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Full Length Research Paper

Path analysis and multivariate factorial analyses for determining interrelationships between grain yield and related characters in maize hybrids

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In order to study the association among yield components and their direct and indirect effects on the grain yield, 144 experimental maize hybrids in Kermanshah, Iran were evaluated in a lattice design with two replications. Analysis of variance, factor and sequential path analyses were carried out for the studied traits. Results of path analysis showed that two first-order variables, namely; 100 grain weight (100-GW) and total number of kernels per ear (TNK) revealed highest direct effects on total grain weight (TGW), while ear length (EL), ear diameter (ED), number of kernel rows (NR) and number of kernels per row (NKR) were found to fit as second-order variables. Multivariate factorial analyses showed that six independent factors justified 77.852% of total data variations. The first and third justifications that explain 33.155% of the data variation was called yield and yield components. The second factor (14.121%) called traits was related to kernel depth. Other factors were phenology (11.060%), plant growth (11.038%) and tassel (8.478%). We concluded that hybrid number 69 (860002-2) has the highest grain yield. The traits 100 GW and TNK were shown to be the two important factors that affected the maize performance. Moreover, NKR showed the highest direct effect on TNK which showed the highest direct effect on TGW. Therefore, NKR could be used as a suitable index to improve grain yield too.

Key words: Correlation, sequential path analysis, indirect selection.

INTRODUCTION

Maize (*Zea mays* L.) is an important crop in the world due to its harvest and production areas. It is known as valuable crop because of its economic importance and nutritional value. This crop is used in human nutrition, animal and poultry feed and industrial and pharmaceutical consumptions (Delangizan, 2005).

Grain yield is a complex trait that is influenced by a large number of physiological processes. These processes are manifested in growing, morphological and physiological traits, and these traits are measurable (Hobbs and Mahon, 1982). Yield genetically controlled indirectly through physiological components are correlated with economic yield. Although, performance of crops has increased decades ago, but the process by morphological and physiological mechanism that underlies this increase has not been known (Tollenaar, 1991). If the sources of variation in yield and the components are known, it may be a way to improve yield potential through specification of the modification of crops and improved farming operations (Fraser and Eaton, 1983). Most programs to improving crops are primarily based on single plant selection in terms of superior performance and the second composition of crop-desired

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properties. These methods are costly and time-consuming; they do not result to much success when used for the direct selection of yield and do not cause a significant increase in yield components. Therefore, using yield components and suitable morphological or physiological traits as indicators for indirect selection has been proposed for achieving progress in increasing the performance (Dwyer et al., 1991, 1994; Willman et al., 1987).

Path coefficient analysis has been widely used in crop breeding to know the nature of relationships between grain yield and its components and to identify those components with significant effects on yield for potential use as selection criteria (Puri et al., 1982; Kang et al., 1983; Milligan et al., 1990; Williams et al., 1990; Board et al., 1997; Moghaddam et al., 1997; Samonte et al., 1998; Mohammadi et al., 2003). Path analysis is used to determine the amount of direct effect (path coefficient); indirect effects (effects exerted through other independent variables) of the causal components on the dependent variable (Li, 1975; Amjad et al., 2009). This method helps breeders to select the best genotypes based on yield and related traits.

On the other hand, multivariate factorial analyses can be used to identify associated-traits to specific traits that have high effect in its expression, but efficiency of it is in doubt in spite of convergences among traits and restriction for explanation of relations between most characters (Lee and Kaltsikes, 1973; Pailwal and Solanki, 1984; Johnson and Wichern, 1996). This method is a powerful multiple method to apply evaluation yield component (Guertin and Bailey, 1982), identify biological relationships among traits (Acquaah et al., 1992), decrease associated-traits to a few factors (Johnson and Wichern, 1996) and description of correlations among variables (Lawley, 1941). Factor analysis has the potential of enhancing our knowledge of causal relationship of variables and can help to know the nature and sequences of traits to be selected for breeding program.

Path analysis is used by many researchers to discover relationships between yield as dependent variable and its related traits as predictor variables (all as first order variables) (Xu, 1986; Han et al., 1991; Simon, 1993; Agrama, 1996; Board et al., 1997; Kumar et al., 1999). This approach might result in multi-collinearity for variables, particularly, when coefficient correlations among some of the traits are high (Samonte et al., 1998). Samonte et al. (1998) applied a sequential path analysis for determining the relationships among yield and related traits in rice (*Oryza sativa* L.) by organizing and analyzing various predictor variables in first-, second-, and third-order paths. However, the collinearity of predictor variables was not tested before organization of variables in different path orders.

