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RESEARCH ARTICLE

# Simultaneous evaluation of yield and stability of sugar beet (*Beta vulgaris* L.) varieties under Egyptian conditions using AMMI and GGE biplot approaches

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## Abstract

An experiment was conducted on stability analysis of seven diverse monogram sugar beet (*Beta vulgaris* L.) varieties for root and sugar yields and their attributes grown under three harvesting dates after sowing during 2021-22 and 2022-23. The data generated from eighteen environments representing the combinations among harvesting dates, locations, and seasons were subjected to additive main effects and multiplicative interaction (AMMI) genotype main effect and genotype x environment interaction (GGE Biplot) analysis. Results obtained from AMMI combined analysis of variance showed that the main effects of sugar beet varieties, environments, and their interaction were highly significant for all studied traits. It is observed that sugar beet plants grown in the Nubaria region and harvested after 210 days, gave the best results for most root and sugar quality traits. The analysis further revealed that Volna and Klara varieties were the elite ones regarding root and sugar yields, and juice quality parameters as an overall mean across the environments. AMMI stability analysis indicated the variety Vangelis was broadly or narrowly stable under different environments and reflected somewhat good performance for most studied traits, while Klara and Volna were considered very promising as above stable ones using GGE Biplot graphs. The findings indicated that GGE Biplot graphs are more accurate and more informative as compared to AMMI stability analysis.

**Keywords:** Sugar beet, stability, AMMI, biplot graphs, AMMI, stability value, selection index

## Introduction

Sugar beet (*Beta vulgaris* L.) belongs to Chenopodiaceae sub-family and the Amaranthaceae family is commercially cultivated as a main source of sugar in Egypt (Abu-Ellail et al. 2021). It is considered as economically very important, agricultural crop used as an industrial crop. It produces a conical root that is almost completely buried under the soil surface giving a high soluble sugar content that depends on several important factors e.g., season, climatic change, cultivation region, agricultural practices, harvest time, and post-harvest practices etc. In Egypt, sugar beet is the spearhead for horizontal expansion and cultivation in newly reclaimed lands due to its salt tolerance, produce sugar yield under lower water requirement than sugarcane crop (Abu-Ellail et al. 2019; Abu-Ellail and Sasy 2021). Unfortunately, sugar beet does not produce beet seeds commercially under Egyptian climatic conditions, which forces the Egyptian government annually to import seeds at huge cost. It is, therefore, necessary to characterize the imported sugar beet varieties for their adaptability and productivity across the environments in Egyptian conditions in order to maximize the net return of the land and water unit and the cost.

The difference between sugar production and consumption in Egypt amounted to 17.21%, where the total sugar production was 2.79 million tons and the total sugar consumption was 3.370 million tons indicating that about 0.58 million tons must be imported annually from foreign

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countries. This difference between sugar production and consumption may be attributed to the increases in population density and the excessive consumption of sugar. However, sugar production from sugar beet in season 2022 reached 1.708 million tons, representing 61.2% of the total production of sugar, with a decrease of 0.127 million tons from the 2021 season, which is due to a decrease in the cultivated area by about 35 thousand feddans (Annonymous 2022). The decrease in the sugar yield may also be attributed to farmers who did not choose the appropriate sugar beet varieties that perform well under different environments.

One of the vital steps in most crop improvement programs is the evaluation of genotypes in diverse environments, locations, year of cultivation, sowing, and harvest time. The impact of harvest date on sugar beet is an important determinant of root and sugar yields (Al-Sayed et al. 2012; Alami et al. 2021; Altunbay and Kıllılt 2022). The stability of some sugar beet varieties during different planting and harvest dates was investigated by Curcic et al. (2018) who found that delaying the harvesting date reduces the sugar yield fluctuations among sugar beet varieties grown under different sowing dates as the quantitatively inherited traits are strongly affected by the genotype x environment (G x E) interactions. The stable genotype must give a high mean performance with low fluctuations among environments. It is well known that the nature of G x E interaction helps to select the high-yielding and stable genotypes (Gauch and Zobel 1996).

