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COMPARISON OF SAFETY- FIRST RULE AND CLUSTER ANALYSIS FOR EVALUATING WHEAT GENOTYPES WITH SIGNIFICANT GENOTYPE-ENVIRONMENT INTERACTION

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For genotype's performance across diverse environments, where genotype x environment (GE) interaction occurs, a selection criterion that takes GE interaction into consideration does not exist. However, an output obtained by using proper methods help the breeder to asses which genotypes are more stable. Twenty selected genotypes of spring wheat were evaluated across thirty one different locations in Pakistan for stability parameter of grain yield. GE interaction was highly significant that indicated the influence of environments on grain yield. On the basis of Safety – First Rules proposed by Kent, M.E (5), genotypes such as V-97046, 97B2210 V-98059 and V-97052 were found as stable genotypes with respect to wheat yield (T.ha^{-1}). Moreover, the genotypes performing similar response pattern over the environments and the environments over all genotypes were grouped by using, Ward's fusion strategy of hierarchical classifying technique (cluster analysis) on wheat GE interaction data.
Keywords: *Triticum aestrivum* L., safety-first rule, hierarchical classification, Dendrogram and GE

INTRODUCTION

Pakistan has attained self sufficiency in wheat production and is ready to enter the export market where she will have to compete with long established wheat exporters. Wheat is mainly produced in Punjab, Khan, *et al.* (2002) and secondly in Sindh Provinces under varied agro-climatic conditions that are known to affect the yield. Wheat is the main staple food of the country's population and largest grain crop of the country. It contributes 12.5 percent to the value added in agriculture and 3.1 percent to GDP (2005).

GE interaction is a known factor in cultivar evaluations. Because most genotypes respond in some manner to different environments, a problem arises for the evaluator; which genotype should I select given that some are better in some locations, Rasul et.al.(2005). One way to look at this is through stability analysis that assess which genotypes are more stable and could grown for wider adaptability.

Bonny and Michael (1985) used the methods of regression and genotype grouping (clustering) to evaluate yield stability in segregating populations of cowpea, and showed that these two methods identified the same lines and bulks as stable. But the genotype grouping method would be most useful when a large number of genotypes are evaluated.

Lins, Binns and Lefkovitch (1986) compared nine stability statistics and nine similarity measures and reported three concepts of stability. A genotype may be considered to be stable (i) if its among environment variance is small, (ii) if its response to environments is parallel to the mean response of all genotypes in the trial, and (iii) if the residual mean square from a regression on the environmental index is small. Unfortunately these concepts represent different aspects of stability and do not always provide a complete picture of the response.

Kent (1990) concluded that safety-first rule can be useful to plant breeders when genotypes × environment interaction is large and poor yield has severely adverse consequences. He also reported that safety-first approach is based on the reasonable assumption that the plant breeder is primarily concerned with avoiding disaster by choosing the cultivars, which have little chance of producing poor yields. Also, the safety-first index has intuitive appeal in that it is simply a lower confidence bound. In addition, a safety-first index explicitly weighs the importance of stability relative to yield.

Clustering is an unsupervised learning problem which aims at extracting hidden structure in a data set. Cluster analysis is an important tool for investigating and interpreting data. Sneath and Sokal (1973) described that cluster analysis or numerical classification is one technique used to simplify the data set by grouping individuals with similar responses for all attributes. In the case of genotype × environment tables of yields, clustering is used to simplify the data set by grouping the genotypes over all environments.

Byth *et al.* (1976) reported that clustering is used to simplify the data set by grouping the genotypes over all environments with similar response patterns for all yields, then grouping the environments over all genotypes with similar response patterns for yield.

William (1976) suggests an agglomerative hierarchical technique, which requires a measure of association among the individuals and a fusion strategy. The fusion strategy is the algorithm used to determine which individual should join another individual to form a new cluster using the chosen proximity.

Kroonenberg (1995) described a method for the calculation of a coordinate representing each genotype and each environment, which help to draw biplots. Biplots are used to represent the information contained in genotype × environment tables in a two or three-dimensional graph.

