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Study of relationship between grain yield and yield components using multivariate analysis in barley cultivars (*Hordeum vulgare* L.)

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Abstract

This experiment was performed to evaluate the correlation between grain yield and other characteristics of 20 cultivars and advanced breeding lines of barley in the Research Station, Agricultural collage, Shiraz University, Shiraz, Iran. The experimental design was a randomized complete block with four replications. Biological and grain yields and yield component were measured. Genotypic and phenotypic variation, mean comparison, correlation coefficient, regression and Path analysis were used for analysis of data. The Path analysis showed that the effects of spikes per square meter, kernel weight on grain yield were significantly different ($p \leq 0.01$). Also the results showed spikes per square meter had a negative correlation with kernels per spike and kernel weight. Regression analysis confirmed that kernel per spike is the most important yield component and increasing it can be improved the grain yield.

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Introduction

Barley (*Hordeum vulgare* L.) is one of the oldest and most widespread cereals and currently ranks fourth of fifth in acreage and crop production worldwide (De Candolle, 1895). The greatest share of the world's barley grain is used for animal feed, followed by malting and human food. Archaeologists and scientists who have attempted to reveal more of the historical developments of human and their attempts at cultivating barley do not conclusively agree on exactly where these events occurred (De Candolle, 1895). The currently accepted theory is that barley was first domesticated in the Fertile Crescent in the Near East, which spans present-day Israel, northern Syria, southern Torkey, eastern Iraq and western Iran. In Iran, barley as second important crop is cultivated at a level equivalent to 1.5 million hectares. Mainly, 60% is devoted to water and 40% to dry farming (Poehlman, 1985).

Barley is a tolerant crop that was adapted to dry conditions and environmental stresses and having attributes such as green pastures at tillering stage, grain yield and its use in the food industry cropping systems in arid regions of the world including our country (Pakniyat *et al*., 1997; Abay *et al*., 2008). Therefore, morphological and phenological evaluation of barley is necessary to determine their importance on grain yield increasing (De Candolle, 1895). On the other hand, yield increasing of barley is one of the important aims in producing livestock and poultry feed. Genetically, spike number is the first yield component that has a positive correlation with grain yield (Qualset *et al*., 1965; Fathi and Rezaie, 2000). This component leads to increase leaf surface and photosynthetic source (Qualset *et al*., 1965; Simane *et al*., 1993). It should not be forgotten that any increase in components leads to similar decrease in other. Hence, the most high-yielding crops show yield components in intermediate level. Grain number per spike and grain weight is the other important yield components that affects grain yield (Pakniyat *et al*., 2013). Grains which are located in the middle spike have the most growth and weight. Stoskopt *et al*. (1974) reported that correlation between yield and yield components can be changed with fertility level, plant data and cultivar type. Also, Adams (1967) pointed that the reaction of yield components against environmental changes is not similar together and stresses caused competition and a negative correlation between them. Consequently, optimal level should be considered for each component. Grafius (1978) pointed that this genetically optimal level for each component has a different manifestations in different environment. In addition to grain yield, biological yield is also important for animal consumption. To select for biological yield, the breeders can obtain larger plants with larger photosynthetic surface that will produce more carbohydrates and hence larger spike with more grain. According to the findings, breeders deal with broad masses in the early stages of selection, they should determine criteria to select single plant based on relationship between different characteristics and yield. Using crop management, we can change morphological characteristics of plant such as vegetative growth and grain filling period. If these changes be consistent with effective characteristics of yield, it will be increased it. Based on these finding the aims of this study were formed to determine the relationship between yield and its component of barley genotypes using different statistical methods in order to apply the results in breeding programs.

Materials and methods

Experimental design

A field experiment was conducted on a silty loam soil at the research station of College of Agriculture, Shiraz University, Shiraz, Iran (29°50′ N, 52°46′ E, Altitude 1810 m above sea level). The cultivars were arranged in a randomized complete block design with four replications. Twenty barley cultivars were grown in this experiment (Table 1). Each plot consisted of 6 rows, 4 m long and 20 cm apart with a density of 250 seeds m^{-2}. The cultivars were planted on 15 November.