Various statistical models have been proposed including the two graphical presentations using additive main effects and multiplicative interaction (AMMI) analysis (Gauch 1988) and genotype main effect plus genotype x environment interaction (GGE Biplot graph) approach (Yan, 2001) for analyzing G x E interactions and mean performance to select stable varieties. Keeping in view the above, an investigation was carried out to evaluate the mean performance and stability of seven imported sugar beet varieties for root and sugar quality traits across the diverse environments using AMMI and GGE Biplot graph approaches to identify the superior varieties suitable and adaptable under Egyptian environmental conditions.

## Materials and methods

### *Materials and the experimental sites*

Seven sugar beet varieties are imported from different countries. The name of the companies developed and their place of origin is given in Table 1. The field experiment was conducted during 2021-2022 and 2022-2023 seasons at three locations, namely, Nubaria, El-Buhira governorate (latitude of 30° 37 N, longitude of 42° 07 E, and 34 m above sea level), Malawi Agricultural Research Station, El-Minya governorate (latitude of 28° 10′ N, longitude of 30° 75′ E and altitude of 55 m above sea level), and Sinnuris, El-Fayoum governorate (latitude of 29° 18 N and longitude of 30° 25 E and elevation of 13 m beyond sea level), Egypt. Harvesting dates, 180, 195 and 210 days after sowing were considered. Each harvest date was considered a separate experiment. Accordingly, there are 18 environments that represent the combination of three locations, two growing seasons (macro-environments), and three harvesting dates (micro-environment). The environments represent different conditions of soil types, climatic zones, and other agro-climatic items that may be facing sugar beet cultivation in Egypt (Table 2). The material was planted in a randomized complete block design (RCBD) with three replicates. The plot area was 21 $m^2$ (1/200 fed) that consisted of 6 ridges, 7 m in length, and 0.5 m in width with 0.2 m spacing between hills.

Table 2 shows the physical and chemical properties of soil samples that were analyzed according to Piper (1955). It is clear that EC values for Nubaria location were the lowest one in the soil salinity level followed by Malawi and Sinnuris while the largest nitrogen content was found at the same previous order of the three locations during the two seasons. The soil texture of Nubaria locations was sandy while it was silty clay loam for Sinnuris and Malawi locations.

Monthly meteorological data for the three locations during the two growth seasons are presented in Fig. 1. The sowing was done in the first week of September at all the locations in both seasons. Flooded irrigation was used for all experiments. Plants were thinned to ensure one plant/hill after the appearance of 4 leaves on the plant. During seedbed preparation, the recommended dose of phosphorus fertilizer was applied at the rate of 200 kg (15.5% $P_2O_5$). nitrogen fertilizer was applied with 90 kg of urea (46.5% N) split into two equal doses after thinning and four weeks later. Moreover, potassium fertilizer was applied at the rate of 48 kg/fed in the form of potassium sulfate (48% $K_2O$). Other agronomic practices were carried out as recommended in sugar beet fields.

### *Observations recorded*

At harvest, a random sample of ten guarded plants was taken to determine the root length $plant^{-1}$ (cm), root diameter $plant^{-1}$ (cm), root weight $plant^{-1}$ (g), top fresh weight $plant^{-1}$

**Table 1.** A list of names, companies, and origins of the tested mono germ sugar beet varieties

| S. No. | Sugar beet varieties | Company | Origin |
|---|---|---|---|
| 1 | Carma | MARIBO | Denmark |
| 2 | Fantazja | KHBC | Poland |
| 3 | FD18B4 018 | Florimond Desprez | France |
| 4 | SV2173 (desert) | SESVANDRHAVE | Belgium |
| 5 | Vangelis | SCHREIBERS | US |
| 6 | Volna | DLF Beet Seed | Italy |
| 7 | Klara | WHBC | Poland |

