7.46	5 versus 19	1.54–5.95	3.47
1 versus 6	6.39–27.67	10.98	3 versus 11	3.80–13.88	7.30	5 versus 20	1.31–7.94	4.41
1 versus 7	2.15–17.64	5.67	3 versus 12	2.63–12.43	7.13	5 versus 21	1.19–8.38	4.58
1 versus 8	1.05–7.40	3.33	3 versus 13	3.30–12.27	6.55	5 versus 22	2.12–6.26	4.40
1 versus 9	4.18–9.49	6.20	3 versus 14	1.51–13.01	5.28	5 versus 23	3.18–7.53	5.03
1 versus 10	0.60–10.01	3.50	3 versus 15	1.36–10.94	4.94	5 versus 24	2.70–8.84	5.20
1 versus 11	1.86–6.68	3.81	3 versus 16	2.07–11.03	5.48	5 versus 25	1.41–6.66	4.15
1 versus 12	1.41–6.83	4.07	3 versus 17	1.96–11.60	5.03	6 versus 7	5.63–18.55	8.81
1 versus 13	2.36–5.27	3.54	3 versus 18	2.17–10.60	5.54	6 versus 8	5.58–25.68	10.19
1 versus 14	5.02–10.32	6.84	3 versus 19	1.74–9.48	4.63	6 versus 9	4.52–22.27	9.11
1 versus 15	2.84–6.13	4.13	3 versus 20	0.79–10.64	4.58	6 versus 10	6.45–28.29	11.22
1 versus 16	4.98–10.69	6.94	3 versus 21	1.13–11.68	5.40	6 versus 11	6.97–30.90	11.71
1 versus 17	3.45–8.97	5.47	3 versus 22	1.86–11.91	5.58	6 versus 12	6.72–26.82	10.97
1 versus 18	4.43–13.89	7.67	3 versus 23	2.53–11.96	6.29	6 versus 13	6.16–28.72	10.87
1 versus 19	3.15–8.85	5.48	3 versus 24	2.29–11.97	6.00	6 versus 14	2.93–23.37	7.48
1 versus 20	3.03–7.34	5.19	3 versus 25	1.56–12.13	4.71	6 versus 15	4.65–24.19	8.53
1 versus 21	3.34–8.88	5.65	4 versus 5	2.38–8.88	6.34	6 versus 16	3.17–21.06	7.03
1 versus 22	4.59–11.72	6.54	4 versus 6	6.17–26.60	10.51	6 versus 17	4.54–24.66	8.64
1 versus 23	4.92–12.32	7.42	4 versus 7	2.35–16.06	5.22	6 versus 18	1.74–18.74	5.48
1 versus 24	4.88–11.65	7.26	4 versus 8	1.09–4.96	3.16	6 versus 19	3.44–20.33	7.14
1 versus 25	3.05–5.87	4.07	4 versus 9	2.89–9.59	6.54	6 versus 20	4.02–21.15	7.46
2 versus 3	2.25–9.86	6.31	4 versus 10	0.95–7.53	2.68	6 versus 21	4.18–22.39	7.94
2 versus 4	3.34–10.27	6.10	4 versus 11	1.83–6.30	3.61	6 versus 22	1.96–18.52	5.70
2 versus 5	2.51–9.53	4.67	4 versus 12	0.60–7.61	3.65	6 versus 23	2.38–18.71	5.49
2 versus 6	3.52–20.87	7.56	4 versus 13	1.77–5.78	3.82	6 versus 24	2.84–19.79	6.89
2 versus 7	2.93–16.46	6.54	4 versus 14	4.47–9.77	6.92	6 versus 25	4.27–24.20	8.42
2 versus 8	3.06–8.28	5.58	4 versus 15	1.70–5.83	3.77	7 versus 8	0.37–15.03	3.97
2 versus 9	2.65–9.99	6.67	4 versus 16	4.56–11.21	7.03	7 versus 9	4.43–18.00	8.27
2 versus 10	3.78–10.97	6.74	4 versus 17	2.82–8.92	5.79	7 versus 10	2.04–18.05	5.51
2 versus 11	3.84–15.84	7.71	4 versus 18	4.15–13.92	7.59	7 versus 11	1.49–20.62	5.99
2 versus 12	3.23–9.19	5.71	4 versus 19	2.78–8.76	5.57	7 versus 12	2.17–17.40	6.60
2 versus 13	3.31–12.10	6.34	4 versus 20	2.84–7.16	5.08	7 versus 13	1.60–17.60	4.89
2 versus 14	2.51–9.28	5.67	4 versus 21	2.84–8.94	5.79	7 versus 14	4.29–19.52	7.67
2 versus 15	1.58–8.89	4.57	4 versus 22	3.71–11.44	6.28	7 versus 15	1.61–15.98	4.91
2 versus 16	2.30–10.72	4.86	4 versus 23	4.58–12.18	7.21	7 versus 16	3.70–19.57	7.19
2 versus 17	2.27–10.95	5.46	4 versus 24	4.57–11.96	7.30	7 versus 17	2.37–18.70	6.29
2 versus 18	2.21–9.59	4.78	4 versus 25	2.67–5.73	4.06	7 versus 18	4.38–18.32	7.53
2 versus 19	1.21–9.09	4.15	5 versus 6	4.01–22.07	7.83	7 versus 19	2.47–16.69	5.93
2 versus 20	2.05–9.71	4.69	5 versus 7	3.50–17.60	7.08	7 versus 20	1.84–15.69	5.37
2 versus 21	2.28–10.94	5.01	5 versus 8	3.01–11.49	6.54	7 versus 21	2.23–17.59	6.16
2 versus 22	2.28–8.55	4.79	5 versus 9	1.28–7.83	4.86	7 versus 22	3.61–17.65	6.47
2 versus 23	1.87–9.54	5.21	5 versus 10	3.71–14.04	7.84	7 versus 23	4.15–18.17	7.33