Ramezani et al. (2008) studied seven agronomic and morphologic traits of maize hybrids through factor analysis. They showed that four independent factors explained 98.03% of variations. Moreover, they opined that the first factor has phenological characteristics, while the other factors have the feature of an ear and ear number.

Our objectives were (1) to determine the relationships between grain yield and its related traits; (2) introduce appropriate indicators to improve the maize yield in the breeding programs, and (3) access new hybrids with high performance.

MATERIALS AND METHODS

In this study, 134 hybrids generated from crosses of S_6 maize lines (from 18 populations) to tester MO17; and 10 common hybrids as testers: KSC 500, DK 670, DK 720, PRODONA, OSK 602, ZP 677, KSC 704, DS 499, ZP 434 and KSC 647 were evaluated. The experimental test was carried out at Razi University Experimental Farm, Kermanshah, Iran in 2009. The farm has the following characteristics: latitude 34° 21´ north, longitude 47° 9´ east, altitude 1319 m above the sea level, soil with silt-loam texture and an average annual precipitation between 450 and 480 mm. The field tests were performed in a lattice design with two replications, two rows per replication. Row length and width were 3 and 0.75 m, respectively. Plots were overplanted and thinned to a uniform plant stand of approximately 15 plants per row. All plots were hand weeded as necessary to maintain proper weed control. Data were collected on the following 21 characteristics in all replications on five competitive and normal plants per plot.

Plant height (PH) and ear height (EH) were measured as the distance (cm) from the soil surface to the node of the flag leaf and to the highest ear-bearing node, respectively, at the harvest stage. Other plant characters recorded were: Tassel upper axe length (TUAL) (cm) was measured as the distance from the lowest axe to highest tassel point, tassel main axis length (TMAL) was measured as the distance (cm) from the tassel leaf to the lowest axe and Number of ears per plant (NE) is the total number of ears harvested from the plot divided by the number of plants in the plot; leaf area (LA) as [(leaf width + leaf length) × 0.7] (Yazdandost and Rezaee, 2001) and dry weight (DW) (g). The following characters were recorded on ears from five competitive plants from each plot: ear length (EL) (cm), ear diameter (ED) (cm), cob diameter (CD) (cm), number of kernel rows (NR), total number of kernels per ear (TNK), the depth of grain (DG) (cm), 100-grain weight (100 GW) (g), ear weight (EW) (g), cob weight (CW) (g) and total grain weight per ear (TGW), measured as an average weight (g) of shelled kernels from ears and adjusted to 14% moisture content. In addition, number of kernels per row (NKR), days to silking (DS) (d), days to tasselling (DT) (d), and days to maturity (DM) (d) were measured respectively.

The data set was first tested for skewness and kurtosis. Appropriate transformation (logarithm and square root transformations) was applied for specific characters that showed non-normal distributions. Data were subjected to analysis of variance (ANOVA). To know the efficiency of the Lattice design, analysis of variance was applied in two parts: (i) Lattice design was used for evaluating the most efficient Randomized Complete Block Design (RCBD) and (ii) RCBD was used for evaluating the less efficient RCBD. The correlation coefficients between various pairs of the characters were computed. A preliminary analysis was performed by means of the conventional path model in which all yield-related characters were considered as first-order predictor variables with TGW as the response variable (Mohammadi et al., 2003) (Model 1 in Table 6). Multivariate factorial analyses were performed through principal component analysis method and varimax rotation on a temporary factor using SPSS software. Factor coefficient more than 0.5, regardless of its mark was considered as a significant factor for any independent factors (Mohammadi et al.,

Table 1. Analysis of variance (based on square lattice design).

