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UNIVARIATE STABILITY ANALYSIS OF GENOTYPE×ENVIRONMENT INTERACTION OF OILSEED RAPE SEED YIELD

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Abstract

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Thirteen stability statistics were used to analyze genotype × environment (GE) interaction of 36 canola genotypes. Combined analysis of variance indicated that GE interaction significantly influenced seed yield performance. According to Type I stability concept (environmental variance, coefficient of variation and stability variance) genotypes G7, G9 and G13 were the most stable genotypes, while based on the Type II concept (coefficients of three linear regression models), genotypes G33, G27 and G29 could be selected as the most favorable genotypes. Also, genotype G7 was the most favorable genotype according to Type III stability concept (deviation from linear regression method). Genotypes clustering based on stability properties and mean yield grouped them into three distinct classes. Coefficient of determination for the canola genotypes indicated that genotypes G27 and G33 were the most stable genotypes but the genotypes G1, G10 and G25 had the highest desirability index and were the most stable ones. The plot of principal component analysis was used for graphic display of the relationships among statistics and the first axis distinguished the Type II of stability concept from other types and mean yield groups near this stability type. However, based on most statistics and mean yield performance, genotypes G9 or Fanaei-6 (2592.47 kg ha^{-1}), G11 or Fanaei-14 (2592.47 kg ha^{-1}), G12 Fanaei-15 or (2592.47 kg ha^{-1}) and G19 or Dez-7169 (2592.47 kg ha^{-1}) were the most stable and favorable genotypes and are recommended for national release Iran.

Keywords: adaptation, *brassica napus*, multi-environmental trials, regression analysis

INTRODUCTION

Seeds from canola (*Brassica napus* L.) are used for oil extraction, which makes canola the world's third most important source of vegetable oils, grown on over 36 million ha worldwide in 2013 (FAOSTAT, 2015). In the last decades, the importance of canola has significantly increased in world, mainly due to the diverse use possibilities of its products (Popovic *et al.* 2010). Worldwide canola production is approximately 73 million tons and the main producers are Canada, 24 %; the Economic European Community, 21 %; China, 20 % and India, 11 % (FAOSTAT, 2015). In Iran, canola is the first-largest broad-acre oilseed crop (before soybean and cotton) and is widely grown as a cash crop. Iranian breeders successfully improved seed yield as well as the other target traits such as drought tolerance and the availability of better cultivars and crop agronomy packages has made canola attractive to farmers and led to rapid expansion (Sabaghnia *et al.* 2010). The total production of canola in Iran in the 2013–2014 season was 350,000 tones which produced from 170,000 ha area with about 2000 kg ha^{-1} average mean yield (FAOSTAT, 2015).

Canola producing areas were located in regions with low average annual rainfall and it is grown at areas averaging less than 300 mm average annual rainfall. An understanding of the environmental and physiological factors causing genotype × environment (GE) interaction helps breeders to exploit specific adaptation (Basford and Cooper, 1998). The GE interaction is the response of each genotype to variations in the environment and it has been one of the principal subjects of study in plant breeding, allowing the generation of different methodologies for genetic improvement and recommendation of stable genotypes (Rodriguez *et al.* 2002). Despite of the importance of canola as a major oilseed crop in Iran, a limited investigation has been carried out on its adaptation to the Middle East climatic zone-type areas. The study of GE interaction for canola is important for Iranian agriculture due to the fact that most commercialized cultivars in the country originate from other countries where environmental conditions are different.

The presence of GE interaction for quantitative traits such as yield performance has led to the development of several statistical methods for stability analysis that can be used to identify genotypes with consistent performance across environments. These statistics, advantages and disadvantages, as well as the relationships between them have been reviewed previously (Lin *et al.* 1986; Flores *et al.* 1998; Sabaghnia *et al.* 2012). Flores *et al.* (1998) compared several stability methods to analyze GE interaction and classified them into three main groups including univariate parametric, univariate non-parametric and multivariate methods. There are two famous strategies for interpreting GE interaction with univariate parametric methods including analysis of variance and linear regression analysis. The importance of yield stability was recognized in 1917 by Roemer (in Becker, 1981), who used the variance across environments or environmental variance (EV) for yield stability. Francis and Kannenberg (1978) proposed the use of the coefficient of variation (CV) as a measure of genotype stability.