Table 13 continued

Comp.	Min–Max	Mean	Comp.	Min–Max	Mean	Comp.	Min–Max	Mean
2 versus 24	2.39–11.26	5.19	5 versus 11	3.61–11.47	7.01	7 versus 24	3.78–19.17	7.18
2 versus 25	2.00–9.08	5.04	5 versus 12	2.38–9.19	6.36	7 versus 25	1.41–17.55	4.70
3 versus 4	2.65–11.25	6.00	5 versus 13	2.70–9.66	6.19	8 versus 9	3.62–10.60	7.09
3 versus 5	0.76–12.26	5.14	5 versus 14	1.99–7.55	4.66	8 versus 10	1.28–5.82	2.86
3 versus 6	3.98–23.33	8.95	5 versus 15	0.94–6.98	4.44	8 versus 11	1.12–10.58	3.94
8 versus 12	1.10–8.52	4.14	11 versus 17	2.90–11.40	6.25	15 versus 21	1.32–4.43	3.19
8 versus 13	1.83–8.53	3.61	11 versus 18	5.19–17.83	8.76	15 versus 22	2.32–8.33	4.28
8 versus 14	4.28–11.39	6.95	11 versus 19	3.24–12.37	6.00	15 versus 23	3.10–8.72	4.70
8 versus 15	1.87–7.03	3.65	11 versus 20	2.73–10.78	5.44	15 versus 24	3.07–8.32	4.61
8 versus 16	4.19–12.41	6.38	11 versus 21	2.95–11.34	6.05	15 versus 25	1.24–4.38	2.28
8 versus 17	2.87–11.52	5.48	11 versus 22	4.23–14.66	7.03	16 versus 17	1.32–6.63	2.86
8 versus 18	4.64–14.83	7.47	11 versus 23	4.82–15.61	7.78	16 versus 18	2.54–7.24	4.31
8 versus 19	2.83–10.29	5.14	11 versus 24	4.55–15.35	7.67	16 versus 19	2.02–4.19	3.11
8 versus 20	2.26–9.27	4.44	11 versus 25	1.97–8.70	4.61	16 versus 20	2.01–5.30	2.84
8 versus 21	2.44–9.58	4.83	12 versus 13	1.69–9.68	4.26	16 versus 21	1.90–4.47	2.77
8 versus 22	3.80–12.63	5.93	12 versus 14	4.47–10.47	7.06	16 versus 22	1.48–4.51	3.05
8 versus 23	3.81–13.36	6.77	12 versus 15	1.85–9.50	4.67	16 versus 23	1.63–5.18	3.01
8 versus 24	4.12–13.01	6.47	12 versus 16	4.46–11.38	7.41	16 versus 24	0.78–2.74	1.61
8 versus 25	1.51–8.97	3.53	12 versus 17	2.99–11.56	6.37	16 versus 25	2.37–6.34	4.01
9 versus 10	3.97–12.61	7.74	12 versus 18	4.38–13.17	7.78	17 versus 18	2.20–8.81	4.83
9 versus 11	3.77–10.91	6.95	12 versus 19	2.83–8.29	5.67	17 versus 19	1.85–5.99	3.54
9 versus 12	2.95–10.77	6.73	12 versus 20	2.75–10.68	5.44	17 versus 20	1.73–5.61	2.69
9 versus 13	3.30–10.82	6.68	12 versus 21	2.78–11.06	5.94	17 versus 21	1.05–5.29	2.56
9 versus 14	2.20–11.39	4.56	12 versus 22	3.73–10.92	6.91	17 versus 22	1.87–8.22	4.44
9 versus 15	1.76–10.49	5.15	12 versus 23	4.57–11.46	7.49	17 versus 23	1.92–7.86	4.20
9 versus 16	2.43–12.11	5.60	12 versus 24	4.47–11.81	7.50	17 versus 24	0.50–7.38	3.07
9 versus 17	1.63–12.82	5.43	12 versus 25	2.52–8.72	5.11	17 versus 25	1.10–4.85	2.98
9 versus 18	3.00–9.09	5.60	13 versus 14	4.07–9.76	6.16	18 versus 19	2.11–7.34	3.82
9 versus 19	1.41–8.61	3.75	13 versus 15	2.08–5.46	3.21	18 versus 20	2.89–8.61	4.64
9 versus 20	0.92–11.93	4.87	13 versus 16	4.33–12.58	6.51	18 versus 21	2.55–7.65	4.77
9 versus 21	0.98–12.83	5.16	13 versus 17	2.19–7.34	4.69	18 versus 22	1.85–7.44	3.66
9 versus 22	1.52–10.17	5.39	13 versus 18	4.59–14.22	7.48	18 versus 23	1.50–6.71	3.07
9 versus 23	2.34–11.13	5.68	13 versus 19	2.72–10.78	5.37	18 versus 24	1.80–6.67	4.21
9 versus 24	2.17–13.26	6.06	13 versus 20	2.60–9.36	4.70	18 versus 25	2.75–9.74	5.30
9 versus 25	0.68–10.76	5.03	13 versus 21	3.25–8.93	5.18	19 versus 20	0.80–4.03	2.10
10 versus 11	1.93–11.49	4.40	13 versus 22	4.17–13.61	6.68	19 versus 21	1.04–4.26	2.45
10 versus 12	1.30–8.35	4.41	13 versus 23	4.19–13.60	7.07	19 versus 22	0.53–4.60	2.91
10 versus 13	2.38–9.94	4.51	13 versus 24	4.21–13.42	6.79	19 versus 23	1.78–4.53	3.23
10 versus 14	5.38–12.91	8.02	13 versus 25	2.09–7.06	4.01	19 versus 24	1.62–4.87	3.08
10 versus 15	2.92–9.75	5.10	14 versus 15	2.68–5.78	4.28	19 versus 25	1.08–4.34	3.12
10 versus 16	4.92–14.75	8.00	14 versus 16	1.21–8.90	3.95	20 versus 21	0.78–2.94	1.68
10 versus 17	3.49–13.42	6.99	14 versus 17	1.53–8.79	4.07	20 versus 22	1.04–4.66	2.96
10 versus 18	4.68–15.55	8.36	14 versus 18	2.20–8.21	4.42	20 versus 23	2.28–5.86	3.32
10 versus 19	3.28–12.88	6.61	14 versus 19	2.01–6.49	3.82	20 versus 24	1.92–5.60	2.67
10 versus 20	2.99–12.14	6.07	14 versus 20	1.61–7.74	4.00	20 versus 25	0.84–3.39	2.36