SOV	df	Mean square							
		TUAL	**NR**	**ED**	**EW**	**DW**	**DS**	**DT**	**DM**
Replications	1	1.805	3.818	0.013	1720.938	0.097	4.014	28.125	7.031
Treatments									
-Unadjusted	143	7.653^{ns}	2.451*	0.126*	1201.735**	0.009^{ns}	3.199**	12.077^{ns}	3.997**
-Adjusted	143	7.656^{ns}	2.466*	0.124*	1201.729**	0.009 ^{ns}	3.204**	12.381 ^{ns}	3.989**
Blocks within									
-Reps(adj.)	22	7.191	1.663	0.070	860.105	0.011	2.654	15.625	3.096
Error									
-Effective	121	6.959	1.247	0.060	858.323	0.009	2.118	13.024	2.707
-RCB design	143	6.961	1.268	0.060	858.324	0.009	2.140	13.111	2.717
-Intrablock	121	6.919	1.196	0.058	858.000	0.009	2.046	12.654	2.648
CV (%)	-	7.758	8.296	6.002	20.871	4.252	2.540	6.157	1.117

* Significant at the 0.05 probability level. ** Significant at the 0.01 probability level. TUAL, tassel upper axis length; EW, ear weight; NR, number of kernel rows; ED, ear diameter; DW, dry weight; DS, days to silking; DT, days to tasseling; DM, days to maturity.

2003).

At the end, sequential stepwise multiple regressions were performed as suggested by Mohammadi et al. (2003) by means of SPSS 9.0 statistical software. Tolerance value is the amount of variability of the selected independent variable not explained by other independent variables given as:

$(1 - R^2_{i},)$

Where R^2_i is the coefficient of determination for the prediction of variable *i* by the predictor variables).

Variance inflation factor (VIF) indicates the extent of the effects of other independent variables on the variance of the selected independent variable given as:

$\text{VIF} = 1/(1- R^2_i)$

Thus, very small tolerance values (much below 0.1) or large variance inflation factor values (above 10) indicate high collinearity (MohammadI et al., 2003). Based on tolerance and variance inflation factor values, besides the magnitude of direct effects, TNK and 100 GW were considered as first-order variables among various yield characters under study. This method was again performed separately taking TNK and 100 GW as dependent variables to find out the first-order variables for these two response variables, which, consequently, resulted to the second-order variables for TGW. Similar procedure was followed to determine the third-order variables for TGW but PH was not considered in the path model because of their high multi-collinearity.

RESULTS

Analysis of variance based on lattice and randomized complete blocks design is shown in Tables 1 and 2, respectively. As shown, there are significant differences among hybrids in terms of the number of kernel rows (NR), ear diameter (ED), ear weight (EW), days to silking (DS), days to maturity (DM), cob diameter (CD), cob weight (CW), total grain weight per ear (TGW), ear length (EL), plant height (PH) and leaf area (LA). Results of mean comparison for 144 hybrids showed the highest weight of ear, cob weight and 100-grain weight were obtained for the genotypes 139, 79 and 61, and the lowest for genotypes 35, 38, 121, 14, 38 and 47. Genotypes 69 (860002-2) and 11 (860027-1) were identified as the highest and lowest genotypes for grain yield (Data not shown). Maximum number of kernel per row, kernel rows and number of kernels per ear were obtained for genotypes 53, 134 and 139 and the minimum number of the mentioned characters was allocated to the genotypes 35, 27 and 35, respectively. The highest ear and cob diameter were obtained in genotypes 78 and 69; and the lowest were genotypes 110 and 30. The tallest ear hybrids were 68, 25 and the shortest ear hybrids was 38. Maximum number of ears per plant was related to the genotype 61 and the lowest was genotype 47 (Data not shown). All characters except TUAL, TMAL, EH, PH and DW showed significant correlations with TGW (Table 3). The highest correlation was between EW and TGW (0.86), NKR and TGW (0.86) and TNK and TGW (0.73).

Multivariate factorial analyses divided the studied traits into six independent factors accounted for nearly 78% of the total variation among characters (Table 4). The first factor justified 21.285% of variation among the data, and showed high and positive coefficients for ear weight, cob weight, total grain weight per ear, number of kernels per row, number of kernels per ear and ear length. The third factor justified 11.870% of variation among the data, and

Table 2. Analysis of variance (based on randomized complete block design).

