

ASSESSMENT OF PAKISTANI AND IRANIAN BREAD WHEAT LANDRACES USING MULTIVARIATE ANALYSIS FOR GRAIN YIELD

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Abstract

The cereal crops depend, in their production sustainability, on germplasm improvement and genetic diversity. The role of multivariate techniques is vital in classification of germplasm as well as studying the interrelationship between grain yield and its various components. Germplasm consisting of 192 Iranian and 202 Pakistani wheat landraces from different regions of Pakistan and Iran were evaluated for six quantitative traits, through simple correlation, stepwise regression, path coefficient analysis, cluster analysis and factor analysis. The results showed that grain yield in Pakistani wheat landraces has most commonly been affected by two traits, i.e., spike weight and 1000-grain weight. Similarly, for Iranian wheat landraces, spike weight, 1000-grain weight and number of grains/spike are the prominently influencing morpho-physiological traits affecting the yield. These variables will be helpful in the selection of suitable genotypes for wheat improvement programs to get high yielding genotypes. Cluster analysis divided the Pakistani and Iranian wheat landraces into four and three groups respectively. Principal component analysis confirmed the results of the cluster analysis. Iranian landraces were clearly separated into three groups. High genetic diversity among landraces is eligible to be used in future crosses to produce segregating populations.

Key words: Wheat landraces, Agro-morphological traits, Grain yield, Multivariate analysis.

Introduction

Germplasm diversity forms the base for the genetic betterment of crops. The amount of genetic enrichment is reliant on the extent of genetic diversity inherent in a population (Kumbhar *et al.*, 2015). For enhanced food production, genetic diversity of plants should be determined for their better efficacy and their use in various breeding programs (Ormoli *et al.*, 2015). Existing information about germplasm's genetic diversity and its distribution in different crops is useful for germplasm preservation (Teklu *et al.*, 2006).

It is necessary to evaluate various wheat resources. For the preservation of wheat genetic resources, the identification of local landraces is necessary. This, in turn, can promote their sustainable use in order to bring economic benefits to the farmers (Croston, 1981). Both nature's and farmer's selection are responsible for the emergence of landraces (Belay *et al.*, 1995). Typically landraces provide a broader genetic base and thus offer valued characteristics that are significant for breeding (Keller *et al.*, 1991; Tesemma *et al.*, 1998). Till now landraces and old cultivars have been grown showing adverse effects on the production, quality and food security (Parry *et al.*, 2004). As local cultivars are not recognized as those with high yield and increased protein content, so genetic improvement of such cultivars is required in order to enhance grain yield and grain stability in diverse environmental conditions (Ortiz-Monasterio *et al.*, 1997). Newly introduced wheat cultivars contain a narrow genetic base due to which the grain yield in many semi-arid and arid areas is reduced (Annicchiarico & Pecetti, 1993). Identification of genetic resources is

required to utilize these landraces in breeding related programs. These local cultivars and landraces adapt to different conditions; therefore, they serve as a better tool for achieving increased grain yield in arid and semi-arid areas by identifying proper strategies (van Bueren *et al.*, 2005). Landraces with unique characters can be recognized by estimating the diversity of germplasm. Akçura *et al.* (2011) reported the superiority of landraces over modern genotypes under stress conditions. These identified landraces with novel characteristics can be incorporated into the crop improvement programs (Asif *et al.*, 2005; Paterson *et al.*, 1991; Devos & Gale, 1992).

Usually, pedigree, agronomic and morphological traits are used for estimating the genetic diversity of germplasm (Nasir *et al.*, 2011). A wider genetic diversity can favor the quick improvement of cultivars. A reduction in germplasm diversity is an obstacle to plant breeding and reduce the tendency of plants to resist unfavorable environments (Xiyong *et al.*, 2012). Phenotypic identification based on morphological traits has been used successfully for genetic diversity analysis (Fakhfak *et al.*, 1998; Feillet, 2000). Smith & Smith, (1989) revealed that for the description and classification of crops morphological characterization is important. A breeding program is primarily dependent on the extent of genetic diversity germplasm (Smith *et al.*, 1991). Morphological markers are considered the best substitute to molecular markers for evaluating genetic diversity (Hailu *et al.*, 2010). It is desirable for many breeders and physiologists to identify those specific characters that enhance the yield and can be incorporated in wheat genotypes (Major *et al.*, 1992).

