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Interrelationships among grain yield and related characters of four oilseed rape (*Brassica napus* L.) cultivars under drought stress conditions

R. Naderi[a], Y. Emam[b*]

[a] *PhD student, College of Agriculture, Shiraz University, Iran*
[b] *Professor, College of Agriculture, Shiraz University, Iran*

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Abstract

Four rapeseed cultivars (Hayola 401, Hayola 308, RGS and Option) were evaluated for some physiological traits under stress (50 % field capacity (FC) and non-stress (irrigated) conditions. The factorial set of treatments was arranged within a randomized complete block design with three replications. The collected data were analyzed using path and factor analyses. These results showed that based on correlation coefficient, path and factor analysis number of seeds per silique was the best criteria for rapeseed cultivar selection under non-stress conditions and silique length, number of seeds per silique and photosynthesis rate at flowering stage were the best criteria for selection and yield improvement under stress conditions. Our results also indicated that selection based on simple correlation may not be efficient. The results of this study may guide breeders to introduce suitable drought resistant rapeseed cultivars for arid regions.

Keywords: Oilseed rape; Drought stress; Cultivar selection; Path analysis; Factor analysis

1. Introduction

Rapeseed, from *Brassicaceae*, provides a convenient alternative in cereal-based agricultural systems, for its broad leaves and capacity to be a break crop in continuous run of cereals (Kachatourians *et al*., 2001). It is also becoming a popular oilseed crop in Iran, including Fars Province, due to its high oil and protein contents.

Drought is a major abiotic constraint responsible for heavy production losses (Khan *et al*., 2007; Ricciardi *et al*., 1997). This stress is considered as one of the most important limiting factors for rapeseed growth and production. Photosynthetic activity is also hampered under water deficit conditions and stomatal closure is one of the earliest plant responses (Hsiao, 1973) which limits CO_2 diffusion into the chloroplast (Muller and Whitsitt, 1996) and reduce photosynthetic activity substantially and eventually causes yield reduction (Wilhite, 1993). Drought stress also affects crops growth (Gabriela and Foyer, 2002), photosynthesis (Legg *et al.*, 1997) and leaf senescence (Siddique, 1999). The stress affects almost all plant processes; however, stress response depends on the intensity, rate and duration of exposure to stress and the stage of crop growth (Brar *et al*., 1990).

Simple correlation analysis often inadequately explains the relationships, because correlation dose not imply that a direct cause-and-effect relationship exist. Path analysis is a statistical technique that partitions correlation coefficients into direct and indirect effects and distinguishes between correlation and causation (Zhang *et al*., 2005).This analysis has been widely used in crop breeding to determine the nature of relationships between grain yield and

[*] Corresponding author. Tel.: +98 711 6280913,
Fax: +98 711 2286134.
E-mail address: yaemam@shirazu.ac.ir

its components with significant effects on yield for potential use as selection criteria. A path coefficient is a standardized partial regression coefficient, and measures the direct influence of predictor variable on the response variable (Mohammadi *et al*., 2003).

The factor analysis can be used successfully to analyze large amounts of multivariate data, and describes the interrelationships among all traits on the basis of overall pattern of the data, whereas the correlation coefficient only describes the relationships between two traits. Thus using factor analysis by plant breeders has the advantage of increasing the understanding of the casual relationships of variables in breeding programs (Seiler and Stafford, 1985).

The objectives of this study were to examine some physiological traits and their relationships with the aim of determination of the best criteria for screening oilseed rape cultivars under drought stress and non-stress conditions using path and factor analyses.

