Journal of AgriSearch 4(1):45-50
An Open Access International Peer Reviewed Quarterly
ISSN : 2348-8808 (Print), 2348-8867 (Online)
http://dx.doi.org/10.21921/jas.v4i1.7419

Diversity Analysis through Principle Component Analysis in Wheat (*Triticum aestivum*)

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ARTICLE INFO

Received on	:	27.01.2017
Accepted on	:	15.02.2017
Published online	:	01.03.2017

ABSTRACT

Wheat is agronomically and nutritionally most important cereal essential for the food security, poverty alleviation and improved livelihoods. Genetic diversity is necessary to be present in the base population from which potential parents are to be selected as diverse parent for hybridization. For this purpose, various multivariate analytical techniques, which simultaneously analyze multiple measurements on each individual under investigation, are widely used in analysis of genetic diversity. Among these, principal component analysis (PCA) is useful method used for diversity analysis. For the principal component analysis each genotype was identified on the basis of correlation matrix as a single point in a standardized multidimensional space. The axes of this space were principal components obtained from the original data as orthogonal transformation of the original variety. In this way each principal component becomes a linear combination of the varietal scores corresponding to the original variables.

Keywords: *Triticum aestivum*, germplasm, Eigen vector, Character

INTRODUCTION

Wheat is second most important cereal crop after rice of India and grown under diverse agro-climatic conditions (Meena *et al*., 2016). A major effort of a plant breeder is the constant improvement of the best available genotypes for further enhancement in their yield potential either directly or through improvement of various factors which contribute indirectly to high yield. The breeding methodology, therefore, should be such that it could incorporate the favorable changes either through selection or through hybridization of superior genotypes. The annual production of wheat in India during 2011-12 was 94.88 million tonnes (MT) (Sharma, 2013) unfortunately fall by 2.47 MT in 2012- 13. Wheat provides a large fraction of the dietary protein and total food supply, and is grown all throughout the world, in a wide variety of climates. The knowledge about nature and magnitude of genetic diversity is of prime importance for a systematic breeding programme. The presence of considerable genetic diversity in the base material causes better chance of evolving desirable plant types. Yield is a complex polygenic character and is resultant of interactions of several genetic and environmental factors hence it requires continuous improvement involving the diverse material. Principal component analysis suggested by Hotelling (1933) after its original concept given by Pearson (1901) and non-hierarchical Euclidean cluster analysis described by Beale (1969) was used for grouping the genotypes into different clusters.

MATERIALS AND METHODS

The present investigation was carried out at the G. B. Pant University of Agriculture and Technology, Pantnagar during Rabi season of 2009-10 and 2010-11. The experimental material comprised of 300 indigenous germplasm accessions of wheat along with 4 checks namely DBW 17, UP 2338, PBW 550 and C 306. The experiment was planted in Augmented Design. Each plot consisted of 2 rows measuring 2m long. A spacing of 30 cm (row to row) and 10 cm (plant to plant) was maintained. The Euclidean distance between any two points represents the degree of similarity or dissimilarly between the two varieties whose score on the principal axes determines their respective position in the hyperspace. The Euclidean distance is a Pythagorean distance extended to multiple axes and consists of difference in scores of any two varieties on each of the principal axes retained. If two varieties are closely related genetically, they are expected to occupy the same region in the hyperspace, the distance between them being small, if they are more distantly related or genetically diverse. For calculating Euclidean distances, the first few components in reduced dimension were used that accounted for sufficient variation.

Principal component are no scale invariant and the results depends on the units of measurements. To avoid such drawback of principal components, raw data was standardized in the following way:

$$x_{ij} = \frac{(x_{ij} - x_j)}{\sqrt{\sum_{i=1}^{n}(x_{ij} - x_j)^2}}$$

Where, ij is the observation on ith genotypes for character 'j'.

The first step in the procedure was to compute successive powers of the correlation matrix. Starting with R, the values of $RR = R^2$, $R^2R^2 = R^4$, $R^4R^4 = R^8$ and so on, were computed until the element of the vector a' R^i and a' R^{2i} become proportional to each other. The vector a' can be any arbitrary vector and when a' R^i is proportional to a' R^{2i} is proportional to the largest latent vector of eigen vector. For more rapid

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convergence, it was best to have the elements by a' proportional to the row total of the correlation matrix.

