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GGE biplot analysis for SCMR and Yield of groundnut genotypes under Iron deficient calcareous soil

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Abstract
In recent decade use of graphical approach or GGE biplot for study genotype x environment (G×E) interaction become popular in plant breeding programs. In this approach the effects of genotype and G×E interaction are not separated and selection is based on both of above effects. In the present study eleven groundnut genotypes were evaluated at two environment condition during *kharif* 2016-17. In order to analyse the effects of G×E interaction on the SCMR score and yield, the generated multi environmental data was subjected to GGE biplot stability analysis. The GGE biplot is an effective method for analysing the MET data to screen stable performing genotypes at particular location and to identify ideal environments for better evaluation of traits under consideration. The environment E2 was shown to discriminate and represent genotypes for both traits considered. The genotypes 5, 6, 4, 3, 11 and 1 were found as iron deficiency tolerant genotypes whereas genotypes 9, 2, 10 and 7 marked as iron deficiency susceptible genotypes. The genotypes 11 and 8 were found high yielder with iron deficiency tolerance.

Keywords: GGE Biplot, G×E interaction, Iron Deficiency, SCMR, Yield

Introduction
Groundnut (*Arachis hypogaea* L.) is an important oilseed legume crop. The crop plants require many essential nutrient for competing their life cycle among them iron is an essential nutrient required for completing life-sustaining process *i.e.* respiration to photosynthesis. It plays an important role in the synthesis of chlorophyll, carbohydrate production and cell respiration, chemical reduction of nitrate and sulphate and nitrogen assimilation. To maintain optimum growth, plants need to maintain 10-9 to 10-4 M Fe in the concentration but it is a challenging due to low solubility of Fe in soil solution. Any factor that interfere its absorption and translocation may cause the plant to develop chlorosis. Iron present in abundant in nature but in the presence of oxygen at neutral or basic pH it forms insoluble hydroxide complexes which is an unavailable form of iron for the plants (Guerinot and Yi, 1994) [1]. The deficiency of iron indicates by yellowish interveinal parts of leaves on younger leaves referred as 'iron chlorosis'. In severe deficiency leaves convert into almost pale white due to loss of chlorophyll. In general, plants are prone to iron deficiency in soils which are alkaline, calcareous, coarse textured and eroded soils with low organic matter and cold-weathered except flooded rice (Tandon, 1998) [7].

The soils with high calcium carbonate content show the chlorosis immediately after irrigation or high rainfall because in the presence of high bicarbonate plant cannot absorb the iron. The IDC problem can be overcome by the soil application of iron in the form of ferrous sulphate ($FeSO_4$) but this approach is not feasible to the farmer and crop as iron gets convert into ferric compound which are unavailable to plants. The most feasible approach to overcome the iron chlorosis is development of iron deficiency chlorosis resistant cultivars by exploiting the genetic variability and identifying best stable genotypes which can produce high yield under iron deficient soil (Reddy *et al*., 1993; Kulkarni *et al*., 1994; Samdur *et al.*, 1999, 2000) [4, 2, 5-6]. The yield, yield attributing traits and iron deficiency observations *viz.*, SPAD chlorophyll meter reading, Visual chlorophyll ratting (VCR), chlorophyll and active iron estimation are governed by polygene which are environment sensitive so, by creating multi environment by evaluation of genotype under iron deficient (Environment 1) and non deficient (Environment 2) condition we can select the genotypes having low G x E interaction which perform stably. During these times of climate change assessment of varietal adaptation is very much necessary to screen out the environment specific stable performing genotypes. The use of environment specific adapted genotypes for cultivation will automatically get us good yields. By conducting stability analysis, we can also analyse ideal environments in which the concerned trait expresses its maximum capacity and to study the genotype x environment interactions in producing the phenotype. So, the multi-environment trials are being conducted across various locations and the generated data is subjected to various stability analysing statistical techniques to screen out the stable performing genotypes.

