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THE RELATIONSHIP BETWEEN MORPHOLOGICAL TRAITS AND SEED YIELD OF IRANIAN GARDEN CRESS ACCESSIONS

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ABSTRACT

In order to evaluate the relationship between traits affecting the seed yield of the garden cress, phenotypic correlations between seed yield and yield components were detected, direct and indirect effects of yield components on yield and its role in the description of diversity were estimated, and the experiment was conducted in a randomized complete block design with three replications in 2017. The ANOVA showed that the difference among accessions was significant for all traits. There was a significant phenotypic correlation between yield and most of the traits. The highest value of phenotypic correlation was obtained between seed yield and the 'thousand seed weight' (0.97). The regression analysis showed that the seed yield was highly influenced by the 'thousand seed weight', leaf height and the number of seeds per silique of the lateral branches and the main axis. These three traits constituted about 89% of changes in the total yield, while the 'thousand seed weight' was the most effective trait that entered the model and explained 51% of the variation. The path analysis of phenotypic correlation showed that the 'thousand seed weight' had the greatest direct effect on the yield (7.21). The 'thousand seed weight' had a positive indirect impact on other traits as well. As a result of the factor analysis, 3 independent factors explained about 79.33% of the yield variation. These factors consisted of the number of seeds per silique of the lateral branches, the number of seeds per silique of the main axis and the 'thousand seed weight'.

Key words: correlation, direct effect, PCA, path analysis, stepwise regression, yield

INTRODUCTION

Garden cress (*Lepidium sativum* L.) belongs to the *Brassicaceae* family and is an important vegetable crop planted in temperate and cold climates. The origin of *Lepidium sativum* is not known precisely. However, it is believed to have originated from the central and south west of Asia, and then it spread to other parts of the world [Muhammad and Hussain 2010]. Nowadays, the cultivation of garden cress is very usual in North America and Europe, except from the United Kingdom. It is an exclusively abundant source of antioxidants [Souri et al. 2004].

The seeds of garden cress have been used in traditional medicine since ancient times, because they are believed to contain varied medicinal components such as galactogogue, which is a compound that cures the general debility of young girls and babies after childbirth. It increases the production of breast milk [Sharma and Agarwal 2011]. The edible oil of garden

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cress constitutes up to 58% of the seed weight and can be used for the reduction of body weight in obese patients [Sumeet et al. 2010].

Lepidium sativum L. seeds contain flavonoids, coumarins, sulfur, glycosides, triterpenes, sterols and various imidazole alkaloids [Bedassa et al. 2013]. There are ethno-medicinal uses of *L. sativum* leaves as salads, cooked vegetables and curries. They are also used as fodder for cattle [Moser et al. 2009].

Seed yield is a product of an organized interaction of several factors, which are highly influenced by environmental changes. However, the yield can be estimated based on the efficiency of components that make the integrity of the yield [Diepenbrock 2000]. Apart from direct selection for seed yield, the performance of several components that comprise the yield are closely associated with seed yield [Emam and Borjan 2000].

Correlation analysis provides information about the association of plant traits and therefore leading to a directional pattern for yield prediction. When the number of independent variables affecting the dependent variable increases, the degree of dependence of traits is limited to each other. It has been observed that path coefficient analysis is able to show the exact relationship between various traits of plants, thereby providing more information than simple correlation analysis. This suggests that correlation analysis is a weaker tool in contrast to path coefficient analysis [McGiffen et al. 1994].

By stepwise regression analysis, it is possible to eliminate ineffective or weak traits that have negligible effects on the yield, and one can only consider the traits that justify a significant amount of variation, which therefore deserve to remain in the model [Vicente et al. 2005].

So far, few studies have investigated the yield of garden cress by the use of correlation coefficients and path analysis, in which the yield has a significant correlation with the number of branches, the number of seeds per plant and leaf length [Bedassa et al. 2013]. This method has been used to investigate the relationships between traits in other plant species. For instance, a previous study reported that dry matter yield and leaf number were the most important components that define the total yield of sorghum, and these traits had the most direct effects on yield [Manickam and Das 1994].

A couple of studies have shown that the number of silique per plant, number of seeds per silique and plant height had significant role in the yield of rapeseed. Also, traits such as harvest index and stem diameter were effective in increasing or decreasing the yield of rapeseed [Singh and Singh 1995]. The yield had a positive and significant correlation with leaf traits in coriander accessions [Diederichesen 1996].

