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Identification of drought tolerant progenies in oil palm (*Elaeis guineensis* Jacq.)

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Abstract

An experiment was conducted at the Nigerian Institute for Oil Palm Research (NIFOR), Benin City, Edo State, Nigeria to evaluate the adaptability and stability of five Oil Palm genotypes under different moisture deficit environments using GGE Biplotinorder to identify moisture stress tolerant genotypes at an early stage of development. Five Oil Palm genotypes which were second generation offspring from among NIFOR germplasm were evaluated in a 5 x 5 factorial of complete randomized design, replicated three times in a green house.Five environments representing four moisture stress levels and a non stressed condition were imposed on the genotypes and data were collected on the growth parameters after six months.The oil palm genotypes were notsignificantly different from one another with respect to dry matter yield.However, there were significant differences among the environments ($p < 0.01$) with respect to dry matter yield. The response of the genotypes to the environments was also significantly different with respect to dry matter yield ($p < 0.05$) suggesting that genotype by environment interaction influenced the performance of the genotypes.With respect to plant height, there were no significant differences among the genotypes.The non stressed environment was highest with respect to dry matter yield with a mean value of 64.27 while E5 (100% soil available water) had the lowest yield. The mean dry matter yield of all the stressed environments were not significantly different from one another but they were, however, significantly lower than that of the non stressed environment. The unstressed environment (E1) was significantly higher in dry matter yield with respect to other environments.The GGE biplot graphic analysis of the five oil palm genotypes tested at five environments which correspond to unstressed and the various stressed levels revealed that the first two principal components explained 86.1% of the total variance identified G5 as more favourable and adapted to drought stress conditions in comparison to other genotypes with respect to dry matter yield and its height was also not significantly different from other genotypes. E4 (environment corresponding to 75% of soil available water) was identified as good test environments for selecting generally adapted genotypes with respect to moisture stress.This information will be useful in identifying moisture stress tolerant Oil Palm genotypes at an early stage of development considering the long gestation period of Oil Palm for incorporation into the ongoing breeding programs.

Keywords: Oil Palm, moisture stress, GGE Biplot, and stability.

Introduction

The Oil Palm (*Elaeis guineensis* Jacq.) is cultivated in the rain forest belt of West and Central Africa where there is abundant rainfall. It is also cultivated in Asia as well as South America, also under conditions of rain-fed agriculture. However, in Africa, except perhaps for the Congo, the West Africa dry season introduces a period of moisture deficit to the environment, which affects the growth and productivity of the Oil Palm (Asemota and Bonaventure, 2010).

Faced with scarcity of water resources, drought is the single most critical threat to food security. It was the catalyst of the great famines of the past. Increase in plant generally, is accomplished through cell division, cell enlargement and differentiation, and involves genetic, physiological, ecological and morphological events and their complex interaction and water plays an important role. The quality and quantity of plant growth depends on these events which are affected by water deficit (Farooq *et al*., 2009). Cell increase is one of the most drought sensitive physiological processes due to the reduction in turgor pressure (Taiz and Zeiger, 2006). Drought stress occurs when plants are exposed to a period without significant rainfall resulting to a reduction in soil available water. Though drought stress could result to loss of water and stomata closure hindering photosynthetic activities, in severe cases it could lead to cessation of enzyme catalyzed reaction of photosynthesis including RUBISCO and to death of the plant (Smirnoff, 1993). It is important to improve the drought tolerance of crops under the changing circumstances. Valuable work has been done on drought tolerance in plants (Farooq *et al*., 2009). In rice, drought stress during vegetative stage greatly reduced the plant growth and development (Tripathy *et al*., 2000, Manikavelu *et al*., 2006) where the height of rice was greatly reduced in stress plant.