In 1971 Gabriel reported the use of biplots for data visualization tool. In this approach the effects of genotype and G×E interaction are not separated and selection is based on both of above effects. Cultivar evaluation and mega-environment identification are among the most important objectives of multi-environment trials. Although the measured yield is a combined result of effects of genotype (G), environment (E), and genotype × environment interaction (GE), only G and GE are relevant to cultivar evaluation and mega-environment identification. The GGE biplot is a two-dimensional graphical representing technique which displays genotype main effects and G×E interaction which are the two sources of variation important for cultivar evaluation (Yan, 2002) [8]. The GGE biplot creates different graph patterns each having specific applications like which won where pattern for mega environment analysis, mean *vs* stability pattern for cultivar evaluation and discrimination *vs* representativeness pattern for test environment evaluation (Bandeira *et al*., 2017). So, the main motive of this work was to screen out the stable performing genotypes in two different environmental conditions. When applied to SPAD chlorophyll meter reading and yield under iron deficient (Environment 1) and non deficient (Environment 2) condition, the GGE biplots clearly identified winning genotypes which can be grown under iron deficient calcareous soil.

Materials and Methods

The study was conducted in calcareous soil at RARS, Vijayapur. Vijayapur comes under Northern dry zone (Zone 3) of Karnataka, India. The soil collected for the experimentation is clay in texture. The soil samples were collected from a depth of 0 to 15 cm and chemical properties were analyzed by standard procedures. The soil was found calcareous in nature with low availability of iron to plant. Details of chemical properties and available nutrients in soil are given in Table 1. Eleven selected groundnut genotypes based on their reaction to iron chlorosis *viz.*, ICGV 86031, TAG 24, RIL 52, RIL 146, RIL 307 (Recombinant Inbred Lines from TAG 24 x ICGV 86031), A30b, ICGV 06146, GPBD 5, Dh 86, TMV 2 and G2-52 (Pedigree is given in Table 2) were sown in 2 environments, during *kharif* 2016 season at RARS, Vijayapur under Factorial randomized block design (Factorial RBD). One set was sown under calcareous soil without any iron supplementation (Environment E1) and second set in calcareous soil but with iron supplementation (foliar application 0.5% Fe EDDHA at two stages *i.e.* 30 and 45 DAS) (Environment E2). Each genotype was planted in five rows of 3 m length with a spacing of 30 X 10 cm in 3 replications of each set. The recommended cultivation practices were followed to maintain healthy plant population. Iron containing fertilizers were avoided.

Observations

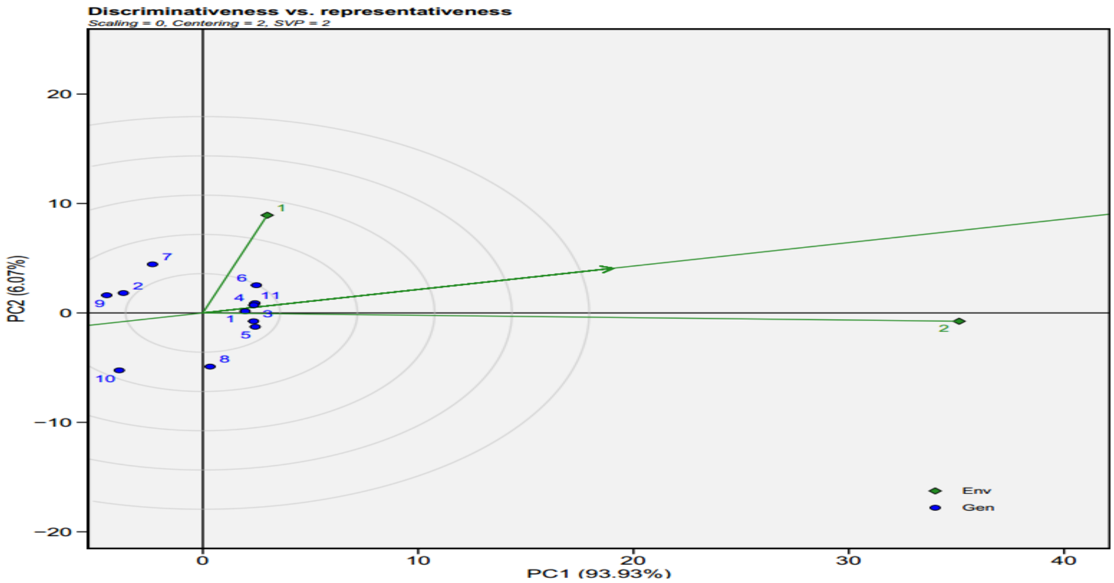
The iron absorption efficiency trait *viz.*, SPAD Chlorophyll meter reading (SCMR) was recorded on randomly selected five plants of each genotype at severe stage *viz.*, 60 days after sowing (DAS) whereas Yield and yield parameters were recorded on the five randomly selected plants in each genotype at harvest or after harvest for all the genotypes.