$R = (r_{ij})$

$R^2 = (r_{ij})(r_{ij})$

$a'R^2 = (a')(R^2)$

$= (a_1, a_2, \ldots\ldots a_p)$

Where,

p = number of elements in the vector = number of variables

Now this vector can be standardized by dividing each element by the largest elements of the vector, say, a_i:

$$= \left[\frac{a_1}{a_1}, \frac{a_2}{a_2}, ---------\frac{a_p}{a_i}\right]$$

$= [a_1s', a_2s' ------------- a_ps]$

Where, subscript s in all the elements represents standardization. Next step was to compute $R^4 = R^2R^2$

$a'R^4 = (a')(R^4)$

$= (b_1, b_2 \ldots\ldots\ldots b_p)$

$$= \left[\frac{b_1}{b_1}, \frac{b_2}{b_2}, ---------\frac{b_p}{b_i}\right]$$

Standardized vector:

$b = [b_1s', b_2s' \ldots\ldots\ldots b_ps]$

Where,

a and b = Vector of coefficient

Next step was to compare this vector with the previous one for their agreement with each other. If they agree with each other upto third decimal place, next order of power is not computed, otherwise, next and successive order of power is computed until two successive vectors showed close agreement with each other.

The classificatory analysis gave clusters of genotypes where similar types occur in one cluster. The solution provides classified genotypes. The cluster mean were graphically depicted in the form of bar diagram. Principal component analyses help researchers to distinguish significant relationship between traits. This is a multivariate analysis method that aims to explain the correlation between a large set of variables in terms of a small number of underlying independent factors (Beheshtizadeh *et al.*, 2013). For finding the regularities, multidimensional analyses are used, one of which is principal component analysis (PCA). PCA makes it possible to transform a given set of traits, which are correlated, into a new system of traits, known as principal components, which are not correlated (Janmohammadi *et al.*, 2014).

RESULTS AND DISCUSSION

Diversity and variability in yield attributing traits

Major yield attributing traits viz., Days to flowering, Days to maturity, Plant height (cm), Spike length (cm.), No. of spikelets per spike, Number of grains per spike, Grains weight per spike (g), Number of tillers per meter, Biological yield per m^2 (g), Harvest index and Grain yield/plot depicted in the Table 1 and Table 2 for the year 2009-10 and 20101-11. Data represented in Table 1 and Table 2 revealed that very good amount of variability exists in the materials/ germplasm under test. Every parameter under test shows good amount of diversity and variability as well.

Table 1: Yield attributing traits wheat germplasm accessions during 2009-10

Characters	Range		Mean
	Minimum	Maximum	
Days to flowering	70	105	87.5
Days to maturity	110	166	138
Plant height (cm)	75	143	109
Spike length (cm.)	6	13	9.5
No. of spikelets per spike	9	27	18
Number of grains per spike	19	87	53
Grains weight per spike (g)	0.13	2.9	1.5
1000 Grain weight	11	58	34
Number of tillers per meter	35	140	87.5
Biological yield per m^2(g)	400	1800	1100
Harvest index	8	84	45
Grain yield/plot	120	900	510

Table 2: Yield attributing traits wheat germplasm accessions during 2010 -11

Characters	Range		Mean
	Minimum	Maximum	
Days to flowering	69	100	84.5
Days to maturity	111	164	137.5
Plant height (cm)	70	144	107
Spike length (cm.)	6	14	10
No. of spikelets per spike	10	28	19
Number of grains per spike	18	86	52
Grains weight per spike (g)	1	3	1.9
1000 Grain weight	19	59	39
Number of tillers per meter	30	140	85
Biological yield per m^2(g)	300	1900	1100
Harvest index	7	100	53.5
Grain yield/plot	100	800	450

Principal Component Analysis

The principal component analysis of 300 wheat accessions based on correlation matrix of yield and yield attributing traits yielded the eigen roots (eigen values) and eigenvectors.