All plants are exposed to drought stress in the form of diminished growth(plant height and girth, root length, number of leaves etc), reduction in fresh and dry biomass accumulation (Farooq *et al*., 2009) and harvestable yield and within a plant species the tolerance could vary from one progeny to another. This difference could be exploited for selecting drought tolerant progenies. Numerous different parameters have been used to measure Oil Palm growth. In general a parameter with some obvious physiological significance should be chosen, for example, leaf area and plant height which have been found to influence yield by some authors. Several workers have found significant correlation between vegetative characters of oil palm in the nursery and yield. Subronto *et al* (1989) in a study on nursery seedlings of oil palm showed that on several crosses the butt diameter and leaf area could be used as selection criteria in 9-month-old seedlings as each was highly correlated with yield. Lucas (1980) observed leaf number, seedling height and girth to be highly and positively correlated with one another and with the dry weight of seedlings in a polybag nursery in Nigeria. Hardon *et al* (1969) observed a positive correlation between leaf area and bunch yield in oil palm. Marhalil *et al* (2013) obtained a positive correlation between palm height (HT) and fresh fruit bunch, bunch number and average bunch weight. Agho*et al.* (unpublished) identified height of the oil palm seedlings in the nursery and canopy spread as main factors for improving oil palm yield using canonical correlation analysis and concluded that selection for these traits in early generation is expected to increase the oil palm yield. The effects of drought stress can be managed by production of the most appropriate plant genotypes together with adjustment of sowing time, plant density and soil management. (Farooq *et al*., 2009).Within several drought stress environments and several genotypes, the buffering capacity (stability)of genotypesin terms of its growth traits could be an indirect assessment of their drought tolerance since some of these morpho-physiological traits have been correlated with yield. Plant growth such as height, girth and number of leaves has been identified as some of the visible parameter that responds to drought stress. Other parameters are root and shoot biomass, root proliferation(number), dry matter yield. Identification of high yielding and stable genotypes under different drought stress environment using early growth parameters could save time and hasten the breeding program in Oil Palm breeding in Nigeria where drought is a major stress factor. The differential performances of genotypes based on environment give rise to the concept of genotype by environment interaction. The goal of GxE interaction in plant breeding is to identify superior plant genotypes that can adapt to specific environments. The most adopted method of measuring G x E interaction has focus on the analysis of stability of genotypes. The stability in performance of a genotype is the most important factor to consider before it is released for wide cultivation. Different methods are used to identify stable genotypes which include the univariate and multivariate methods. The multivariate statistics which includes the AMMI (additive main effect and multiplicative interaction) and the most recent GGE Biplot are now mostly used because of their high quality and trustworthy as it completely remove “noise” in the data set (for example, to distinguish systematic and non-systematic variation); it summarize the information and reveal a structure in the data (Crossa , 1990; Gauch, 1992).

A number of G x E interaction studies to identify high yielding and stable genotypes from different oil palm breeding trials of NIFOR has been reported (Obisesan and Fatunla, 1983; Ataga, 1993).The objective of this study was to evaluate the adaptability and stabilityof five Oil Palm genotypes under different moisture deficit environments using GGE Biplot.This information will help to identify moisture stress tolerant genotypes at an early stage of development considering the long gestation period of oil palm for incorporation into the ongoing breeding programs.

Materials and Methods

The experiment was conducted in the green house of Nigerian Institute for Oil Palm Research (NIFOR) Benin City, Edo State.

One month old Oil Palm seedlings of five progeny designated by E1, E2, E3, E5, and E9 which are second generation offspring from among NIFOR germplasm was used. The seedlings were planted in black poly bags measuring 12’’x 14’’ filled with 13kg top soil and later subjected to four moisture stress levels (severe, moderate, mild and no stress). The four moisture stress levels as different environments (E2, E3, E4 and E5) were created by moistening the poly bags with 1140, 2280, 3420 and 4560ml of water corresponding to 25, 50, 75 and 100% of soil available water determined gravimetrically (Kramer, 1983). The control (E1) was the normal daily water requirement for oil palm at the seedling stage which is between 1-1.5 litres of water applied daily. The soil moisture levels were maintained for a period of six months when the experiment was terminated by periodic application of water at two weeks interval. The experiment was laid out in a 5 x 5 factorial of complete randomized design, replicated three times. The palm height was measured with a graded two metres long metric ruler, from the palm base to the top of the drawn upleaf. Dry matter yield was estimated using 6 month sold seedlings. Destructive sampling was carried out by carefully removing the seedlings from the polythene bags without damage to the seedlings. The ball of the earth was carefully loosed off the seedling and the root washed in water to remove the soil completely. Fresh weight of the harvested seedlings was measured and the harvested seedlings were taken to laboratory for oven drying in order to obtain the dry matter yield. The dry matter yield was obtained by oven drying the seedlings at 85 °C for 48 hours until a constant weight was obtained. Data on plant height and dry matter content were collected and subjected to individual as well as combined analysis of variance of the two-way model using SAS(SAS Institute, Inc. 2002). A combined two factor analysis of variance was performed on data collected using the statistical model:

$$Y_{ijkl} = \mu + B_i + G_j + E_k + (GE)_{jk} + e_{ijkl}$$

Where:

Y_{ijk}= performance of genotype j in the k^{th} environment.