Cornelius and Crossa (1999), studied a cross-validation involving five multi-environment cultivar trials, found that shrinkage estimates of multiplicative models were usually more accurate for predicting the response of cultivars within sites that were best truncated multiplicative models fitted by least squares, best linear unbiased predictors (BLUPs) based on a two-way random effects model with interaction and the empirical cell means. The shrinkage estimates of multiplicative models were better predictors than BLUPs and empirical cell means.

Yan *et al.* (2000) presented standard biplots of the sites regression (SREG) model that helped to enhance its interpretation for selecting the best performing cultivars in subsets of sites. They proposed (i) connecting the markers of the farthest cultivars in the biplot such that they are the corners of an irregular polygon, and (ii) for each side of the polygon drawing a line segment perpendicular to that side and passing through the origin. These line segments subdivide the polygon into sectors involving different subsets of sites and cultivars. The cultivar that is at the polygon corner located in one sector is the best performer.

One important related question is estimating the true number of clusters in a data set so that clusters which arise due to random chance can be separated from those which represent 'true' clusters. The null hypothesis that is being tested here is that of no structure in the data. This is being tested here as that of no structure in the data. This is often referred to as a global hypothesis of clustering, Ben – Hur *et al.*(10).

MATERIAL AND METHODS

Twenty promising genotypes of spring wheat (Triticum aestivum L.) were evaluated through National Uniform Wheat Yield Trials (NUWYT), conducted by National Agricultural Research Centre (NARC), Islamabad. The experiment was conducted in thirty one locations of Pakistan for the year 2001-02. At each location, the trials were laid in Randomized Complete Block design (RCBD) with four replications and net plot size was 1.2 x 5 m^2.The crop was sown under normal sowing time (Nov.10-30). At maturity the crop was harvested and grain yield (kg/plot) recorded that was converted into (t/ha).

Using decision-theory concept known as safety-first rule to model such behaviour, an index incorporating mean yield and stability parameters was developed for each of four different definitions of stability Lin *et.al*., (1986). It was assumed that the plant breeder prefers a genotype with small probability of low yield (Kent, 1990).

Squared Euclidean distance is used as the measure of dissimilarity and the fusion strategy is incremental sum of squares (Ward's method). This method is usually implemented with loss of information taken to be an increase in an error sum of squares (ESS) criterion, i.e.

$$ESS = \sum_j (x_j - \bar{x})'(x_j - \bar{x})$$

Where x_j the multivariate measurement is associated with the jth item and $\bar{X}$ is the mean of all the items.

A graphics output of data in the form of dendrograms and performance plots were taken and also a measure of each environmental group's contribution to the fusion of two genotype groups and of each genotype's contribution of two environment groups was studied. When incremental sum of squares was selected as fusion strategy, contributions analysis gives information on the importance each environment group.

RESULTS AND DISCUSSION

Two-way Hierarchical ANOVA revealed that between genotype groups accounted for 98.58% and within genotype groups only 1.42% of the interaction variation, in analysis of variance for the partition of the sum of squares for the G x E model for the two-way grouping model between environment groups accounted for 57.35% and within environment groups is 42.65%. The genotype × environment groups accounted for high percentage that is 81% of the total interaction variation. This high percentage was then subject to stability analysis to assess the stable genotypes.

Safety-First Rule

Additionally the safety-first rule Kent (1990), the index values were calculated by using mean of genotypes over the environments and stability parameters defined by Lin *et al.* (1986). In parentheses ranking of each index by ascending order were given. Therefore by observing these index values it revealed that genotype 'V-97046' was ranked first based on the mean yield, SH and ER indices but second by EV & FW indices, followed by the genotype '97B2210' that was ranked first by EV & FW indices, second by SH & ER indices but third based on mean yield. Whereas the genotype 'V-7014' was ranked last by mean, SH and ER, but was ranked second last by EV & FW indices. Similarly the wheat genotype 'V-1076' was ranked last by FW, eighteenth by SH & ER indices and seventeenth based on mean yield but ranked third by EV index. This may have been due to the early maturity, which would lower yield but also produce smaller across-environment variance. The other genotypes 'V-98059', 'PR-74' and 'V-97052' were ranked better by mean yield, SH, ER & FW and also by EV except the last genotype that was at ninth level according to this index.

