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Full Length Research Paper

Sequential path analysis for determination of relationships between yield-related characters with yield in rice (*Oryza sativa* L.)

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Rice (*Oryza Sativa* L.) is one of the most important food crops in the world. Path coefficient analysis has been widely used in crop breeding to determine the nature of relationships between the grain yield (GY) and its contributing components. A field experiment was conducted in 2009 at Rice Research Station in Tonekabon, north of Iran. This experiment was arranged in a randomized complete block design with four replications. Seven rice cultivars and three lines were transplanted at its own optimum density. Sequential path analysis showed fertile tiller number m^{-2} (FT), filled grain number $panicle^{-1}$ (FG) and thousand grain weight (THGW) as the first-order variables accounted for 73% of GY. The results indicated rice total dry matter at heading stage (RtdmHD) and rice tiller number at heading stage (RtillerHD) as predictor variables for FT as dependent variable. Three characters contain FG, panicle length (PL) and rice leaf area index (LAI) at heading stage (RlaiHD) explained 61% of the total variations of THGW. This procedure did not detect any predictor variable in the model for FG as response variable. The predictor variables were ordered in the first- and second-order paths for grain yield as response variable. The results indicated that grain yield depended mostly on FT, FG, THGW, RtdmHD, RtillerHD and PL and these traits can be good selection criteria for improving grain yield in rice.

Key words: Rice (*Oryza sativa* L.), path coefficient, phenotypic correlation, yield components.

INTRODUCTION

Rice (*Oryza Sativa* L.) is one of the most important food crops in the world and especially in most Asian countries. Grain yield of rice can be the result of a complex cause and effect systems from the very beginning of plant life, environmental factors affect plant and crop traits. Researchers have studied complex cause and effect systems to determine traits that influence the final grain yield and the other important traits during plant ontogeny (Maman et al., 2004; Mohammadi et al., 2003; Samonte et al., 1998).

Since a simple correlation analysis is not able to provide detailed and actual knowledge in the relation between dependent variable and predictor variables, path analysis were employed in the most of causation relationships. This method, developed by Wright (1921) as a statistical tool, enables to study complex relationships between traits. It has been used to organize the effect and present the causal relationships between the predictor variables and response variables through a path diagram based on experimental results or on a priori grounds (Samonte et al., 1998). In the most studies involving path analysis, researchers considered entire characters as the first-order variables to analyze their effects on a dependent variable such as yield. This approach might result in multi-collinearity for variables, and there may be difficulties in interpretation of the actual

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Abbreviations: GY, Grain yield; **BY,** biological yield; **FT,** fertile tiller number m^{-2}; **TG,** total grain number $panicle^{-1}$; **UFG,** unfilled grain number; **FG,** filled grain number; **PUFG,** percentage of unfilled grain number; **PFG,** percent of filled grain number; **THGW,** thousand grain weight; **PL,** panicle length; **HI,** harvest index; **Rlai25,** rice leaf area index; **Rsla25,** rice specific leaf area; **Rtdm25,** rice total dry matter; **Rcgr25,** rice crop growth rate; **Rrgr25,** rice relative growth rate; **Rtiller25,** rice tiller number; **Rhigh25,** rice plant height at 25 day after transplanting; **HD,** heading stage.

Table 1. Cultivar or line name, year of release, optimum density and recommended rate of nitrogen for the chosen 10 rice cultivars or lines.

No.	Cultivar or line name	Year of release	Optimum density (Plant m^{-2})	Nitrogen application rate (kg ha^{-1})
1	Line843	-	16	200
2	Shiroodi	2006	16	200
3	Line830	-	16	200
4	Sepidrood	1987	16	200
5	Fajr	2001	16	200
6	Line841	-	16	200
7	Nemat	1995	16	200
8	Dorfak	2001	16	200
9	Dailamani	traditional	25	100
10	Khazar	1983	16	200

contribution of each variable (Hair et al., 1995). For prevent of this mistake interpretation, researchers applied a sequential path analysis for determining the relationship between the yield and related characters in rice (Samonte et al., 2006; Samonte et al., 1998) and in the other crops such as maize (Mohammadi et al., 2003), sorghum (Ezeaku and Mohammed, 2006; Maman et al., 2004), wheat (Ahmadizadeh et al., 2011), cassava (Adeniji et al., 2011) and ajowan (dalkani et al., 2011).