SOV	Mean square							
	df	**CD**	**CW**	**DG**	**100GW**	**TGW**	**NKR**	**TNK**
Replications	1	0.060	0.002	23.279	2.567	4.815	207.570	12973.920
Treatments								
-Unadjusted	143	0.066*	30.320*	5.945^{ns}	11.667^{ns}	3.761*	44.397^{ns}	10456.576^{ns}
Blocks within -Reps (adj.)	22	0.036	20.437	5.218	10.619	2.252	34.967	8471.396
Error								
-RCB Design	143	0.038	20.437	5.928	10.619	2.252	34.967	8471.396
-Intrablock	121	0.039	21.662	6.057	10.649	2.322	35.429	8685.752
CV (%)	-	9.975	25.708	13.678	11.232	15.315	16.156	18.918

SOV	**df**	**TMAL**	**EL**	**PH**	**EH**	**LA**	**NE**
Replications	1	242.734	0.004	568.154	94077.484	3777.181	0.000
Treatments							
-Unadjusted	143	12.403^{ns}	0.015**	23.246*	4177.687^{ns}	149.519*	0.001^{ns}
Blocks within -Reps (adj.)	22	7.014	0.009	14.949	3683.742	61.893	0.001
Error							
-RCB Design	143	9.665	0.011	17.460	5645.845	102.615	0.001
-Intrablock	121	10.146	0.011	17.916	6002.591	110.019	0.001
CV (%)	-	7.568	9.836	10.148	15.744	11.592	3.293

* Significant at the 0.05 probability level. ** Significant at the 0.01 probability level. ^{ns}, not significant; CD, cob diameter; CW: cob weight; DG, the depth of grain; 100GW, 100 grain weight; TGW, total grain weight per ear; NKR, number of kernels per row; TNK, number of kernels per ear. TMAL, tassel main axis length; EL, ear length; PH, plant height; EH, ear height; LA, leaf area; NE, number of ears per plant.

showed high and positive coefficients for 100-grain weight and number of ears per plant. These factors are called yield and yield component factors. The second factor called characteristics is related to the kernel depth. This factor justified 14.121% of variation between data and showed high and positive coefficients with number of kernel rows, ear and cob diameter. The fourth factor called phenology factor; this factor justified 11.060% of variation between data and had high and positive coefficients with days to silking, tasseling and maturity. The fifth factor called plant growth, justified 11.038% of changes between data and had high and positive coefficients with plant and ear height, leaf area and dry weight. Finally, the sixth factor called tassel factor. This factor justified 8.478% of variation between data and had high and positive coefficients for tassel main and upper length (Table 4).

In this study, the direct effects of the variables were estimated by conventional path analysis (Table 5), where the yield-related characters were considered as first-order variables with TGW as the response variable, and analysis of multi-collinearity indicating relationships among the variables. However, 100-GW, NKR, TNK, ED, EL and NR had positive direct effects on TGW. High correlations were observed between some of the predictor variables, namely: PH and EH (r = 0.831), TNK and NKR (r = 0.828), ED and CD (r = 0.732), and NKR and EL (r = 0.806), leading to high multi-collinearity and inability. It is certain that the actual contribution of each independent variable to the total variance of TGW is due to the mixed or confounded effects.

In contrast to the aforementioned results, sequential path analyses (Figure 1) revealed a better understanding of the interrelationships among studied variables and their relative contribution to TGW. One-hundred grain weight and TNK as first-order variables accounted for nearly 78% of the variation in TGW (Table 6); both the independent variables displayed high and positive direct effects on TGW. The direct effect of TNK on TGW (0.713) was found to be relatively higher than that of 100 GW (0.690). Because of a low and non-significant correlation between 100 GW and TNK (0.06), their indirect effects on TGW were found to be low and negligible. The path analysis of second-order variables over the first-order variable

Table 3. Correlation coefficients between characters measured in the Kermanshah-2009.