μ = grand mean.
B_i= block effect.
G_j= main effect of the j^{th} genotype.
E_k= main effect of the k^{th} year.
e_{ijkl} = random error term

The data were subjected to GGE Biplot Analysis. The GGE-biplot methodology, which is composed of two concepts, the biplot concept (Gabriel, 1971) and the GGE concept (Yan *et al*., 2000), was used to visually analyze the data. This methodology uses a biplot to show the effects of G and GE that are important in genotype evaluation and that are also the sources of variation in GE interaction analysis of MET data (Yan *et al*., 2000, 2001). Using GGE-biplot methods, genotypes can be evaluated for their performance, stability, and adaptation in individual environments and across environments. Simultaneously, environment relationships can be evaluated and mega-environment can be set up by using the biplots (Yan and Kang, 2003).

Results and Discussion

The oil palm genotypes were notsignificantly different from one another with respect to dry matter yield (Table 1). However, there were significant differences among the environments ($p < 0.01$) with respect to dry matter yield. The response of the genotypes to the environments was also significantly different with respect to dry matter yield ($p < 0.05$) suggesting that genotype by environment interaction influenced the performance of the genotypes. With respect to plant height, there were no significant differences among the genotypes (Table not shown). The mean yield of the genotypes with respect to dry matter yield ranges from 45.95 to 53.12 with a grand mean of 49.5.The highest yielding genotype was G4 with a yield of 53.12 followed by G5 with a yield of 51.38. G2 was the lowest yielding genotype with a yield of 45.95.The non stressed environment was highest with respect to dry matter yield with a mean value of 64.27 while E5 (100% soil available water) had the lowest yield. The mean dry matter yield of all the stressed environments were not significantly different from one another (Table 2) but they were, however , significantly lower than that of the non stressed environment.

Table 1 .Analysis of variance for dry matter

Source of Variation	**DF**	**MS**	**Pr> F**
Environment	4	1057.02^{**}	0.0029
Reps within Env.	4	447.22^{NS}	0.0543
Genotype	4	154.37^{NS}	0.594
G x E	16	478.90^{*}	0.023
Error	40	219.17	

Table 2. Mean dry matter of five oil palm genotypes and five environments

Treatments	DM
Genotype (Gen.)	
1	46.25a
2	45.95a
3	50.69a
4	53.12a
5	51.38a
$LSD_{0.05}$	10.92^{ns}
Environment (Env.)	
1	64.27b
2	45.69a
3	46.87a
4	47.11a
5	43.45a
$LSD_{0.05}$	10.93**
Gen. x. Env.	*

DM, dry matter yield; ** = Significant at P<0.01and NS= Not Significant.

The GGE biplot was used to facilitate visual analysis of the genotype by environment data. In the present investigation, the GGE biplot graphic analysis of the five oil palm genotypes tested at five environments which correspond to unstressed and the various stressed levels revealed that the first two principal components explained 86.1% of the total variance (Fig 1).In the which-won-where concept of GGE biplot, markers of the genotypes furthest from the plot origin (0, 0) are connected with straight lines to form a polygon such that markers of all other genotypes are contained in the polygon. To each side of the polygon, a perpendicular line, starting from the origin of the biplot, is drawn and extended beyond the polygon so that the biplot is divided into several sectors and the markers of the test environments are separated into different sectors. The cultivar at the vertex for each sector is the best performer at environments included in that sector, provided that the GGE is sufficiently approximated by PC1 and PC2 (Emmanuel and Robert, 2006). In Fig. 1, there were four sectors into which the genotypes were delineated; three mega-environments were identified. E4 and E5 were one mega environment with Genotype 5 as the winning genotype; the winning genotype for E1 and E3 (second mega-environment) was Genotype 4; while the winning genotype at E2 (the third mega-environment) was Genotype 2. G1 without any environment in its sector did not win in any environment in terms of dry matter yield and thus could be regarded as poorlyadapted to these testing environments. According to the findings of Yan and Tinker (2006), the vertex genotypes were the most responsive genotypes, as they have the longest distance from the origin in their direction.

