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Casual explanation of the relationships between seed yield and some yield components in cumin (*Cuminumcyminum* L.) by different multivariate statistical analysis at different sowing dates

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Abstract

Cumin (*Cuminumcyminum* L.) is one of the most important cultivable medicinal plants in Iran and today, it is the second most popular spice in the world after black pepper. It is essential to know the relationships between yield and its components in cumin breeding programs. Therefore, different multivariate statistical analysis was performed on plant characters in cumin to determine the relationships between seed yield and seed yield components under field conditions.Positive and significant relationships were found statistically between the umbel number/plant, seed number/plant and biomass in all sowing dates**.** There were also very high correlation coefficients for plant height and number of branches with seed yield/plant at most of the sowing dates. Stepwise multiple linear regression analysis for each sowing dates indicated that 89% to 97.2% of the total variation in seed yield/plant was explained by the variation of the seed number/plant, umbel number/plant and 1000-seed weight in the different sowing dates. Path analysis revealed that seed number/plant had strong direct effects on seed yield of cumin in all sowing dates and 1000-seed weight in most sowing dates had positive direct effects on seed yield/plant which shows their potentials in breeding programs. There were high and significant correlation coefficients between umbel number/plant and plant height with seed yield/plant that was resulted from greatest indirect effects of mentioned traits through seed number/plant. In accordance with results of this research, it can be concluded that seed number/plant and 1000-seed weight are good selection criteria for improving seed yield in the cumin, meanwhile umbel number/plant and plant height have good potential to improve seed yield through indirect selection in breeding strategies.

Introduction

Cumin (*Cuminum cyminum* L.) is an important seed spice and it is one of the earliest known minor spices used by mankind (Divakara Sastry & Anandaraj n.d.). Cumin is one of the most important medical plants in Iran and today, it is in the second level of popularity between spices in the world after black pepper (kafi., 2002; Bettaieb et al., 2012). Cumin is believed to be native of the Mediterranean and near-east region. It is mainly cultivated in the countries like India, Egypt, Israil, Libya, Iran, Pakistan, Morocco, Japan and Turkey (Parthasarathy & Kandiannan., 2007), but The western world got to know it as a spice from Iran, and the name cumin has its roots in the word *Kerman*, a city in Iran around which it was extensively cultivated (Divakara Sastry & Anandaraj n.d.). Cumin is an aromatic plant used as flavoring and seasoning agent in foods. Cumin seeds have been found to possess significant biological (Zaman & Abbasi., 2009) and have been used for treatment of toothache, dyspepsia, diarrhoea, epilepsy and jaundice (Nostro et al., 2005; Bettaieb et al., 2012).

When initiating a breeding program with any crop having genetic variation, it is important to gather information on the traits of agronomic importance in order to select and breed better varieties (Dubley & Moll., 1969). The ultimate goal of the most plant breeding programs is to improve the productivity of grains as measured in terms of the yield per plant (Golkar et al., 2011).

Correlation coefficients generally show relationships among the independent characteristics and the degree of linear relation between these characteristics. It is not sufficient to describe this relationship when the causal relationship among characteristics is needed (Güler et al., 2001).

Path analysis determines the relative importance of direct and indirect effects of agronomic component traits on seed yield. This method has been used by plant breeders to assist for identifying high-heritable traits associated with seed yield. Stepwise regression analysis is used to determine the percentage contribution of more important traits that had significant association with seed yield. (Golkar et al., 2011). However, path analysis, regression on standardized variables, determines the relative importance of direct and indirect effects on seed yield (Bhatt., 1973).

The relationships among some morphological traits have been determined in most crops (Seker & Serin., 2004; Güler et al., 2001; Cokkizgin et al., 2013; Kassahun et al., 2013; Golkar et al., 2011; bahraminejad et al., 2011). Bahraminejad et al. (2011) in the study on forty nine cumin ecotypes using different multivariate statistics, showed number of umbel per plant and number of seed per umbel were effective traits on seed yield of cumin. Kassahun et al., (2013) reported that the most direct effect was obtained from umbels per plant, on coriander.