The stability variance (SV) is an unbiased estimate of the variance of a genotype across environments (Shukla, 1972). Lin *et al.* (1986) classified EV, CV and SV univariate stability methods into Type I concept of stability. Regression models were proposed by Finlay and Wilkinson (1963), Eberhart and Russell (1966), Perkins and Jinks (1968), Freeman and Perkins (1971) and Tai (1971) for studying GE interaction. Lin *et al.* (1986) classified their line slopes as Type II concept of stability while mean squares of residuals in each repression model were denoted into Type III concept of stability. Pinthus's (1973) approach uses the coefficient of determination (CD) of linear regression model for determining stability. Hernandez *et al.* (1993) proposed a desirability index (DI) that would combine both yield potential and regression coefficient in a single parameter. Although, each stability method gave an indication of stability, most plant breeders preferred to use more than one method for accurate assessment of yield stability and there is no consensus among breeders as to which methodology is the best (Adugna and Labuschagne 2002; Sabaghnia *et al.* 2006). Previous reports indicated that efficiency between different stability parameters also differed in canola (Escobar *et al.* 2011; Zhang *et al.* 2013).

The major objective of this study is to understand the adaptation of canola across Iran with a Middle East climatic zone-type climate. This study employs Types I, II and III stability parameters to evaluate the significance of the GE interactions on seed yield, determine the best performing genotype, and discuss the implication of the GE interactions to canola breeding.

MATERIALS AND METHODS

Plant material for field trials consisted of two winter rapeseed cultivars (RGS003 and Hyola 401) and 34 inbred lines. The inbred lines were selected from different rapeseed breeding programs of the Seed and Plant Improvement Institute (SPII), Karaj (35°59′N; 51°6′E), Iran, and were developed by self-pollination of selected individuals from different gene pools. The study was carried out during 2011–2012 growing season at the experimental fields of the SPII in the Dezful, Zabol, Sari and Gorgan stations. Climatic and geographic parameters of these locations are variable and presented in Table I. Also, monthly values of both precipitation and means temperature of test locations were given in Table II.

The field trials in all years were arranged in a randomized complete block design (RCBD), with three replicates. Seeds were sown by hand in four rows, 5.0 m long, with between-row spacing of 30 cm and thinning provided within-row spacing of 5 cm. Seeding depth was 2 cm in every location and plots were irrigated after sowing. In Dezful and Zabol locations irrigation was repated at heading, flowering and seed filling stages but field plots of Sari and Gorgan locations were not irrigated due to proper raining. Other agricultural practices were performed according to recommended optimal practices for local agro-ecological conditions.

The fertilizer recommendations are broadcasted before disk harrow and leveler actions of cultivated land. Irrigation date until seedling establishment, once every 5 days and after seedling establishment, I: *Geographical properties of test locations which 36 canola genotypes were studied.*

Rainfall (mm)	Soil Texture	Longitude Latitude	Altitude (meter)	Location	Code
250	Silty Clay Loam	32°48′N 32°24′E	80.5	Dezful	1
76	Clay Loam	32°61′N 32°05′E	489	Zabol	2
650	Clay Loam	10°53′N 41°36′E	29	Sari	3
450	Silty Clay Loam	20°54′N 36°55′E	5.5	Gorgan	4

II: *Monthly values of both precipitation and means temperature of test locations*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
	Average of mean daily temperature in °C												
Dezful	14.0	15.6	20.0	24.4	30.4	36.8	38.1	37.6	33.4	28.2	20.3	14.9	26.1
Zabol	10.6	13.6	20.4	25.9	30.7	34.1	35.8	34.2	28.6	25.9	15.3	9.6	23.7
Sari	8.4	7.6	12.1	16.3	20.8	24.3	28.1	27.9	25.5	20.6	14.2	12.2	18.2
Gorgan	9.2	9.0	11.2	15.0	21.9	28.7	30.8	29.3	25.7	21.9	14.1	11.6	19.0
	Monthly total of precipitation in mm.												
Dezful	69.7	6.4	2.1	24.6	2.1	0.0	0.0	0.2	0.2	13.1	128.6	3.0	250.0
Zabol	11.2	4.4	9.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	48.6	76.0
Sari	31.2	43.5	58.5	18.8	81.4	24.4	21.9	24.8	65.8	54.2	156.6	68.9	650.0
Gorgan	28.5	36.6	98.5	20.5	66.4	3.5	26.0	2.6	37.5	27.2	67.5	35.2	450.0

