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Correlation and sequential path analysis in Ajowan (*Carum copticum* L.)

M. Dalkani[1], R. Darvishzadeh[2,3]* and A. Hassani[1]

[1]Department of Horticulture, Urmia University, Urmia, Iran.
[2]Institue of Biotechnology, Urmia University, Urmia, Iran.
[3]Department of Agronomy and Plant Breeding, Urmia University, Urmia, Iran.

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Study on the relationships between yield and its components will improve the efficiency of breeding programs by determining appropriate selection criteria. An investigation was carried out on 10 populations of Ajowan to investigate the association among yield components and their direct and indirect effects on the seed yield of Ajowan. Populations were collected from different regions of Iran including, Hamadan, Rafsanjan, Ardabil, Khorasan, Isfahan and Alamoot-e-Ghazvin. The experiment was conducted in completely randomized design with 8 to 10 replications in greenhouse conditions. Correlation coefficients were calculated among 16 studied traits. Positive and significant correlations were detected between single plant yield and most of the studied traits while the correlation between single plant yield and ripening period lenght was negative and significant (r = -0.41). A sequential path analysis was used to order the various variables based on their maximum direct effect and minimal colinearity. Based on sequential path analysis, plant height and number of umbels can be used as selection criteria for improving seed yield in Ajowan breeding programs.

Key words: Colinearity, landrace, medicinal plant, direct effect, indirect selection, predictor variables, sequential path analysis.

INTRODUCTION

Ajowan (*Carum copticum* L.) with 2n=2x=18 chromosomes, is a grassy annual plant belong to family Apiaceae. It grows in the east of India, Iran, and Egypt with white flowers and small and brownish seeds (Zargary, 1988). Ajowan is an aromatic seed spices, generally used as a digestive stimulant or to treat liver disorders. Thymol, the major phenolic compound of Ajowan, has been reported to be a germicide, antispasmodic, and antifungal agent (Nagalakshmi and Shankaracharya, 2000). P-cimene, γ-terpinene, α-pinene and β-pinene are another components of Ajowan essential oil (Majnoon and Davazdah, 2007).

Most of the medicinal and aromatic plants are not cultivated and their demands are met by gathering of wild populations. Production of a stable quality and quantity of these plants is important to growing world market, which make it necessary to breed varieties with high yield and quality. Seed yield is a quantitative trait and highly affected by environmental factors (Poormohammad Kiani et al., 2009). Plant breeders, commonly prefer yield components that indirectly increase seed yield (Yasin and Singh, 2010). Correlation of a particular character with other characters contributing to seed yield is of great importance in indirect selection of genotypes for higher

*Corresponding author. E-mail: r.darvishzadeh@mail.urmia.ac.ir. Tel: + 98 441 2972399. Fax: + 98 441 2779558.

Abbreviations: SD, Main stem diameter; **PH,** plant height; **NB,** number of branches; **NL,** number of leaf; **NLlet,** number of leaflet; **NU,** number of umbles; **NUI,** number of umbellet in a inflorescence; **NFU,** number of flower per umblet; **NFWI,** number of flower in whole inflorescence; **LL,** leaf length; **I,** average length of internodes per plant; **DWAP,** dry weight of aerial parts; **HSW,** one hundred seed weight; **SPY,** single plant yield; **BY,** biological yield; **NS,** number of seeds; **RPL,** ripening period length.

seed yield (Choudhry et al., 1986; Ali et al., 2003). Simple correlation analysis that relates seed yield to a single variable may not provide a complete understanding about the importance of each component in determining seed yield (Dewey and Lu, 1959). Path coefficient analysis is a statistical technique of partitioning the correlation coefficients into its direct and indirect effects, so that the contribution of each character to yield could be estimated (Wright et al., 1921; Dewey and Lu, 1959).

Path coefficient analysis have been widely used in plant breeding programs to determine the nature of the relationships between yield and yield components that are useful as selection criteria to improve crop yield. In most studies involving path analysis, researchers considered the predictor characters as first-order variables in order to analyze their effects over a dependent variable such as yield. This approach might result in multi-colinearity for variables, and possibly make difficulties in interpretation of the actual contribution of each variable (Hair et al., 1995). Recently the sequencial path coefficient analysis has been used by many researchers in different crops (Samonte et al., 1998; Mohammadi et al., 2003; Das et al., 2004; Asghari-Zakaria et al., 2007; Feyzian et al., 2009; Karuppaiah and Senthil Kumar, 2010), for complete identifition of impact of independent variables on dependent ones. The objective of present study was to determine the interrelationships among yield and related characteristics in Ajowan for developing selection criteria for improving seed yield using a sequential path model.