Plant breeding may alleviate the deficiency in crop production by developing varieties with higher yield potential under the severe ecological conditions. Sowing date is an important and well known factor in production management of all crops. Considering that any changes in sowing time causes significant changes in weather parameters, and consequently the performance of the crops (Soleimani et al., 2011), So this research is carried out to detect the most effective traits which affect seed yield under different sowing dates, and this study was also aimed to identify a suitable selection criteria for breeding strategies using different multivariate statistical analysis such as correlation coefficients, stepwise regression and path coefficients analysis.

Materials and methods

- **Plant Materials and growing conditions**

In this study nine cumin ecotypes which are belonged to nine different provinces of Iran that has the biggest variation for cumin, were cultivated in five sowing dates based on randomized complete block design (RCBD) with split plot arrangement and 3 replication on growing season of 2011-2012. The experiment was carried out in Faculty of agriculture research field of Shahid Bahonar University of Kerman (56º,58'E, 30º, 15'N and 1754 m elevation). Soil type was a Sandy-loam, with pH 7.4, EC 4.4 (dS/m), and mean annual precipitation of 150 mm. Table 1 shows regional meterological records of study site. Nine cumin ecotypes including Semnan, Fars, Yazd, Golestan, Khorasan-Razavi, Khorasan-Shomali, Khorasan-Jonoubi, Esfahan and Kerman were sown on 26th December (D1), 10th January (D2), 25th January (D3), 9th February (D4) and 24th February (D5) dates. Dimensions of the experimental plots were 2 m long and 1.2 m width that included three rows with 40 cm row spacing and the distance between plants was 5cm. All experimental plots were treated uniformly.

Table 1-Regional meterological records of study site during the growing season of 2011-2012

		26-31 Dec.	Jan.	Feb.	Mar.	Apr.	May
Mean of temperature (˚c)	Min.	-4.5	-2.43	-0.17	3.87	8.87	14.11
	Max.	12.8	14.03	12.11	19.51	24.19	31.14
Rainfall (mm)		0	19.4	50.7	14.5	3.3	0.2

- **Studied traits**

Measurements and observations of the studied characters were done on five plants which had been chosen randomly in the mid-row of each plot.The measured quantitative traits were including: plant height (X1), number of branches (X2), umbel number/plant (X3), umbellate number/umbel (X4), seed number/umbel (X5), seed number/plant (X6), 1000-seed weight (X7), biomass (X8) and seed yield/plant (X9).

- **Statistical analysis**

In order to determine the relationships between examined traits and yield, correlation coefficients were first calculated. Simple phenotypic correlation and stepwise multiple regression analysis were carried out using SPSS ver 17.0 statistical program, using seed yield as dependent variable and the remaining traits as independent variables.Genetic correlation (r_g) was done using phenotypic correlation coefficient and error SSCP matrix by SAS 9.1. As well as the relative importance of direct and indirect effects on seed yield and residual were calculated by MATLAB 7.10.0 (R2010a) and Excel softwares according to equations 1, 2 and 3, respectively (Rezaei & Soltani., 2008).

$$(1)\ \begin{bmatrix} P1y \\ \vdots \\ Pny \end{bmatrix} = \begin{bmatrix} r11 & \cdots & r1n \\ \vdots & \ddots & \vdots \\ r1n & \cdots & rnn \end{bmatrix}^{-1} \begin{bmatrix} r1y \\ \vdots \\ rny \end{bmatrix}$$

$$(2)\ Q_{1n}=r_{1n}P_{ny}$$

$$(3)\ R=\sqrt{1-(p_{1y}r_{1y}+p_{2y}r_{2y}+\cdots+p_{ny}r_{ny})}$$

P_y: Direct effects of X on Y
r_n: Correlation coefficient between X and X_n
r_y: Correlation coefficient between X and Y
Q_{1n}: Indirect effect of X_1 through X_n on seed yield
R: Residual

Results

- **Correlation coefficients of traits with seed yield/plant**

Phenotypic and genotypic correlation coefficients of each sowing date and averages of all sowing dates, have been shown in Tables 2 to 7, respectively. These results indicated that there are significant differences between the phenotypic and genotypic correlation coefficients which are related to considerable impact of environmental factors.