Results and Discussion

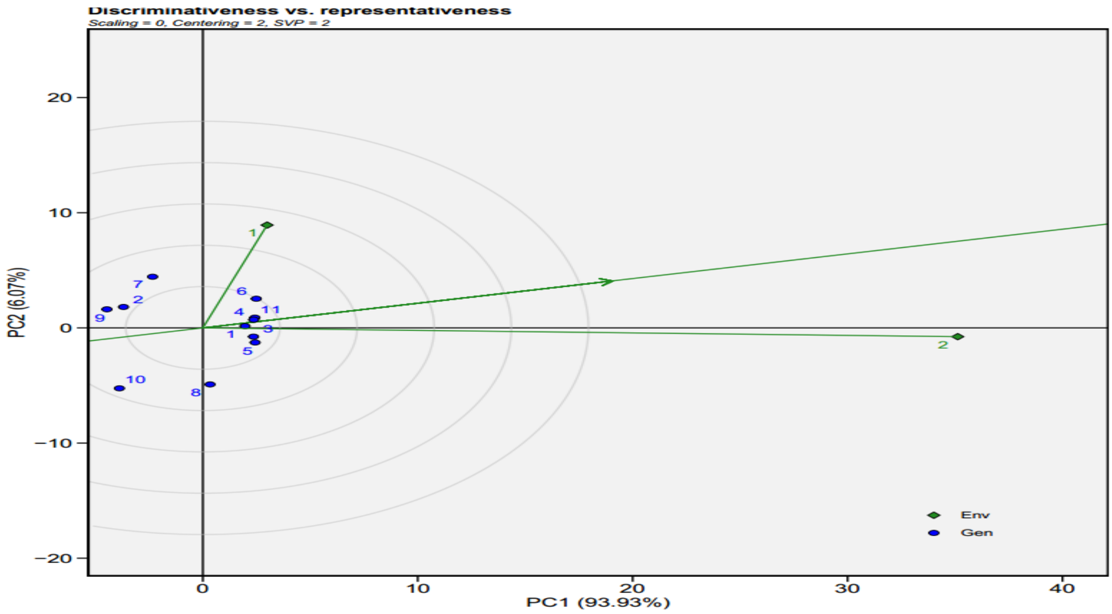
(A) Test environment evaluation

The "Discrimination *vs* representativeness" pattern of GGE biplot is used to identify best test environments from a mega environment group which effectively identify superior genotypes for the trait under consideration (Yan *et al*., 2007) [11]. By using this pattern, the capacity of the test environments to discriminate the genotypes can be understood like if the test environment is having high discriminating ability, it gives more information on the genotypes about the particular character in study. If the test environment is having low or no discriminating ability, it provides less or no information on the genotypes about the particular character in study. Therefore, the non-discriminating environments providing little information on the genotypes could be ignored during evaluation about the character under study. The discriminating ability of the environments from the graph can be interpreted by observing the length of environment vectors which are originating from the origin. The concentric circles on the biplot help to measure the length of environment vectors which is directly proportional to the standard deviation within the respective environments which measures the discriminative ability. So, if the length of environment vector is long its discriminative ability will be high giving more information on genotypes and vice versa. The representativeness of the test environments can be analysed by measuring the angle made by different environment vectors with the Average Environmental Axis (AEA). The AEA also called as average tester axis which consists of average coordinates of all test environments passing through the average environment from the biplot origin. The environmental vector making the small angle with the AEA is more representative than the other test environments. The test environments which are both discriminating and representing are used to select generally adapted genotypes. The environments which are discriminative *i.e.*, having long environmental vectors but not representing are used to select genotypes which are specifically adapted to that environment.

From the Fig. 1A environment E2 was found to be best discriminating and representing than other environments for SCMR for selecting generally adapted genotypes. The same pattern for yield per hectare (Fig. 1B) also showed that environment E2 as best discriminating and representing genotypes for general adaptation.