In cereals, grain yield is a dependent variable which is affected by many physiological mechanisms. Grain yield can be increased by choosing morphological characters related to grain, which positively and directly affect grain yield and can be easily measured (Blum, 1996). Genetic diversity can be estimated by using multivariate statistical methods in which several measurements can be considered simultaneously (Shamsi *et al.*, 2011). Correlation coefficient of two traits segregates two components, measuring direct and indirect effect. From the stepwise regression analysis, non-effective traits on yield in regression model can be removed and traits that only significantly affect the yield are included (Farshadfar, 2004). Many investigators such as (Mohamed, 1999; Soleymanifard *et al.*, 2012; Hannachi *et al.*, 2013) have used this analysis in wheat. Path analysis is used by a number of investigators in wheat that provides important information and relationship among the traits affecting each other. According to Mollasadeghi *et al.* (2011) several components like number of grains/spike, grain weight, 1000-kernel weight and biological yield have the most direct and positive influence on grain yield. Factor analysis is usually applied to reduce the number of variables into some hidden factors, to recognize some chief components of yield, to group traits on the basis of intrarelationship between them and to study genetic diversity (Azizi *et al.*, 2001). Cluster analysis can be employed to assemble the set of variables into clusters, in such a way that cases in the same cluster have more similarities to each other than other clusters (Leilah & Al-Khateeb, 2005).

Wheat production can be boosted by increasing the crop growing area or by increasing yield per unit area. But unfortunately the crop growing area cannot be increased due to competition with other crops and limited water supply for crop growth. Only yield can be increased by better crop management and introducing varieties with higher yield that can tolerate both biotic and abiotic stresses (El-Mohsen & El-Shafi, 2014).

This study aims at evaluation of genetic diversity amidst wheat landraces from Pakistan and Iran, for the evaluation of direct and indirect effects of several morphological traits on grain yield.

Materials and Methods

In order to evaluate the genetic variability in Iranian wheat landraces and to establish the relationship between grain yield and other traits, 192 Iranian wheat landraces (collected from 1937 to 1968) provided by the Gene Bank of Agronomy and Plant Breeding Department of University of Tehran, Karaj, Iran were evaluated. The seeds were planted by hand on four rows with 1.5 m length and 20 cm width on the basis of an Augmented design with three check cultivars (Azar, Nanvid and Pishtaz) in seven incomplete blocks in 2014, in the research field of the College of Agriculture and Natural Resource of Tehran University, Karaj, Iran (50° 58' E and 35° 56' N).

Seeds of 300 Pakistani wheat landraces were obtained from the gene bank of Plant Genetic Resources Institute (PGRI), National Agricultural Research Center (NARC) Islamabad, Pakistan. Out of these 202 selected landraces (collected from 1981 to 2002) were used in this study. The experiment was conducted on the basis of an Augmented design in 2013-14 in the field of National Agricultural Research Center (NARC) Islamabad (33° 33' N and 73° 06'E). In both experiments, morphological traits, such as plant height (cm), spike length (cm), number of grains/spike, spike weight (gr), 1000-grains weight (gr) and yield/plant (gr.plant⁻¹) was recorded.

Data analysis: The data recorded on quantitative traits was averaged and analyzed for descriptive statistical approaches, like mean, minimum, maximum, standard deviation and coefficient of variation in order to determine the extent of genetic diversity among the studied genotypes. Normality of residuals tested using Kolmogorov-Smirnov and Shapiro-Wilk methods, correlation, regression analysis, cluster analysis based on ward's method using squared euclidian distance and factor analysis in both Iranian and Pakistani wheat landraces, were done using the statistical software SPSS version 21 (SPSS, Chicago, USA). Path analysis was performed using Path74.