MATERIALS AND METHODS

In order to determine the most important characteristics affecting single plant yield, 10 Ajowan populations from different regions of Iran were evaluated in Urmia University, Iran, using completly randomized design with 8 to 10 replications. Populations were collected from different regions including Hamedan, Rafsanjan, Ardabil, Khorasan, Isfahan and Alamoot-e-Ghazvin.The seeds were sown in greenhouse in July, 2009. All pots were hand weeded. Data were collected on the following 16 characters on plants per pot: main Stem Diameter (SD), Plant Height (PH), Number of Branches (NB), Number of Leaf (NL), Number of Leaflet (NLlet), Number of Umbles (NU), Number of Umbellet in a Inflorescence (NUI), Number of Flower per Umblet (NFU), Number of Flower in Whole Inflorescence (NFWI), Leaf Length (LL), average length of internodes per plant (I), Dry Weight of Aerial Parts (DWAP), one Hundred Seed Weight (HSW), Single Plant Yield (SPY), Biological Yield (BY), Number of Seeds (NS), Ripening Period Length (RPL). Foliage characters were measured in the stage of full blum and traits related to seed were recorded after harvesting. Correlation coefficients between various pairs of variables were computed.

In order to predict relationships between yield and its components and also eliminate less important variables by sequential path model, SPSS software (stepwise comment) (SPSS/PC-15, SPSS Inc., Chicago, IL, USA; http://www.spss.com) was used. Sequential stepwise multiple regression was performed to organize the predictor variables into first and second-order on the basis of their respective contributions to the total variation of Single Plant Yield (SPY) and minimal collinearity. The level of multicollinearity was measured from two common measures, namely, the "tolerance" value and the "Variance Inflation Factor" (VIF) as suggested by Hair et al. (1995). Tolerance value is the amount of variability of the selected independent variable not explained by other independent variables ($1-R^2_i$, where R^2_i is the coefficient of determination for the prediction of variable i by the predictor variables). VIF indicates the extent of effects of other independent variables on the variance of the selected independent variable [$VIF = 1/(1-R^2_i)$]. Thus, very small tolerance value (much below 0.1) or large variance inflation factor value (above 10) indicate high collinearity (Hair et al., 1995). On the basis of the magnitude of direct effects, plant height, stem diameter, ripening period length, number of umbels, number of leaflet and number of seeds were considered as first-order variables. This procedure was again performed separately taking the indicated variables as dependent variables to find out first-order variables for these six response variables, which shall be, consequently, second-order variables for single plant yield. Sequential path analysis diagram was drawn by AutoCAD software.

RESULTS AND DISCUSSION

Simple correlation coefficients computed between different pairs of characters are presented in Table 1. Significant relationship between most of the studied traits was detected. The number of branches positively and significantly correlated with the number of umbels (r = 0.46). This result is in agreement with the findings of Gurbuz (2001) in coriander and Cosge et al. (2009) in sweet fennel. Plant height and number of umbels were positively and significantly correlated with number of umbllets. In addition, positive and significant correlations were found between biological yield and plant height as well as number of umbels and number of umbellets that is in agreement with the results of Cosge et al. (2009) in sweet fennel. Most of studied characters showed positive and significant correlations with single plant yield, whereas ripening period lenght had negative and significant correlation with single plant yield (r = -0.41). Results show that biological yield has the high positive correlation with single plant yield (r = 0.86). This result is in agreement with the findings of Singh and Mittal (2003) and Cosge et al. (2009) in sweet fennel.

Medicinal value of Ajowan is for active substances of seeds. Active substances of Ajowan are mainly accumulated in seeds. In other hand, seeds yield is a complex trait that characterized by low heritability and highly affected by environmental factors. Therefore, yield components with simple genetic control that indirectly affect seed yield can be effectively used as selection criteria for improving Ajowan seed yield.