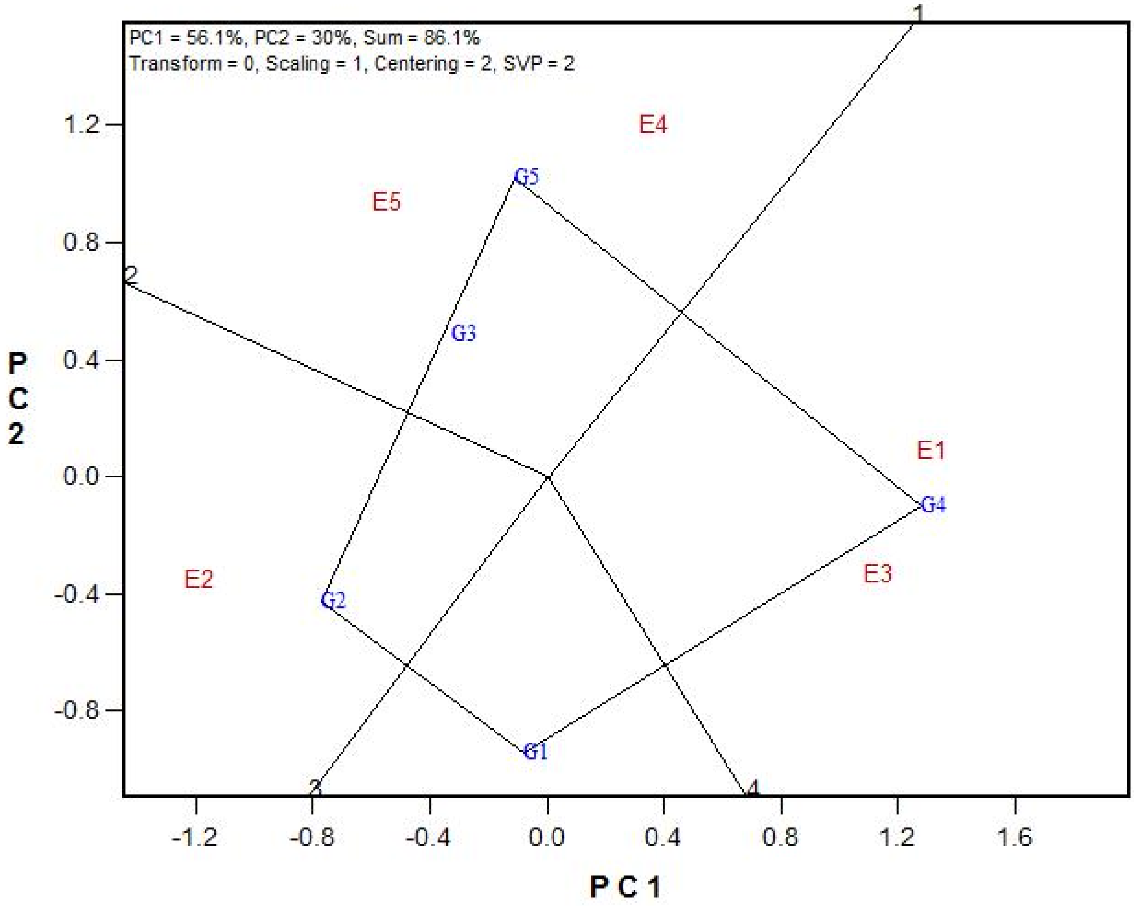

Figure 1: The 'which-won-where feature of the biplot. (Where, G = names of genotypes; the names of environments are abbreviated as E1, E2, E3, E4, and E5 corresponding to no stress, 25%, 50%, 75% and 100% of soil available water respectively.

The ideal genotype concept of GGE biplot indicates that the closer a genotype is located relative to the “ideal” genotype; the more desirable it is in terms of both mean performance and stability (Emmanuel and Robert, 2006). In considering the ranking of the genotypes, using the “ideal genotype” concept of GGE biplot, G5 was closer to the ideal genotypes (Fig.2) with high mean yield and stability in terms of accumulated dry matterand since its height was also not significantly different from other genotypes, it means that G5 will be more favourable and more adapted to drought stressconditions in comparison to other genotypes. G1and G2 were far away from the ideal genotype with G1 been the poorest performer.