Results and Discussion

Genetic variation in a plant material is the base for crop improvement (Iqbal *et al.*, 2014). The usage of germplasm can be determined by the extent of available variability in the material (Kumbhar *et al.*, 2015). Different marker systems such as agro-morphological, biochemical and molecular, can be used to study genetic diversity (Smith & Smith, 1989; Khan *et al.*, 2014).

Based on the results of descriptive statistics and coefficient of variation, high variation was observed for the investigated traits in both Iranian and Pakistani landraces (Table 1) which revealed high phenotypic variation among these landraces. Iranian landraces showed high variation for plant height, spike length, number of grains/spike and grain yield, in comparison to Pakistani landraces. On the other hand, Pakistani landraces showed high variation in spike weight and 1000-gains weight in comparison with Iranian landraces. Sabaghnia *et al.* (2014) analyzed the variations in bread wheat genotypes of Iran on the basis of morphological traits and observed variations in plant height, grain properties and spike characters. It was suggested that they can be used to select favorable crosses in wheat breeding programs.

Iranian landraces have been collected from 1937 to 1968 but Pakistani landraces have been collected from 1981 to 2002. Since, not only Iranian landraces have been collected in a long period but also they were collected long time ago. Therefore, it seems that genetic diversity in Pakistani landraces is decreased due to human activities and selection during the last century. This considerable variation within landraces can provide a great opportunity to improve grain yield in the future breeding program. The means and percentage of variations of investigated traits in Pakistanis wheat landraces are given in Table 1.

Table 1. Means and percentage of variations of investigated traits in Pakistani and Iranian wheat landraces.

Traits	Origin	Range	Mean	Standard deviation	Standard error	Coefficient of variation
Plant height (cm)	Pakistan	72.00-138.00	93.62	10.27	0.72	10.97
	Iran	72.00-149.11	112.29	12.19	0.88	10.86
Spike length (cm)	Pakistan	6.06-13.44	8.37	0.94	0.07	11.26
	Iran	6.50-14.52	10.57	1.40	0.10	13.20
No. of grains/spike	Pakistan	23.60-61.40	39.64	7.60	0.53	19.17
	Iran	14.54-62.35	32.91	8.94	0.64	27.15
Spike weight (gr)	Pakistan	0.61-3.84	1.84	0.50	0.04	27.19
	Iran	0.70-3.60	1.93	0.55	0.04	28.62
1000-grain weight (gr)	Pakistan	13.99-66.72	31.45	7.85	0.55	24.97
	Iran	18.26-53.99	35.65	6.63	0.48	1+68.60
Yield (gr.plant ⁻¹)	Pakistan	0.66-3.63	2.09	0.52	0.04	25.00
	Iran	0.78-4.73	2.35	0.77	0.06	32.75

Table 2. Correlation coefficients between investigated traits in Pakistani (lower off-diagonal) and Iranian (upper off-diagonal) wheat landraces.

Traits	1	2	3	4	5	6
1. Plant height	1	0.354**	0.284**	0.394**	0.288**	0.370**
2. Spike length	0.102 ^{ns}	1	0.271**	0.353**	0.213**	0.337**
3. No. of grain per spike	-0.068 ^{ns}	0.566**	1	0.755**	0.049 ^{ns}	0.775**
4. Spike weight	0.227**	0.343**	0.447**	1	0.549**	0.922**
5. 1000-grain weight	0.300**	-0.087 ^{ns}	-0.284**	0.717**	1	0.634**
6. Yield	0.232**	0.431**	0.518**	0.885**	0.544**	1

^{ns}, * and ** Non-significant, significant at 5% and 1% probability level, respectively

Simple correlation analysis: Yield is a complex character. Poehlman, (1994) described that yield depended on the number of grains/spike, average kernel weight and number of spikes/unit area. Whenever a new cultivar is released, breeders are always interested in studying the relationship between different components effecting its yield. The study of yield components is important in increasing yield in a successful breeding program (Chowdhry *et al.*, 1986).