(A)



(B)

Fig 1: The Discrimination *vs* representativeness pattern of GGE biplot to show the discriminating ability and representativeness of different test environments for (A) SPAD Chlorophyll meter reading and (B) yield

(B) Man *vs* Stability

The "Mean *vs* stability" pattern of GGE biplot is used for genotype evaluation for specific mega environment (Yan, 2002) [8]. The single arrowed horizontal line in the graph indicates the AEC abscissa which direction indicates the increasing mean values of the concerned trait in study. The ordinate is made by drawing a line perpendicular to AEC abscissa. The vertical projections on the AEC ordinate indicates stability where greater the projection the higher the G×E interaction and instability (Mortazavian *et al.*, 2014) [3]. The genotype having high mean performance and high stability with in a mega environment is considered to be as an ideal genotype.

The mean of the genotypes for SCMR score is in following order (Fig. 2A): G6 >G4>G11>G3>G5>G1>G8>G7>G2>G9>G10 whereas for yield (Fig. 2B): G10>G11>G8>G3>G5>G4>G2>G6>G9>G7>G1, This order is highly consistent with the actual mean SCMR score and yield of the genotypes. Since the biplot contains both G and GEI and since the two axes of the mean-environment coordination are orthogonal, if projections of the genotypes on to the AEC abscissa approximate the mean yield of the genotypes, projections of the genotypes on to the perpendicular axis must approximate the GEI associated with the genotypes. The longer the projection of a genotype, regardless of direction, the greater the GEI associated with the genotype, which is a measure of variability or instability of the genotype across environments. Thus the performance of genotypes G6, G4, G11, G1, G8 and G10 for SCMR score are highly stable except G3, G5, G7, G2 and G9 whereas for yield the genotypes G11, G5, G4, G2, G9 and G7 are highly stable except genotypes G10, G8, G3, G6 and G1. It should be pointed out that high stability is not necessarily a positive thing per se. High stability is desirable only when associated with a high mean yield. A genotype with high stability is highly undesirable if it is associated with a low mean yield; it is simply a genotype that is consistently poor. It is even less desirable than genotypes with poor stability. An ideal genotype is one that has both high mean yield and high stability. Thus, genotypes G11, G8, G3, G5 and G4 are high yielding with high stability whereas genotypes G10 is high yielding with low stability. If the genotypes showing stable performance across both the environment can be marked as iron deficiency tolerant genotypes with high yield ability.