The purpose of this research is to investigate the relationship between morphological traits and yield using correlation and stepwise regression. The aim is also to determine the direct and indirect effects of traits affecting the yield of garden cress using the path analysis.

MATERIALS AND METHODS

This experiment was conducted in an academic agriculture research farm in April 2017. The average annual temperature of the location was 20°C at the time of the experiment. The altitude measured 1200 m and the average annual rainfall was 112 mm. Plant materials were comprised of 35 *Lepidium sativum* accessions collected from different regions of Iran (Tab. 1). The accessions were planted in a randomized complete block design with three replications. A total 15 × 15 m area was used in order to plant the 35 accessions. Each accession was represented by a single plot per replication with 20 cm gaps between the accessions. Each plot had 30 plants and the spacing between plants of each plot was 7 cm. To study the quantitative data, seven individual plants were tagged within each plot randomly, and therefore a total of 21 plants per accession were tagged from three replications for later morphological evaluations of variation.

Plants were selected for recording observations based on 13 quantitative traits, including the percentage of seedling emergence, number of days to emergence, number of days to flowering, height of the first branch, length of the main axis, number of lateral branches, number of siliques per plant, number of seeds per silique on the lateral branches, number of seeds per silique on the main axis, leaf height, leaf width, 'thousand seed weight' and seed yield (Tab. 2).

The collected data were subjected to analysis of variance using SPSS (version 16). The same statistical

Table 1. List of geographical origins of garden cress accessions

Accession number	Location of collected accessions	Province	Longitude(E)	Latitude(N)
1	Birjand	South Khorasan	E 591256	N 325003
2	Kerman	Kerman	E 570729	N 301424
3	Semnan	Semnan	E 532505	N 353228
4	Aradan	Semnan	E 522948	N 351428
5	Minudasht	Golestan	E 552225	N 371258
6	Pakdasht	Tehran	E 514120	N 352805
7	Varamin	Tehran	E 513721	N 352010
8	Sari	Mazandaran	E 530144	N 363429
9	Shiraz	Fars	E 523824	N 292513
10	Sorkhe	Semnan	E 352712	N 531248
11	Ghazvin	Ghazvin	E 495759	N 355847
12	Kardavan	Semnan	E 521803	N 351158
13	Arjalan	Semnan	E 522806	N 351310
14	Damghan	Semnan	E 542342	N 360934
15	Sirjan	Kerman	E 554124	N 292236
16	Maku	West Azerbaijan	E 442807	N 391644
17	Shahrod	Semnan	E 550019	N 362248
18	Sanandaj	Kurdistan	E 470241	N 351853
19	Damavand	Tehran	E 520403	N 354335
20	Eyvanekey	Semnan	E 520236	N 351955
21	Shahrerey	Tehran	E 512749	N 352909
22	Tabriz	East Azerbijan	E 461248	N 380439
23	Ghom	Ghom	E 510639	N 344220
24	Lahijan	Guilan	E 495847	N 371308
25	Fuman	Guilan	E 491844	N 371228
26	Farokhshahr	Charmahal and Bakhtiari	E 505747	N 321458
27	Garmsar	Semnan	E 521904	N 351244
28	Yasuj	Kohgiloyeh and Boyer Ahmad	E 513551	N 303844
29	Esfahan	Esfahan	E 514441	N 324008
30	Kashmar	Razavi Khorasan	E 582702	N 351502
31	Robatkarim	Tehran	E 510531	N 352818
32	Shahryar	Tehran	E 510230	N 353901
33	Maraghe	East Azerbaijan	E 461404	N 372133
34	Oromyeh	West Azerbaijan	E 450743	N 373445
35	Sabzevar	Razavi Khorasan	E 574314	N 361137