Table 13 continued

Comp.	Min–Max	Mean	Comp.	Min–Max	Mean	Comp.	Min–Max	Mean
10 versus 21	3.16–11.55	6.56	14 versus 21	1.90–7.84	4.14	21 versus 22	1.11–5.62	3.13
10 versus 22	4.21–14.89	7.15	14 versus 22	1.78–7.29	4.10	21 versus 23	2.07–5.12	3.17
10 versus 23	4.85–14.82	7.94	14 versus 23	1.21–6.64	3.81	21 versus 24	1.14–4.69	2.19
10 versus 24	4.76–15.26	8.12	14 versus 24	1.61–8.84	4.16	21 versus 25	0.97–4.69	2.67
10 versus 25	2.88–11.14	5.17	14 versus 25	2.34–8.17	4.54	22 versus 23	1.04–3.01	2.07
11 versus 12	1.59–8.11	4.37	15 versus 16	2.98–7.58	4.26	22 versus 24	0.95–5.40	2.67
11 versus 13	1.41–8.39	3.82	15 versus 17	1.79–5.24	3.27	22 versus 25	1.35–7.00	3.37
11 versus 14	5.31–11.91	7.31	15 versus 18	3.18–10.25	5.47	23 versus 24	1.03–3.76	2.49
11 versus 15	3.13–9.16	4.88	15 versus 19	1.95–5.45	3.27	23 versus 25	2.24–7.56	4.29
11 versus 16	3.95–14.48	7.51	15 versus 20	1.58–4.16	2.83	24 versus 25	2.21–7.12	4.11