These values and associated percentage of variation explained by eigen root. The principal component had the largest eigen root 2.003 followed by 1.952, 1.531, 1.410, 1.251, 1.096, 0.953, 0.749, 0.603, 0.391, 0.036 and 0.024 from second to twelve principal components, respectively in the year 2009-10. Similarly in the year 2010-11 had the largest eigen root was 2.208 followed by 1.848, 1.541, 1.427, 1.206, 1.026, 0.778, 0.716, 0.551, 0.536, 0.116 and 0.049 from second to twelve principal components, respectively.

The eigen root of first principal component accounted for 16.69 per cent of total variation followed by second to twelve principal components which accounted for 16.27, 12.76, 11.75, 10.43, 9.14, 7.94, 6.24, 5.03, 3.26, 0.30 and 0.20 per cent of total variations present in the genotypes, respectively. The per cent of variation explained by 11th and 12th components were small. First eight principal components accounted for 95.15 per cent variation of the original data in the year 2009-10. The eigen root of first principal component accounted for 18.40 per cent of the total variation followed by second to twelve principal components which accounted for 15.40, 12.84, 11.89, 10.05, 8.55, 6.48, 5.96, 4.59, 4.46, 0.97 and 0.41 per cent of total variations present in the genotypes, respectively. The per cent of variation explained by 11th and 12th components were small like in the year 2009-10 (Table 3). The eigenvector of twelve principal components have been scaled in such a way that the largest element in each vector is unity. These were interpreted as relative weight of the variables in each component. The important variables are those which have high positive/negative relative weight values.

Table 3: Eigen vector, eigen root and associated variation for principal components in wheat germplasm accessions for various yield attributing traits in the year 2009-10.

Characters	Eigen vector											
	1	2	3	4	5	6	7	8	9	10	11	12
Days to flowering	0.41	-0.019	0.415	-0.153	0.153	-0.485	-0.542	-0.199	0.074	0.074	0.106	0.130
Days to maturity	-0.09	-0.099	0.197	-0.076	-0.001	0.011	0.255	0.299	0.281	-0.140	0.616	0.552
Plant height (cm)	0.27	0.116	0.439	-0.010	-0.152	-0.166	0.352	0.610	-0.109	0.241	-0.285	-0.146
Spike length (cm.)	0.40	0.388	0.131	0.130	0.594	0.346	0.190	-0.076	-0.085	-0.312	0.128	-0.119
No. of spikelets per spike	0.13	0.334	-0.058	-0.106	-0.064	0.314	0.042	-0.234	-0.136	0.682	-0.025	0.460
Number of grains per spike	-0.09	0.312	0.017	0.785	-0.049	-0.148	-0.090	0.110	0.474	0.133	-0.042	0.026
Grains weight per spike (g)	-0.10	0.522	-0.123	0.107	-0.306	-0.276	-0.140	0.105	-0.590	-0.261	0.254	0.099
1000 Grain weight	0.03	-0.484	-0.169	0.445	0.413	-0.157	0.013	0.155	-0.478	0.214	0.042	0.207
Number of tillers per meter	0.41	-0.333	0.236	0.331	-0.560	0.322	0.046	-0.271	-0.149	-0.167	0.115	-0.004
Biological yield per m^2 (g)	-0.60	0.001	0.689	0.081	0.128	0.154	-0.030	-0.217	-0.233	0.004	-0.089	0.008
Harvest index	0.04	0.002	-0.016	0.013	0.001	0.246	-0.333	0.272	0.029	-0.383	-0.565	0.535
Grain yield/plot	0.04	0.016	-0.019	-0.015	0.006	-0.456	0.581	-0.457	0.008	-0.218	-0.322	0.304
Eigen root	2.00	1.952	1.531	1.410	1.251	1.096	0.953	0.749	0.603	0.391	0.036	0.024
Percent variation	16.6	16.27	12.76	11.75	10.43	9.14	7.94	6.24	5.03	3.26	0.30	0.20

The first principal component had the highest positive weight to days to flowering (0.416) followed by number of tillers per meter (0.410) and 1000 grain weight (0.408) and the high negative weight for biological yield per m^2 (-0.607g) followed by grains weight per spike (-0.100g) and days to maturity (-0.095) in the year 2009-10 where as 2010-11 it had the highest positive weight to biological yield per m^2 (0.409g) followed by plant height (0.348) and days to maturity (0.227) and had high negative weight to number of tillers per meter (-0.549) followed by spike length (-0.454 cm) and 1000 grain weight (-0.243) (Table 4).