Simple correlation analysis that relates seed yield to a single variable may not provide a complete understanding about the importance of each component in determining seed yield (Dewey and Lu, 1959). Path coefficient analysis is a statistical technique of partitioning the correlation coefficients into its direct and indirect effects, so that the contribution of each character to yield could be estimated.

Estimation of direct effects by conventional path

Table 1. Correlation coefficients among 16 characters measured on 10 Ajowan populations.

	SD	PH	NB	NL	NLlet	NU	NUI	NFU	NFWI	LL	I	DWAP	HSW	SPY	BY	NS
PH	0.58*															
NB	0.32*	0.34*														
NL	0.48*	0.53*	0.45*													
NLlet	0.55*	0.62*	0.29*	0.78*												
NU	0.55*	0.50*	0.46*	0.57*	0.60*											
NUI	0.64*	0.58*	0.21*	0.47*	0.59*	0.43*										
NFU	0.47*	0.57*	0.18	0.50*	0.55*	0.38*	0.56*									
NFWI	0.57*	0.60*	0.34*	0.54*	0.60*	0.61*	0.74*	0.68*								
LL	0.39*	0.43*	0.15	0.52*	0.59*	0.47*	0.54*	0.47*	0.50*							
I	0.36*	0.66*	0.06	0.48*	0.52*	0.24*	0.35*	0.45*	0.37*	0.29*						
DWAP	0.68*	0.70*	0.40*	0.64*	0.69*	0.64*	0.68*	0.57*	0.69*	0.55*	0.43*					
HSW	0.14	0.19	0.06	0.23*	0.20	0.37*	0.04	0.08	0.15	0.22*	0.07	0.24*				
SPY	0.56*	0.57*	0.32*	0.40*	0.36*	0.52*	0.49*	0.42*	0.47*	0.40*	0.23*	0.67*	0.19			
BY	0.70*	0.72*	0.40*	0.63*	0.65*	0.67*	0.66*	0.57*	0.67*	0.54*	0.41*	0.94*	0.24*	0.86*		
NS	0.50*	0.42*	0.27*	0.35*	0.49*	0.46*	0.46*	0.30*	0.49*	0.41*	0.11	0.60*	0.03	0.49*	0.61*	
RPL	-0.28*	-0.31*	-0.13	-0.23*	-0.21*	-0.16	-0.25*	-0.30*	-0.28*	-0.24*	-0.18	-0.37*	-0.09	-0.41*	-0.41*	-0.20

SD: main stem diameter, PH: plant height, NB: number of branches, NL: number of leaf, NLlet: number of leaflet, NU: number of umbles, NUI: number of umbellet in a inflorescence, NFU: number of flower per umblet, NFWI: number of flower in whole inflorescence, LL: leaf length, I: average length of internodes per plant, DWAP: dry weight of aerial parts, HSW: one hundred seed weight, SPY: single plant yield, BY: biological yield, NS: number of seeds, RPL: ripening period length.

analysis, where yield-related traits were considered as the first-order variables and single plant yield as the response variable, and analysis of multicollinearity indicated high multicollinearity for some characters, particularly for those showing high direct effects such as biological yield (VIF=11.6) and dry weight of aerial parts (VIF=10.1) (Table 2).

Sequential path analysis provided a better understanding of the interrelationships between seed yield and its components and their relative contribution to single plant yield. Single plant yield as dependent variable was analyzed against other measured characters as independent variables. Plant height, stem diameter, ripening period, number of umbels, number of leaflet and number of seeds were considered first-order variables, which accounted for 51% of the variation of single plant yield (Table 3 and Figure 1). The path analaysis of second-order variables over the first-order variables showed that 71% of the total variation for number of leaflet was explained by four characters including number of leaf, number of umbellet in a inflorescence, leaf length and average distance of internodes per plant, and 63% of the total variation for plant height was explained by average distance of internodes per plant, number of flower in whole inflorescence, number of branch and number of umbellet in a inflorescence (Table 3). All of the characters had highly direct effects on single plant yield. Among the direct effects of first-order variables on single plant yield, plant height and number of umbels showed high positive direct effects on single plant yield whereas number of leaflet and ripening period lenght showed negative direct effects on single plant yield. It seems that selection for low number of leaflet and short ripening period may improve single plant yield.