2. Materials and methods

Four rapeseed cultivars (Hayola 401, Hayola 308, RGS and Option) were compared under two moisture regimes (field capacity (FC) and 50 % FC on pot weight basis) in a glasshouse experiment at Department of Crop Production and Plant Breeding, College of Agriculture, Shiraz University, Shiraz, Iran during the year 2006. Rapeseed cultivars were grown in pots containing 5 kg soil. Six uniform seeds were sown in each pot and thinned to three uniform plants at 3 leaf stage. To each pot, 150 mg kg^{-1} urea was applied at 3 leaf and stem elongation stages and 100 mg kg^{-1} triple superphosphate at sowing. Plants were irrigated up to FC for three weeks after sowing, and then were subjected to two water regimes. The pots were regularly weighted to keep the moisture treatments. The factorial set of treatments was arranged within a randomized complete block design with three replications. Net photosynthesis (A) and stomatal conductance (g_s) were measured using photosynthesis meter (LCi, UK) at both vegetative and flowering stages. Brassica aphids were controlled using metasistox during the experimental period. Plants were harvested at maturity for yield and yield components. All statistical analyses (correlation, path and factor analysis) performed using SAS software (2000).

3. Results and disscussion

Simple correlation coefficients calculated among measured traits in non-stress conditions are shown in Table 1. There were positive and significant relationship between grain yield, 1000 seeds weight (r=60, p<0.01), number of seeds per silique (r=90, p<0.01) and net photosynthesis at flowering stage (r=76, p<0.01).

Table 1. Simple correlation coefficients among the traits in four rapeseed cultivars under non-stress conditions

	GY	SL	LA	SIP	1000-seed	SIS	A1	Gs1	A2	Gs2
GY†	1									
SL	0.46	1								
LA	0.55	0.31	1							
SIP	0.28	0.11	0.75**	1						
1000-seed	0.61**	0.18	0.24	0.13	1					
SIS	0.90**	0.17	0.65*	0.35	0.49	1				
A1	0.48	0.49	0.44	0.14	0.45	0.47	1			
gs1	0.52	0.40	0.52	0.17	0.17	0.53	0.61	1		
A2	0.76**	0.72**	0.70*	0.33	0.41	0.70*	0.82**	0.69*	1	
gs2	0.41	0.59*	0.60*	0.29	0.15	0.46	0.62*	0.51	0.79**	1

†GY: Grain yield, SL: Silique length, LA: Leaf area, SIP: Number of siliques per plant, 1000-seed: 1000 seeds weight, SIS: Number of seeds per silique, A1and 2: Net photosynthesis at vegetative and flowering stages, gs1 and 2: Stomatal conductance at vegetative and flowering stages

*, **: significant at 5 % and 1 % respectively

The relationships determined by path analysis between grain yield and the measured traits under non-stress conditions are shown in Figure 1. There was a significant path coefficient, direct effect, among seed yield, silique length (p=0.43, p<0.05), number of seeds per silique (p=0.91, p<0.001) and stomatal conductance at flowering stage (p=0.25, p<0.05) under non-stress conditions (Fig 1).

In the present study, there was a highly significant correlation between yield, and 1000 seeds weight, number of seeds per silique and net photosynthesis at flowering stage under non-stress conditions, however, path coefficient was significant only for number of seeds per silique, indicating that selection based on simple correlations may not be efficient as also indicated by others (e.g. Gravvois and Helms, 1992; Samonte *et al*., 1998). Furthermore, linear relations between yield and examined characteristics seem to be insufficient in plant breeding programs (Mohammadi *et al*., 2003). Therefore, selection upon both coefficients might be more reliable (Guler *et al*., 2001). The apparent conflict between the results of the two analyses arises largely because the two methods measure different parameters. Whereas correlation simply identifies mutual associations between the various parameters and variables, the path coefficient analysis is concerned with the relative importance of parameters (Campbell *et al*., 1980). Path analysis has been used by many workers for selection in breeding programs, of such crops as maize (*Zea mays* L.) (Mohammadi et al., 2003), chickpea (*Cicer arientinum* L.) (Guler *et al.*, 2001) and Soybean (*Glycine max* L.) (Board *et al.*, 2003).