Where $\overline{Y_{ij}}$ = the observed mean of genotype i in environment j.

$$\overline{Y_{i.}} = \frac{\sum_j y_{ij}}{q}$$ (Mean over q environments, for genotype i.)

$$EV = \overline{Y_{i.}} - Z_{(1-\alpha)} S_i$$ (Variance across environments)

$$FW = \overline{Y_{i.}} - Z_{(1-\alpha)} \left[(b_i - 1)^2 S_{\bar{y}}^2 (1 - \frac{1}{q}) \right]^{\frac{1}{2}}$$

(Finlay & Wilkinson's Reg. Coefficient)

$$SH = \overline{Y_{i.}} - Z_{(1-\alpha)} \left[\sigma_E^2 + \sigma_i^2 \right]^{\frac{1}{2}}$$

(Shukla's stability variance)

Table 1. Safety-first selection indices and associated rankings (in parentheses) for twenty genotypes of wheat grown at thirty – one locations in Pakistan for seed yield

Entry	Genotypes	$\overline{Y_{i.}}$	EV	FW	SH	ER
1	V-7014	3.448 (20)	1.916 (19)	3.276 (19)	1.743 (20)	2.724 (20)
2	V-97046	4.100 (1)	2.362 (2)	3.963 (2)	2.499 (1)	3.645 (1)
3	97B2210	4.084(3)	2.479 (1)	4.064 (1)	2.463 (2)	3.568 (2)
4	92T009	3.804(11)	2.232 (7)	3.726 (10)	2.156 (11)	3.213 (10)
5	PR-75	3.519(19)	1.938 (18)	3.405 (18)	1.825 (19)	2.817 (19)
6	IBW-96405	3.768 (13)	2.194 (11)	3.692 (12)	2.120 (13)	3.178 (11)
7	V-98059	4.092 (2)	2.257 (5)	3.895 (6)	2.436 (3)	3.484 (3)
8	TD-1	3.737 (15)	1.903 (20)	3.532 (16)	2.093 (14)	3.159 (13)
9	V-1076	3.607 (17)	2.339 (3)	3.207 (20)	1.906 (18)	2.901 (18)
10	D-97603	3.932 (7)	1.997 (17)	3.712 (11)	2.178 (10)	3.108 (14)
11	V-5	3.773 (12)	2.083 (14)	3.732 (9)	2.124 (12)	3.178 (12)
12	V-8975	3.717 (16)	2.098 (13)	3.675 (13)	2.058 (15)	3.098 (15)
13	MAW-1	3.811 (10)	2.215 (10)	3.803 (8)	2.213 (9)	3.365 (6)
14	PR-74	3.948 (6)	2.303 (4)	3.930 (3)	2.285 (5)	3.320 (7)
15	97B2333	3.911 (8)	2.234 (6)	3.898 (5)	2.245 (8)	3.275 (8)
16	V-97052	4.022 (4)	2.224 (9)	3.857 (7)	2.379 (4)	3.444 (4)
17	SKD-1	3.882 (9)	2.057 (16)	3.665 (14)	2.261 (6)	3.369 (5)
18	SI 91195	3.755 (14)	2.194 (12)	3.609 (15)	2.047 (16)	3.023 (16)
19	91BT010-84	3.602 (18)	2.077 (15)	3.451 (17)	1.925 (17)	2.940 (17)
20	Local Check	3.954 (5)	2.225 (8)	3.924 (4)	2.249 (7)	3.228 (9)

$$ER = \overline{Y_{i.}} - Z_{(1-\alpha)}\left[(b_i - 1)^2 S^2_{\bar{y}}\,(1 - \frac{1}{q}) + \delta^2_i\right]^{\frac{1}{2}}$$

(Finlay and Wilkinson's Regression Coefficient and Eberhart & Russell's residual Mean Square)

$Z_{(1-\alpha)}$ = $(1 - \alpha)^{th}$ percentile of the standard normal distribution.

It was decided that acceptable probability (α) of having a disastrously low yield (say, a 1 in 20 chance or α= 0.05).

and $$S^2_{\bar{y}} = \frac{\sum_{j=1}^{q}\left(\overline{Y}_{.j} - \overline{\overline{Y}}_{..}\right)^2}{(q-1)}$$

$$\sigma^2_E = \frac{[MS(E) - MS(GE)]}{p}$$ (Variance of random effect of environments)

$$MS(E) = \frac{p\sum_{j=1}^{q}\left(\overline{Y}_{.j} - \overline{\overline{Y}}_{..}\right)^2}{(q-1)}$$ and

$$MS(GE) = \frac{SS(GE)}{(p-1)(q-1)}$$

After calculation of the above indices and ranking their values with respect to the yields of genotypes across environments (highest value ranked one) the genotypes having top ranks are declared as stable over the environments.