Characters	TUAL	TMAL	100GW	TGW	NKR	NR	TNK	ED	CD	DG
TUAL	1									
TMAL	0.71**	1								
100GW	-0.09	0.04	1							
TGW	0.06	0.00	0.63**	1						
NKR	0.18*	0.13	0.15	0.86**	1					
NR	-0.03	-0.08	-0.13	0.24**	-0.07	1				
TNK	0.13	0.05	0.06	0.73**	0.83**	0.50**	1			
ED	-0.07	-0.06	0.37**	0.60**	0.15	0.59**	0.46**	1		
CD	-0.10	-0.14	0.19*	0.45**	0.07	0.60**	0.38**	0.73**	1	
DG	-0.01	0.06	0.33**	0.39**	0.13	0.24**	0.26**	0.68**	0.01	1
EL	0.17*	0.10	0.23**	0.60**	0.81**	0.12	0.64**	0.08	0.10	0.05
EW	0.10	0.05	0.38**	0.86**	0.73**	0.36**	0.84**	0.62**	0.49**	0.38**
CW	-0.00	-0.03	0.47**	0.60**	0.42**	0.34**	0.55**	0.59**	0.63**	0.19**
EH	-0.26**	-0.11	0.04	0.05	0.08	0.05	0.09	-0.04	0.10	-0.16*
PH	-0.28*	0.12	0.02	0.07	0.04	0.02	0.04	-0.01	0.14	-0.18*
LA	-0.11	-0.01	0.11	0.23**	0.06	0.13	0.12	0.19*	0.24**	0.01
NE	-0.08	0.05	0.29**	0.32**	0.15	-0.13	0.05	0.37**	0.18*	0.33**
DS	-0.07	0.00	-0.12	-0.26**	-0.17*	-0.22**	-0.27**	-0.15	-0.15	-0.06
DT	-0.11	0.02	0.03	-0.19*	-0.21*	-0.05	-0.20*	-0.03	-0.07	0.04
DM	-0.09	-0.00	-0.11	-0.27*	-0.16	-0.22*	-0.26*	-0.14	-0.16	-0.03
DW	0.13	0.00	0.08	0.08	0.18*	0.16	0.24**	0.13	0.12	0.08

Characters	EL	EW	CW	EH	PH	LA	NE	DS	DT	DM	DW
EL	1										
EW	0.67**	1									
CW	0.43**	0.75**	1								
EH	0.11	-0.00	0.12	1							
PH	0.08	-0.00	0.16	0.83**	1						
LA	0.12	0.23**	0.26**	0.19*	0.09	1					
NE	0.23**	-0.23*	-0.20*	-0.04	0.03	0.11	1				
DS	-0.10	-0.27*	-0.12	0.03	0.10	-0.05	-0.10	1			
DT	-0.14	-0.16	-0.04	-0.08	-0.07	0.11	0.03	0.40**	1		
DM	0.02	-0.27*	-0.10	0.02	0.08	-0.06	-0.09	0.93**	0.35**	1	
DW	-0.12	0.27**	0.26**	-0.02	-0.06	0.21	0.09	0.06	0.00	0.07	1

* Significant at the 0.05 probability level. **Significant at the 0.01 probability level. TUAL, tassel upper axe length; TMAL, tassel main axis length; 100GW, 100-grain weight; TGW, total grain weight per ear; NKR, number of kernels per row; NR, number of kernel rows; TNK, total number of kernels per ear; ED, ear diameter; CD, cob diameter; DG, the depth of grain; EL, ear length; EW, ear weight; CW, cob weight; EH, ear height; PH, plant height; LA, leaf area; NE, number of ears per plant; DS, days to silking; DT, days to tasselling; DM, days to maturity; DW, dry weight.

showed that 70% of the total variation for 100 GW was explained by four characters, namely; ED, NR, EL, and NKR (Table 6). Among these characters, ED and EL showed positive direct effects, while NR and NKR showed negative direct effects on 100 GW. The direct effects were significant and the highest effect was recorded for ED (p = 0.689). Similar to the aforementioned description, only NR and NKR had significant effects on TNK, and together these characters accounted for about 99% of variation in TNK. Both the characters had high positive effects on TNK, but their indirect effects were small because of a low and non-significant correlation (-0.108) between them (Table 6 and Figure 1).

When the third-order variables were used as predictors and second-order variables as response variables, it indicated that CD and DG positively influenced ED and accounted for 99% of the observed variation in ED (Table 6). Since the correlation between CD and DG was non-significant. Number of ear along with CD, DG and DS explained 74% of the total variation for NR. However, among these characters, CD and DG recorded positive direct effects, while NE and DS showed negative direct

Table 4. Matrix rotation factors for the studied traits.