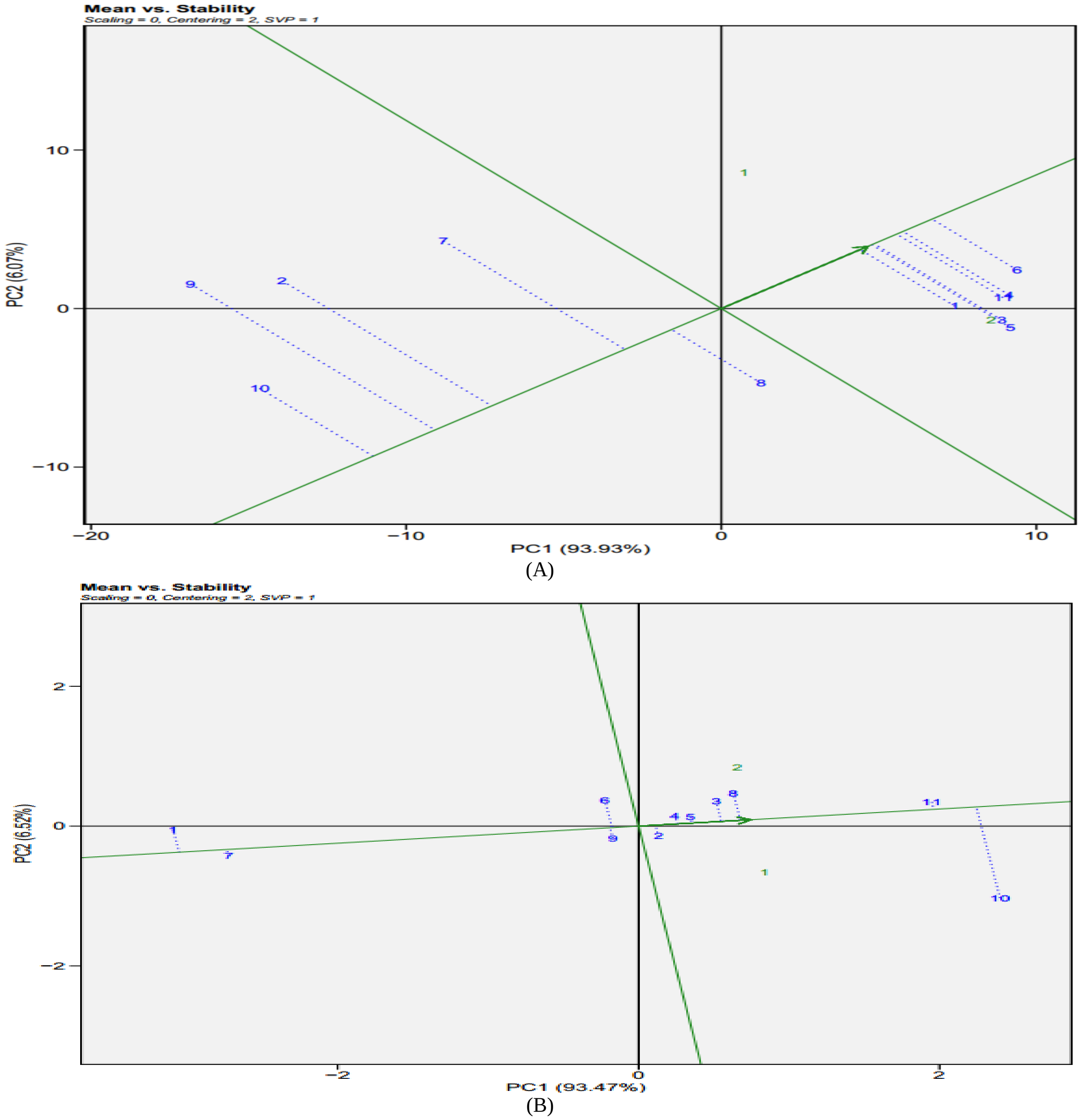


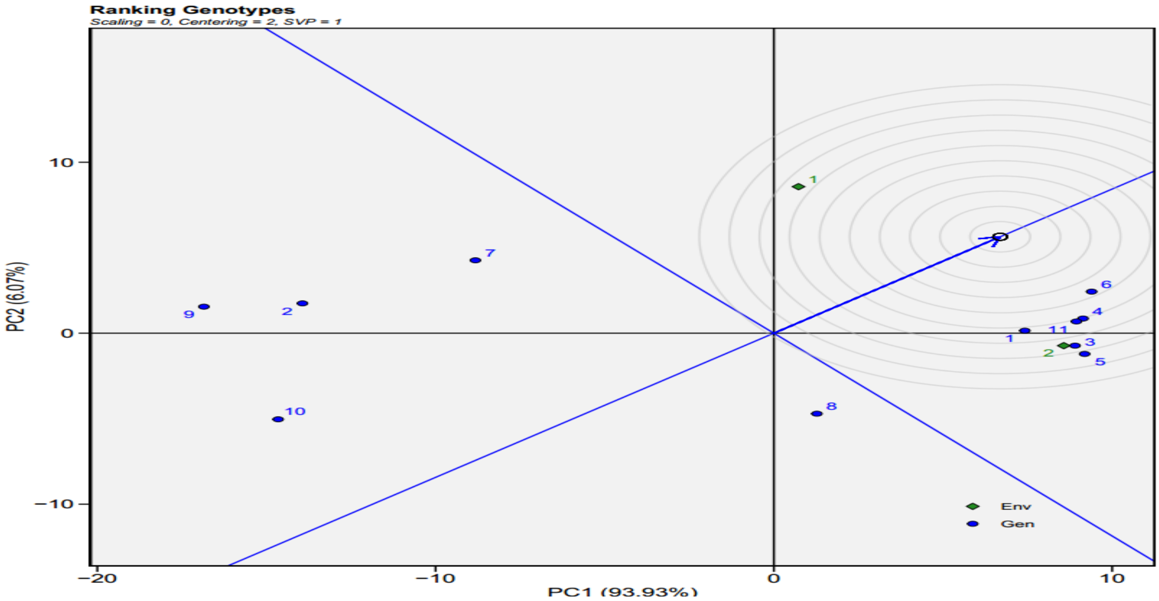
Fig 2: The mean *vs* stability pattern of GGE biplot analysis showing single arrowed line representing AEC absicca and perpendicular axis drawn to it known as AEC ordinate. The direction of AEC absicca towards arrowhead indicates increasing values and the vertical projections indicate stability *i.e.*, greater the projection, higher is the instability.