Table 2. Rank correlation between entry rankings from four selection indices

Indices	Mean	EV	FW	SH
EV	0.64			
FW	0.90	0.68		
SH	0.97	0.63	0.90	
ER	0.91	0.62	0.85	0.97

The rank correlation between mean and the index rankings (table 1) quantified how similarly the indices rank the genotypes. The FW, SH and ER indices all produced similar genotype rankings (rank corr. ≥ 0.90) highly correlated with mean. Similar ranking produced by FW and SH would be expected, since the both indices define stability to be type-2 Lin *et al.* (1986). Likewise, the ER index would be expected to produce ranking similar to FW and SH because the ER index also used a type-2 in addition to a type-3 measure of stability. The EV produced ranking (rank corr. ≤ 0.62) with other indices, since the EV index defined uses type-1 measure of stability. The mean ranking was correlated (rank corr. = 0.64) with EV ranking, which meant that EV index was affected by the across – environment variance in addition to mean yield. It meant that a smaller stability statistics in a safety-first index produced rankings closer to the mean ranking Kent, (1990). On the basis of above facts and the average rankings produced by the four indices of safety-first rule it was concluded that the genotypes namely 'V-97046', '97B2210', 'V-98059', and 'V-97052' were found stable as compared to the other genotypes across all the different agro-climatic locations of Pakistan for better wheat yield.

Cluster Analysis.

The data of genotype × environment table of yields, clustering was used to simplify the data set by grouping the genotypes over all environments, with similar response pattern of all yields. The method of hierarchical classification was used, which require a measure of association (proximity measure) among the individuals and a fusion strategy. The proximity measure provides a measure of the distance or closeness in multidimensional space.

The group membership of genotypes and environments are presented in Fig. 1 and Fig. 2 respectively. An effective choice of the genotype and environment levels allows the individual performance pattern of the members of any group to be characterized by the mean performance pattern of the group to which it belongs. This reduces the full data set to a smaller array without a large reduction in information. For this data set group levels (10, 15) were used for genotypes and environments as 81% was retained at these levels in two-way table of percentage of between genotype × between environment group sums of squares. The dendrogram resulting from cluster analysis of twenty wheat-promising genotypes was presented in Fig 1. Clearly ten groups of twenty genotypes at the fusion level 10 were formed. The performance of genotypes '97B2333' and 'D-97603' was as an individual. The genotypes 'V-97046' and 'V-97052' cluster at the minimum fusion level. In other words these genotypes had a maximum similarity between them. Also the genotypes 'V-98059' joined this cluster at the shortest distance that showed the maximum similarity at fusion level 3. When the allowable distance was increased '97B2210' was added to the above cluster mentioned. The genotypes