To determine the relationship between grain yield and other traits, simple phenotypic correlation analysis was performed on both Iranian and Pakistani wheat landraces (Table 2). According to the results of phenotypic correlation analysis, in both wheat landraces, plant height, spike length, number of grains/spike, spike weight and 1000-grain weight showed highly significant positive correlation with grain yield, suggesting the usefulness of these parameters in selecting higher grain yield. It has previously been described in many studies that number of grains/spike have a positive impact on yield (Dogan, 2009; Aycicek & Yildirim, 2006). But, the value of correlation coefficient between plant height and spike length with grain yield is low, which may represent a lack of genetic correlation between the traits and thus reduce their biological importance. Despite the presence of a wide range of genetic diversity in wheat landraces, these positive correlations can be utilized to develop new varieties. Sourour *et al.* (2010) studied morphological characterization of thirty Tunisian bread wheat landraces and observed a positive correlation among plant height, 1000-grain weight and yield. Hannachi *et al.* (2013) has also reported positive and significant correlation with the number of grains/spike and a negative correlation with plant height and 1000-grain weight.

Stepwise regression analysis: Regression analysis is a method for evaluating the relationship among different quantitative traits. In this case, changes can be predicted using one variable (Farshadfar, 2004) and those traits that have significantly influenced yield changes can be analyzed (Mollasadeghi *et al.*, 2011). Ashmawy *et al.* (2010) used stepwise regression analysis and find out that number of spike/m², 1000-grain weight and number of grains/spike are the most significant factors affecting grain yield.

Stepwise regression analysis was used to decide most important traits that significantly contributed to grain yield variability. Variance inflation factor (VIF) was calculated to detect the presence of multicollinearity within independent traits. The value of VIF was less than 10 for all independent variables that indicate no colinearity within independent variables. The results of stepwise regression analysis for Pakistani wheat landraces showed that spike weight, spike length and 1000-grain weight have higher F value entered into the model respectively and explain 80.3% of grain yield variation (Table 3). This shows that increase in the quantity of these traits would increase the yield of Pakistani landraces. Similarly, stepwise regression analysis for Iranian landraces showed different results where spike weight, 1000-grains weight and number of grains/spike entered in the model respectively and explained 96.1% of grain yield variation (Table 4). Afiuni & Mahlooji, (2006) studied the relationship among different traits and grain yield in saline conditions. Using stepwise regression analysis, it showed that grain yield, the number of grains/spike, number of spike/m² and plant height entered the model and is found to be most effective in yield. Tahmasebi *et al.* (2013) by using stepwise regression analysis observed that 1000-grain weight, plant height and number of spikes remained in the model. Soleymanifard *et al.* (2012) reported 75% variation in grain yield is due to number of spike/m², 1000-grain weight and plant height.

Table 3. Stepwise regression analysis for grain yield per plant and other investigated traits in Pakistani wheat landraces.

Step	Traits	A	b ₁	b ₂	b ₃	Adjusted R ²	P-value
1.	Spike weight	0.465**	0.888**	-	-	0.782	<0.001
2.	Spike length	-0.069 ^{ns}	0.839**	0.075**	-	0.799	<0.001
3.	1000-grainweight	0.194 ^{ns}	0.944**	0.050*	-0.008*	0.803	<0.001

$$Y = 0.194 + 0.944X_1 + 0.050X_2 - 0.008X_3$$

^{ns}, * and ** Non-significant, significant at 5% and 1% probability level, respectively

Table 4. Stepwise regression analysis for grain yield per plant and other investigated traits in Iranian wheat landraces.