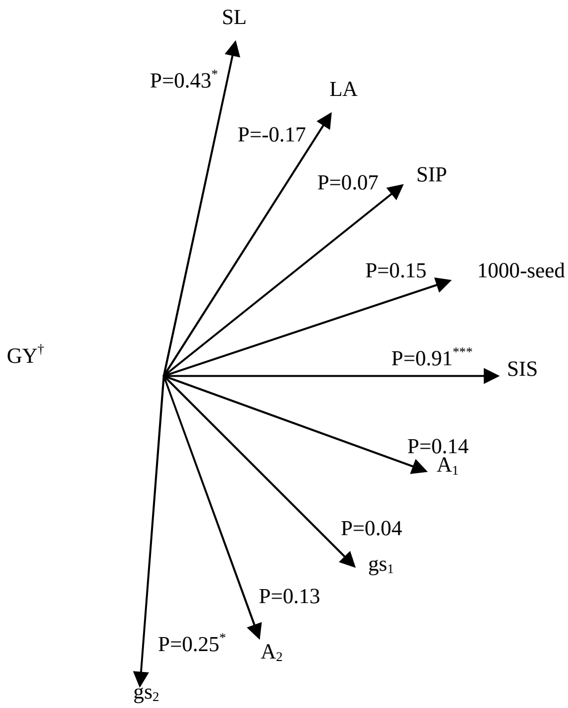

Fig. 1. Path coefficient diagram showing the direct effects of some rapeseed traits and grain yield of four rapeseed cultivars under non-stress conditions.
†GY: Grain yield, SL: Silique length, LA: Leaf area, SIP: Number of siliques per plant, 1000-seed: 1000 seeds weight, SIS: Number of seeds per silique, A1and 2: Net photosynthesis at vegetative and flowering stages, gs1 and 2: Stomatal conductance at vegetative and flowering stages.

In the present investigation, in addition to using path analysis and simple correlation, factor analysis was also used to increase the accuracy of selection. Under non-stress conditions, factor analysis divided the 10 traits into three factors which explained 80% of the total genetic variation in the dependence structure (Table 2). If loading of the traits is greater than 0.6 in a factor it is considered as major (Acquaah, *et al*., 1992).

Factor I was associated with grain yield, silique length, leaf area, number of seeds per silique, net photosynthesis and stomatal conductance at both vegetative and flowering stages. This factor explained 54.5% of the total genetic variation. In this factor all traits loaded with positive sign. The sign of the loading indicates the direction of the relationship between the factor and the variable. Thus two variables with high magnitude of loading in the same factor would be expected to exhibit a high correlation (Seiler and Stafford, 1985). Thus the traits may be influenced by the same gene or genes and may be advantageous for suitable rapeseed genotypes screening.

This analysis also showed that among all measured traits, number of seeds per siliques was the best criteria for selection. Factor II and III explained 13.2 and 12.2 of the total genetic variation, respectively (Table 2). Factor II was associated with number of siliques per plant with positive sign and factor III was associated with 100-seeds weight with negative sign. Thus, these two factors may be not important in rapeseed breeding programs. Studying correlation, path coefficient and factor analysis in cotton (*Gossypium hirsutum* L.), Alishah *et al*. (2008) reported that factor analysis decreased numerous correlated variables to few main factors.

Table 2. Loading of the first three most important principal factors from a factor analysis of 10 physiological traits under non-stress conditions in rapeseed. *Values above 0.6 are considered as major

Variables	Factor (matrix of factor coefficients)			Communality
	1	2	3	
GY†	0.83*	0.15	-0.39	0.87
SL	0.61*	-0.52	0.19	0.69
LA	0.78*	0.42	0.34	0.92
SIP	0.45	.67	0.44	0.86
1000-seed	0.50	0.13	-0.69*	0.75
SIS	0.80*	0.33	-0.29	0.84
A1	0.77*	-0.34	-0.08	0.72
gs1	0.72*	-0.19	0.09	0.57
A2	0.96*	-0.19	0.04	0.97
gs2	0.76*	-0.25	0.36	0.77
Proportion of total variation (%)	54.5	13.2	12.2	
Cumulative variance (%)	54.5	67.8	80.0	

†GY: Grain yield, SL: Silique length, LA: Leaf area, SIP: Number of siliques per plant, 1000-seed: 1000 seeds weight, SIS: Number of seeds per silique, A1and 2: Net photosynthesis at vegetative and flowering stages, gs1 and 2: Stomatal conductance at vegetative and flowering stages.