Table 2. Quantitative morphological traits of *Lepidium sativum*

Measured traits	Scale	Abbreviation	Data recording criteria
Emergence percentage	%	EP	Emergence percentage
Days to emergence	day	DE	The number of days from planting until 50% seedling emergence
Days to flowering	day	DF	Number of days from the date of sowing to the date at which 50% of the plants in the plot showed blooming on about 50% of their flower buds
Height of first branch	cm	HFB	The average length of randomly selected primary branches per plant
Main axis length	cm	MAL	The height of plant in each plot measured in cm from the ground surface to the top of the main stem at maturity
Number of lateral branches	no	NLB	Number of lateral branches
Number of siliques per plant	no	NSP	The average numbers of seed taken from randomly selected 7 plants that were tagged to take the whole quantitative data
Number of seeds per silique of lateral branches	no	SLB	Number of seeds per silique of lateral branches
Number of seeds per silique of main axis	no	SMA	Number of seeds per silique of main axis
Leaf height	cm	LH	The length of 7 randomly selected leaves/ plant
Leaf width	cm	LW	The width of 7 randomly selected leaves/ plant
Thousand seed weight	g	TW	Average of Thousand seed weight in 7 plant
Seed yield	g	Y	Seed yield of accessions

package was used for correlation analysis, stepwise regression analysis and factor analysis. The path coefficient analysis was performed using the Excel computer program that applied the matrix methods [Singh and Chaudhary 1995].

RESULTS AND DISCUSSION

The analysis of variance revealed significant differences among garden cress accessions based on morphological traits (data not shown). Results were in accordance with results of previous research on other species of garden cress using morphological and agronomic traits [Mohammed and Tesfaye 2015].

Variations were revealed to some extent *via* comparison of mean values of 35 garden cress accessions for 13 morphological traits (Tab. 3). These results display a good variation among the accessions for most of the traits that can be separated into discrete phenotypic ingredients. The lowest coefficient of variation (CV) was 5.77%, which pertained to the percentage of seedling emergence, and the highest one was 29.27%, which was related to the height of the first branch. The seed yield of each accession varied from 17.23 to 24.54 grams. Variability of the seed yield indicated that this trait was controlled by genetic and environmental factors. Accordingly, using an indirect selection of one or more effective traits that relate to the yield, the efficiency of this trait can be increased.

Roughani et al. [2018] reported in *Lepidium latifolium* that there was a significant variation among 8 populations for all the traits studied, except from leaf number. The population Asad abad showed major values for the shoot height, dry weight, leaf length, width and thickness and root dry weight.

Sabaghnia et al. [2014] found that the ‘number of siliques per lateral branches’ and the ‘main axis’ had important contributions to the total variation. The

Table 3. Comparison of mean values for 35 garden cress accessions

Character	Minimum	Maximum	Mean	Std. deviation	Cv (%)
Emergence percentage	70.00	91.23	83.22	4.802	5.77
Days to emergence	4.52	8.23	6.71	1.02	15.2
Days to flowering	45.00	58.00	51.3	6.23	12.1
Height of first branch	19.00	27.13	24.34	7.12	29.27
Main axis length	35.86	53.71	46.41	9.29	20.01
Number of lateral branches	9.00	23.33	15.52	4.45	28.67
Number of siliques per plant	21.00	41.72	32.15	9.23	28.7
Number of seeds per silique of lateral branches	42.76	225.22	128.70	27.25	21.17
Number of seeds per silique of main axis	63.5	86.4	74.3	19.23	25.88
Leaf height	4.25	7.32	6.12	0.89	14.54
Leaf width	0.64	4.80	2.45	0.51	21.16
Thousands of seed weight	1.63	2.22	1.96	0.35	17.85
Seed yield	17.23	24.54	22.68	5.34	23.54

Table 4. Correlation coefficients of studied traits among 35 garden cress accessions

	EP	DE	DF	HFB	MAL	NLB	NSP	SLB	SMA	LH	LW	TW	Y
EP	1												
DE	0.09^{ns}	1											
DF	0.14^{ns}	0.51^{**}	1										
HFB	0.16^{ns}	0.21^{ns}	0.72^{**}	1									
MAL	0.22^{ns}	0.19^{ns}	0.62^{**}	0.86^{**}	1								
NLB	0.41^{ns}	0.25^{ns}	0.14^{ns}	0.19^{ns}	0.23^{ns}	1							
NSP	0.19^{ns}	0.11^{ns}	0.24^{ns}	0.67^{**}	0.75^{**}	0.18^{ns}	1						
SLB	0.019^{ns}	0.32^{ns}	0.28^{ns}	0.71^{**}	0.76^{**}	0.82^{**}	0.55^{**}	1					
SMA	0.008^{ns}	0.17^{ns}	0.21^{ns}	0.43^{*}	0.51^{**}	0.87^{**}	0.40^{*}	0.86^{**}	1				
LH	0.12^{ns}	0.19^{ns}	0.41^{*}	0.69^{**}	0.22^{ns}	0.68^{**}	0.58^{**}	0.91^{**}	0.85^{**}	1			
LW	0.11^{ns}	0.17^{ns}	0.37^{*}	0.67^{**}	0.69^{**}	0.73^{**}	0.68^{**}	0.85^{**}	0.79^{**}	0.82^{**}	1		
TW	0.07^{ns}	0.12^{ns}	0.37^{*}	0.61^{**}	0.67^{**}	0.71^{**}	0.58^{**}	0.89^{**}	0.83^{**}	0.86^{**}	0.92^{**}	1	
Y	0.12^{ns}	0.17^{ns}	0.25^{ns}	0.62^{**}	0.67^{**}	0.82^{**}	0.56^{**}	0.95^{**}	0.81^{**}	0.87^{**}	0.78^{**}	0.97^{**}	1