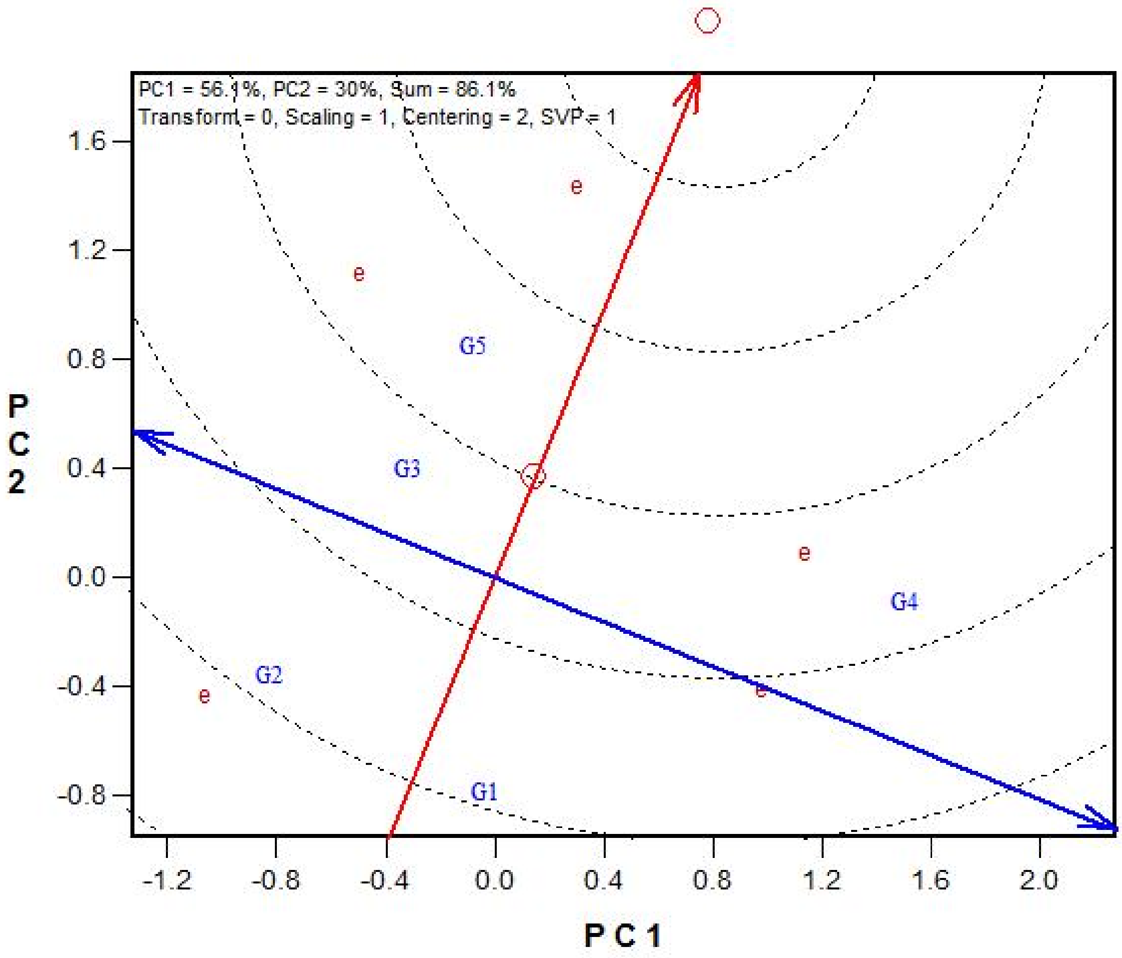

Figure 2. Ranking of genotypes based on both mean and stability.