Simple correlation coefficients calculated among measured traits under stress conditions are shown in Table 3. There were positive and significant relationships between grain yield, 1000 seeds weight (r=0.87, p<0.001), number of seeds per silique (r=0.87, p<0.001), stomatal conductance at vegetative growth (r=0.91, p<0.001), net photosynthesis at flowering stage (r=89, p<0.001) and stomatal conductance at flowering (r=87, p<0.001). There was also a significant positive direct effect among seed yield, silique length (p=0.67, p<0.001), number of seeds per silique (p=1.05, p<0.001), and net photosynthesis at flowering stage (p=2.24, p<0.001) under stress conditions (Fig 2). On the other hand, there was a highly significant negative direct effect between grain yield and stomatal conductance at flowering stage (p=-2.71p<0.001) (Fig. 2). Campbell *et al*. (1980) examined path coefficient analysis of seed yield components in soybean and reported that the path analysis gave a somewhat different picture than did the simple correlation analysis.

The results of our study revealed that although the simple correlation, between yield and some traits were statistically significant under stress conditions, the path coefficients, direct effect, were non-significant. Similar to non-stress conditions, our results suggest that selection should be done based on both coefficients. Ali *et al*. (2009) in an investigation on evaluation of chickpea (*Cicer arientium* L.) genotypes criteria selection using correlation coefficient and path analysis reported that biological yield, number of seeds per pod and 100 seed weight could be used as selection criteria.

Table 3. Simple correlation coefficients among the traits in four rapeseed cultivars under stress conditions.

	GY	SL	LA	SIP	1000-seed	SIS	A1	Gs1	A2	Gs2
GY†	1									
SL	0.43	1								
LA	0.54*	0.27	1							
SIP	0.73**	0.31	0.54	1						
1000-seed	0.87***	0.13	0.59*	0.82***	1					
SIS	0.87***	-0.02	0.61*	0.75**	0.75*	1				
A1	0.44	0.02	0.47	0.35	0.32	0.68*	1			
gs1	0.64*	0.01	0.70*	0.70*	0.56	0.85***	0.79**	1		
A2	0.89***	0.60*	0.57*	0.81***	0.88***	0.74**	0.39	0.62*	1	
gs2	0.87***	0.65*	0.58*	0.81**	0.83***	0.76**	0.43	0.64*	0.98***	1

†GY: Grain yield, SL: Silique length, LA: Leaf area, SIP: Number of siliques per plant, 1000-seed: 1000 seeds weight, SIS: Number of seeds per silique, A1and 2: Net photosynthesis at vegetative and flowering stages, gs1 and 2: Stomatal conductance at vegetative and flowering stages.
*, **: significant at 5 % and 1 % respectively.