height of the first lateral branch and the height of the first silique are important traits not only in garden cress, but also in all genera of the *Brassicaceae* family, particularly during harvesting. These factors can guide plant breeders to design plans for development of high yielding genotypes with desirable plant architectures [Marjanovic et al. 2008].

Correlation coefficients of studied traits (Tab. 4) showed that there was highly significant correlation between the seed yield of each accession and the height of the first branch, main axis length, number of lateral branches, number of siliques per plant, number of seeds per silique on the lateral branches, number of seeds per silique on the main axis, leaf height, leaf width and 'thousand seed weight' ($P \leq 0.01$). Similar findings have been reported previously, which indicate that the seed yield of accessions correlate significantly with the number of lateral branches and the number of days to flowering [Bedassa et al. 2013].

According to the results of Diederichesen [1996], there was significant correlation with leaf characteristics. Therefore, in order to evaluate the seed yield, the

Table 5. Stepwise regression analysis for seed yield as the dependent variable and other characteristics as independent variables in garden cress accessions

Regression parameters	Standard coefficients	Standard deviation	Coefficient of stepwise determination	Coefficient of cumulative determination for model	F
Intercept	17.2	2.44			4.71**
Thousands of seed weight	12.6	1.82	0.51	0.51	3.75**
Number of seeds per silique of lateral branches	8.5	1.12	0.18	0.69	3.21**
Number of seeds per silique of main axis	7.4	0.95	0.12	0.81	3.19**
Leaf height	3.2	0.51	0.08	0.89	2.95**

Table 6. Path analysis for seed yield in garden cress accessions, based on phenotypic correlation

Traits	Direct effect	In direct effect				
		thousands of seed weight	number of seeds per silique of main axis	number of seeds per silique of lateral branches	leaf height	leaf width
Thousands of seed weight	7.21	–	4.22	3.67	2.29	1.96
Number of seeds per silique of main axis	5.22	3.76	–	1.22	0.96	–1.50
Number of seeds per silique of lateral branches	3.98	2.94	0.78	–	0.77	–0.58
Leaf height	3.28	3.45	1.12	0.68	–	3.21
Leaf width	–1.14	–1.52	–1.50	–0.58	0.96	–

traits that shape the leaf and seed should be considered as major criterion for selection.

Regression analysis was used in order to identify the traits that affect the seed yield among garden cress accessions. Therefore, the seed yield was considered a dependent variable and other traits were considered as independent. The variables that affect the yield and other traits were entered step by step into the regression (Tab. 5).

The ‘thousand seed weight’, leaf height and the number of seeds per silique on the lateral branches and on the main axis were entered into the regression model. These traits totally justified 89% of the seed yield variation, but other traits were removed from the model. The first trait that entered into the model was ‘thousand seed weight’ that explained more than 51% of the variation among different yields of seeds. The second and third traits that entered the model were the number of seeds per silique on the lateral branches and the number of seeds per silique on the main axis, which justified 18 and 12% of the total variation in seed yield, respectively (Tab. 5). The last trait that entered the model was the leaf height which justified 8% of the total variation in seed yield. The results were consistent with simple correlation results, where traits that entered the regression model correlated more strongly with seed yield.