Step	Traits	A	b ₁	b ₂	b ₃	Adjusted R ²	P-value
1.	Spike weight	-0.129 ^{ns}	1.284**	-	-	0.849	<0.001
2.	1000-grainweight	-0.617**	1.143**	0.021**	-	0.872	<0.001
3.	No. of grain per spike	-1.957**	0.258**	0.058**	0.052**	0.961	<0.001

$$Y = -1.194 + 0.258X_1 + 0.058X_2 - 0.052X_3$$

^{ns}, * and ** Non-significant, significant at 5% and 1% probability level, respectively

Table 5. Phenotypic path coefficient analysis for grain yield per plant in Pakistanis wheat landraces.

Traits	Correlation coefficients	Direct effect	Indirect effect via				
			1	2	3	4	5
Plant height	0.232	0.050	-	0.009	-0.014	0.151	0.034
Spike length	0.431	0.091	0.005	-	0.115	0.229	-0.011
No. of grain per spike	0.518	0.204	-0.004	0.051	-	0.298	-0.033
Spike weight	0.885	0.667	0.011	0.031	0.091	-	0.083
1000-grainweight	0.544	0.116	0.015	-0.008	-0.059	0.478	-

Residual=0.434

Path coefficient analysis: Grain yield may be directly or indirectly affected by yield components. It was, therefore, necessary to determine their effects on grain yield. For this purpose path coefficient analysis is commonly used. It can offer a mean to measure the interrelated components of yield and can specify whether they have a direct impact on yield or the effect produced is caused by some other pathways (Khaliq *et al.*, 2004). Various plant breeders have used this analysis to detect traits that provide a valued selection criteria for improving crop yield (Dewey & Lu, 1959; Milligan *et al.*, 1990; Ahmed *et al.*, 2003; Del Moral *et al.*, 2003; Khaliq *et al.*, 2004).

The results of path coefficient analysis using yield components, including plant height, spike length, number of grains/spike, spike weight and 1000-grain weight, were considered as independent variables and grain yield as the dependent variable in both Iranian and Pakistani wheat landraces are presented in Tables 5 and 6, respectively. Based on Path analysis for Iranian wheat landraces, the highest positive direct effect on grain yield was observed by the number of grains/spike (+0.612) and 1000-grain weight (+0.506) and the highest indirect positive effect on grain yield was detected for spike weight (+0.462) via the number of grains/spike. Similarly Aycicek & Yildirim (2006) observed that the number of grains/spike had a direct and positive effect on yield along with grain weight/spike which was also having a positive influence on grain yield. A positive correlation among number of grain/spike, 1000-grain weight, grain weight/spike and grain yield was witnessed by Dogan (2009) in durum wheat.

In case of Pakistani wheat landraces, spike weight (+0.667) was having highly positive direct effect on grain yield. Whereas 1000-grain weight (+0.478) via a spike weight had a highest indirect positive effect on grain yield. On the other hand, the lowest direct and indirect

effects were obtained for plant height and spike length. Similarly a positive direct effect between spike weight and grain yield was pointed in many early studies (Hohan *et al.*, 1993; Moghaddam *et al.*, 1998; Ismail, 2003).

Therefore, based on the results of path coefficient analysis for both Iranian and Pakistani wheat landraces, it can be concluded that traits like 1000-grain weight, number of grains/spike and spike weight are most effective in increasing wheat yield in these landraces .

Cluster analysis: For the effective utilization of germplasm, it remains essential to explore the magnitude of available germplasm diversity. For studying genetic diversity and cultivar development, morphological traits have been successfully used. As morphological traits offer a simple way of studying genetic variation (Fufa *et al.*, 2005). Studying genetic diversity in different germplasms can help in the classification and identification of genotypes that can be used for explicit breeding goal (Mohammadi & Prasanna, 2003). Through cluster analysis genotypes are divided into clusters which have increased similarity within clusters and higher heterogeneity between two different clusters (Jaynes *et al.*, 2003). Soleymanifard *et al.* (2012) used cluster analysis for studying agronomical traits of durum wheat genotypes under drought stress to classify genotypes under study into three groups.