Character	Factor					
	1	2	3	4	5	6
EW	0.831**	0.403	0.239	-0.077	0.024	0.064
CW	0.595**	0.468	0.305	0.015	0.141	-0.009
TGW	0.784**	0.346	0.219	-0.080	0.027	0.020
NKR	0.955**	-0.074	-0.058	-0.063	-0.023	0.052
TNK	0.852**	-0.387	-0.172	-0.102	-0.004	0.036
EL	0.894**	-0.143	0.097	-0.046	0.063	0.077
NR	0.056	0.862**	-0.244	-0.092	0.024	0.000
ED	0.245	0.811**	0.279	-0.007	0.008	-0.036
CD	0.154	0.825**	0.111	0.003	0.152	-0.060
100GW	0.103	0.059	0.971**	-0.016	0.050	0.000
NE	0.104	0.056	0.971**	-0.024	0.044	0.002
DS	-0.034	-0.085	-0.088	0.941**	0.041	-0.020
DT	-0.143	0.069	0.098	0.626**	-0.034	0.046
DM	-0.016	-0.096	-0.071	0.935**	0.030	-0.032
PH	-0.049	-0.007	-0.073	-0.047	0.860**	-0.169
EH	-0.004	0.010	-0.134	-0.095	0.867**	-0.175
LA	0.104	0.183	0.208	0.076	0.551**	0.073
DW	0.042	0.029	0.105	0.070	0.608**	0.116
TMAL	0.027	-0.103	0.023	0.005	-0.133	0.869**
TUAL	0.118	0.033	-0.024	-0.001	0.043	0.917**
Relative variance	21.285	14.121	11.870	11.060	11.038	8.478
Cumulative variance	21.285	35.406	47.276	58.336	69.374	77.852

EW, ear weight; CW, cob weight; TGW, total grain weight per ear; NKR, number of kernels per row; TNK, total number of kernels per ear; EL, ear length; ; NR, number of kernel rows; ED, ear diameter; CD, cob diameter; 100GW, 100 grain weight; NE, number of ears per plant; DS, days to silking; DT, days to tasseling; DM, days to maturity; PH, plant height; EH, ear height; LA, leaf area; DW, dry weight; TMAL, tassel main axis length; TUAL, tassel upper axis length.

Table 5. Direct effects of first-order predictor variables on total grain weight per ear and measures of collinearity in Model 1 (all predictor variables as first-order variables).

Characters	Direct effect	Tolerance	VIF‡
TUAL	-0.001	0.627	1.209
100GW	0.563	0.130	6.480
NKR	0.240	0.012	81.170
NR	0.173	0.030	33.852
TNK	0.224	0.010	103.703
ED	0.195	0.002	41.385
CD	-0.004	0.005	22.289
DG	-0.067	0.005	19.413
EL	0.191	0.060	20.308
EH	0.019	0.841	1.190
NE	-0.041	0.413	2.348
DS	-0.080	0.338	2.853
DT	-0.025	0.388	2.720

TUAL, tassel upper axe length; 100GW, 100-grain weight; TGW, total grain weight per ear; NKR, number of kernels per row; NR, number of kernel rows; TNK, total number of kernels per ear; ED, ear diameter; CD, cob diameter; DG, the depth of grain; EL, ear length; EH, ear height; NE, number of ears per plant; DS, days to silking; DT, days to tasselling. ‡ Variance Inflation Factor.

Table 6. Tolerance and variance inflation factor (VIF) values for the predictor variables in Model I (all predictor variables as first-order variables) and Model 2 (predictors grouped into first-, second-, and third-order variables).

Predictor variable	Response variable	$R^2_{Adj.}$	Tolerance		VIF	
			M_1‡	M_2‡	M_1	M_2
100GW	TGW	0.78	0.130	0.997	6.480	1.003
TNK			0.010	0.997	103.703	1.003
ED	100GW	0.70	0.002	0.613	41.385	1.630
NR			0.030	0.621	33.852	1.612
EL			0.060	0.346	20.308	2.887
NKR			0.012	0.342	81.170	2.920
NR	TNK	0.99	0.030	0.996	33.852	1.004
NKR			0.012	0.996	81.170	1.004
CD	ED	0.99	0.005	0.997	22.289	1.003
DG			0.005	0.997	19.413	1.003
CD	NR	0.74	0.005	0.945	22.289	1.058
DG			0.005	0.885	19.413	1.130
NE			0.413	0.853	2.348	1.172
DS			0.338	0.970	2.853	1.031
NE	EL	0.34	0.413	0.991	2.348	1.009
EH			0.841	0.930	1.190	1.075
TUAL			0.627	0.926	1.209	1.080
NE	NKR	0.31	0.413	0.994	2.348	1.006
TUAL			0.627	0.983	1.209	1.017
DT			0.388	0.988	2.720	1.013

TGW, total grain weight per ear; 100GW, 100-grain weight; TNK, total number of kernels per ear; ED, ear diameter; EL, ear length; NR, number of kernel rows; NKR, number of kernels per row; CD, cob diameter; DG, the depth of grain; NE, number of ears per plant; DS, days to silking; EH, ear height; TUAL, tassel upper axe length; DT, days to tasselling. ‡ M_1, Model 1; M_2, Model 2.