(C) Performance of different genotypes.

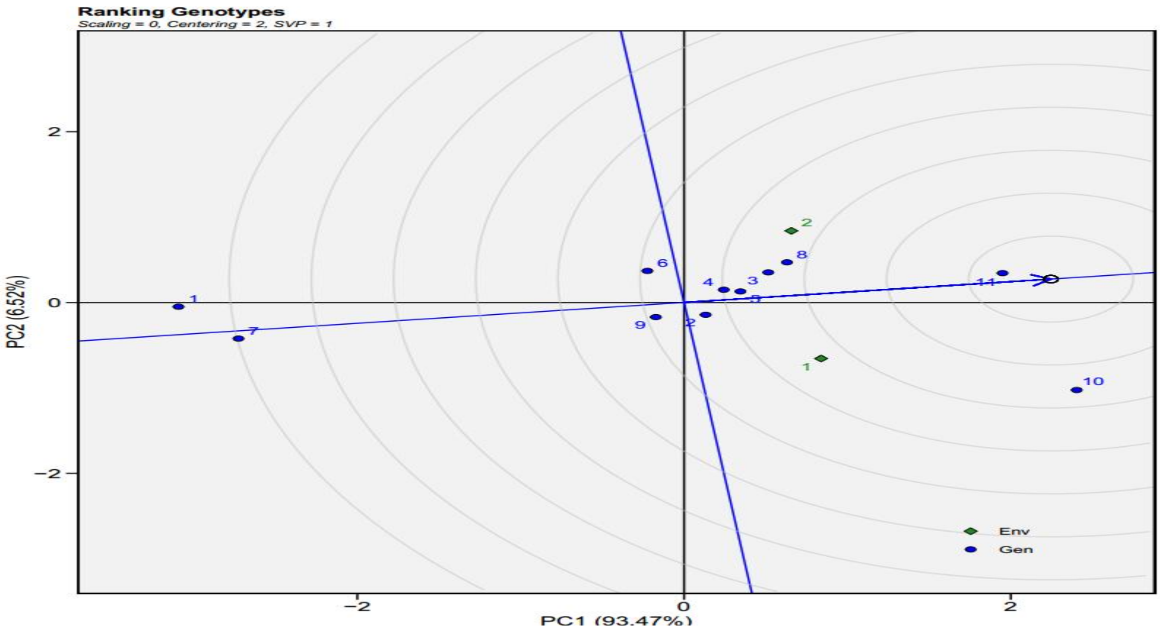
To visualize the performance of genotypes in different environments namely, iron deficient Environment E1 and non deficient Environment E2 for a particular traits draw a line that passes through the biplot origin and the marker of environment E1 and E2; this may be called the environment E1 and E2 axis. The genotypes will be ranked according to their projections on to the environment E1 and E2 axis (Fig. 4).

Thus, order of genotypes for the SCMR score in first environment is (Fig. 4A): G7>G6>G4>G11>G1>G2>G9>G3>G5>G8>G10, all genotypes are placed near the mean line it means all genotypes showed no difference regarding to SCMR score. It is because addition iron has been provided to the crop by foliar application 0.5% Fe EDDHA at two stages *i.e.* 30 and 45 DAS which increase the chlorophyll content of leaf. The SPAD meter record the greenness of the leaf which are directly proportionate to the chlorophyll content therefore all the genotypes show the similar amount of chlorophyll content or SCMR score. In the second environment the order of genotypes for SCMR score is G5>G6>G4>G3>G11>G1>G8>G7>G2>G10>G9, in this environment or iron deficient condition genotypes G5, G6, G4, G3, G11and G1 shows the above the mean these can be called iron deficient tolerance genotypes whereas genotypes; G9, G2, G10 and G7 show the below the mean therefore these genotypes marked as iron deficiency susceptible genotypes.

The order of genotypes for yield per plant in first environment is (Fig. 4B): G10>G11>G8>G2>G5>G3>G4>G9>G6>G7>G1, in this environment all the genotypes yielded more the mean or around the mean (all genotypes are high yielding) except genotypes G7 and G1 which are below the means less yielding genotypes. In the second environment genotypes order for yield is; G11>G8>G10>G3>G5>G4>G6>G2>G9>G1>G7, in this environment genotypesG11,G8,G10,G3 and G5 yielded more than the mean value whereas genotypes G4,G6,G2 and G9 placed around the mean and G1 and G7 are below the mean. In both the condition genotypes G11, G8 and G10 can be marked as iron deficient tolerant with high yield genotypes.