In order to group the Iranian and Pakistani wheat landraces, hierarchical cluster analysis based on Ward's method and standardized variables was performed, based on investigating traits separately. Cluster analysis divided 202 Pakistani landraces into four clusters (Table 7). One-way multivariate analysis of variance (MANOVA) confirmed that each variable was differentiated by the cluster analysis (Pillai's Trace= 1.307, $p < 0.001$; Wilks' Lambda= 0.127, $p < 0.001$; Hotelling's Trace= 3.794,

$p < 0.001$; Roy's Largest Root = 2.855, $p < 0.001$). Univariate analysis of variances also demonstrates significant differences (all $p < 0.001$). The first cluster consists of 55 genotypes. In the second cluster, 49 genotypes are present which is characterized by increased spike length, number of grains/spike, improved spike weight and greater grain yield. In the third cluster, 58 genotypes are present with average traits. Fourth cluster has 40 genotypes with increased plant height and 1000-grain weight. Cluster analysis for Iranian wheat landraces (Table 8) classifies the genotypes into three clusters. Cluster grouping of Iranian wheat landraces also was confirmed using one-way multivariate analysis of variance (Pillai's Trace = 0.995, $p < 0.001$; Wilks' Lambda = 0.234, $p < 0.001$; Hotelling's

Trace = 2.297, $p < 0.001$; Roy's Largest Root = 1.732, $p < 0.001$). The first cluster consists of 72 genotypes with the lowest amount of investigating traits. The second cluster has 100 genotypes characterized by maximum plant height, spike length and thousand grain weight. The third cluster includes 20 genotypes with the highest grain yield, number of grains/spike and spike weight. The cluster analysis grouped landraces on the basis of their morphological similarities; landraces from the same geographical origin may not be included in the same cluster (Zubair *et al.*, 2007; Ahmad *et al.*, 2008; Ali *et al.*, 2008). Amurrio *et al.* (1995) and Rabbani *et al.* (1998) have also described the lack of relationship between agronomic traits and origin.

Table 6. Phenotypic path coefficient analysis for grain yield per plant in Iranian wheat landraces.

Traits	Correlation coefficients	Direct effect	Indirect effect via				
			1	2	3	4	5
Plant height	0.370	-0.027	-	0.001	0.174	0.074	0.145
Spike length	0.337	0.005	-0.010	-	0.166	0.067	0.107
No. of grain per spike	0.775	0.612	-0.008	0.001	-	0.143	0.024
Spike weight	0.922	0.189	-0.011	0.001	0.462	-	0.277
1000-grain weight	0.634	0.506	-0.008	0.001	0.030	0.104	-

Residual=0.192

Table 7. Mean comparison and standard deviation of clusters in Pakistanis wheat landraces.

Traits	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Average
No. of genotypes	55	49	58	40	202
Plant height	84.75 ^d ± 4.36	97.37 ^b ± 2.93	89.36 ^c ± 6.78	107.43 ^a ± 9.52	93.62 ± 10.27
Spike length	8.38 ^b ± 0.62	8.83 ^a ± 0.86	8.04 ^b ± 0.67	8.23 ^b ± 1.44	8.37 ± 0.94
No. of grain per spike	42.37 ^b ± 5.61	46.39 ^a ± 6.06	34.73 ^c ± 3.80	34.42 ^c ± 7.29	39.64 ± 7.60
Spike weight	1.58 ^c ± 0.37	2.15 ^a ± 0.44	1.79 ^b ± 0.53	1.92 ^b ± 0.49	1.84 ± 0.50
1000-grain weight	24.97 ^d ± 5.03	30.92 ^c ± 5.12	34.08 ^b ± 8.02	37.51 ^a ± 6.90	31.45 ± 7.85
Yield	1.88 ^c ± 0.43	2.48 ^a ± 0.48	1.98 ^{bc} ± 0.44	2.14 ^b ± 0.47	2.09 ± 0.52

Table 8. Mean comparison and standard deviation of clusters in Iranian wheat landraces.