Many researchers have studied cause and effect relationships among yield and yield-related traits in the rice. Genotypic correlation among grain quality and its components provide the information about the plant performance traits and their genetic association with one another (Rasheed et al., 2002). In summary, previous studies have indicated grain yield to be influenced by number of spikelets per panicle, grain weight and percentage of filled spikelets, number of panicles per square meter (Miller et al., 1991), 1000-grain weight, tiller number per plant, number of filled grains per panicle, biological yield, panicle density and harvest index (Surek et al., 1998), panicle weight (Kozak et al., 2007; Samonte et al., 1998), plant height (Kozak et al., 2007), panicle length, flowering time and spikelet number per panicle (Ibrahim et al., 1990).

This study was carried out to determine direct and indirect effects of some morphological traits and yield components on grain yield and to estimate correlations between grain yield and the other studied characters in rice varieties.

MATERIALS AND METHODS

Field experiment was conducted in 2009 at Rice Research Station in Tonekabon (36°54' N, 40° 50' E; 20 m above sea l evel), in north of Iran. Soil properties of the experimental field were 2.2% organic matter content, 37% clay, 44% silt, 19% sand, 6.8 pH, 29.9 cation exchange capacity (CEC) (meg 100 g). The field experiment was arranged in a randomized complete block design with four replications. Rice seeds were disinfected with thiophanate-methyl pesticide in 2 per 1000 dose and then were sown in the nursery on 17 April, 2009. Cultivars and lines seedling were manually transplanted in plots sized 18 m^2 (3 m by 6 m) on 19 May, 2009. Each cultivar or line was transplanted at its own optimum density (Table 1). Recommended rates of nitrogen (Table1), phosphorous (100 kg ha^{-1}) and potassium (150 kg ha^{-1}) were applied. One-third amount of nitrogen and whole phosphorous and potassium were applied as a basal rate at transplanting stage. The Remaining two-thirds of nitrogen were utilized in two split doses 30 days after transplanting (DAT) and at the time of panicle initiation. Two hand weeding were done 30 and 50 days after transplanting. The permanent flood water level was maintained at 10 cm during rice growing period. The observations were recorded on 20 plants randomly selected from the four centre rows in each plot at three stages: 25 days after transplanting, heading stage (HD) and maturity stage. In the analysis, the following traits were measured based on, Standard Evaluation System for Rice (SES, 2002): plant height (PH), fertile tiller number per square meter (FT), panicle length (PL), grain number per panicle (GN), biological yield (BY), unfilled grain number per panicle (UFG), percentage of unfilled grain number (PUGN), grain number per panicle (GN), filled grain number per panicle (FG), percentage of filled grain number (PFG), harvest index (HI), 1000-grain weight (ThGW) and grain yield per hectare (GY). Abbreviations shall be used in the proceeding text and tables.

To obtain physiological growth indices at 25 day after transplanting and rice heading stage, the means of the total dry matter (TDM) data were transformed to natural logarithms to obtain homogeneity of errors (Steel and Torrie, 1980) and then were regressed against time (as days after transplanting) (Equation 1). A quadratic polynomial function was fitted to describe the relationships between plant dry matter data and time. Relative growth rate (RGR) was calculated as the first derivative of the TDM function (Equation 2). Crop growth rate (CGR) was calculated by multiplying TDM by RGR (Equation 3).

$$TDM = \exp\left(f_W(t)\right) \quad (1)$$

$$RGR = f_W'(t) \quad (2)$$

$$CGR = TDM \times RGR \quad (3)$$

Leaf area was measured with a leaf area meter (LI-3100A, LiCor Inc., Lincoln, Nebraska, USA) at 25 DAT and rice heading stage and then LAI was calculated as the following equation (Equation 4):

$$LAI = LA / GA \quad (4)$$

Where LA is the leaf area and GA is the ground area. Moreover, specific leaf area (at 25 DAT and at rice heading stage) was calculated as the ratio of leaf area (m^2) to leaf dry weight (g).