III: *Combined ANOVA of 36 canola genotypes across four test locations.*

Source	DF	MS	% of G + L + GL
Location (L)	3	6617883.9^{ns}	62.8
Replication/R	8	4131693.0	
Genotype (G)	35	2884630.8^{**}	27.4
G × L	105	1028033.9^{**}	9.8
R × G / L	280	397343.6	

**and ^{ns} significant at the 0.01 probability level, and non-significant.

on average, once every 10 days were done. Traditional tillage was employed and fertilizers and application rates were adjusted according to soil tests. Weeds and insects were controlled by applying the following products: herbicide: Terflan 2 L ha^{-1} [(2,6-Dinitro-N,N-dipropyl-4-(trifluoromethyl) aniline], and insecticides: Metasystox [Oxydemeton-methyl] and Ekatin [Thiomton]. The harvest was done manually, when most plants reached the second technical level of maturity (Harper and Berkenkamp, 1975), and seed yield per plot (kg) was calculated in the two center rows of each experimental unit and 0.5 m of plants were discarded from the end of the rows (2.4 m^2).

Analyses of variance were done for each environment (location) to plot residuals and identify outliers and homogeneity of residuals variance was determined by Bartlett's homogeneity test. Effect of location was assumed to be random but the genotype effect was assumed to be fixed and a combined analysis of variance was performed to partition out (environment) E, genotype (G) and GE interaction. The main effect of location was tested against the replication within environment (R/E) as Error I. The main effect of G was tested against the GE interaction and the GE interaction was tested against Error II. Thirteen stability parameters with different Types (I, II and III) were applied for stability analysis. These parameters were computed using the IML procedure of SAS 9.1 (SAS, 2004). A comprehensive SAS program (Hussein *et al.* 2000) was used to calculate different stability statistics. Principal component analyses (PCA) based on the correlation matrix was performed to obtain an understanding of the relationship among different stability parameters as well as three different Types of stability. Ward's hierarchical clustering was used to group tested genotypes using SPSS version 13.0 (SPSS, 2004).

RESULTS AND DISCUSSION

The results of the combined analysis of variance for seed yield of 36 genotypes in canola are presented in Table III. The effects of G and G × L interaction were significant ($P < 0.01$). Similarly, highly significant differences were observed among the environments or locations for seed yield. This reveals that these environments represented a wide range of agro-climatic conditions of Iran to assess the performance and the stability of the genotypes. The highly significant differences of GE interaction for seed yield indicate the differential response of genotypes to environments. The combined ANOVA also showed that seed yield was significantly affected by E, which explained 62.8 % of the total (G + E + GE) variation, whereas G and GE interaction accounted for 9.8 % and 27.4 %, respectively (Table III). Genotype seed yields ranged from 1773.6 kg ha^{-1} for G 27 (Ogh-2) to 3834.4 kg ha^{-1} for G10 (Fanaei-9) with a mean of 3220.5 kg ha^{-1} (Table IV). From the registered cultivars (G14 to G15), merely G14 (RGS003) had higher grain yield than the average, whereas 22 out of 34 advanced lines were higher yielding ones and genotypes G10 (Fanaei-9), G12 (Fanaei-15) and G25 (Dez 06182) indicated the best yield performances (Table IV).

The results of various nonparametric tests verified the results combined ANOVA. According to chi square statistic of Azzalini and Cox (1984) procedure, the existence of crossover (non-additive) GE interaction were demonstrated ($\chi^2 = 295$). Seed yield is a quantitative trait and its expression is the result of genotype, environment and GE interaction and the large magnitude GE interaction, cause to the more dissimilar genetic systems, which controlling the physiological processes (Cooper *et al.* 2001). The relative contribution of GE interaction effects for canola seed yield found in this study are similar to those found in other studies (Marjanovic-Jeromela *et al.* 2011; Zhang *et al.* 2013) and makes it difficult to select the most favorable genotypes in any plant breeding program. Once combined ANOVA revealed that GE interaction was statistically significant, 13 parametric stability approaches were performed the multi-environment yield data, in order to measure the stability levels of 36 canola genotypes. Details of parametric stability statistics are given in Table IV.