**Table 2.** The physical and chemical analyses of the soil sites before planting the material during the growth seasons

| Physical and chemical properties | Year 2021-2022 | | | Year 2022-2023 | | |
|---|---|---|---|---|---|---|
| | Sinnuris, El-Fayoum | Malawi, El-Minya | Nubaria, El-Buhira | Sinnuris, El-Fayoum | Malawi, El-Minya | Nubaria, El-Buhira |
| **Practical size distribution percent** | | | | | | |
| Sand % | 24.12 | 9.35 | 93.40 | 23.63 | 8.65 | 91.10 |
| Silt % | 39.35 | 54.45 | 4.30 | 38.73 | 53.52 | 6.20 |
| Clay % | 36.53 | 36.20 | 2.30 | 37.64 | 37.83 | 2.70 |
| Textural class | Silty clay loam | Silty clay loam | Sandy | Silty clay loam | Silty clay loam | Sandy |
| **Available macronutrients (mg/kg)** | | | | | | |
| N | 19.43 | 37.03 | 19.13 | 18.66 | 39.35 | 17.21 |
| P | 6.25 | 7.85 | 4.52 | 5.47 | 8.50 | 5.00 |
| K | 138.51 | 175.00 | 95.20 | 136.75 | 181.00 | 109.00 |
| **Soil properties** | | | | | | |
| pH | 8.20 | 8.00 | 8.10 | 7.67 | 8.10 | 7.90 |
| EC (ds/m) | 4.68 | 1.76 | 0.32 | 4.15 | 1.97 | 0.50 |
| O.M. (%) | 0.72 | 1.24 | 0.54 | 1.22 | 1.17 | 0.51 |
| $CaCO_3$ %(%) | 1.69 | 2.86 | 10.43 | 2.03 | 2.91 | 12.61 |
| **Soluble cations (meq/L)** | | | | | | |
| Ca++ | 15.17 | 9.78 | 1.00 | 13.42 | 8.45 | 1.59 |
| Mg++ | 7.22 | 2.72 | 0.50 | 8.54 | 2.75 | 0.56 |
| Na+ | 13.36 | 4.95 | 1.60 | 13.43 | 4.45 | 2.85 |
| K+ | 1.75 | 0.24 | 0.13 | 2.21 | 0.23 | 0.48 |
| **Soluble anions (meq/ L)** | | | | | | |
| $HCO_3^-$ | 2.14 | 3.68 | 0.50 | 2.00 | 3.25 | 1.00 |
| $CL^-$ | 21.20 | 5.80 | 2.05 | 20.44 | 4.90 | 3.50 |
| $SO_4^-$ | 14.16 | 8.21 | 0.68 | 15.16 | 7.73 | 0.98 |

(g). Also, juice quality was determined in samples having thirty harvested roots that were randomly selected and sent to sugar factories to determine the following parameters:

Impurities of juice, i.e. Na and K (meq/100 g beet) were determined in the lead acetate extract of fresh macerated root tissue using Flame Photometry method as described by Browen and Lilliand (1964); Alpha amino-nitrogen (meq/100 g beet) was determined using "ninhydrin hydrindantin" according to the method of Cooke and Scott (1993).

Quality traits such as sucrose percentage (Pol.%) were parametrically determined in a lead acetate extract of fresh minced root according to A.O.A.C. (2012), and sugar lost to molasses percentage (SLM%) was determined using the following equation described by Devillers (1988):

Sugar lost to molasses (SLM%) = 0.14 (Na + K) + 0.25 (α-amino N) + 0.50

Extractable sugar percentage (EXT%), which was calculated according to the equation of Dexter et al. (1967) as follows:

Extractable sugar (%) = Sucrose (%) - SLM% - 0.6

Sugar beet yields were recorded at harvest by uprooting all guarded plants in each plot, separating them into roots and tops and weighing them to estimate the following:

Root yield (ton/fed) was calculated from root weight of the experimental unit then converted into ton/fed and sugar yield (ton/fed) was calculated according to the method of Devilles (1988):

Sugar yield (ton/fed) = root yield (ton/fed) x extractable sugar (%)

### *Statistical analysis*

The additive main effects and multiplicative interaction (AMMI) is a statistical method that combines analysis of variance (ANOVA) and principal components analysis (PCA) into a unified approach (Gauch, 1988). The method first fits the usual analysis of variance (ANOVA) procedure and then partitioned multiplicative effects for G×E (genotype × environment) by principal component analysis. It is used as