The second principal component had the highest positive weight for grain weight per spike (0.522) followed by spike length (0.388) and number of spikelets per spike (0.334) while the highest negative weight for 1000 grain weight (-0.484) followed by number of tillers per meter (-0.333) and days to maturity (-0.099) in the year 2009-10. Where as it had the highest positive weight for number for spikelets per spike (0.421) followed by days to flowering (0.282) and number of tillers per meter (0.147), and the highest negative weight for grain weight per spike (-0.805) followed by spike length (-0.214) and days to maturity (-0.069) in the year 2010-11.

The third principal component exhibited the highest positive weight for biological yield per m^2 (0.689) followed by plant height (0.439) and days to flowering (0.415) while the highest negative weight was for 1000 grain weight (-0.169) followed by grain weight per spike (-0.123) and number of spikelets per spike (-0.058) in the year 2009-10. In the year 2010-11 the third principal component had the highest positive weight for plant height (0.543) followed by number of grain per spike (0.424)

Table 4: Eigen vector, eigen root and associated variation for principal components in wheat germplasm accessions for various yield attributing traits in the year 2010-11.

Characters	Eigen vector											
	1	2	3	4	5	6	7	8	9	10	11	12
Days to flowering	0.17	0.28	-0.18	0.40	0.35	0.19	0.14	0.01	-0.36	-0.06	-0.41	-0.44
Days to maturity	0.22	-0.06	0.05	-0.15	-0.09	-0.32	-0.64	-0.49	-0.08	0.18	-0.27	-0.19
Plant height (cm)	0.34	0.03	0.54	0.11	-0.03	-0.24	0.17	0.39	0.08	0.48	-0.26	0.08
Spike length (cm.)	-0.45	-0.21	-0.07	-0.21	-0.47	0.23	0.17	-0.01	-0.03	0.29	-0.47	-0.26
No. of spikelets per spike	0.11	0.42	0.004	-0.11	0.06	0.54	0.04	-0.39	0.01	0.44	0.04	0.37
Number of grains per spike	0.17	0.13	0.42	-0.33	0.08	0.29	0.07	-0.10	0.49	-0.36	-0.05	-0.42
Grains weight per spike (g)	0.13	-0.80	0.08	0.07	0.41	0.28	0.12	-0.17	-0.02	0.10	-0.01	0.07
1000 Grain weight	-0.24	0.03	-0.24	0.45	0.17	-0.10	-0.09	-0.08	0.74	0.18	-0.15	0.01
Number of tillers per meter	-0.54	0.14	0.17	-0.37	0.64	-0.14	-0.09	0.17	-0.11	0.12	-0.07	0.03
Biological yield per m_2 (g)	0.40	-0.02	-0.61	-0.51	0.14	-0.08	0.11	0.27	0.18	0.16	-0.07	-0.04
Harvest index	0.03	-0.05	-0.02	0.07	-0.05	0.49	-0.66	0.53	0.01	-0.05	-0.09	0.09
Grain yield/plot	-0.04	-0.01	0.01	0.07	-0.02	0.07	-0.09	0.07	-0.02	0.47	0.63	-0.58
Eigen root	2.20	1.84	1.54	1.42	1.20	1.02	0.77	0.71	0.55	0.53	0.11	0.04
Percent variation	18.4	15.4	12.8	11.8	10.0	8.5	6.48	5.96	4.59	4.46	0.97	0.41

and number of tillers per meter (0.171) while the highest negative weight for biological yield per m^2 (-0.619) followed by 1000 grain weight (-0.249) and days to flowering (-0.185).