Fig. 3 shows the representative as well as the discriminative test environment for the genotypes. The average environment (represented by the small circle at the end of the arrow) has the average coordinates of all test environments, and AEA is the line that passes through the average environment and the Biplot origin. A test environment that has a smaller angle with the AEA is more representative of other test environments. Thus, E4 (75% of soil available water) is most representative whereas E2 (50% of soil available water) was least representative. The concentric circles on the biplot help to visualize the length of the environment vectors, which is proportional to the standard deviation within the respective environments and is a measure of the discriminating ability of the environments. Therefore, among the fiveenvironments, E4 and E1 were most discriminating (informative) as indicated by the longerdistance between their markers and the origin and E3 (50% of soil available water) least discriminating (Fig. 3). Test environments that are discriminating (informative) provide reliable information on the genotypes and, therefore, should be used as test environments.Test environments that are both discriminating and representative (e.g., E4) are good test environments for selecting generally adapted genotypes. The mean dry matter yield for each environment is shown in table 2. The unstressed environment (E1) was significantly higher in dry matter yield with respect to other environments.

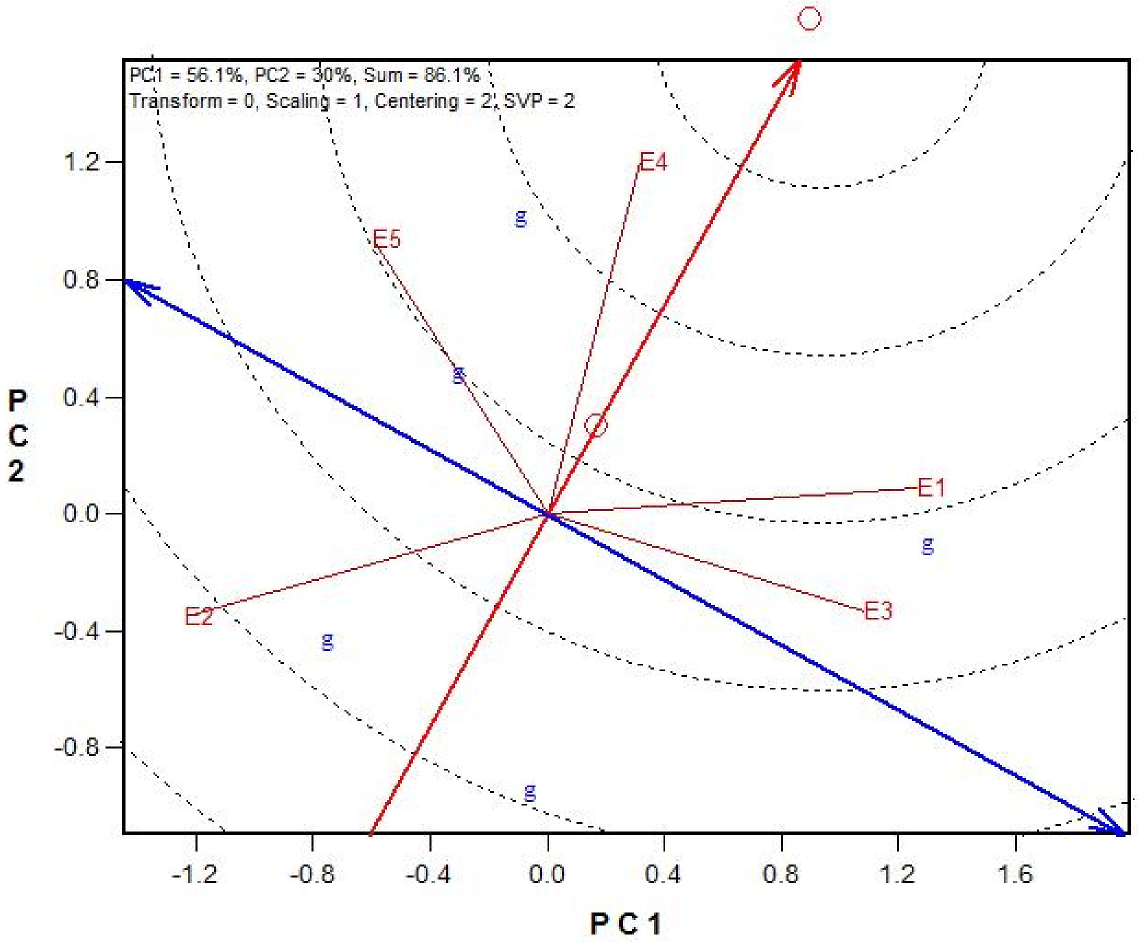

Figure 3. Ranking environments based on both discriminating ability and representativeness

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