According to the environmental variance (EV) and coefficient of variation (CV) stability parameters, genotypes G7, G17 and G37 were more stable (Table IV), but their yield performance were near or lower than average yield of all studied genotypes. Genotypes G17, G4 and G2 were the most stable genotypes according to stability variance (SV) parameter of Shukla (1972). All of the above mentioned stability statistics (EV, CV and SV) represent Type I stability concept and usually introduce low mean yielding genotypes as the most stable genotypes but in this study, they could identify relatively moderate mean yielding genotypes as the most stable genotypes (Table V). According to Adugna (2007), a genotype has Type-1 stability if its environment variance is small and it is useful for measuring stability in a limited range of environments, which may be useful for selecting genotypes for specific adaptation

According to the coefficients of linear regression slope (Finlay and Wilkinson, 1963), Perkins and Jinks' (1968) modified regression coefficient and α parameter of Tai's (1971) regression model, genotypes G33, G27 and G29 were the most stable and responsive genotypes (Table V) while based on coefficients of linear regression model of Freeman and Perkins (1971), genotypes G3, G5 and G19 were the most stable and responsive ones. Lin *et al.* (1986) classified regression slope-based parameters as Type II stability, which, the yield response of a stable genotype in each environment is always parallel to the mean response of the tested one. The measure of Type II stability depends on the specific set of tested genotypes, unlike the measure of static concept of stability (Lin *et al.* 1986). In agreement to these reports, some of the most stable genotypes based on regression model such as G19 had high mean yield performance.

According to deviation from linear regression method (Eberhart and Russel, 1966) genotypes G7, G15 and G36 were the most favorable genotypes while regression residuals of Perkins and Jink's (1968) model, genotypes G7, G12 and G17 were the most stable genotypes (Table VI). Freeman and Perkins's (1971) deviation from linear regression showed that genotypes G20, G23 and G29 were the most stable genotypes while based on lambda statistics of Tai (1971), genotypes G1, G25 and G34 were the most favorable genotypes. An ideal genotype is the one that combines high mean yield with stability of performance (Eberhart and Russell, 1966). Deviation from linear regression is the measure of agronomic stability and indication of Type III stability concept, and stable genotypes based on this concept are acceptable over a wide range of environmental conditions (Allard and Bradshaw, 1964). Finally, genotype G29 was the most favorable genotype according to Type II and Type III stability concepts.

Pinthus's (1973) stability parameter or coefficient of determination (CD) values for the canola genotypes indicated that genotypes G27 and G33 were the most stable genotypes but the genotype response to environments is not linear because most of the studied genotypes had low CD values (Table VI). Genotypes G1, G10 and G25 had the highest desirability index (DI) values and thus were the most stable ones, but genotype genotypes G7, G32 and G35 had the lowest DI values and were