Correlation and path analysis were done on mean of four replications of data and consequently. Correlation coefficients between various pairs of the characters were computed by SPSS 17.0 statistical software (SPSS, 2009). Sequential stepwise multiple regressions were conducted to organize the predictor variables into the first- and second-order paths based on their respective contributions to the total variation of respective variable (GY) and minimum colinearity. The level of multi-colinearity in each component of path was measured from two common measures, namely the tolerance and its inverse the variance inflation factor (VIF) as suggested by Hair et al. (1995). Thus, very small tolerance values (much below 0.1) or large variance inflation factor (above 10) indicate a high colinearity.

Direct effects of the yield characters were estimated by the procedure described by Williams et al. (1990). Partial coefficient of determination (analogues to R^2 of linear regression) was calculated from the path coefficients for all the predictor variables.

Collected data were analyzed by means of path coefficient analysis as outlined by Duarte and Adams (1972). In this method, the linear correlation coefficient between the yield components (A is fertility tiller, B is fill grain and C is thousand grain weight) as defined and the grain yield (G) is partitioned into direct (p) and indirect (rxp) effect according to the model.

$$r_{GA}= p_{GA} + r_{AB}\, p_{GB} + r_{AC}\, p_{GC}$$

$$r_{GB}= r_{AB}\, p_{GA} + p_{GB} + r_{BC}\, p_{GC}$$

$$r_{GC}= r_{AC}\, p_{GA} + r_{BC}\, p_{GC}+ p_{GC}$$

Where, p is standard partial regression or path coefficient and r is correlation coefficient.

RESULTS AND DISCUSSION

Correlation matrices for traits are presented in Table 2. Grain yield (GY) was significantly correlated with BY, FT, THGW, PL, HI, Rsla25, Rtiller25, Rhigh25, RslaHD, RlaiHD, RcgrHD, RtdmHD, RtillerHD and RhighHD. Our interpretation of the relationships among the traits was based on correlations (Table 2), sequential path and overall effect (Table 4 and Fig.1) as well as indirect path coefficient (Table 5). The overall effect of a trait on a dependent trait is equal to the sum of the corresponding direct path (effect) between the two traits and all the indirect effects leading from the trait to the dependent trait (Kozak et al., 2007). Direct effects of the first-order predictor variables on grain yield and measures of colinearity in the model 1 (all the predictor variables as the first-order variables) were shown in Table 3.

Due to low correlation between some of predictor variables, namely FT, FG and THGW, no multi-collinearity was observed between them (Table 2). Based on tolerance and inflation factor values, besides the magnitude of direct effect FT, FG and THGW were considered as the first-order variables among the various yield related characters under study. These three traits explained 73% of the total variation for GY; this means that the most of the variation in grain yield was explained by the traits included in the model. FT had the highest direct effect of the predictor variables on GY (0.65). This procedure was again performed separately taking FT, FG and THGW as dependent variables to find out the first order variables for these three response variables, which shall be consequently, the second-order variables for GY. Results of this process indicated RtdmHD and RtillerHD as predictor variables for FT as dependent variable. The direct effects were positively significant and the highest direct effect was recorded for RtdmHD (p = 0.53). FG, PL and RlaiHD explained 61% of the total variations of THGW. Between these predictor variables FG and RlaiHD had negative effects on THGW; however this response variable was positively affected by PL. Moreover, any predictor variable was not detected as a response variable for FG in the model. The path analysis of second-order variables for above response variables showed that 78% (for FT) and 61% (for THGW) of the total variations was explained by characters that included in the model.