Traits	Cluster 1	Cluster 2	Cluster 3	Average
No. of genotypes	72	100	20	192
Plant height	100.74 ^c ± 9.19	120.98 ^a ± 6.92	110.44 ^b ± 4.80	112.29 ± 12.19
Spike length	10.05 ^b ± 1.42	10.95 ^a ± 1.30	10.58 ^{ab} ± 1.18	10.57 ± 1.40
No. of grain per spike	28.60 ^c ± 7.63	33.12 ^b ± 6.85	47.38 ^a ± 7.06	32.91 ± 8.94
Spike weight	1.62 ^c ± 0.50	2.04 ^b ± 0.47	2.52 ^a ± 0.45	1.93 ± 0.55
1000-grain weight	32.86 ^b ± 6.26	37.82 ^a ± 6.01	34.89 ^b ± 7.23	35.65 ± 6.63
Yield	1.90 ^c ± 0.66	2.49 ^b ± 0.67	3.25 ^a ± 0.55	2.35 ± 0.77

Factor analysis: Factor analysis is helpful in decreasing the volume of data to get the data indicating primary variables with high correlation among them (Cooper, 1983). This method was found effective in identifying the relationship and the structure of yield components in cultivated plants (Bramel *et al.*, 1984) and wheat (Walton, 1971). Factors with eigen value higher than 1 are selected for performing loading factor matrix. After extracting main factors, a varimax orthogonal rotation is used to make the matrix of factor loading, and then the variance of uncorrelated variables is computed by the highest correlation coefficient in each array. But before factor analysis, two indices, including Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity are calculated to determine the suitability of

data for factor analysis. The values of KMO are more than 0.6 and Bartlett's test of sphericity are highly significant for both Iranian and Pakistani landraces, which indicates a sufficient correlation among the variables. So it can be concluded the data is suitable for factor analysis. In order to validate data, the genotypes are divided into two random parts and factor analysis is performed for each part separately. Based on the result of factor analysis for Pakistani landraces, the first two factors explain 47.93% and 24.41% of total variation, respectively (Table 9). The first factor includes spike length, spike weight, 1000-grains weight and yield which can be called grain yield factor. The second factor includes plant height with positive loading sign and the number of grains per spike with a negative loading sign which indicates a negative

relation between plant height and number of grains/spike. The dispersion of 202 Pakistani wheat landraces (in four clusters) is shown based on the first and second factors in Fig. 1. The scattered landraces of the first cluster are on the left of the first factor axis with the lowest value of spike weight, 1000-grain weight and grain yield. Whereas most of landraces from the second and fourth cluster are placed on the right of the first factor axis and show higher of spike weight, 1000-grains weight and grain yield. Yildirim *et al.* (1996) also mentioned spike's length as a second factor, whereas plant height was revealed as the fourth factor by Golparvar *et al.*, 2002.

Similarly, according to factor analysis for Iranian wheat landraces, the first two factors have the eigen value higher than 1 which are selected as main factors (Table 10). The first factor explains 55.5% of total variation and includes number of grains/spike, spike weight and yield which can be named grain yield factor. A total variation

of 16.38% is explained in the second factor and includes plant height and 1000-grain weight with positive loading sign and spike length with a negative loading sign which indicates a positive relationship amongst plant height and 1000-grain weight and a negative relationship of plant height and 1000-grain weight with spike length. Based on the result of distribution of 192 Iranian wheat landraces on factor analysis biplot, landraces of the third cluster have higher value of grains/spike, spike weight and grain yield and are grouped on the right of the first factor (Fig. 2). The landraces of the first cluster is on the lower left and correspond to the lower value of grains/spike, spike weight and grain yield. The landraces in the second cluster are on top of the second factor and have higher value of plant height and 1000-grain weight. Therefore, in order to select genotypes with high grain yield for both Iranian and Pakistani wheat landraces, genotypes with high value of the first factor are valuable.