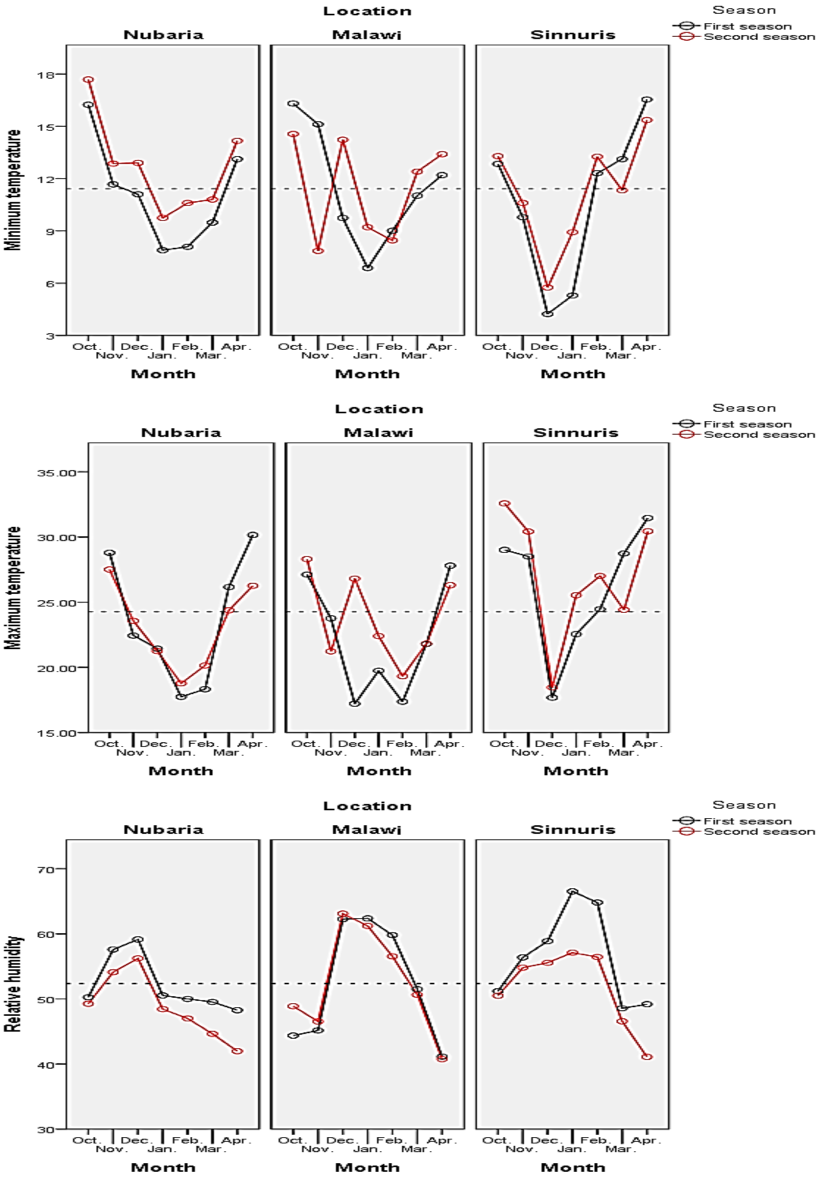

**Fig. 1.** Monthly meteorological data at Nubaria, El-Buhira governorate; Malawi, El-Minya governorate and Sinnuris, El-Fayoum governorate during the two growing seasons

an effective tool for understanding complex GxE interaction patterns. However, the AMMI model does not give a stability measure to quantify and rank genotypes in terms of yield stability. Accordingly, Purchase et al. (2000) proposed the AMMI Stability Value (ASV) which formulated as follows:

$$ASV = [[(PC_1\ SS \div PC_2\ SS)\ (PC_1\ score)]^2 + (PC_2\ score)^2]^{1/2}.$$

where, $PC_1$ and $PC_2$ are the 1st and 2nd principal components, respectively while $PC_1$ SS and $PC_2$ SS indicate the sum of squares of $PC_1$ and $PC_2$, respectively. The lowest ASV values expressed a more stable genotype across environments. The treatment means of each main factor (environments and varieties) were compared using least significant difference values (LSD) at 0.05 probability level. Using the rank of sugar beet varieties for each trait as a grand mean across environments (RT) and rank of AMMI stability value (RASV), a stability parameter namely genotype selection index (GSI) was calculated for each variety, as outlined by Farshadfar (2008): GSI = RASV + RT