Simple phenotypic correlation coefficients calculated among examined characteristics of cumin in different sowing dates, are presented in Tables 2 to 6. Positive and very high relationships existed between seed yield and most of components such as umbel number/plant, seed number/plant and biomass in all sowing dates (Tables 2 to 6). Very high correlation coefficients were found for umbel number/plant, biomass, seed number/plant, plant height and number of branches while the others were positive and not significant in the 1st sowing date (Table 2).

There were statistically positive and significant relationships between the biomass and seed number/plant with seed yield/plant at 1% probability level (0.987 and 0.951, respectively) and between umbel number/plant and seed yield at 5% probability level. Negative and not significant relationships were determined statistically between the seed number/umbel and seed yield/plant (-0.2). There was no high correlation between other traits and seed yield/plant in the 2nd sowing date (Table 3).

Estimated correlation coefficients of phenotypic components were positive and significant between seed yield/plant and most agronomic traits (biomass (0.975), seed number/plant (0.953), umbel number/plant (0.866), plant height (0.829) and number of branches (0.779)) in the 3rd sowing date. There was non-significant positive phenotypic correlation between umbellate number/umbel and seed yield/plant (0.613) and between seed number/umbel and seed yield/plant (0.145). There was non-significant and negative correlation between 1000-seed weight and seed yield/plant (-0.168) (Table 4).

The highest correlation coefficients were found for biomass in the 4th sowing date (0.991) (Table 5). Positive and significant relationships were determined statistically between the seed number/plant and seed yield/plant (0.926), between umbel number/plant and seed yield/plant (0.913), between number of branches and seed yield/plant (0.892) and between plant height and seed yield/plant (0.839). Negative and not significant relationship was determined statistically between the seed number/umbeland seed yield/plant (-0.475). There was positive and no high correlation between seed yield/plant and other two agronomic traits (umbellate number/umbel (0.158) and 1000-seed weight (0.252)) (Table 5).

There was significant positive phenotypic correlations between seed yield/plant and the seed number/plant (0.973), biomass (0.957), umbel number/plant (0.904), number of branches (0.903) at 5th sowing date (Table 6). Negative relationships existed between seed yield/plant and 1000-seed weight, seed number/umbel and plant height (-0.650, -0.592, -0.195 respectively) and between umbellate number/umbeland seed yield/plant was positive and not significant (0.337) (Table 6).

Tables 2 to 6- Phenotypic correlation coefficients of measured traits in cumin at the first (D1) to fifth (D5) sowing dates, respectively.

Table 2- Phenotypic correlation coefficients at the 1st sowing date (D1).

	X1	X2	X3	X4	X5	X6	X7	X8
X2	0.545	1						
X3	.711*	.800**	1					
X4	0.518	0.335	0.038	1				
X5	0.489	0.387	0.431	0.265	1			
X6	.805**	.867**	.885**	0.453	0.477	1		
X7	-0.082	0.085	0.422	-.682*	-0.234	0.161	1	
X8	.859**	.772*	.873**	0.440	0.421	.933**	0.106	1
X9	.808**	.805**	.968**	0.236	0.409	.951**	0.326	.957**

Table 3- Phenotypic correlation coefficients at the 2nd sowing date (D2).

	X1	X2	X3	X4	X5	X6	X7	X8
X2	0.266	1						
X3	0.072	.887**	1					
X4	0.312	0.104	0.255	1				
X5	-0.228	0.002	0.244	-0.253	1			
X6	0.421	.716*	.797*	0.470	-0.041	1		
X7	0.39	0.44	0.215	-0.162	-0.455	0.512	1	
X8	0.480	0.568	.669*	0.569	-0.157	.952**	0.449	1
X9	0.419	0.587	.672*	0.534	-0.200	.951**	0.538	.987**

Table 4- Phenotypic correlation coefficients at the 3rd sowing date (D3).

	X1	X2	X3	X4	X5	X6	X7	X8
X2	0.596	1						
X3	0.660	.973**	1					
X4	0.659	0.302	0.319	1				
X5	0.138	0.023	0.125	-0.118	1			
X6	.825**	.878**	.940**	0.556	0.110	1		
X7	-0.234	-0.301	-0.299	-0.340	-0.285	-0.377	1	
X8	.834**	.871**	.921**	0.596	0.049	.985**	-0.266	1
X9	.829**	.779*	.866**	0.613	0.145	.953**	-0.168	.975**

Table 5- Phenotypic correlation coefficients at the 4th sowing date (D4).