Fig. 1. Dendrogram illustrating ten clusters for twenty genotypes of wheat

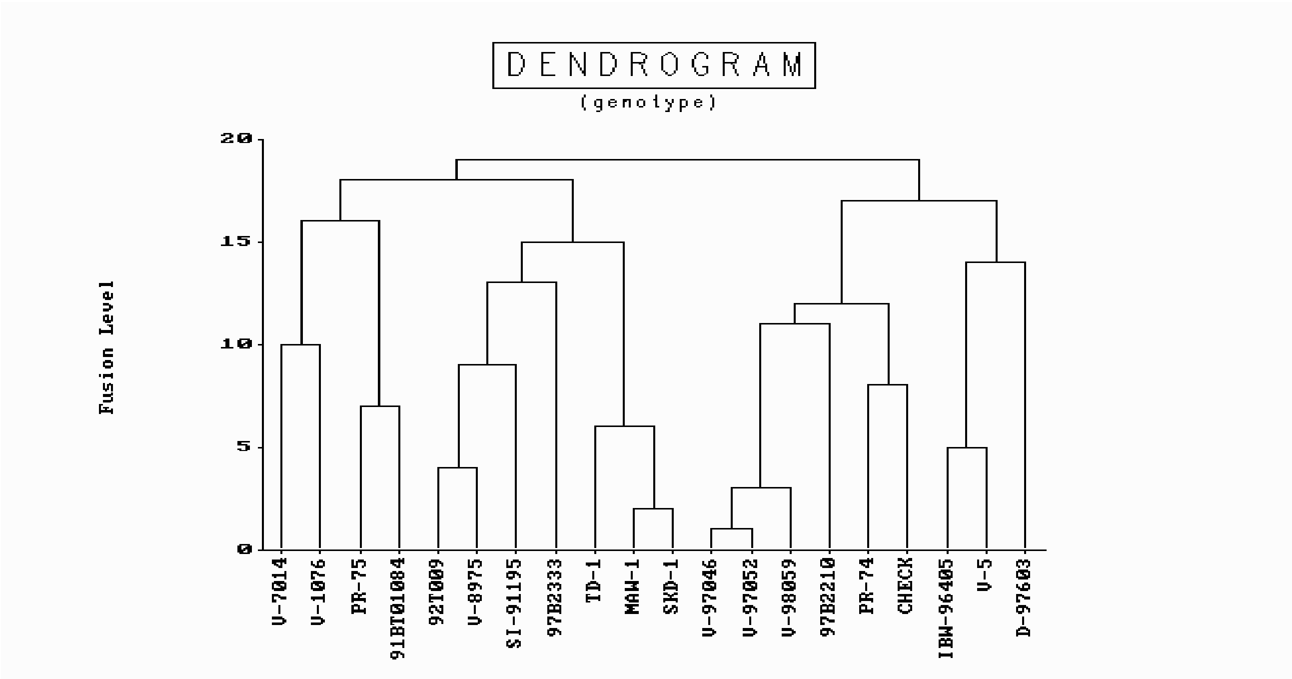
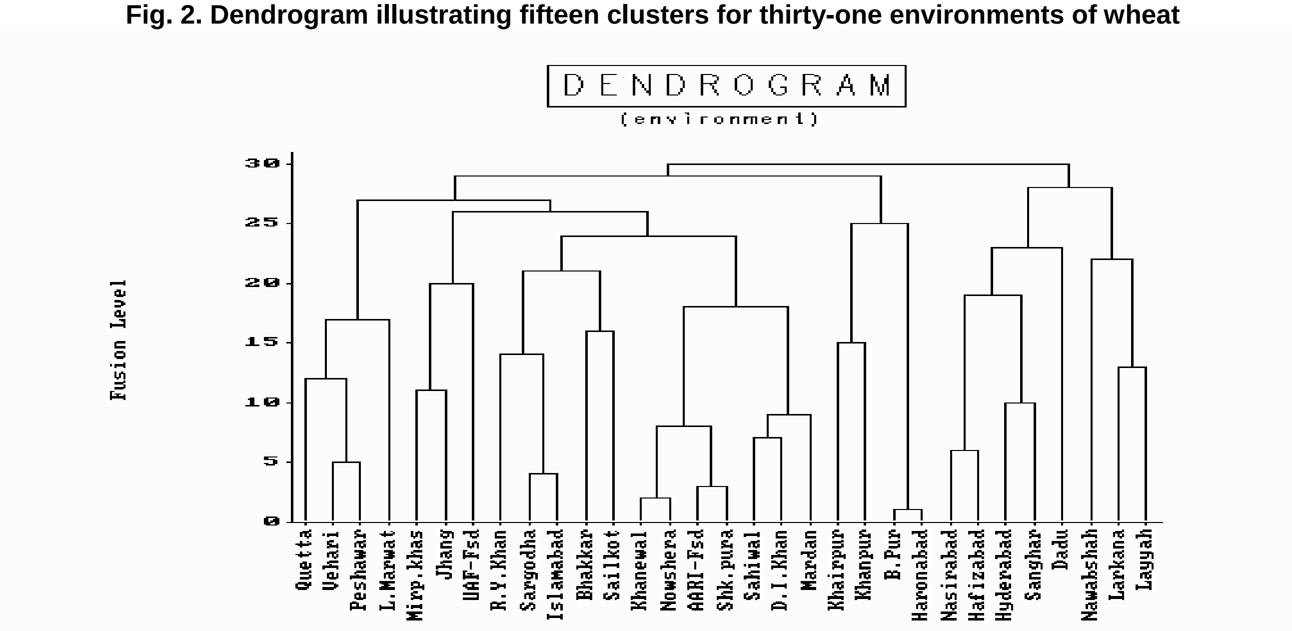