The GGE biplot (Genotype main effect plus genotype by environment interaction) approach was proposed by Yan (2001) to analyze the multi-environment trial (MET) data using a graphical presentation. GGE biplot depends on principal components analysis to interpret the two items of genotype (G) and genotype x environment (GxE) interaction while the AMMI method interprets only the GxE interaction item. The graphical presentation of the biplot would be valid and reliable if the first two principal components ($PC_1$ and $PC_2$) explained the largest part (at least 70%) of the two items being genotype (G) and GxE interaction (Yan et al. 2007). Both the AMMI and GGE biplot methods produce a set of shapes that can visually represent Multi-Environment Trial (MET) data. However, as suggested by Yan (2011), GGE biplots are preferable to AMMI because they are a more information-rich tool. In accordance, with the present investigation, the GGE biplot graphs were used rather than AMMI graphs. The stability methods of AMMI analysis and GGE biplot graphs were applied to sugar beet crop by Ghareeb et al. (2014), Mostafavi et al. (2018), Bayomi et al. (2022) and Taleghani et al. (2023).

## Results and discussion

### *Analysis of variance*

The main source of variation for AMMI combined analysis of variance for root traits and sugar quality parameters for seven sugar beet varieties grown under 18 environments is presented in Table 3. The levene test proved the homogeneity of individual error variances for all studied traits (data not shown). The coefficient of variation (CV%) values were statistically acceptable and valid for all traits under study ranging from 4.9 for sugar lost to molasses percentage (SLM%) to 17.9 for root weight (Table 3).

Results showed the main effects of sugar beet varieties, environment and their G x E interactions were highly significant (*p-value* $< 0.01$) for all examined traits. Accordingly, AMMI analysis further divided the G x E interaction sum of squares (G x E, SS) using principal component analysis. It is revealed that the 1st and 2nd principal components ($PC_1$ and $PC_2$) were significant while the residual component was not significant for most studied traits. Yan (2011) reported that the best AMMI model prediction can be applied when the first two principal components ($PC_1$ and $PC_2$) are significant while the residual component is not significant. On the other hand, the combined analysis showed that the largest proportion of the total sum of squares was explained by environment item followed by G x E interaction effect while the lowest proportion of the total sum of squares belongs to sugar beet varieties. Zobel et al. (1988) and Gauch and Zobel (1996) stated that the environmental effect often explained the largest proportion of the total sum of squares while genotype and interaction items accounted for the lowest partitions. Taleghani et al. (2023) reported that the environmental conditions mask the plant's genetic potential, causing it to perform poorly in commercial fields. Partially, the gap between the yields measured in the experimental fields and those measured in the actual farmers' fields is estimated to exceed 30%. They confirmed that the main reason is the lack of genotype stability as a consequence of the G x E interaction effect.

When the phenotypic expression of a genotype has severely fluctuated among the different environments causing a significant G x E interaction; this may reduce the chance of the successful selection of superior genotypes. G x E interaction reduces the agreement between phenotypic and genotypic expression for the tested genotypes and reflects a bias in the estimation of genetic effects of traits making them less amenable to selection (Farshadfar et al. 2008). Results indicated that the largest proportion of the G x E interaction sum of squares was accounted for by the first two principal components ($PC_1$ and $PC_2$) whereas the residual item explained a trivial quantity of the GxE sum of squares. These results supported the validity and goodness of fit for the AMMI model and justified the use of AMMI stability value (ASV) and GGE biplot graphs for the stability study. The present findings are in support of previously reported results (Ghareeb et al. 2014; Abbasi and Bocianowski 2021; Bayomi et al. 2022).

### *Mean performance*

#### Environmental effect

Results revealed the presence of significant differences among the three environmental factors (season, location and harvesting date) in terms of all root traits and sugar quality parameters (Table 4). This result may be due to the tangible differences among eighteen environments in terms of climatic factors, and soil properties (Tables, 1 and 2) which affected the characteristics and productivity of sugar beet plants. It is appeared that most root traits and sugar quality parameters reflected good performance in the 2nd season compared to the 1st season which may be attributed to the different climatic conditions. However, the sugar beet plants cultivated at the Nubaria location gave the best root traits and sugar quality parameters followed by those cultivated at the Malawi location but the highest values of N, K, Na, and SLM% were recorded under the Sinnuris location indicating that this location was the poorest environment for cultivation sugar beet. As shown in Table 1 the Nubariya location had actually less saline soil and higher nitrogen content, while the Sinnuris region had the contrary pattern. These results are consistent with that of indicated in Table 2, with respect to the minimum and maximum air temperatures and relative humidity degrees at Sinnouris; El-Fayoum governorate reflected sharp up-down fluctuations during the two growing seasons affecting the chemical components of the sugar beet roots. The lately harvested sugar beet plants after 210 days gave good performance for most of the root traits and sugar quality parameters followed by those that have been harvested after 195 days, and early harvested after 180 days as well. Al-Sayed et al. (2012) elucidated that the sunny days and cool nights of the autumn season represent the best conditions for sugar production and storage in sugar beet. Mohamed and Yasin (2013) and Nagib et al. (2018) explained that sugar beet plants when stay in field for a long period of growth until harvest, have the advantage of accumulating more assimilates resulting from the photosynthesis process to