IV: *Stability parameters which performance Types I and II stability concepts.*

Code	Genotypes' name	Mean yield	Type I			Type II			
			EV	CV	SH	FW	PJ	FP	α
G1	Rameh–1	3747.6	964520	26.21	614338	3.56	2.56	0.22	6.81
G2	Rameh–2	3390.4	90780	8.89	10521	1.08	0.08	–1.48	0.22
G3	Rameh–3	3487.5	112454	9.62	45583	0.99	–0.01	0.49	–0.03
G4	Rameh–4	3505.6	71916	7.65	24607	0.82	–0.18	–1.47	–0.48
G5	Rameh–5	3165.7	365251	19.09	217503	1.73	0.73	–1.61	1.93
G6	Rameh–6	3555.8	428869	18.42	364278	1.11	0.11	0.36	0.30
G7	Rameh–7	3265.1	44238	6.44	204907	–0.80	–1.80	–0.30	–4.78
G8	Rameh–8	3250.1	307105	17.05	121195	1.99	0.99	–1.06	2.65
G9	Fanaei–6	3683.2	727917	23.16	389654	3.36	2.36	–0.53	6.28
G10	Fanaei–9	3834.4	700947	21.84	437103	2.77	1.77	–2.84	4.72
G11	Fanaei–14	3663.5	218353	12.76	119571	1.28	0.28	–1.82	0.75
G12	Fanaei–15	3797.3	261813	13.48	73507	1.99	0.99	–1.27	2.64
G13	Fanaei–16	3555.9	211515	12.93	341639	–0.48	–1.48	–2.30	–3.95
G14	RGS003	3315.2	91886	9.14	34573	0.91	–0.09	–1.41	–0.25
G15	Hyola 401	3012.0	69683	8.76	181541	–0.41	–1.41	–0.25	–3.75
G16	Dez 11182	3215.0	136672	11.50	172805	0.21	–0.79	–1.01	–2.11
G17	Dez 16169	3161.2	47531	6.90	2286	0.79	–0.21	–0.93	–0.55
G18	Dez 04182	3499.3	314336	16.02	180307	1.60	0.60	–1.81	1.59
G19	Dez–7169	3664.0	390538	17.06	205955	2.02	1.02	–2.33	2.72
G20	Dez 19169	3773.3	654247	21.44	571988	1.35	0.35	–3.23	0.94
G21	Dez 01182	3308.3	454254	20.37	617051	–0.63	–1.63	–2.21	–4.33
G22	Dez 02169	3435.0	924738	28.00	900862	1.03	0.03	–3.47	0.07
G23	Dez 05169	3024.1	91934	10.03	31899	0.93	–0.07	–0.06	–0.20
G24	Dez 03169	3407.3	420021	19.02	377165	0.94	–0.06	–2.29	–0.15
G25	Dez 06182	3785.0	952499	25.79	559112	3.89	2.89	–2.84	7.68
G26	Ogh–1	2265.7	513011	31.61	555494	0.33	–0.67	1.19	–1.79
G27	Ogh–2	1773.6	613271	44.15	768145	–0.49	–1.49	2.93	–3.97
G28	Ogh–7	2791.4	590429	27.53	285157	3.04	2.04	–0.84	5.44
G29	Ogh–9	2738.5	483692	25.40	605303	–0.30	–1.30	1.27	–3.45
G30	Ogh–14	3150.8	226223	15.10	242383	0.40	–0.60	0.18	–1.60
G31	Roodi–8	2674.9	134774	13.72	196197	0.01	–0.99	0.46	–2.64
G32	Roodi–9	2504.4	270347	20.76	486413	–1.12	–2.12	0.44	–5.64
G33	Roodi–10	2275.4	1297165	50.05	1446565	–0.14	–1.14	3.24	–3.04
G34	SAN–12	3306.5	731773	25.87	389143	3.39	2.39	–1.52	6.37
G35	Behbahan–2	2612.6	265158	19.71	477717	–1.10	–2.10	0.60	–5.58
G36	Varamin–3	3341.8	19837	4.22	83950	–0.06	–1.06	–0.18	–2.83

unstable (Table VI). The existence of GE interaction is a major concern in multi-environmental trials and different efforts have been made to analyze yield stability, and although no method perfectly accommodates GE interaction, most plant breeders utilize some forms of stability analysis in their varietals selections (Pinthus, 1973). However, based on the different stability parameters, genotypes G3, G4, G25, G8, G12, G17 and G23 following to genotypes G2, G9, G11, G14, G18, G19 and G36 were the most stable genotypes, but only yield performance of genotypes G9, G11, G12 and G19 were high and could be recommended as the most favorable genotypes based on yield and stability issues.

Each of the mentioned stability statistics produced a unique genotype ranking and the Spearman's rank correlations between each pair of them were calculated (Table VI). Among the different 13 univariate stability statistics, only desirability index of Hernandez *et al.* (1993) and lambda statistics of Tai (1971), had highly significant correlation with mean yield performance. The indicators of Type I stability concept (EV, CV and SV) were significantly correlated with ER regression parameters (Table VI). The linear regression slope (Finlay and Wilkinson, 1963), modified regression coefficient (Perkins and Jinks, 1968) and α parameter (Tai, 1971) indicated high positive association with DI (Hernandez *et al.* 1993) and lambda statistics (Tai, 1971). Pinthus's (1973) coefficient of determination (CD) did not show any positive association with three stability types but DI (Hernandez *et al.* 1993) had positive correlation with type II stability.