	X1	X2	X3	X4	X5	X6	X7	X8
X2	.730*	1						
X3	.820**	.936**	1					
X4	0.283	0.064	0.264	1				
X5	-.742*	-0.519	-0.613	-.685*	1			
X6	.813**	.958**	.962**	0.095	-0.566	1		
X7	0.031	-0.089	-0.029	0.278	0.201	-0.099	1	
X8	.851**	.899**	.928**	0.256	-0.553	.923**	0.238	1
X9	.839**	.892**	.913**	0.158	-0.475	.926**	0.252	.991**

Table 6- Phenotypic correlation coefficients at the 5th sowing date (D5).

	X1	X2	X3	X4	X5	X6	X7	X8
X2	-0.111	1						
X3	-0.293	.947**	1					
X4	0.224	0.35	0.364	1				
X5	0.516	-.717*	-0.659	0.125	1			
X6	-0.176	.899**	.939**	0.491	-0.554	1		
X7	0.420	-.675*	-.835**	-0.398	0.442	-.745*	1	
X8	-0.089	.895**	.921**	0.372	-0.473	.959**	-.689*	1
X9	-0.115	.903**	.904**	0.337	-0.592	.973**	-0.65	.957**

X1: plant height; X2: number of branches; X3: umbel number/plant; X4: umbellete number/umbel; X5: seed number/umbel; X6: seed number/plant; X7: 1000-seed weight; X8: biomass and X9: seed yield/plant.

** *P<0.01*

* *P<0.05*

Table 7- Genotypic correlation coefficients of measured traits in cumin, based on the total data of all sowing dates.

	X1	X2	X3	X4	X5	X6	X7	X8
X2	-0.276*	1						
X3	-0.275*	-0.009	1					
X4	-0.088	0.100	0.041	1				
X5	0.203	-0.149	-0.145	0.162	1			
X6	-0.117	-0.164	-0.178	0.094	0.339*	1		
X7	-0.265*	-0.032	-0.022	-0.096	0.267*	0.082	1	
X8	-0.197	-0.100	-0.106	0.107	0.252*	-0.004	0.016	1
X9	-0.195	-0.186	-0.197	0.080	0.408**	0.002	0.087	-0.015

X1: plant height; X2: number of branches; X3: umbel number/plant; X4: umbellete number/umbel; X5: seed number/umbel; X6: seed number/plant; X7: 1000-seed weight; X8: biomass and X9: seed yield/plant.

** *P<0.01*

* *P<0.05*

- **Stepwise multiple linear regression analysis**

Data in table 8 represented the obtained equations for seed yield/plant and adjusted R^2 as well as the F value and significant levels of different sowing dates. In these equations, seed yield/plant as dependent variable and different agronomic traits (plant height (X_1), umbel number/plant (X_3), seed number/umbel (X_5), seed number/plant (X_6) and 1000-seed weight (X_7)) were considered as independent variables. According to the results, in the 1st sowing date model, 97.2% of the total variation in seed yield/plant could be attributed to umbel number/plant and seed number/plant. At the 2nd, 3rd and 5th sowing dates, seed number/plant entered into the linear model and justified 89%, 89.5% and 94% of seed yield variation, respectively. In total, 97% of the variation in seed yield/plant could be explained by the variation of the two independent variables (seed number/plant & 1000-seed weight) for the 4th sowing date. Some other traits didn't show any significant effect on seed yield/plant and were excluded from the above mentioned models (Table 8).

Table 8- Summary of stepwise multiple regression analysis of seed yield and its components in cumin

	Regression equations	Adjusted R^2	F value	significance
1st sowing date	$Y=-0.095+ 0.022X_3+ 0.001X_6$	.972	138.665	.000***
2nd sowing date	$Y=-0.114+ 0.003X_6$	.890	65.882	.000***
3rd sowing date	$Y=0.165+ 0.002X_6$	.895	69.061	.000***
4th sowing date	$Y=-1.283+ 0.003X_6+ 0.402X_7$	.970	130.694	.000***
5th sowing date	$Y=0.347+ 0.002X_6$	.940	125.482	.000***

Where: X_3: umbel number/plant; X_6: seed number/plant; X_7: 1000-seed weight
*** *P<0.001*