**Table 3.** AMMI combined analysis of variance for root traits and sugar quality parameters across the eighteen environments

| Source of variation | df | Mean square | | | | | |
|---|---|---|---|---|---|---|---|
| | | Root length | Root diameter | Root weight | Top fresh weight | Root yield | Sucrose % |
| Treatments | 125 | 32.23** | 17.13** | 130082** | 5023** | 59.4** | 13.42** |
| Environments | 17 | 198.03** | 93.31** | 484707** | 22664** | 258.15** | 77.29** |
| Genotypes | 6 | 36.46** | 10.13** | 733091** | 10483** | 285.78** | 30.53** |
| Interaction | 102 | 4.35** | 4.85** | 35506** | 1762** | 12.96** | 1.76** |
| PC$_1$ | 22 | 13.4** | 12.22** | 109758** | 5469** | 43.14** | 5.2** |
| PC$_2$ | 20 | 3.8* | 6.43** | 26433** | 1228** | 9.78** | 1.72 |
| Residuals | 60 | 1.21 | 1.61 | 11305 | 581 | 2.95 | 0.52 |
| CV % | | 6.2 | 10.9 | 17.9 | 13.9 | 9.2 | 5.6 |
| **Contribution % of the total sum of squares** | | | | | | | |
| Environments | | 73.62 | 64.59 | 41.83 | 36.70 | 52.77 | 67.46 |
| Genotypes | | 4.79 | 2.48 | 22.33 | 5.99 | 20.62 | 9.41 |
| GxE interaction | | 9.69 | 20.12 | 18.38 | 17.12 | 15.89 | 9.24 |
| PC$_1$ | | 6.45 | 10.95 | 12.26 | 11.46 | 11.41 | 5.87 |
| PC$_2$ | | 1.66 | 5.24 | 2.68 | 2.34 | 2.36 | 1.77 |
| Source of variation | df | N | K | Na | SLM% | Extractable sugar % | Sugar yield |
| Treatments | 125 | 0.465** | 0.869** | 0.952** | 0.134** | 13.63** | 3.984** |
| Environments | 17 | 2.585** | 2.156** | 2.54** | 0.5424** | 74.82** | 19.351** |
| Genotypes | 6 | 0.345** | 4.996** | 5.204** | 0.3197** | 36.74** | 16.896** |
| Interactions | 102 | 0.119** | 0.412** | 0.437** | 0.055** | 2.08** | 0.663** |
| PC$_1$ | 22 | 0.437** | 1.542** | 1.748** | 0.2341** | 6.69** | 2.481** |
| PC$_2$ | 20 | 0.0757** | 0.213** | 0.115 | 0.0087* | 1.66 | 0.373** |
| Residuals | 60 | 0.017 | 0.064 | 0.064 | 0.005 | 0.53 | 0.09 |
| CV % | | 6.7 | 13.1 | 16.1 | 4.9 | 6.3 | 10.9 |
| **Contribution % of the total sum of squares** | | | | | | | |
| Environments | | 72.08 | 26.54 | 29.46 | 49.86 | 64.38 | 61.41 |
| Genotypes | | 3.40 | 21.71 | 21.30 | 10.37 | 11.16 | 18.93 |
| GxE interaction | | 19.90 | 30.46 | 30.42 | 30.36 | 10.73 | 12.64 |
| PC$_1$ | | 15.76 | 24.57 | 26.24 | 27.85 | 7.45 | 10.19 |
| PC$_2$ | | 2.48 | 3.08 | 1.58 | 0.94 | 1.68 | 1.40 |

*and **: significant at 0.05 and 0.01 probability levels

store more dry matter in their roots. If the harvest time is delayed, all examined characteristics were increased, except root weight as also reported by Altunbay and Kıllılt (2022). The present results are in accordance with the findings of Ghareeb et al. (2014), Abu-Ellail et al. (2019) and Bayomi et al. (2022), who confirmed that root yield and its related traits of sugar beet plants are strongly affected by the surrounding environmental conditions in Egypt.