To better understand the relationships among the stability methods, a principal component analysis (PCA) based on the correlation matrix was performed. When applying the PCA, the two first PCAs explained 80.6 % (47.5 and 33.1 % by PCA1 and PCA2, respectively) of the variance of the original variables. The loadings of the first two PCAs were used for graphic display of the relationships among them (Fig. 1). In this plot, the PCA1 axis mainly distinguishes the type II of stability concept from other types of stability. Mean yield also groups near this stability type, and we refer to these as class 1 (C1) stability measures including the coefficient of linear regression slope (FW), α and lambda parameters of Tai (1971) and DI (Hernandez *et al.* 1993). It seems that PCA1 axis could divide these methods according to mean yield and yield stability based on type II. The PCA2 axis distinguishes the FP regression slope and CD from the type I (EV, CV and SV) and type III (MSFP, MSPJ and ER) of stability concepts.

The high significance of GE interaction of this study showed that the genotypes exhibited both crossover and additive types of GE interaction. The present research exhibited a more complex GE interaction which could be associated with the nature of the canola crop, environmental conditions or diverse genetic background of canola genotypes obtained from different sources. Seed yield is the result of genotype, environment and GE interaction and its complexity due to diver processes which occur during crop development. The remarkable magnitude of GE interaction on seed yield found in canola genotypes is similar to those found in other crops (Sabaghnia *et al.* 2013). This suggests that it would be very difficult to achieve an indirect response to selection over all the canola target population of environments from selection in a few environments, ignoring the observed GE interactions. Different environmental factors (such as, temperature and rainfall and etc.) play important role in the genotypes performance besides edaphic factors (such as fertility and soil properties) and the GE interaction and yield stability are the main problems facing plant breeders producing improved cultivars (Sabaghnia *et al.* 2006). Increasing canola yield has been the main objective of the breeders and so the assessment of yield stability can be approached in various ways or various concepts. The adaptability of a genotype over environments is tested by its interaction with different environments (Cooper *et al.* 1999; Sabaghnia *et al.* 2012).

According to the most stability statistics which is applied to canola multi-environmental trials, genotypes G9 or Fanaei-6 (2592.47 kg ha^{-1}), G11 or Fanaei-14 (2592.47 kg ha^{-1}), G12 Fanaei-15 or (2592.47 kg ha^{-1}) and G19 or Dez-7169 (2592.47 kg ha^{-1}) were the most favorable genotype due to its stability and high mean yield. These genotypes are therefore recommended for release as a cultivar by the Seed and Plant Improvement Institute of Iran for cultivation by farmers. Although, yield performance of check cultivars (RGS003 and Hyola 401) were higher (3315.2 and 3012.0 kg ha^{-1}, respectively) than the above mentioned genotypes, but their stability were very poor. They are good candidates for further evaluation in the next years and can be used as the proper plant materials in the future canola breeding programs. There is need to improve more adapted and high yielding genotypes for cultivation with unpredictable environmental conditions. Usually genotypes have mostly been selected for favorable environments and proper technologies such as fertilizers, pesticides, etc., and all breeding efforts should be done in the target environment. Yield stability depends on yield components and other plant characteristics, such as tolerance to environmental stress factors, e.g. drought conditions. Reductions in canola yield is chiefly observed after a preseason drought, particularly if the season is also dry.

To reveal associations among canola genotypes, the dataset was analyzed using Ward's hierarchical clustering procedure and the dendrogram of clustering showed that the 36 studied genotypes could be divided into three major groups according to mean yield and different stability statistics (Fig. 2). Group-1 contains 10 genotypes which were the relatively low yielding genotypes and moderate stability. Group-2 contains 10 genotypes which were the relatively moderate yielding genotypes with high stability and group-3 contains 16 genotypes which were the relatively moderate or high yielding genotypes with high or moderate stability (Fig. 2).