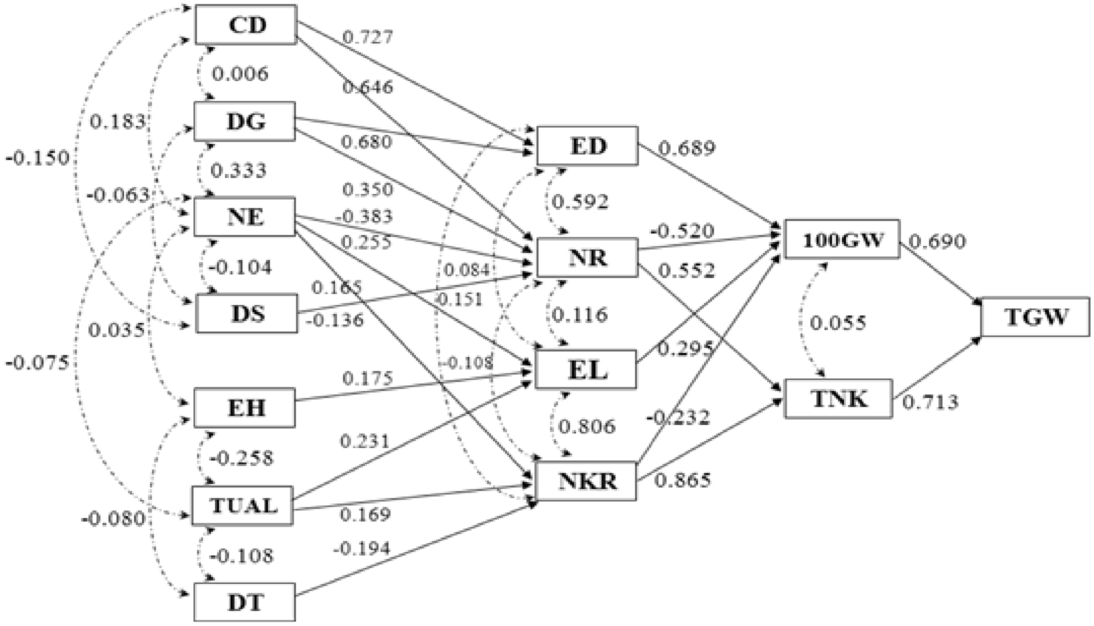

Figure 1. Sequential path model illustrating interrelationships among various characters contributing to grain yield (Kermanshah-2009 dataset). TGW, total grain weight per ear; 100GW, 100-grain weight; TNK, total number of kernels per ear; ED, ear diameter; NR, number of kernel rows; EL, ear length; NKR, number of kernels per row; CD, cob diameter; DG, depth of grain; NE, number of ears per plant; DS, days to silking; EH, ear height; TUAL, tassel upper axe length; DT, days to tasselling.

effects on NR. When EH, NE, and TUAL were regressed on EL, the direct effect of EH on EL was smaller than those of NE and TUAL. Together, the contribution of NE, EH, and TUAL to EL was relatively small, as indicated by the adjusted R^2 (0.341). Similar to EL, NKR was considered as the response variable with NE, DT, and TUAL as predictor variables. These three variables together accounted for 31% of variation in NKR. NE and TUAL showed positive direct effects, while DT recorded negative direct effects on NKR.