Fertilization method and weed removed

Nitrate fertilizer (120 kg/ha) was split in two parts that was applied at planting and spike-emergence stages and phosphorus fertilizer (60 kg/ha) was added at planting stage. All plots were irrigated at 100% Field Capacity and weeds were removed mechanically at several steps. Weather data at the experimental site are given in Table 2.

Sampling and statistical analysis

Fifty cm either side of each row was left as border and samples were taken from the remaining plants at maturity. Grain yield and its components were measured. Statistical analysis was performed using SAS 9.2 (SAS 2009) and EXCEL softwares and the means were compared using LSD test at 5% probability level. Phenotypic and genotypic coefficients of variation were calculated according to following formulas, where $\delta^2 ph$, $\delta^2 g$ and $\delta^2 e/r$ are phenotypic, genotypic and error variance, respectively.

GVC$= \frac{\sqrt{\delta^2 g}}{\bar{X}}$ (Singh and Chaudhury, 1985)

PCV$= \frac{\sqrt{\delta^2 ph}}{\bar{X}}$ (Singh and CHaudhury, 1985)

$$\delta^2 ph = \delta^2 g + \delta^2 e/r$$

Phenotypic and genotypic correlation coefficients were calculated using phenotypic and genotypic variances and co-variances as below:

$r_g = \frac{\delta_{g1.2}}{\sqrt{\delta^2{}_{g1} \times \delta^2{}_{g2}}}$ (Miller *et al.*, 1980)

$r_p = \frac{\delta_{p1.2}}{\sqrt{\delta^2{}_{p1} \times \delta^2{}_{p2}}}$ (Miller *et al.*, 1980)

(r_g: genetic correlation coefficient, $\delta_{g1.2}$: genetic co-variance, r_p: phenotypic correlation coefficient and $\delta_{p1.2}$: phenotypic co-variance).

To determine regression model, ascending regression was performed using grain yield as a dependent variable and also to find the direct and indirect effects of yield component on grain yield, path analysis was calculated based on genotypic correlation as described by Dewey and Lu (1959) as first model and Doting and Knight (1992) as second model.

Results and discussion

Phenotypic and genotypic coefficients of variation

The average of yield and yield components and phenotypic and genotypic coefficients of variation are shown in Table 3. Genotypic coefficients of variation is part of phenotypic coefficients of variation and therefore, is smaller in value. Except grain yield, for other traits, the difference between the phenotypic and genotypic coefficient of variation is relatively low which shows the low environment effect on them. From yield component, number of spikes per square meter and number of grains per square meter had higher coefficient of variation while thousand kernel weight showed low variation. Ramos *et al.* (1982) and Garcia *et al.* (1985) reported that grain weight is a stable yield component in barley. Hence, selection for traits phenological show higher variation in all conditions is more effective have appropriate heritability.

Table 1. Barley cultivars (six-row barley), used in the experiment.

No.	Varieties	No.	Varieties
1	Reyhane	11	Na – CC- 4000-123/walfajre
2	Torsh/9 Cr. 279-07/BM58	12	Walfajr// Amp/ He 1905/Roho
3	Zarjow// Rihane/ L.640	13	Zarjow/ Bit/ CM67
4	Toji's'/79w 40762	14	Kavir / M ch – M4/ 3A pm// Dwarf
5	Rihane3	15	Roho / 608 / arivat // Local – PB
6	Aths/ DMR27//-2197	16	121266 / Walfajre
7	Suifu/ Cina	17	Torsh / 9cr-279- 07 //Bgs
8	Kavir/ Badia	18	Cht/ ROHO / Alger – Ceres
9	Karoon/ kavir	19	Karoon
10	80-5010-/Mona	20	Walfajre