Number of leaflet, in spite of its positive and significant correlation with single plant yield, (Table 1) had negative direct effect on single plant yield (-0.268). In fact, the most part of the correlation between number of leaflet and single plant yield is the result of indirect effects of this trait by other characters such as number of umbels, plant height, number of leaflet, main stem diameter and number of seeds.

Table 2. Direct effects of first-order predictor variables on grain yield and measures of collinearity in model 1 (all predictor variables as first-order variables over grain yield as response variable) in studied Ajowan populations.

Predictor variables	Direct effect	Tolerance	VIF
SD	0.012	0.415	2.407
PH	0.014	0.272	3.671
NB	0.026	0.588	1.702
NL	-0.054	0.286	3.493
NLlet	-0.185	0.242	4.141
NU	-0.004	0.338	2.956
NUI	0.034	0.290	3.452
NFU	0.013	0.422	2.371
NFWI	-0.009	0.254	3.930
LL	0.051	0.529	1.891
I	-0.050	0.409	2.445
DWAP	-1.108	0.099	10.100
HSW	0.015	0.757	1.322
YB	1.990	0.086	11.600
NS	-0.014	0.492	2.032
RPL	-0.034	0.780	1.282

SD: main stem diameter, PH: plant height, NB: number of branches, NL: number of leaf, NLlet: number of leaflet, NU: number of umbles, NUI: number of umbellet in a inflorescence, NFU: number of flower per umblet, NFWI: number of flower in whole inflorescence, LL: leaf length, I: average length of internodes per plant, DWAP: dry weight of aerial parts, HSW: one hundred seed weight, SPY: single plant yield, BY: biological yield, NS: number of seeds, RPL: ripening period length.

Table 3. Direct effects, tolerance, and variance inflation factor (VIF) values for the predictor variables in model 2 (predictors grouped into first- and second-order variables) in studied Ajowan populations.

Response variable	Predictor variables	Adjusted R2	Direct effect	Tolerance	VIF
SPY	PH	0.51	0.315	0.510	1.961
	SD		0.198	0.522	1.914
	RPL		-0.231	0.883	1.132
	NU		0.288	0.549	1.823
	NLlet		-0.268	0.472	2.119
	NS		0.207	0.663	1.509
PH	I	0.63	0.501	0.849	1.177
	NFWI		0.172	0.402	2.489
	NB		0.196	0.875	1.143
	NUI		0.242	0.445	2.248
SD	NUI	0.45	0.541	0.782	1.278
	NL		0.223	0.782	1.278
RPL	NFU	0.09	-0.302	1.000	1.000
NU	NFWI	0.53	0.383	0.687	1.434
	NL		0.201	0.610	1.640
	HSW		0.252	0.944	1.059
	NB		0.225	0.780	1.282
NLlet	NL	0.71	0.518	0.591	1.691
	NUI		0.209	0.650	1.538
	LL		0.169	0.621	1.609
	I		0.152	0.751	1.332
NS	NFWI	0.26	0.386	0.751	1.332
	LL		0.214	0.751	1.332

SD: main stem diameter, PH: plant height, NB: number of branches, NL: number of leaf, NLlet: number of leaflet, NU: number of umbles, NUI: number of umbellet in a inflorescence, NFU: number of flower per umblet, NFWI: number of flower in whole inflorescence, LL: leaf length, I: average length of internodes per plant, DWAP: dry weight of aerial parts, HSW: one hundred seed weight, SPY: single plant yield, BY: biological yield, NS: number of seeds, RPL: ripening period length.