DISCUSSION

It is noteworthy to find the variation available for grain yield components in a crop. A comprehensive understanding of grain yield components and their effect on the yield formation will be obtained using path analysis. Path analysis showed any yield component compensations when two or more variables positively increase the yield and the other components negatively decrease the yield (Sabaghnia et al., 2010). Several plant researchers have earlier on used the application of path-coefficient analysis for estimating the direct and indirect effects of various yield-related traits on grain yield in different crop plants (Agrama, 1996; Mohammadi et al., 2003; Amjad et al., 2009; Bahraminejad et al., 2011; Darvishzadeh et al., 2011). Authors used conventional and sequentional path analysis. Sequentional path analysis was done in this work on maize considered as grain yield components on first, second and third order variables and grain yield as the dependent variable and did take into account the multi-collinearity factor as suggested by Mohammadi et al. (2003) and Samonte et al. (1998), while in the most of path analysis, all of yield components was considered as first order variables which make high multi-collinearity. Mohammadi et al. (2003) showed the advantages of using sequential path analysis to conventional path analysis in better understanding of the interrelationships of predicted variables and TGW as response variable in maize.

In the present work, we revealed that 100 GW and TNK have important roles in maize grain yield formation. Mohammadi et al. (2003) showed that 100 grain weight and TNK have high direct effect on total grain weight per ear in all their datasets. Number of ears per plant (Agrama, 1996), ear length (Shalygina, 1990; Tyagi et al., 1988), number of kernels per ear (Singh and Singh, 1993; Agrama, 1996; Wang et al., 1999), kernel weight (Debnath and Khan, 1991; Simon, 1993), ear height (Farhatullah, 1990), and kernel abortion (Fisher and Palmer, 1983; Saha and Mukherjee, 1985) were the traits that need to be noticed.

When the conventional path model was applied, ear diameter (ED) had a negligible effect on TGW (Table 5), indicating that this character had no significant contribution to grain yield. However, the sequential path model clearly showed that, ED had a positive and significant effect on TGW through 100 GW (Figure 1). Such effects could not be detected through the conventional path model because of high multi-collinearity of characters, such as NR, and NKR. To minimize the collinearity caused by yield related traits, a sequential stepwise regression was applied. In this method, characters removed after the first-order path analysis was re-analyzed as possible predictor variables in the next order path.

Logical relationship among variables was noticed in our study. In an analysis of 11 traits in high-lysine maize, Han et al. (1991) found that yield components that develop physiologically earlier had a negative effect on those that developed later, that is, NR on NKR, NR on 100 GW, and NKR on 100 GW. Our results are largely in agreement with the findings of Han et al. (1991), as reflected by negative and significant direct effects of NR on 100GW ($p = -0.520$), and NKR on 100GW ($p = -0.232$), whereas, the correlation between NR and NKR was found to be non-significant (Figure 1). Path analysis of the correlation coefficients between TGW and the first-order variables, namely: 100 GW and TNK, revealed high direct and indirect effects for both characters. The importance of these two characters in influencing TGW was indicated by the observation that nearly 78% of observed variation for 100 GW was explained only by these two first-order variables. Previous studies have also showed strong positive direct contribution of TNK and 100 GW on grain yield in maize (Xu, 1986; Han et al., 1991; Kumar et al., 1999; Mohammadi et al., 2003; Ahmad and Saleem, 2003).

Sequential path analysis showed that selection of lines based on only correlation coefficient may not be effective, for instance, the negative direct effects of NR and NKR, in combination with their positive indirect effects through other characters, caused compensation that consequently resulted in no significant correlation between these characters and 100 GW. The high negative direct effects of these characters on 100 GW were largely compensated by their positive indirect effects through NR and NKR, resulting in reduced correlation coefficients. In the same order path, about 99% of variation in TNK was accounted for by two second-order variables (NR and NKR) having significant and positive direct effects on TNK.

The factor analysis divided all the studied variables into six main factors. It is obvious that the variables effective in the first factor (with 21.285% of all variation in TGW) had a high level of loading coefficients and contribute much more on the response structure. All of these variables showed significant and positive correlations with grain yield as in Table 3. Therefore, NKR, EL, TNK, EW, CW were the most important indices to get high yield. Zeinali et al. (2005) concluded that traits such as ear leaf, stem thickness, plant height, number of kernels per row, the depth of grain, cob diameter, number of kernel rows, and number of kernels per plant and 100-grain weight are the most important indices for selecting maize hybrids to obtain high performance. Traits such as cob diameter, cob percentage, anthesis-silking interval and the number of ear had less importance.

We concluded that Genotypes 69 (860002-2) has the highest grain yield. We also showed and emphasized that 100 GW and TNK are the two important factors that affects the performance of maize. But, attention to the second order variables such as ED, NR, EL and NKR is needed.

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