The fourth principal component exhibited the highest positive weight for number of grains per spike (0.785) followed by 1000 grain weight (0.445) and number of tillers per meter (0.331), and the Highest negative weight was exhibited for days to flowering (-0.153) followed by number of spikelets per spike (-0.106) and days to maturity (-0.076) in the year 2009-10. In the year 2010-11 the fourth principal component exhibited the highest positive weight for 1000 grain weight (0.455) followed by days to flowering (0.408) and plant height (0.115). The highest negative weight was exhibited for biological yield per m^2 (-0.513) followed by number of tillers per meter (-0.373) and number of grains per spike (-0.332).

The fifth principal component exhibited the highest positive weight for spike length (0.594) followed by 1000 grain weight (0.413) and days to flowering (0.153) while the highest negative weight for number of tillers per meter (-0.560) followed by grain weight per spike (-0.306) and plant height (-0.152) in the year 2009-10. In the year 2010-11, the fifth principal component exhibited the highest positive weight for number of tillers per meter (0.643) followed by grain weight per spike (0.417) and days to flowering (0.350) while the highest negative weight for spike length (-0.472) followed by harvest index (-0.050) and plant height (-0.038). The sixth principal component had the highest positive weight for spike length (0.346) closely followed by number of tillers per meter (0.322) and number of spikelets per spike (0.314) while the highest negative weight for days to flowering (-0.485) and by grain yield (-0.456) the year 2009-10. In the year 2010-11, the sixth principal component had the highest positive weight for number of spikelets per spike (0.540) followed by harvest index (0.490) and number of grains per spike (0.295), and the highest negative weight was exhibited for days to maturity (-0.323) followed by plant height (-0.242).

The seventh principal component had the highest positive weight for grain Yield (0.581) followed by plant height (0.352) and days to maturity (0.255), and the highest negative weight was observed for days to flowering (-0.542) followed by harvest index (-0.333) and grain weight per spike (-0.140) in the year 2009-10. In the year 2010-11 the seventh principal component had the highest positive weight for plant height (0.179) followed by spike length (0.178) and days to flowering (0.145) while the highest negative weight was for harvest index (-0.661) followed by days to maturity (-0.645) and number of tillers per meter (-0.094).

The eighth principal component exhibited the highest positive weight for plant height (cm) (0.610) followed by days to maturity (0.299) and the highest negative weight for yield (-0.457) followed by number of tillers per meter (-0.271) and biological yield per m^2 (-0.217) in the year 2009-10. This has exhibited the highest positive weight for harvest index (0.539) followed by plant height (0.392) and the highest negative weight for days to maturity, yield (-0.490) followed by number of spikelets per spike (-0.396) and Grain weight per Spike (-0.177) in the year 2010-11.

The ninth principal component had the highest positive weight for number of grains per spike (0.474) followed by days to maturity (0.281) and days to flowering (0.074) while the highest negative weight for grains weight per spike (-0.590) followed by 1000 grain weight (-0.478) and biological yield per m^2 (-0.233) in the year 2009-10 where as it had the highest positive weight for 1000 Grain Weight (746) followed by number of grains per spike (0.493) and biological yield per m^2 (0.186) while the highest negative weight for days to flowering (-0.368) followed by number of tillers per meter (-0.113) and days to maturity (-0.085) in the year 2010-11.

The tenth principal component exhibited the highest positive weight for number of spikelets per spike (0.682) followed by 1000 grain weight (214) and number of grains per spike (0.133) while the highest negative weight for harvest index (-0.383) followed by spike length (-0.312) and grain weight per spike (-0.261) in the year 2009-10 where as it had the highest positive weight for plant height (0.489) followed by grain yield (0.470) and number of spikelets per spike (0.446) while the highest negative weight for number of grains per spike (-0.362) followed by days to flowering (-0.060) and harvest index (-0.052) in the year 2010-11.

The eleventh principal component had the highest positive weight for days to maturity (0.616) followed by grains weight per spike (0.254) and the highest negative weight for harvest index (-0.565) followed by grain yield (-0.322) in the year 2009-10 where as it had the highest positive weight for grain yield 0.637 followed by number of spikelets per spike (0.048) and had the highest negative weight for spike length (-0.476) followed by days to flowering (-0.412) in the year 2010-11.