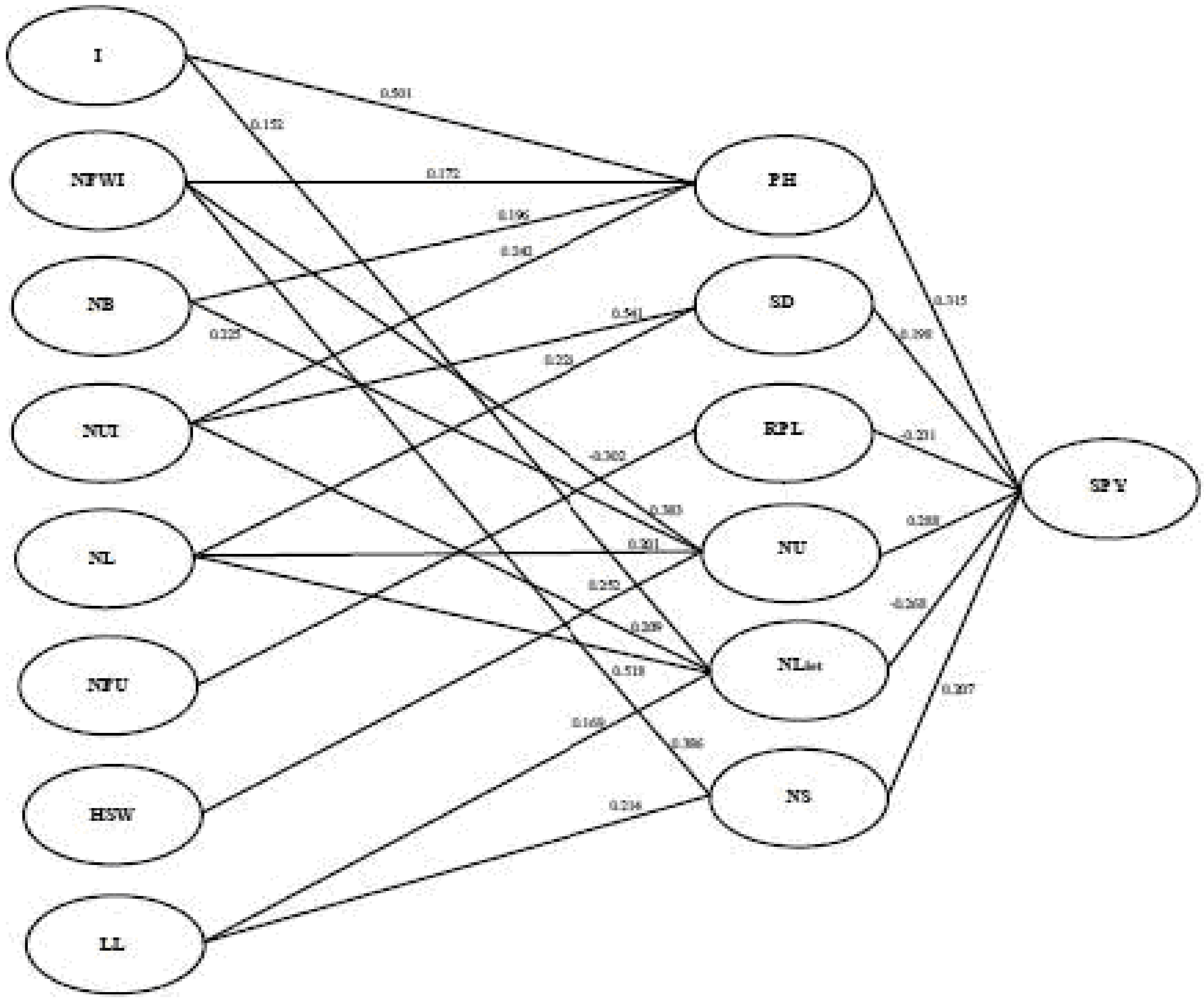

Figure 1. Sequential path model illustrating interrelationships among various characters contributing to single plant yield in studied Ajowan populations. SD: main stem diameter, PH: plant height, NB: number of branches, NL: number of leaf, NLlet: number of leaflet, NU: number of umbles, NUI: number of umbellet in a inflorescence, NFU: number of flower per umblet, NFWI: number of flower in whole inflorescence, LL: leaf length, I: average length of internodes per plant, DWAP: dry weight of aerial parts, HSW: one hundred seed weight, SPY: single plant yield, BY: biological yield, NS: number of seeds, RPL: ripening period length.

Among second-order variables number of umbellet in an inflorescence had higher direct and positive effect on first-order variables compared to other variables. Among first-order variables, number of leaflet had the high indirect effect through plant height on single plant yield (0.195). Bhandari and Gupta (1991) reported the maximum direct effects of umbellate per plant, single plant weight, umbels per plant and seeds per umbel on single plant yield in coriander.

Conclusions

In summary, in the present study, we have attempted to use sequential path analysis as a predictive tool for analyzing the interrelationship between yield and yield-related traits in Ajowan. Based on our results, plant height (p=0.315) and number of umbels (p=0.288) exhibited highest direct effect on single plant yield. These yield-related traits can be used effectively as selection criteria for improving single plant yield in Ajowan breeding programms.

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