The results of the present research indicated that FT, FG and THGW (as the first-order variables) and RtdmHD, RtillerHD and PL (as the second-order variables) had positive effects on grain yield (Table 4). The results of path analysis are in agreement with many previous studies (Gravois and Mcnew, 1993; Rasheed et al., 2002; Reddy and Suriya, 1997; Samonte et al., 1998; Sharma and Hore, 1997; Surek and Beser, 2003) that had been shown positive direct effects of these traits on grain yield. Grain yield is a complex phenomenon that results from the interaction of various physiological and chemical processes. It can be increased either through improvement of biological yield without any changes in the harvest index or increase of harvest index. Improvement of harvest index was followed by the enlargement of sink capacity (Kato, 1989) that contains the number of panicles per plant, the number of spikelets per panicles and average weight of grains per spikelets. Enlargement of sink capacity results from association of total carbohydrates in the culms and leaf at the heading time, more activity at this time and effective transfer of photosynthesis material to sink (Akita, 1989). In the present study, GY was positively influenced by FT, THGW and FG. Therefore, these traits can be applied as criteria indices in the breeding programs.

Conclusions

In this study, predictor variables were ordered in the first- and second-order paths for grain yield as response variables. When the results of correlation and path coefficient analysis are examined, it is observed that FT, FG and THGW recorded a direct positive effect on grain yield, and they had a positive indirect effect via RtdmHD, RtillerHD and PL. Grain yield depended mostly on FT, FG, THGW, RtdmHD, RtillerHD and PL. This result indicates that these characters must be chosen to improve the model in future studies. All of these traits

Table 2. Correlation coefficients between the traits.

	GY	BY	FT	TG	UFG	FG	PFG	PUFG	THGW	PL	HI	Rlai25	Rsla25	Rtdm25	Rcgr25	Rrgr25	Rtiller 25	Rhigh 25	Rsla HD	Rlai HD	Rcgr HD	Rrgr HD	Rtdm HD	Rtiller HD	Rhigh HD
GY	1	0.79**	0.67**	0.21	-0.06	0.30	0.06	-0.06	0.50**	0.81**	0.62**	-0.02	0.40*	-0.01	-0.02	-0.07	0.45**	-0.34*	0.43**	0.51**	0.60**	-0.07	0.66**	0.51**	-0.39*
BY		1	0.53**	0.24	-0.04	0.33*	0.05	-0.05	0.39*	0.59**	0.43**	-0.05	0.37*	0.02	0.01	-0.03	0.24	-0.23	0.47**	0.37*	0.45**	-0.03	0.50**	0.39*	-0.35*
FT			1	-0.26	-0.35*	-0.17	0.27	-0.27	0.30	0.49**	0.47**	0.07	0.45**	0.06	0.05	0.01	0.72**	-0.08	0.68**	0.65**	0.77**	0.01	0.83**	0.80**	-0.23
TG				1	0.73**	0.94**	-0.5**	0.52**	-0.25	0.38*	0.32*	-0.25	-0.01	-0.11	-0.12	-0.14	-0.25	-0.5**	-0.22	-0.08	-0.11	-0.14	-0.09	-0.24	-0.47**
UFG					1	0.47**	-0.9**	0.95**	0.08	0.21	0.06	-0.26	-0.26	-0.24	-0.25	-0.27	-0.37*	-0.4**	-0.4**	-0.26	-0.32*	-0.27	-0.26	-0.35*	-0.32*
FG						1	-0.22	0.22	-0.5**	0.39*	0.38*	-0.20	0.10	-0.02	-0.04	-0.05	-0.14	-0.5**	-0.06	0.01	0.01	-0.05	0.01	-0.14	-0.46**
PFG							1	-1**	-0.5**	-0.17	0	0.25	0.32*	0.31	0.32*	0.35*	0.33*	0.38*	0.46**	0.25	0.32*	0.35*	0.23	0.28	0.26
PUFG								1	0.5**	0.17	0	-0.25	-0.32*	-0.31	-0.32*	-0.35*	-0.33*	-0.38*	-0.5**	-0.25	-0.32*	-0.35*	-0.23	-0.28	-0.26
THGW									1	0.40*	0.23	-0.04	0.16	-0.10	-0.09	-0.07	0.26	0.11	0.29	0.08	0.24	-0.07	0.29	0.27	0.10
PL										1	0.56**	-0.16	0.38*	-0.07	-0.08	-0.10	0.28	-0.4**	0.23	0.36*	0.42**	-0.10	0.47**	0.34*	-0.44**
HI											1	0.02	0.45**	0.04	0.03	0	0.30	-0.37*	0.34*	0.38*	0.47**	0.01	0.47**	0.27	-0.45**
Rlai25												1	0.21	0.78**	0.79**	0.78**	0.15	0.35*	0.24	0.27	0.23	0.78**	-0.01	0.10	0.30
Rsla25													1	0.49**	0.48**	0.44**	0.33*	0.07	0.74**	0.57**	0.59**	0.44**	0.46**	0.39*	-0.17
Rtdm25														1	0.99**	0.97**	0.16	0.24	0.35*	0.47**	0.39*	0.97**	0.09	0.11	0.15
Rcgr25															1	0.98**	0.15	0.25	0.34*	0.47**	0.39*	0.98**	0.08	0.10	0.16
Rrgr25																1	0.10	0.29	0.27	0.44**	0.36*	1**	0.04	0.03	0.22
Rtiller25																	1	0.05	0.62**	0.49**	0.64**	0.10	0.66**	0.78**	-0.18
Rhigh25																		1	0.1	-0.01	0.01	0.29	-0.08	-0.03	0.78**
RslaHD																			1	0.55**	0.67**	0.27	0.63**	0.68**	-0.18
RlaiHD																				1	0.93**	0.44**	0.84**	0.53**	-0.10
RcgrHD																					1	0.36*	0.94**	0.66**	-0.13
RrgrHD																						1	0.04	0.03	0.22
RtdmHD																							1	0.71**	-0.21
RtillerHD																								1	-0.21
RhighHD																									1