- **Path coefficient analysis**

The phenotypic correlation coefficients between seed yield/plant and other effective traits were partitioned into direct and indirect effects in different sowing dates (Tables 9 to 13). The results of path analysis for the first sowing date showed that umbel number/plant and seed number/plant had a high positive direct effect (0.542 and 0.367, respectively), while seed number/umbel had a negative direct effect (-0.073) on the seed yield/plant. The highest indirect effects on seed yield/plant were observed with plant height through umbel number/plant (0.368) and seed number/plant (0.295), umbel number/plant through seed number/plant (0.325), seed number/umbel, seed number/plant and 1000-seed weight through umbel number/plant (0.234, 0.480 and 0.229, respectively) (Table 9).

Path analysis showed that seed number/plant was the mere character which had a positive direct effect on the enhancement of seed yield/plant of cumin, in the 2nd sowing date. The seed number/plant showed the greatest direct effect on seed yield/plant (1.164), negative indirect effects of this trait through plant height (-0.029), umbel number/plant (-0.163) and 1000-seed weight (-0.026) reduced its total correlation with seed yield/plant. The direct effects of other traits on seed yield/plant were negative but small. The indirect effects of plant height, umbel number/plant, and 1000-seed weight through seed number/plant substantially increased the total correlations between aforementioned traits and seed yield/plant (Tables 3 and 10).

In the 3rd sowing date, the seed number/plant showed the largest direct effect on seed yield/plant (1.802). The correlation coefficient of seed number/plant and seed yield/plant resulted from positive and high direct effect of seed plant and negative indirect effects through plant height (-0.157), umbel number/plant (-0.586) and 1000-seed weight (-0.121). The direct effects of plant height and umbel number/plant on seed yield/plant were negative. Significant positive correlation coefficients of umbel number/plant and plant height with seed yield/plant resulted from positive indirect effects through seed number/plant. In contrary, negative correlation coefficient of 1000-seed weight in spite of their positive direct effects on seed yield/plant resulted from high and negative indirect effect through seed number/plant (-0.678) (Table 11).

Path analysis showed that all the traits had positive direct effects on the enhancement of seed yield of cumin in the 4th sowing date (Table 12). Seed number/plant had a strong positive direct effect on seed yield/plant (0.814). The direct effect of 1000-seed weight was also positive (0.303). The direct effect of the umbel number/plant on seed yield/plant was positive but very small (0.005), while its correlation coefficient with seed yield/plant was positive and statistically significant (0.913**). It is due to the largest indirect effect on seed yield/plant through seed number/plant (0.783), also plant height had a large indirect effect through seed number/plant on seed yield/plant (0.662). Thenegative total correlation between seed yield/plant and seed number/umbel resulted from negative indirect effects of seed number/umbel through all the traits except 1000-seed weight in spite of its positive direct effect on seed yield/plant (Table 12).

The relationships determined by path analysis among the examined characteristics in the 5th sowing date are shown in Table 13. As seen there, the direct effect of the seed number/planton seed yield/plant had the highest value of the direct effects which was statistically significant (1.016); also the direct effect of the 1000-seed weight on seed yield/plant was positive (0.126).The negative correlation between the plant height and seed yield/plant and between the 1000-seed weight and seed yield/plant resulted from the negative indirect effects through seed number/umbel and seed number/plant (Tables 6 and 13).Negativedirect effect of seed number/umbel (-0.129) and its negative indirect effect through seed number/plant (-0.563) decreased the total correlation of mentioned trait with seed yield/plant (-0.592).

Tables 9 to 13 - Results of path analysis for seed yield at first to fifth sowing dates.