The twelfth principal component had the highest positive weight for days to flowering (0.552) followed by harvest index (0.535) and the highest negative weight for plant height (-0.146) followed by spike length (-0.119) in the year 2009-10 where as it had the highest positive weight for number of spikelets per spike (0.379) followed by harvest index (0.099), and the highest negative weight for yield (-0.588) followed by days to flowering (-0.447) in the year 2010-11. Fig. 1 explains the Variation through Cattel's Screen Graph for yield contributing traits in wheat accessions during 2009-2010.

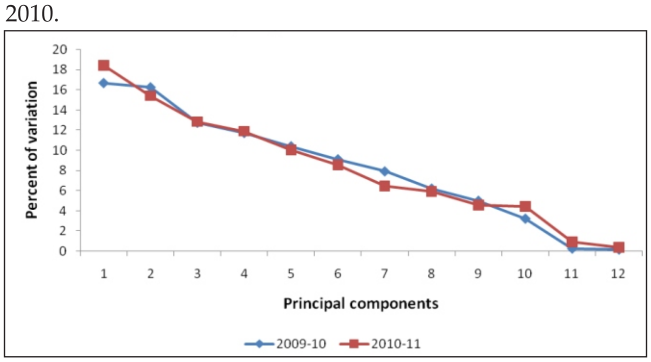

Fig.1 Cattel's screen graph for variation explained by various principal components based on yield attributing traits in wheat accessions during year 2009-10 and 2010-11.

Where, 1 to 12 are the characters, 1 - Days to flowering, 2 - Days to maturity, 3 - Plant height, 4 - Spike length, 5 – No. of spikelets per spike, 6 – No. of Grains per spike, 7 - Grains weight per spike, 8 - 1000 Grain weight, 9 – No. of tillers per meter, 10 - Biological yield per m^2, 11 - Harvest index and 12 - Yield per plot.

The principal component analysis was done on correlation matrix of important economic traits. First vector explained 95.15 per cent variation. All these vectors were utilized for ordination. The maximum variation of 16.69 per cent was explained by first latent vector followed by 16.27 per cent (second vector) and 12.76 per cent (third vector). The variation per cent of twelve principal components in the year 2009-10 where as year 2010-11 the maximum variation of 18.40 per cent was explained by first latent vector followed by 15.40 per cent (second vector) and 12.84 per cent (third vector). Kaiser *et al.* (1958) suggested that only first three principal components be used because of other component eigen root have more than unity but in the present investigation first three components accounted only for 57.80 per cent of total variation.

According to Pankovic *et al.* (1997) the spike length, grains/spike and 1000-grain weight and measured yield parameters were analyzed by the principal component analysis (PCA) and cluster analysis, and phenotypic distances between cultivated wheat and related wild species were found highly significant differences between wild wheat species.

The approach of Rao (1964) based on covering 90 per cent of total variation seems to be more useful and has been adopted now-a-days. The similar approach earmarking distant genotypes have been emphasized by several workers viz., in case of wheat by Gao and Zhang (1989) and He (1991), and in sugarcane by Li and Wang (1991). The scales per corresponding eigenvector for principal component taking the largest element in each vector as unity. These elements may be interpreted as the relative weight given to the variables in each component and important variables are those which possess high positive and high negative weight Jeffers (1967).

One of the important approaches to wheat breeding is hybridization and subsequent selection (Das *et al*., 2014). The cluster analysis showed that there is significant genetic variability among tested wheat genotypes that indicates the presence of excellent opportunity to bring about improvement through hybridizing genotypes from different clusters (Mishra *et al*., 2015).

CONCLUSION

It was concluded from the principal component analysis that important variables in different wheat accessions with respect to agronomic traits were days to flowering, days to maturity, plant height, spike length, number of spikelets per spike, number of grains per spike, grain weight per spike, 1000 grain weight, number of tillers per meter, biological yield per m^2, harvest index and yield, the above variables might be taken into consideration for effective selection of parents during hybridization program.

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Citation:

Singh P, Singh N K, Singh HK and Jaiswal JP. 2017. Diversity analysis through principle component analysis in wheat (*Triticum aestivum*). *Journal of AgriSearch* **4**(1): 45-50