Table 9. Factor analysis using varimax rotation for Pakistanis wheat landraces.

Traits	First factor	Second factor	Communality
Plant height	0.014	<u>0.804</u>	0.646
Spike length	<u>0.517</u>	-0.063	0.271
No. of grain per spike	-0.092	<u>-0.927</u>	0.868
Spike weight	<u>0.805</u>	0.530	0.929
1000-grain weight	<u>0.944</u>	-0.157	0.916
Yield	<u>0.701</u>	-0.631	0.890
Eigenvalues	2.876	1.645	-
Cumulative of variance (%)	47.93	75.34	-

Table 10. Factor analysis using varimax rotation for Iranian wheat landraces.

Traits	First factor	Second factor	Communality
Plant height	0.164	<u>0.619</u>	0.410
Spike length	0.168	<u>-0.689</u>	0.503
No. of grain per spike	<u>0.961</u>	-0.011	0.923
Spike weight	<u>0.845</u>	0.448	0.915
1000-grain weight	0.175	<u>0.772</u>	0.626
Yield	<u>0.846</u>	0.470	0.936
Eigenvalues	3.330	1.101	-
Cumulative of variance (%)	55.50	71.88	-

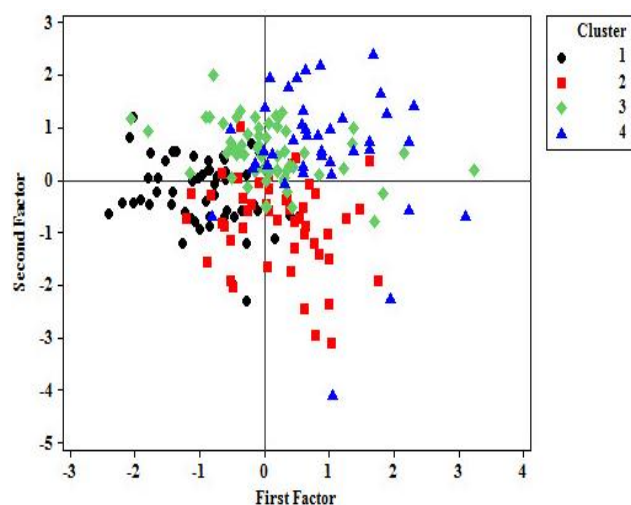


Fig. 1. Factor analysis of investigated traits based on four clusters of 202 Pakistani wheat landraces.

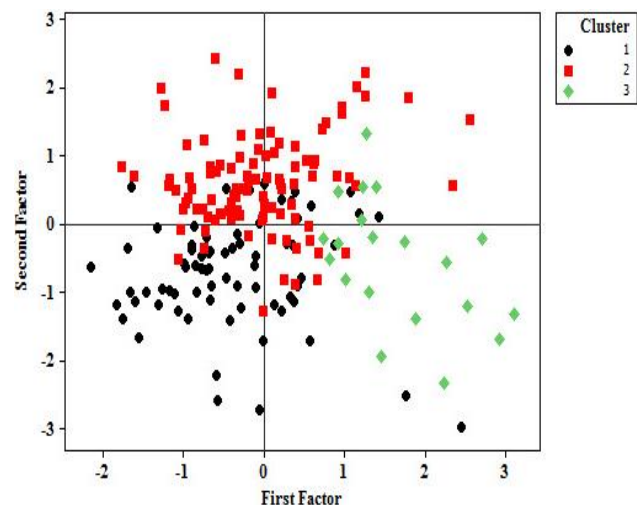


Fig. 2. Factor analysis of investigated traits based on three clusters of 192 Iranian wheat landraces.

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