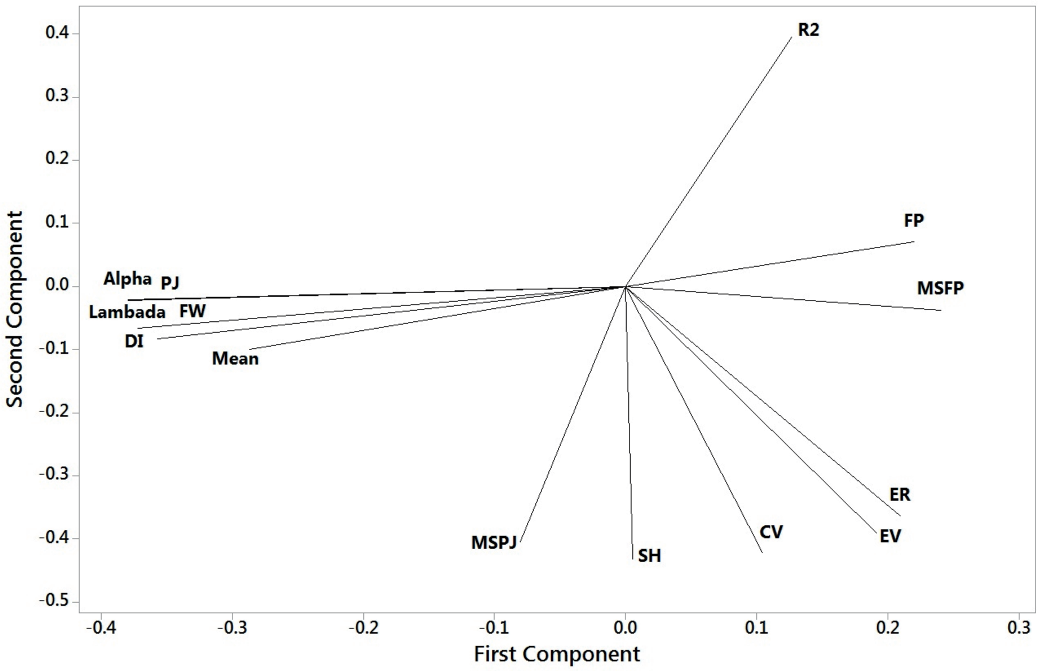
V: *Stability parameters which performance Type III stability concept CD and DI parameters.*

Code	Type III				Other	
	ER	PJD	MSFP	λ	CD	DI
G1	845249	283058	1988900	–64.97	16.97	4390.0
G2	135551	28565	875873	–1.33	5.92	3585.8
G3	168669	78843	715544	1.48	10.28	3666.0
G4	104879	46144	69323	5.72	7.03	3653.5
G5	499363	273893	1883716	–16.66	18.33	3477.4
G6	642098	529134	211590	1.26	18.30	3757.0
G7	–230060	8147	170446	48.12	0.93	3121.4
G8	369797	95111	126938	–24.97	7.47	3610.1
G9	580338	54751	1121163	–61.29	7.20	4289.6
G10	762362	344448	451693	–43.82	14.66	4335.1
G11	320190	176333	958900	–5.61	12.61	3895.1
G12	302237	27930	117200	–25.38	3.97	4156.9
G13	114694	295689	58866	41.88	17.27	3468.4
G14	137011	62439	386720	3.56	6.60	3478.7
G15	–77722	89215	64951	38.44	8.02	2938.3
G16	147037	201114	100997	23.00	14.04	3252.2
G17	67341	13561	89749	6.21	4.58	3304.3
G18	438668	236877	182442	–13.52	12.82	3787.7
G19	489834	210075	462268	–24.90	12.96	4029.0
G20	969928	813153	35647	–3.07	24.67	4017.5
G21	438272	645324	134512	48.04	25.57	3195.3
G22	1387047	1290440	403755	8.87	31.55	3620.1
G23	137406	58974	31240	2.98	7.32	3191.4
G24	629733	548297	149925	5.92	20.17	3577.6
G25	663340	40944	1856256	–75.29	6.31	4486.5
G26	727946	759658	330464	23.64	36.24	2324.8
G27	714974	897550	112580	46.26	55.52	1684.5
G28	502180	34787	627476	–53.07	5.92	3340.7
G29	571254	717507	50258	39.80	27.46	2685.1
G30	306283	324603	378605	18.71	17.17	3223.1
G31	112090	202152	273983	28.17	17.50	2676.7
G32	–7666	290178	66964	58.63	18.36	2302.2
G33	1826089	1943920	304155	44.19	60.58	2250.0
G34	570652	38556	1554036	–62.34	3.72	3919.3
G35	–5886	287421	362168	57.96	20.05	2414.8
G36	–74057	29394	267733	28.90	4.61	3330.5