GY (grain yield), BY (biological yield), FT (fertile tiller number per M^{-2}), TG (total grain number per panicle, UFG (unfilled grain number), FG (filled grain number), PUFG (percentage of unfilled grain number), PFG (percent of filled grain number), THGW (thousand grain weight), PL (panicle length). HI (harvest index), Rlai25 (rice leaf area index), Rsla25 (rice specific leaf area), Rtdm25 (rice total dry matter), Rcgr25 (rice crop growth rate), Rrgr25 (rice relative growth rate), Rtiller25 (rice tiller number), Rhigh25 (rice plant height) at 25 day after transplanting and heading (HD) stage. * and ** significant at the 0.05 and 0.01 probability level, respectively.

had positive effects on grain yield; consequently, improvement of these traits can increase potential of grain yield. In addition, second-order response variables (RtdmHD, RtillerHD and PL) had significant and positive correlations with grain yield. Therefore, selection for the improvement of rice grain yield can be efficient, if it is based on FT, FG, THGW, RtdmHD, RtillerHD and PL. These traits can be utilized for pure line selection in late generations; however, the general applicability of the present sequential path model can be ascertained by analysis of data from

Table 3. Direct effects of the first-order predictor variables on grain yield and measures of collinearity in the model 1 (all the predictor variables as the first-order variables).

Model	Beta	t	Sig.	Colinearity statistics	
				Tolerance	VIF
HG	-0.469	-0.709	0.487	0.008	122.759
Rlai25	0.318	2.220	0.040	0.174	5.759
Rsla25	0.171	0.882	0.389	0.095	10.566
Rtdm25	4.433	1.578	0.132	0.000	2218.117
Rcgr25	-4.765	-1.388	0.182	0.000	3307.419
Rrgr25	-0.488	-0.406	0.689	0.002	405.340
Rtiller25	0.000	-0.005	0.996	0.203	4.921
Rhigh25	-0.042	-0.323	0.750	0.214	4.671
RslaHD	-0.371	-1.766	0.094	0.081	12.395
RlaiHD	-0.021	-0.080	0.937	0.052	19.331
RcgrHD	2.074	0.921	0.369	0.001	1424.542
RtdmHD	-1.645	-0.801	0.433	0.001	1183.552
RtillerHD	0.020	0.128	0.900	0.150	6.687
RhighHD	-0.138	-0.943	0.358	0.167	5.982
FT	0.191	0.905	0.377	0.080	12.495
FG	0.154	0.681	0.505	0.069	14.409
THGW	0.329	1.926	0.070	0.122	8.207
FGP	-0.401	-0.697	0.495	0.011	92.906
BY	0.295	2.507	0.022	0.257	3.888
EL	0.209	1.192	0.249	0.116	8.623
HI	-0.054	-0.430	0.672	0.225	4.444