Variance analysis

Variance analysis of yield and yield components was performed in randomized complete block design (Data not shown). Results showed a significantly different between cultivars for all the measured traits that this significant difference is pointed to substantial genetic variation between them. Therefore, mean comparisons were made to confirm it. Results showed, the highest and lowest grain yield belonged to the cultivars number 17 (290.3 gm^{-2}) and 3 (161 gm^{-2}). Other cultivar such as 12, 2 and 1 with 286.8, 285 and 264 gm^{-2} produced high yields which were not significantly different from genotype number 17 (Table 4). In terms of biological yield, cultivars 12 and 17 with 770 and 730 gm^{-2} were the best and also number 17 had the highest spike number per square meter (Table 4). Overall, the high-yielding cultivars were showed high spike number per square meter.

Table 2. Some weather data at the experimental site during the experiment.

	Temperature (℃)		Preciptation (mm)
Month	Max	Min	
November	19.75	4.07	8
December	14.27	0.47	127
January	11.35	0	85.5
February	12.8	-2.33	194.5
March	15.48	-2.38	2.88
April	20.35	-4.23	97.5
May	26.42	-1.1	0
June	32.06	1145	0
Total			515.38

Table 3. The average, range variation and phenotypic and genotypic coefficients of variation of yield and yield components in twenty barley cultivars.

Traits	Average	Range Variation	GCV	PCV
GY	222.59	145-350	14.80	20.30
BY	608.96	440-830	10.90	14.07
HI	36.87	29.35-52.38	18.98	21.72
TKW	44.37	34.4-51.5	4.56	5.72
GWS	2.06	1.60-2.45	9.79	11.04
GNS	45.21	30-58	9.20	12.00
SN	165.21	88-295	17.40	22.10

Note: GCV: Genotypic Coefficient of Variation (%), PCV: Phenotypic Coefficient of Variation (%), GY: Grain Yield (g m^{-2}), BY: Biological Yield (g m^{-2}), HI: Harvest Index (%), TKW: Thousand Kernel Weight (g), GWE: Grain-Weight per Spike (g), GNE: Grains Number per Spike and SNS: Spike Number per Square meter

Cultivars 16 with 43.15 g had the highest thousand kernel weight (Table 4) but this cultivar showed lower yield in comparison to cultivars 2, 12 and 17. This reason can be referred to lower spike number and grain number per spike. In present study, cultivars 20 and 12 which are high-yielding cultivars, showed high grain weight. Grain number per spike is another important yield component that cultivar 12 ranked first in this regard. The highest and lowest HI belonged to cultivars number 2 (43.78%) and 3 (29.35%) (Table 4). These cultivars showed high and low grain yield, respectively. In general, present results showed that harvest index, thousand kernel weight, grain yield and biological yield had direct relationship with each other. These results are in agreement with Feil (1992) who reported higher grains per spike and thousand kernel weight can lead in improvement of biological and grain yield and it should be considered, under different environmental conditions.

Table 4. Average yield (gm^{-2}) and yield component of 20 six-row barley cultivars under similar irrigation condition.

Nu.	GY	BY	HI	TKW	GWS	GNS	SNS
1	264.00	687.50	40.06	46.80	1.80	38.50	197.30
2	285.00	650.00	43.78	48.05	2.16	45.00	189.80
3	161.00	553.50	29.35	44.75	1.87	41.75	95.25
4	181.50	523.30	35.42	44.95	2.17	48.25	126.80
5	208.30	553.30	37.66	45.85	2.05	44.75	151.30
6	211.80	610.00	35.20	42.28	1.84	43.50	168.80
7	229.80	596.00	38.59	44.55	1.77	39.75	187.80
8	239.80	585.80	41.66	40.45	1.79	44.25	159.00
9	215.00	563.00	38.31	43.63	2.11	48.25	159.80
10	200.00	600.00	33.33	46.70	2.05	44.00	131.30
11	194.00	585.00	32.27	43.72	2.11	48.25	144.80
12	286.80	770.00	37.54	43.15	2.30	53.25	180.50
13	235.50	617.50	39.33	45.65	2.02	44.25	193.30
14	238.00	623.30	38.58	42.15	1.88	44.50	199.80
15	210.80	530.00	39.54	36.75	1.94	52.75	164.00
16	182.30	552.00	33.36	51.75	2.15	41.50	150.30
17	290.30	730.00	42.08	44.95	2.17	48.25	233.00
18	194.50	572.50	33.96	40.45	2.02	50.00	156.30
19	200.80	645.80	31.11	43.85	1.57	35.75	174.80
20	223.00	630.00	35.28	46.95	2.24	47.75	141.00
LSD	43.55	94.01	9.91	0.35	0.01	5.00	31.69