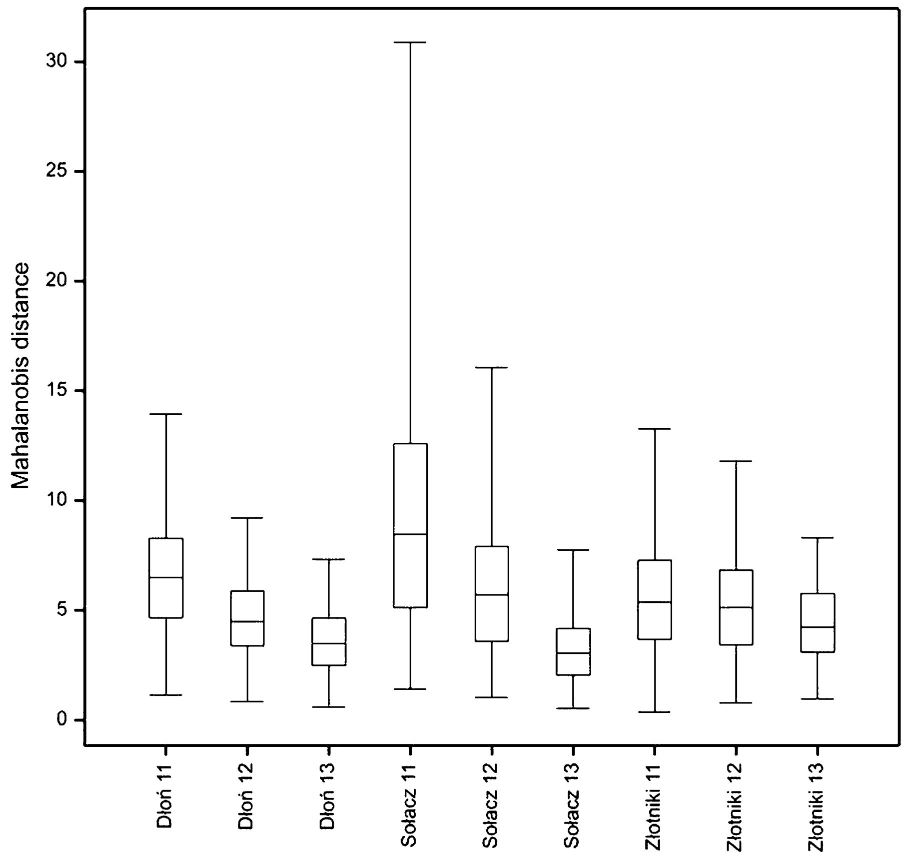

Fig. 2 Box-and-whisker diagram of the values of Mahalanobis distances, classified by the environments

variability. The multidimentional analysis showed that the first and second canonical varieties elucidated 87.98% and 5.81% respectively of multivariate variability of genotypes. NDF, ADF and oil content showed a significant positive correlation with the first canonical variable. Quite opposite observations were made for protein and glucosinolate content, which were negative correlated. Our results are in contrary to

Ahmad et al. (2013), who reported that all tested quality traits were positively correlated with oil content and with one another at both genotypic and phenotypic levels.

In our experiment the largest differences with regard to five tested traits occured between lines 6 and 11, which exhibited different origin (*B.napus* × *B. rapa* ssp. *pekinensis* and *B.napus* × *B. rapa* ssp. *trilocularis cv.* Yellow Sarson respectively. However, the largest similarities were recorded for lines 15 and 25 (*B.napus* MS8 line × B. *rapa* ssp. *pekinensis* and *B. napus* line MS8 respectively).

Moreover, *Brassica* lines numbered as 14, 16, 21 and 22 showed superiority for oil content, whereas genotype 11 exhibited superiority for minimum glucosinolate content. These genotypes may further be utilized in breeding programmes for evolving rapeseed varieties having high oil content and with superior seeds quality.

Taking into account the effect of genotype and environment on all tested seed quality traits in interspecific cross-derived *Brassica* lines, it was demonstrated that genotype had significant impact on glucosinolate content while oil, protein and fiber contents were influenced mostly by environment.

As an extension of our research hereafter genome-wide association studies should be used for the investigation of quantitative trait loci (QTL) linked to seed quality traits in winter oilseed rape (*Brassica napus* L.) genotypes. Genome-wide association analyses would enable identification of highly promising candidate genes and markers for breeding towards improved quality traits in rapeseed.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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