† The symbol of traits is the same as in Table1. ‡ VIF: Variance inflation factor.

Table 4. Estimation path coefficients due to the sequential model.

Predictor variables†	Response variables	R2 adj	Direct effect
FT	GY	0.73	0.65
FG			0.45
THGW			0.34
RtdmHD	FT	0.78	0.53
RtillerHD			0.43
HG	THGW	0.61	-0.76
EL			0.7
RlaiHD			-0.37

The symbol of traits is the same as in Table 2.

Table 5. Direct (under lined) and indirect path coefficient on grain yield.

Response variables	Predictor variables	FT	FG	THGW	Overall effects
GY	FT	<u>0.65</u>	0.11	0.2	0.67
	FG	0.04	<u>0.45</u>	0.08	0.31
	THGW	0.11	0.03	<u>0.34</u>	0.5

The symbol of traits is the same as in Table 2.

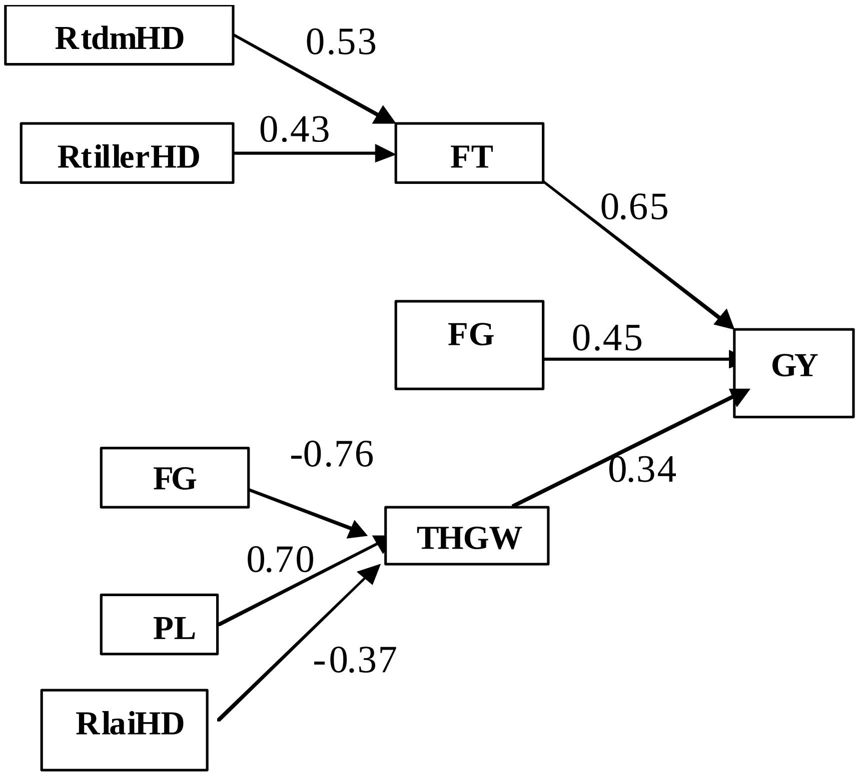

Figure 1. Sequential path model indicating the interrelationships among the total yield and degree of milling whit related characters (2007). The symbols of traits are the same as in Table 1.

different sets of germplasms under different production conditions.

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