Note: Grain Yield ($g\ m^{-2}$), BY: Biological Yield ($g\ m^{-2}$), HI: Harvest Index (%), TKW: Thousand Kernel Weight (g), GWS: Grain-Weight per Spike (g), GNS: Grains Number per Spike and SNS: Spike Number per Square meter.

Phenotypic and genotypic correlation coefficients

Values of phenotypic and genotypic correlation coefficients were not significantly different (Table 5) which shows low environmental effects on relation of crop traits. Since in most cases genotypic correlation coefficients are higher than phenotypic correlation coefficients, it can be concluded that the environment effects had moderated correlation between the two traits. A positive significant phenotypic and genotypic correlation was observed between grain yield and grain number per spike. This correlation was also reported by other researchers such as Doting and Knight, 1992; Ehdaie and Waines, 1989; Saed-Moucheshi *et al.*, 2013a and Garcia del Moral *et al.*, 1991. Spike number per square meter had a high positive significant correlation with grain yield. These results were reported in barley and wheat, Darwinkel *et al.*(1982) and Nerson (1980).

Grain yield and thousand kernel weight had no significant effects. Garcia del Moral *et al.* (1991) reported that the differences between grain yield of barley cultivars is associated with two yield component via spike number per square meter and grain number per spike, and grain weight has a venial effect on grain yield. In some cases a positive significant correlation was reported between grain yield and grain weight (Bhatt, 1973 and Gebeyehou *et al.*, 1982). Grain number per spike had a positive significant correlation with biological yield and harvest index and a negative significant correlation with thousand kernel weight and grain weight, Singh and Singh, 1973 and Yap AND Harvey, 1972 also reported a negative correlation between grain number per spike and grain weight.

Overall, there is a negative correlation between yield components. By increasing grain number, and fixed amount of storage material, lower amount of storage material can be stored in the grains. It can be pointed that besides the genetic nature between these components, it varies from environment to environment (Adams, 1967) and therefore it may cause different results in different researches. Correlation coefficients analysis determines that grain number per spike is the most important crop characteristic for yield improvement. Spike number per square meter, biological yield and spike length are the next important items, respectively.

Table 5. Genotypic (G) and phenotypic (P) correlations coefficients between yield and yield components.

Variables	BY	HI	TKW	GWS	GNS	SNS
GY	0.371^{**} P	0.764^{**}	0.510	0.183	0.439^{**}	0.182
	0.425^{**} G	0.914^{**}	0.194	0.207	0.587^{**}	0.238^{*}
BY		0.213 P	0.054	-0.144	0.136	0.360^{**}
		0.268^{*} G	0.118	-0.163	0.223^{*}	0.414^{**}
HI			0.229^{*} P	0.253^{*}	0.252^{**}	0.063
			0.389^{*} G	0.276^{*}	0.379^{**}	0.138
TKW				0.099 P	-0.132	-0.018
				0.129 G	-0.286^{*}	-0.219
GWS					-0.221^{*} P	-0.117
					-0.268^{*} G	-0.189
GNS						-0.061 P
						0.091^{*}G

Note: ** and * Means with significant difference at 1 and 5% levels of probability, respectively. GY: Grain Yield (g m^{-2}), BY: Biological Yield (g m^{-2}), HI: Harvest Index (%), TKW: Thousand Kernel Weight (g), GWS: Grain-Weight per Spike (g), GNS: Grains Number per Spike and SNS: Spike Number per Square meter.