For a more accurate estimation of the importance and direct and indirect effects of each trait on yield, the path analysis was performed using various combinations of phenotypic correlations (Tab. 6). The results showed that the ‘thousand seed weight’, number

Table 7. Principle Component Analysis of morphological characters in garden cress accessions

Specification	Component		
	1	2	3
Yield	**0.921**	0.128	0.190
Number of seeds per silique of lateral branches	**0.912**	0.214	0.151
Number of seeds per silique of main axis	**0.907**	0.021	0.217
Thousands of seed weight	**0.928**	0.312	0.315
Number of lateral branches	0.871	–0.272	0.074
Leaf width	0.769	0.214	0.192
Leaf height	0.654	0.221	0.253
Number of siliques per plant	0.221	**0.921**	0.281
Emergence percentage	0.245	**0.893**	0.128
Main axis length	0.523	**0.827**	0.528
Height of first branch	0.421	0.612	0.631
Days to emergence	0.125	–0.287	**0.899**
Days to flowering	0.242	0.202	**0.841**
Percent variation	55.28	14.92	9.13
Cumulative percent of total variance	55.28	70.20	79.33

of seeds per silique on the lateral branches, number of seeds per silique on the main axis and leaf height had direct and positive effects on yield. However, leaf width showed negative and direct effect on seed yield.

Based on previous results reported by Badassa et al. [2013], the yield of garden cress was directly affected by the number of seeds per plant, number of days to maturity and leaf length. Meanwhile, plant height and number of days to flowering also had a direct and negative effect on yield.

Previous study on maize showed that the leaf width and stem height are the most important traits for improving the corn yield [Paramathma and Balasubramanian 1986].

In this study, the largest direct and positive effect on yield was ‘thousand seed weight’. In addition to having a direct effect on yield, the ‘thousand seed weight’ showed positive, indirect effect on other traits. The number of seeds per silique on the main axis had direct and positive effect on yield (5.22). This trait had positive, indirect effect on a few traits, i.e. ‘thousand seed weight’ (3.76), number of seeds per silique on the lateral branches (1.22) and leaf height (1.7). However, it had negative indirect effect on leaf width (–1.50). The number of seeds per silique on the lateral branches had direct and positive effect on yield (3.98). This trait had positive indirect effect on ‘thousand seed weight’ (2.94), number of seeds per silique on the main axis (0.78) and leaf height (0.78), whereas it had negative indirect effect on leaf width (–0.58).

According to Gunasekaran et al. (2010), the number of seeds per spike and 1000-seed weight is an important index for the indirect selection and desirable yield in rice. The analysis of fenugreek yield showed that the maximum direct contribution was related to the number of stems and the number of pods per plant [Sharma and Sastry 2008].

According to the principle component analysis (PCA), the first three components took 79.33% of the total variance (Tab. 7). In the first component, there were the ‘yield of accessions’, ‘number of seeds per silique of lateral branches’, ‘number of seeds per silique on the main axis’ and ‘thousand seed weight’, which showed the greatest loading over 55.28% of the total variation. In the second component, ‘number of siliques per plant’, ‘percentage of seedling emergence’ and ‘main axis length’ comprised about 14.92% of the total variation. Finally, the third factor explained 9.13% of the total variation, which mainly consisted of ‘days to emergence’ and ‘days to flowering’.

Roughani et al. [2018] reported that the first three components of *Lepidium draba* took 94.8% of the total variation with variance 51.6%, 22.5% and 20.8% and the first three PCA of *Lepidium latifolium* accounted for 90.6% of total variation with variance of 69.5%, 12.2% and 8.9%, respectively. In hoary cress, shoot fresh weight, shoot height, leaf length and width were showed by PCA analysis to be the most valuable morphological traits that participate to total variation [Roughani et al. 2018].

CONCLUSIONS

The correlation between traits has an important role in most breeding programs. This means that a trait must correlate with other traits in order to be considered for selection. The results obtained from phenotypic correlation analysis showed that most of the traits correlated significantly with each other. The yield had a significant correlation with most traits, which indicates that each of these traits has an important effect on yield. In order to achieve a high yield among garden cress accessions, it is suggested to perform a simultaneous selection based on the number of seeds on the main and lateral axis and the leaf lengths. According to the results of path analysis, it can be concluded that leaf length and the number of seeds on the main and lateral axis are the most important traits that affect the yield of garden cress. Desirable genotypes could be approached according to their seeds and leaves.

According to our results, it can be concluded that the yield has the potential to be increased in breeding programs by the use of appropriate traits for the increase in the number of seeds per plant. Furthermore, effective traits that increase the vegetative growth and leaf area can also be considered for the selection of accessions.

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