Table 9- Results of path analysis for seed yield at first sowing date (D1)

Direct effects		Indirect effects									
		X1 through		X3 through		X5 through		X6 through		X7 through	
X1	0.165	X3	0.386	X1	0.117	X1	0.081	X1	0.133	X1	-0.013
X3	0.542	X5	-0.035	X5	-0.031	X3	0.234	X3	0.480	X3	0.229
X5	-0.073	X6	0.295	X6	0.325	X6	0.175	X5	-0.035	X5	0.017
X6	0.367	X7	-0.003	X7	0.015	X7	-0.008	X7	0.006	X6	0.059
X7	0.035	Residual: 0.104									

Table 10- Results of path analysis for seed yield at second sowing date (D2)

Direct effects		Indirect effects									
		X1 through		X3 through		X5 through		X6 through		X7 through	
X1	-0.068	X3	-0.015	X1	-0.005	X1	0.016	X1	-0.029	X1	-0.027
X3	-0.205	X5	0.032	X5	-0.034	X3	-0.050	X3	-0.163	X3	-0.044
X5	-0.141	X6	0.490	X6	0.927	X6	-0.047	X5	0.006	X5	0.064
X6	1.164	X7	-0.020	X7	-0.011	X7	0.023	X7	-0.026	X6	0.596
X7	-0.051	Residual: 0.243									

Table 11- Results of path analysis for seed yield at third sowing date (D3)

Direct effects		Indirect effects									
		X1 through		X3 through		X5 through		X6 through		X7 through	
X1	-0.190	X3	-0.412	X1	-0.125	X1	-0.026	X1	-0.157	X1	0.044
X3	-0.624	X5	0.020	X5	0.018	X3	-0.078	X3	-0.586	X3	0.186
X5	0.142	X6	1.486	X6	1.693	X6	0.198	X5	0.016	X5	-0.041
X6	1.802	X7	-0.075	X7	-0.096	X7	-0.091	X7	-0.121	X6	-0.678
X7	0.321	Residual: 0.120									

Table 12- Results of path analysis for seed yield at fourth sowing date (D4)

Direct effects		Indirect effects									
		X1 through		X3 through		X5 through		X6 through		X7 through	
X1	0.245	X3	0.004	X1	0.201	X1	-0.182	X1	0.199	X1	0.008
X3	0.005	X5	-0.081	X5	-0.067	X3	-0.003	X3	0.004	X3	0.000
X5	0.110	X6	0.662	X6	0.783	X6	-0.461	X5	-0.062	X5	0.022
X6	0.814	X7	0.009	X7	-0.009	X7	0.061	X7	-0.030	X6	-0.081
X7	0.303	Residual: 0.108									

Table 13- Results of path analysis for seed yield at fifth sowing date (D5)

Direct effects		Indirect effects									
		X1 through		X3 through		X5 through		X6 through		X7 through	
X1	0.075	X3	0.002	X1	-0.022	X1	0.039	X1	-0.013	X1	0.032
X3	-0.007	X5	-0.066	X5	0.085	X3	0.005	X3	-0.007	X3	0.006
X5	-0.129	X6	-0.179	X6	0.954	X6	-0.563	X5	0.071	X5	-0.057
X6	1.016	X7	0.053	X7	-0.105	X7	0.056	X7	-0.094	X6	-0.757
X7	0.126	Residual: 0.181									

X1: plant height, X3: umbel number/plant, X5: seed number/umbel, X6: seed number/plant, X7: 1000-seed weight.

Discussion

As expected, some of the traits such as biomass, umbel number/plant and seed number/plant were positively and significantly related to seed yield/plant in all sowing dates. In general, these components had significant positive correlations with each other (Tables 2 to 6). Only umbellate number/umbel gave not significant correlation with mentioned components (Tables 2 to 6). 1000-Seed weight and seed number/umbel in some sowing dates were negatively correlated with these traits that could be explained due to plant's intra competition. At the 1st sowing date umbel number/plant showed the highest correlation with seed yield/plant (Table 2), but in the 2nd, 3rd and 4th sowing dates, biomass were significantly associated to seed yield/plant (Tables 3, 4 and 5). However, in the 5th sowing date correlation coefficient between seed number/plant and seed yield/plant washigher than other components. Compared with other yield components umbel number/plant seemed to have the highest effect on seed yield/plant for the first sowing date. The plants which have shown better vegetative growth performance, have more desirable seed yield as well, so it can be the reason of the significant correlation between them. Due to shorter growth period, seed number/plant had the most effective impact on seed yield/plant on the 5th sowing date. In this respect, Bahraminejad et al., (2011) indicated that seed number/umbel and umbel number/plant had the highest correlations with yield and was considered as the most effective traits on seed yield of cumin. Our results agree with Kassahun et al., (2013), who found seed yield/plant significantly and positively correlated with seed number/plant in coriander (P<0.01)and they also observed that a positive association of plant height and umbel number/plant with seed yield in coriander. The high correlation between seed yield and seed number/plant has been reported in many studies on different plants (Seker & Serin., 2004; Güler et al., 2001; Bahraminejad et al., 2011; Kassahun et al., 2013).