Regression model

To find the most effective yield component on grain yield, ascending regression was recognized as the best model and following equation regression shows that grain yield is a dependent variable.

GY = − 1526.76 + 1.50 (SNS) + 17.60 (GNS) − 2.45 (TKW).

Due to high coefficient of determination, equation regression is well explained yield changes. After ascending regression and determination of the most important characteristics affecting on grain yield, it was identified that spike number per square meter (SNS), grain number per spike (GNS) and thousand kernel weight (TKW) explained 95% of total variation together and these items may be considered as selection criteria in breeding programmes. Other components had an insignificant effect on grain yield and only explained 5% of the total variation. These results were in agreement with Hamza *et al.* (2004) who considered variation in 26 barley cultivars by measuring 12 agronomic traits. They performed regression and principal component analysis and reported that grain number per spike, spike weight, thousand kernel weight and seed diameter explained 85% of the total variation.

Path analysis

Results of genotypic correlation coefficients analysis to direct and indirect effects on grain yield is shown in Table 6. Based on this model (first model), grain yield is the outcome of spike number per square meter (SNS), grain number per spike (GNS) and thousand kernel weight (TKW). These components are correlated to each other and each component affects grain yield by a direct effect and indirect effects (Fig. 1).

Thousand kernel weight which had a small non-significant genotypic correlation with grain yield (0.194) was consisted of three components. The relative contribution of each component was determined using separation of correlation coefficient to components and calculation of contribution of each component in total correlation (Dewey and Lu, 1959). Direct effect of TKW on grain yield (P_{3y}) was 0.540. It has been showed that grain weight increasing along with keeping other variables, leads to increase in grain yield. Indirect effects can have important role and cover direct effect. Indirect effect of grain weight on grain yield by grain number per spike was -0.251. The reason is that there is a negative significant correlation between TKW and GNS ($r_{32}P_{2y}$= -0.286) and GNS has a significant effect on grain yield (P_{2y}= 0.877). Therefore, the high negative significant indirect effect of TKW by GNS decreases the direct effect of TKW on grain yield and leads to small non-significant correlation between TKW and grain yield. Likewise, genotypic correlation for SNS and GNS with grain yield can be separated into direct and indirect effects.

Table 6. Direct and indirect effects of yield components on grain yield using Dewey and Lu, (1959) model and genotypic correlations.

Path	Effect	Genotypic correlation coefficients
SNS with GY		0.238
Direct effect	0.435	
Indirect effect by GNS	-0.079	
Indirect effect by TKW	-0.118	
Total	0.238	
Equation	$r_{1y}= P_{1y} + r_{11} P_{2y} + r_{12} P_{3y}$	
GNS with GY		0.587
Direct effect	0.877	
Indirect effect by SNS	-0.039	
Indirect effect by TKW	-0.251	
Total	.0587	
Equation	$r_{2y}= P_{2y} + r_{21} P_{1y} + r_{22} P_{3y}$	
TKW with GY		0.194
Direct effect SNP	0.540	
Indirect effect by GNS	-0.095	
Indirect effect by	-0.251	
Total	0.194	
Equation	$r_{3y}= P_{3y} + r_{31} P_{1y} + r_{32} P_{2y}$	

Note: GY: Grain Yield (g m^{-2}), TKW: Thousand Kernel Weight (g), GNS: Grains Number per Spike and SNS: Spike Number per Square meter.

Dewey and Lu, (1959) model can divide genotypic correlation coefficients to direct and indirect effects but in this model some Paths is unreal. For example TKW affects on GNS Path and also GNS affects on SNS Path are unreal. In cereal, yield components which are later determined can not affect on other components that developed earlier (Doting and Knight, 1992). Hence, there is no reason for TKW to have an effect on SNS and also GNS or GNS have an effect on SNS which was developed earlier. Therefore, there is a need to model that yield component were located chronologically. In this model, only yield components were earlier developed can affect on other.

Table 7. Path coefficient in yield component analysis using Doting and Knight (1992) model and genotypic correlation.