Fig. 2. Dendrogram illustrating fifteen clusters for thirty-one environments of wheat

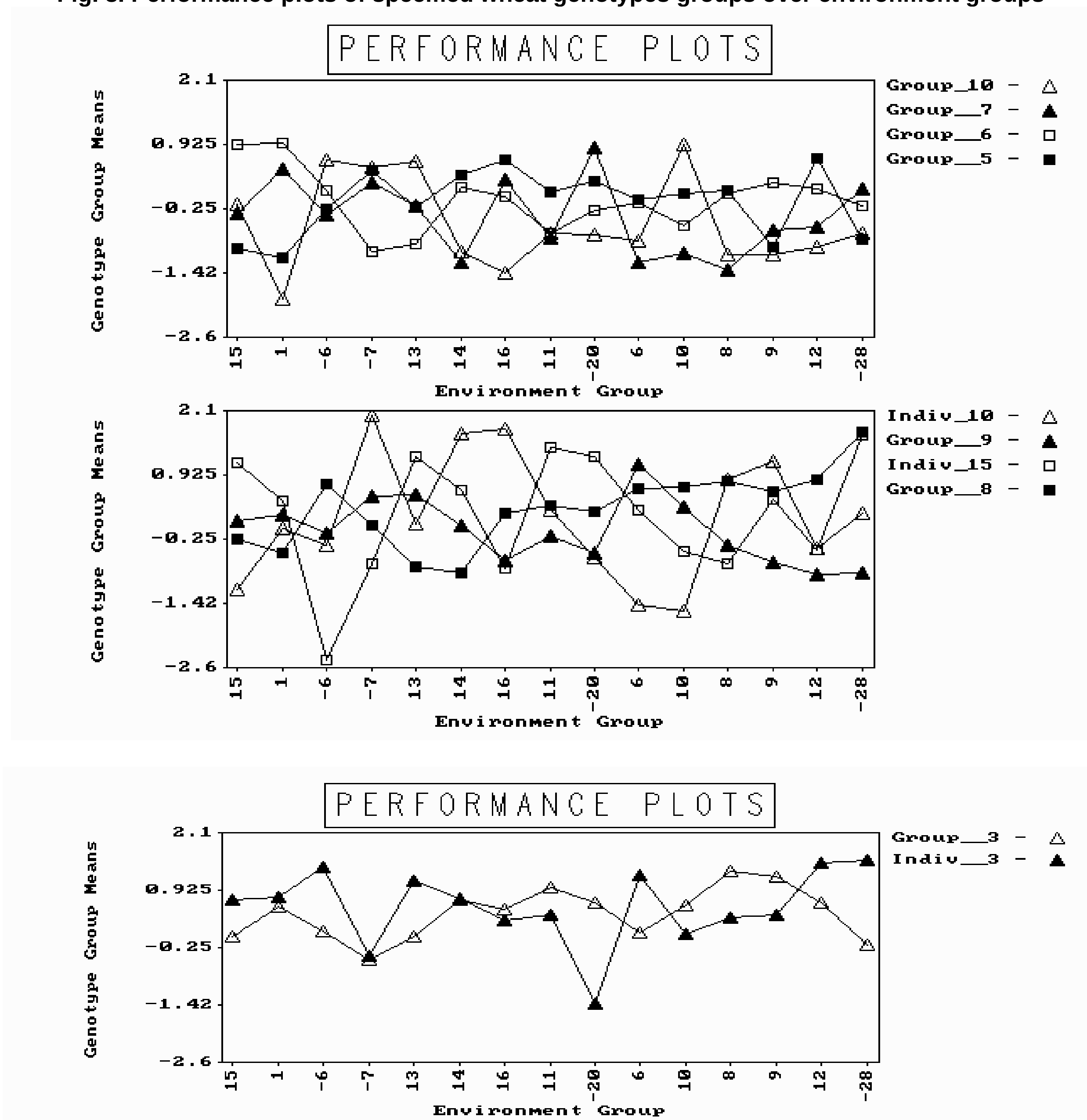


SKD-1 and MAW-1 formed a cluster at the second minimum fusion level, TD-1 also joined them at the fusion level 6.At the allowable distance this cluster joined another cluster of four genotypes (92T009, V-8975, SI-91195 & 97B2333). Another two genotypes (PR-75 & 91BT010-84) formed a cluster that was added to other cluster of two genotypes (V-7014 & V-1076) at about fusion level 16. Wheat genotypes (IBW-96405 & V-5) were similar due to their cluster that was made at the fusion level 5. This revealed that there was a maximum similarity among these genotypes over all the environments. Finally, all the clusters of wheat genotypes were merged into a single cluster at the largest nearest neighbour distance below 20.

In the Fig 2, dendrogram of wheat environments was presented. Thirty-one distinct environments were grouped into sixteen major clusters. The environments Khanewal and Nowshera formed a similar group at the second minimum fusion level.

At the allowable distance another cluster of sites AARI-Faisalabad and Sheikhupura added to this cluster at the fusion level 7. Thus these four environments had

Fig. 3. Performance plots of specified wheat genotypes groups over environment groups



of Bahawalpur and Haroonabad cluster at the minimum fusion level and are more similar to each other than to the other clusters of environments. The locations of maximum similarities with respect to wheat cultivars. The environments of Dadu, Nawabshah and UAF-Faisalabad performed almost individually. Finally all the clusters of wheat environments were merged into a single cluster at the largest nearest neighbour fusion level of 30.

The performance of ten specified wheat genotype groups over fifteen environment groups with respect to average was given in Fig. 3 (a, b, and c). This revealed that performance of some groups was much better than the others. In part (a) of the Fig.3, all the four groups showed good competition pattern across the environment groups. The group 10 of genotypes (V-7014, V-1076) performed inconsistently, as it gave good grain yield at the sites (Dadu, Nawabshah, Larkana, Layyah, Hayderabad & Sanghar), poor yield at (Bahawalpur, Haroonabad, Bhakkar, Sialkot, Sahiwal, D.I.Khan, Mardan, Quetta, Vehari & Peshawar). The performance of group 5 of wheat genotypes (IBW-96405, V-5) was very consistent because it gave good yield at eight environment groups (20 locations) and at other it gave average yield. In Fig 3 (b) all the groups of wheat genotypes except group 8 performed inconsistently over all the specified environments groups. As the performance of indiv 10 (D-97603) was very poor at sit group 15, 6 and 10, good at site groups 7,14,16,8 & 9 and moderate at other location groups. Similarly group 9 of genotype (92T009, V-8975 & SI-91195) performed comparatively well at location groups 1, 7, 13 & 6 and bad at groups 16, 11, 20, 8, 9, 12 & 20. The Indivisual 15 of genotype (97B2333) gave very poor yield at the environments Dadu, Nawabshah, Bhakkar, Sialkot, Hyderabad & Sanghar and performed good only at Khairpur, Khanpur, Larkana, Layyah, Mirpurkhas, Jhang & UAF-Faisalabad. The performance of group 8 of genotypes (PR-74 & Check) performed very consistently well all over the locations except groups 13 and 14 of the environments Larkana, Layyah, R.Y.Khan, Sargodha and NARC-Islamabad.

In third part of the diagram 3 (c) both the two groups of genotypes performed very well all over the locations except UAF-Faisalabad where Individual 3 of genotype 97B2210 gave poor yield. The group 3 of wheat cultivars (V-97046, V-97052 & V-98059) gave better yield at all locations as compared to other genotypes included in this data set. By summarizing the above results of performance plot we got a clear picture of stable genotypes. That is, groups 8, 3 and Indiv.3 containing the genotypes 'PR-74', 'CHECK', 'V-97046', 'V-97052', V-98059 and 97B2210' were the stable and can be adopted for all the environments in order to get maximum wheat yield in Pakistan

Finally, it was concluded that both the mentioned techniques gave almost same results but the Safety-first rule is the best technique due to the reason that this technique explicitly weighs the importance of stability relative to yield. Because the plant breeder is primarily concerned with avoiding disaster by choosing cultivars, which have little chance of producing poor yield. Whereas Cluster Analysis technique is helpful for those researchers who want to know that which genotype performed well at which environments?

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