Plant height and number of branches parameters have positively correlated with umbel number/plant, seed number/plant and biomass for most of the sowing dates (Tables 2 to 6). Correlation between the number of branches and aforementioned traits in the fifth sowing date is positive and significant, but it was negative for plant height; this can be due to less vegetative growth period of plants in this sowing date, in the other words, branching has been higher effect on seed yield than to height increasing (Table 6). Considering the poor competitive ability of cumin, increasing in height cause increase competitive ability and through increased in yield components have a positive impact on seed yield. The role of seed number/plant on seed yield/plant of cumin was highlighted by stepwise multiple regression analysis. Totally, based on regression analysis, it can be concluded that seed number/plant, umbel number/plant and 1000-seed weight parameters had the highest effects seed yield/plant, respectively. Bahraminejad et al. (2011) studied different cumin populations and reported that based on the total data for all the measured populations, seed number/plant justified 73.2% of seed yield linear changes, and umbel number/plant, 1000- seed weight, seed number/umbel and seed length totally justified 89% of seed yield linear changesand their results are consistent with our results. Path coefficients divided the correlation coefficient into a series of direct and indirect effects of yield components on the seed yield/plant of cumin at different sowing dates. The results revealed that most traits were significantly correlated with seed yield/plant; however, path analysis showed that only seed number/plant had strong direct effects on the enhancement of seed yield of cumin in all sowing dates (Tables 9 to 13). The significance of seed number/planthas been noted by others in different plants as well (Güler et al., 2001; Seker & Serin, 2004; Cokkizgin et al., 2013). The direct effect of 1000-seed weight was positive in most of sowing dates. Eser et al., (1991) indicated that 1000-seed mass, seed number/plant, and number of primary and secondary branches can be proposed as prime selection criteria for chickpea breeding. Kassahun et al., (2013) reported that 1000-seed weight had a direct negative effect (-0.61) on seed yield/plant, on the contrary, a positive direct effect of 1000-seed weight on seed yield was reported by Singh & Mittal (2003) in coriander.

The indirect effects of umbel number/plant through seed number/plant substantially increased the total correlations between this component and seed yield/plant in all sowing dates in spite of negative direct effects of this component in some sowing dates (Tables 9 to 13). Sanker and Khader (1991) reported that umbel number/plant had the highest direct positive effect on seed yield/plant in coriander while according to study of Kassahun et al., (2013) the umbel number/plant had a small negative direct (-0.17) effect on seed yield/plant in coriander. In this manner, Bahraminejad et al. (2011) indicated that umbel number/plant and 1000-seed weight had the most indirect effect through seed number on yield of cumin.

Plant height had non-significant positive and negative direct effects on seed yield/plant, but it had significant indirect effect on seed yield/plant through seed number/plant, at all sowing dates, except the 5th sowing date (Tables 9 to 13). Kassahun et al., (2013) reported the direct effect of plant height on seed yield/plant was positive and comparatively high (0.44).

Consequently, umbel number/plantand plant height were the major determinants that had indirect effects through seed/ plant on seed yield of cumin plants which had been grown under field condition. This study also cleared that indirect effects of seed number/umbel and 1000-seed weight through seed number/plant were negative in most sowing dates, suggesting seed yield component compensation.

The present study confirmed that relationship between seed yield and seed yield components of cumin can be affected by different sowing dates. so choosing different sowing dates as the different environments would be as alternative approaches in breeding strategies for adaptation studies.

Also based on the obtained results, using of path coefficients analysis, was detected as a useful statistical method to divide the correlation coefficients into direct and indirect effects. Since seed yield was directly affected by seed number/plant and 1000-seed weight while umbel number/plant and plant height had indirect effects on this trait so these traits are the most reliable components for selecting high-yielding cumin ecotypes, and considering the impact of seed number/plant on seed yield of cumin in all sowing dates, this character can be chosen as parameter for selection breeding strategies for yield improvement of cumin.

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