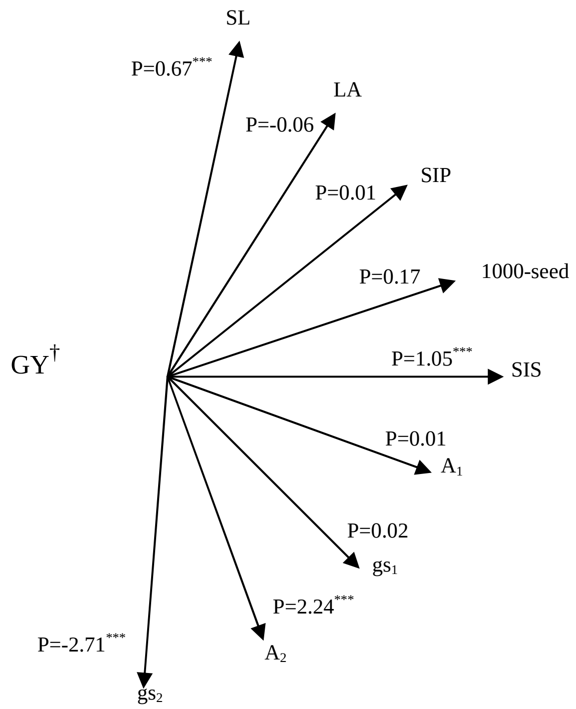

Fig. 2. Path coefficient diagram showing the direct effects of some rapeseed traits and grain yield of four rapeseed cultivars under stress conditions.
†GY: Grain yield, SL: Silique length, LA: Leaf area, SIP: Number of siliques per plant, 1000-seed: 1000 seeds weight, SIS: Number of seeds per silique, A1and 2: Net photosynthesis at vegetative and flowering stages, gs1 and 2: Stomatal conductance at vegetative and flowering stages.

Under stress conditions, factor analysis divided the traits into two factors which explained 88.9% of total genetic variation (Table 4). Factor I was associated with grain yield, leaf area, number of seeds per silique, 1000 seeds weight, number of siliques per plant, stomatal conductance at both stages and net photosynthesis at flowering stage. This factor explained 66.8% of the total genetic variation.

Table 4. Loading of the first most important principal factors (PF) from a factor analysis of 10 physiological traits under stress conditions in rapeseed. *Values above 0.6 are considered as major.

Variables	Factor (matrix of factor coefficients)		Communality
	1	2	
GY†	0.92*	0.14	0.86
SL	0.41	0.76*	0.75
LA	0.71*	-0.21	0.56
SIP	0.86*	.04	0.75
1000-seed	0.88*	0.16	0.80
SIS	0.90*	-0.27	0.90
A1	0.59	-0.61*	0.72
gs1	0.82*	-0.49	0.92
A2	0.93*	0.29	0.96
gs2	0.94*	0.28	0.96
Proportion of total variation (%)	66.8	15.5	
Cumulative variance (%)	66.8	82.3	

†GY: Grain yield, SL: Silique length, LA: Leaf area, SIP: Number of siliques per plant, 1000-seed: 1000 seeds weight, SIS: Number of seeds per silique, A1and 2: Net photosynthesis at vegetative and flowering stages, gs1 and 2: Stomatal conductance at vegetative and flowering stages.

4. Conclusion

Similar to non-stress conditions, under stress conditions, all the traits loaded with positive sign. Thus, these traits were beneficial for suitable rapeseed genotypes screening under stress conditions. Factor II explained 15.5% of the total genetic variation. This factor was associated with silique length. Similar to non-stress condition, the other factor, factor II, may be not important in rapeseed breeding programs. Based on the three analyses using in this research, under stress conditions among all traits, the number of seeds per silique and net photosynthesis at flowering stage appeared to be the best criteria for selection. Ashkani *et al.*

(2007) used factor analysis to introduce some suitable traits for safflower (*Carthamus tinctorius* L.) screening program under non-stress and stress conditions. They concluded that selection based on leaf area index, leaf osmotic potential and rate of water loss from excised leaves might be desirable criteria for suitable safflower genotype screening under non-stress conditions and under stress conditions selection based on leaf area index and rate of water loss from excised leaves are more efficient criteria for genotype screening.

In general, based on correlation, path and factor analyses, the results of the present study suggested that a rapeseed cultivar, for increased yield under non-stress conditions, should have maximum number of seeds per silique and under stress conditions should have maximum number of seeds per silique and net photosynthesis at flowering stage. Therefore, our study revealed that oilseed rape breeding program could be based on these traits as selection criteria. In addition, it can be concluded that selection based on simple correlation may not be efficient. The results of this study may be useful for breeders to introduce suitable drought resistant rapeseed cultivars for arid regions.

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