Path	Effect	Genotypic correlation coefficients
SNS on GY	0.435**	-0.238*
GNS on GY	0.877**	0.587**
GWS on GY	0.540**	0.194
SNS on GNS	-0.091	-0.091
SNS on TKW	-0.168	-0.219
GNW on TKW	-0.289**	-0.286*

Note: ** and * Means with significant difference at 1 and 5% levels of probability, respectively. GY: Grain Yield (g m^{-2}), TKW: Thousand Kernel Weight (g), GWS: Grain-Weight per Spike (g), GNS: Grains Number per Spike and SNS: Spike Number per Square meter.

Based on Doting and Knight (1992) method as second model, a better logical description of relations can be indicated between yield components (Table 7). Figure 2 and 3 shows that, there is a negative relation between yield component and recognized that GNS had a negative significant effect on TKW (-0.289) (Table 7). According to this fact that in second model, the data are standard and grain yield are calculated by multiplying components, it is possible to compare Path coefficient and its relation with grain yield. In this model, the positive and direct effect of SNS on yield (0.435) is more than sum of two negative effects of SNS on GNS (-0.091) and TKW (-0.168), respectively. Therefore, higher SNS leads increasing the yield. Also, positive and direct effect of GNS on grain yield (0.877) was more than its negative effect on TKW (-0.289). It is pointed that higher GNS causes an increase in grain yield (Figure 2).

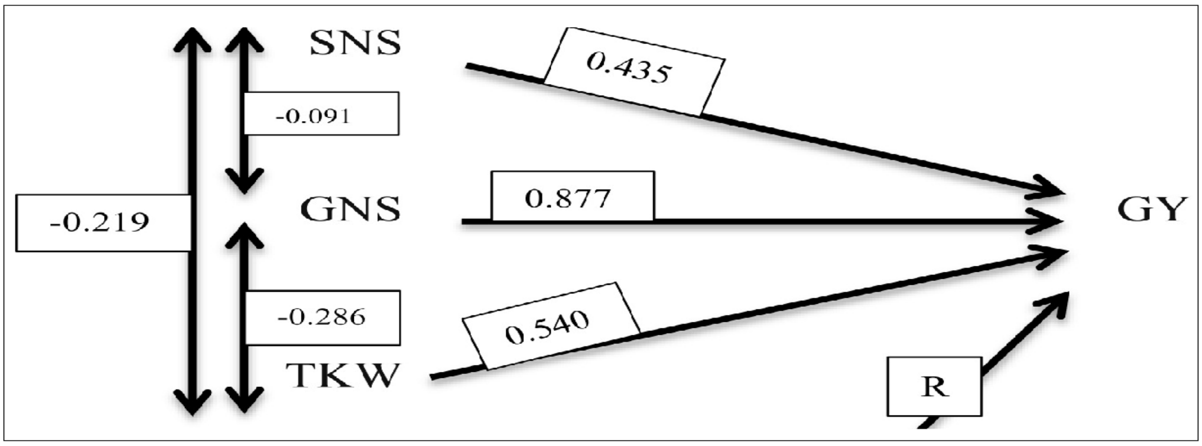

Fig. 1. Path coefficients between grain yield and important yield component using genotypic correlations (first model). GY: Grain Yield (g m-2), TKW: Thousand Kernel Weight (g), GNS: Grains Number per Spike, SNS: Spike Number per Square meter and R: Residuals.

Using the two Path analysis models (direct and indirect effects), it was recognized that grain number per spike had the most direct effect on grain yield (0.877). Simane *et al.* (1993) also reported that GNS had a significant direct effect on grain yield. These results were in agreement with Bhatt (1973); Doting and Knight (1992); Ehdaie and Waines (1989) and Deniz *et al.* (2009). Some researchers reported that grain weight has the most effect which originate during early growing season and therefore, its improvement causes increase in grain yield (Bhatnger *et al.* (1977); Chaudhary (1977); Singh and Singh (1973) and Yap and Harvey (1972)).