(A)



(B)

Fig 3: Ranking of the genotypes based on their performance in environment E1 (A) and environment (B)

Conclusion

- The environment E2 showed to be the best discriminating and representing environment for both traits i.e., SCMR score and Yield.
- All the genotypes are shows near the mean SCMR score in environment E1 whereas genotypes G5, G6, G4, G3, G11 and G1 shows above the mean, these can be called iron deficient tolerance genotypes.
- In environment all the genotypes yielded more the mean or around the mean (all genotypes are high yielding) except genotypes G7 and G1 which are below the mean (less yielding genotypes). In the second environment genotypes G11, G8, G10, G3 and G5 yielded more than the mean value whereas genotypes G4, G6, G2, and G9 placed around the mean and G1 and G7 are below the mean. In both the condition genotypes G11, G8 and G10 can be marked as iron deficient tolerant with high yield genotypes.
- The performance of genotypes G6, G4, G11, G1, G8 and G10 for SCMR score are highly stable whereas for yield the genotypes G11, G5, G4, G2, G9 and G7 are highly stable. Thus, genotypes G11, G8, G3, G5, and G4 are high yielding with high stability whereas genotype 10 is high yielding with low stability.

Table 1: Chemical characteristics of the soil in experimental site

Sl. No.	Parameter	Unit	Values
1	pH		8.02
2	EC	dsm^{-1}	0.53
3	Organic carbon	%	0.64
4	Available Nitrogen	kg/ha	294.00
5	Available P_2O_5	kg/ha	48.75
6	Available K_2O	kg/ha	468.00
7	Available Ca	Cmol (p^+)/kg	19.25
8	Available Mg	Cmol (p+)/kg	5.55
9	Available Sulphur	mg/kg	18.20
10	Free Lime	%	8.93
11	CEC	Cmol (p+)/kg	58.00
12	Base Saturation	%	42.75
13	Zinc	Ppm	3.12
14	Iron	Ppm	0.09
15	Copper	Ppm	2.24
16	Manganese	Ppm	0.23

EC: Electric conductivity; CEC: Cation exchange capacity

Table 2: Pedigree of genotypes used in the study on response to calcium induced iron chlorosis

Sl.	Genotype	Code	Year of release, Institute	Pedigree	Special features
1	ICGV 86031	G1	1982, ICRISAT	(F334A-B-14 x NC Ac 2214) F_2-B_1-8_3-B_2-B_3-B_2-B_3	High-yielding; multiple resistance/ tolerance to *Spodoptera,* leaf miner, jassid, and thrips; resistant to bud necrosis virus and iron chlorosis; insensitive to photoperiod
2	GPBD 5	G2	2010, UAS Dharwad	TG 49 × GPBD 4	High pod and kernel yield
3	Dh 86	G3	2005, UAS Dharwad	Dh-40 x Dh-8	Tolerant to LLS and sucking pests; suitable for *rabi*-summer season
4	G 2-52	G4	2004, UAS Dharwad	GPBD 4 mutant	High yielding; high oil content and O/L ratio
5	TAG 24	G5	1992, BARC, Trombay	TGS 2 × TGE 1	Early maturing; high harvest index and water use efficiency
6	RIL 52	G6	UAS, Dharwad	TAG 24 × ICGV 86031	Resistant to iron chlorosis, low plant height
7	RIL146	G7	UAS, Dharwad	TAG 24 × ICGV 86031	Resistant to iron chlorosis, low plant height
8	RIL307	G8	UAS, Dharwad	TAG 24 × ICGV 86031	Resistant to iron chlorosis, low plant height
9	TMV 2	G9	UAS, Dharwad	Mass selection from Gudia	Susceptible to iron chlorosis, High yielding, widely adapted, well suited for summer season
10	ICGV 06146	G10	ICRISAT, Patancheru	[(ICGV 92069 x ICGV 93184) x (ICGV 96246 x 92 R/75)]	High yield, high oil (52 percent), acceptable pod traits
11	A 30b	G11	UAS, Dharwad	Germplasm	Advanced breeding line resistant to late leaf spot and rust

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