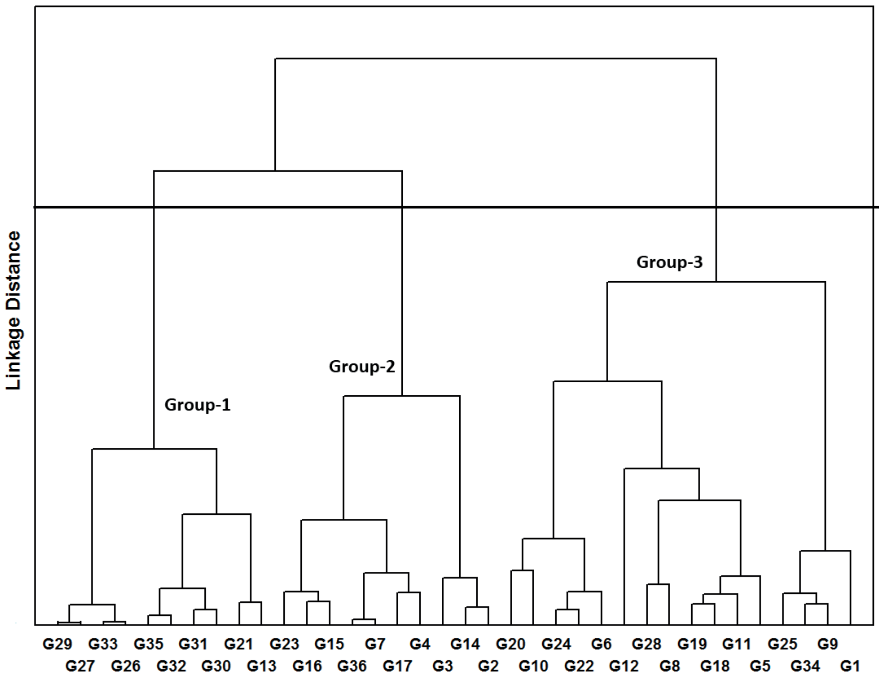
VI: *Spearman's correlation coefficients among ranks of 13 stability methods for 36 canola genotypes*

	Mean	EV	CV	SV	FW	PJ	FP	α	ER	MSPJ	MSFP	λ	CD
EV	–0.15*												
CV	0.13	0.95											
SV	0.12	0.83	0.87										
FW	0.64	–0.44	–0.24	0.07									
PJ	0.64	–0.44	–0.24	0.07	0.99								
FP	–0.68	0.11	–0.08	–0.08	–0.47	–0.47							
α	0.63	–0.44	–0.24	0.07	1.00	1.00	–0.47						
ER	–0.23	0.91	0.83	0.68	–0.50	–0.50	0.16	–0.50					
PJD	0.19	0.55	0.61	0.74	0.26	0.26	–0.09	0.26	0.59				
MSFP	–0.27	0.36	0.29	0.10	–0.59	–0.59	0.15	–0.59	0.33	–0.16			
λ	0.64	–0.35	–0.16	0.17	0.99	0.99	–0.45	0.99	–0.42	0.35	–0.56		
CD	–0.32	–0.48	–0.58	–0.71	–0.37	–0.37	0.20	–0.36	–0.49	–0.97	0.18	–0.44	
DI	0.92	–0.28	–0.02	0.12	0.86	0.86	–0.64	0.86	–0.34	0.26	–0.46	0.86	–0.39

*Critical values of correlation P < 0.05 and P < 0.01 (D.F. 34) are 0.33 and 0.42, respectively.



1: *Principal analysis plot of ranks of stability of yield, estimated by 13 methods using yield data from 36 canola genotypes which showing interrelationships among these parameters.*



2: *Hierarchical cluster analysis of the 36 canola genotypes based on Ward's method using a GE matrix of mean yields.*

CONCLUSION

Overall, it could be concluded that based on the different 13 univariate stability statistics, genotypes G9 (Fanaei-6), G11 (Fanaei-14), G12 (Fanaei-15) and G19 (Dez-7169) were the most stable and favorable genotypes. Therefore, these genotypes are recommended for national release as a cultivar for cultivation in Iran and similar climatic regions in Middle East and other areas of world.

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