In present study grain number per spike had a small indirect effect on grain yield via SNS. Puri *et al.* (1982) reported that indirect effects of GNS by SNS and GWS. It seems that GNS is an important yield component and the breeders can select cultivars based on grain number per spike before reaching the complete purity in pedigree method. Another important yield component, TKW, had a large and direct effect on grain yield but it did not find a positive significant correlation with grain yield. The direct effect of TKW on grain yield was adjusted by indirect effects of GNS. Although Grain weight effect on yield was lower than grain number per spike but this relation was positive and significant. This positive significant was reported by other researches such as Garcia del Moral *et al.* (1991); Puri *et al.* (1982); Adams (1967) and Setotaw *et al.* (2014). The direct effect of SNS on grain yield was positive and significant. Due to negative relation between SNS with both of GNS and TKW, the correlation between SNS and grain yield was partly adjusted this model also is described by Doting and Knight (1992) and Puri *et al.* (1982).

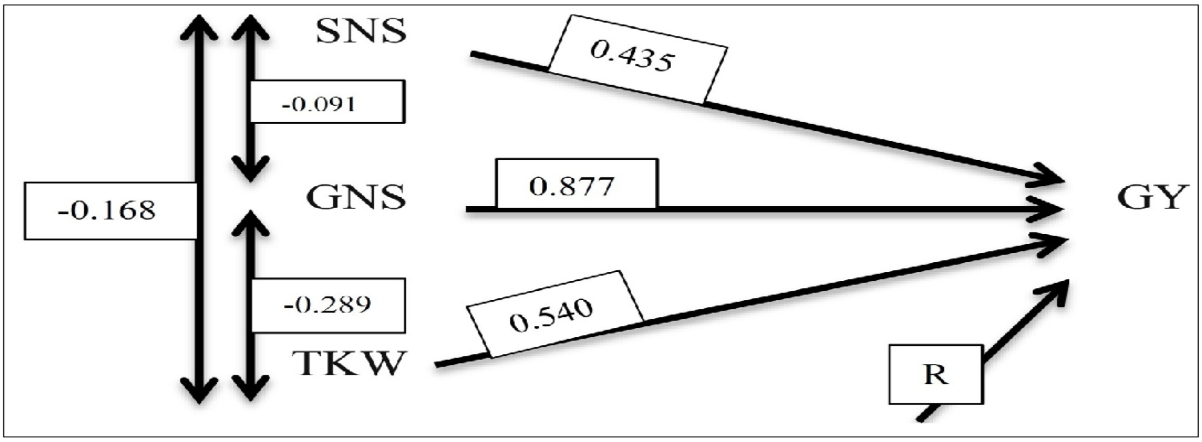

Fig. 2. Path coefficients between grain yield and important yield component using genotypic correlations (second model). GY: Grain Yield (g m-2), TKW: Thousand Kernel Weight (g), GNS: Grains Number per Spike, SNS: Spike Number per Square meter and R: Residuals.

Abbreviations: GCV: Genotypic Coefficient of Variation; PCV: Phenotypic Coefficient of Variation; GY: Grain Yield; BY: Biological Yield; HI: Harvest Index; TKW: Thousand Kernel Weight; GWE: Grain-Weight per Spike; GNE: Grains Number per Spike; SNS: Spike Number per Square meter.

Conclusion

In present study, genotypic and phenotypic variation is considered as necessary items measuring traits in barley cultivars. Based on grain yield and yield component cultivars number 1, 2, 12 and 17 were the best ones. All three statistical analysis consist of ascending regression, genotypic and phenotypic correlation coefficients and path analysis showed similar results and recognized that grain number per spike had the most effect on grain yield. Consequently, this component can be considered as a selection criteria to screen barley cultivars. Path analysis can be more efficient than multiple regression and correlation coefficients because this method has no defects of those methods. It is better that second model of Path analysis be used in cereal such as barley, wheat, because in these crops yield component are determined consecutively and those components which developed earlier, may affect other components.

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