### Varietal effect

The varietal effect on the root traits and sugar quality parameters across the eighteen environments are given in Table 5. Significant differences were detected among sugar beet varieties for all root traits and sugar quality parameters which may be attributed to the different genetic makeup and origin of these imported varieties. Results indicated that the plants of Volna and Klara varieties recorded the

**Table 4.** Mean values of root traits and sugar quality parameters as affected by the eighteen environments (Env.)

| Year | Locations | Harvest date | Env. code | Root length | Root diameter | Root weight | Top weight | Root yield | Sucrose % |
|---|---|---|---|---|---|---|---|---|---|
| 2021/2022 | Nubaria, El-Buhira | 180 days | E1 | 24.62 | 9.72 | 678.21 | 178.41 | 21.31 | 17.52 |
| | | 195 days | E2 | 26.62 | 11.21 | 753.31 | 199.37 | 25.17 | 19.38 |
| | | 210 days | E3 | 28.75 | 12.86 | 958.98 | 226.05 | 22.26 | 21.57 |
| | Malawi, El-Minya | 180 days | E4 | 21.71 | 8.47 | 476.37 | 127.93 | 17.77 | 16.53 |
| | | 195 days | E5 | 23.93 | 10.13 | 560.41 | 149.04 | 17.20 | 18.44 |
| | | 210 days | E6 | 26.15 | 12.75 | 685.22 | 173.05 | 20.81 | 20.99 |
| | Sinnuris, El-Fayoum | 180 days | E7 | 17.56 | 7.38 | 410.86 | 115.10 | 16.24 | 15.70 |
| | | 195 days | E8 | 19.92 | 8.55 | 511.21 | 133.44 | 15.56 | 17.10 |
| | | 210 days | E9 | 22.55 | 10.33 | 593.36 | 154.59 | 19.51 | 19.51 |
| 2022/2023 | Nubaria, El-Buhira | 180 days | E10 | 24.06 | 11.60 | 617.44 | 149.68 | 24.38 | 19.38 |
| | | 195 days | E11 | 25.89 | 13.06 | 739.20 | 171.79 | 22.92 | 20.56 |
| | | 210 days | E12 | 27.72 | 14.38 | 935.37 | 205.32 | 29.06 | 22.51 |
| | Malawi, El-Minya | 180 days | E13 | 20.64 | 9.04 | 518.16 | 127.63 | 21.60 | 18.46 |
| | | 195 days | E14 | 23.27 | 10.09 | 647.25 | 151.81 | 20.39 | 19.79 |
| | | 210 days | E15 | 25.66 | 12.69 | 761.16 | 193.24 | 25.77 | 21.94 |
| | Sinnuris, El-Fayoum | 180 days | E16 | 19.14 | 7.54 | 444.64 | 107.28 | 20.13 | 17.30 |
| | | 195 days | E17 | 20.95 | 7.93 | 572.63 | 134.71 | 19.15 | 18.56 |
| | | 210 days | E18 | 23.31 | 9.60 | 631.77 | 169.77 | 22.97 | 20.30 |
| LSD $_{0.05}$ | | | | 0.94 | 0.61 | 81.0 | 58.64 | 0.83 | 0.52 |
| Year | Locations | Harvest date | | N | K | Na | SLM | EXT. % | Sugar yield |
| 2021/2022 | Nubaria, El-Buhira | 180 days | E1 | 1.27 | 1.90 | 1.53 | 1.30 | 15.62 | 3.33 |
| | | 195 days | E2 | 1.31 | 1.89 | 1.79 | 1.34 | 17.44 | 4.39 |
| | | 210 days | E3 | 1.40 | 2.09 | 1.84 | 1.40 | 19.56 | 4.37 |
| | Malawi, El-Minya | 180 days | E4 | 1.31 | 1.90 | 1.71 | 1.33 | 14.59 | 2.61 |
| | | 195 days | E5 | 1.33 | 2.04 | 1.95 | 1.39 | 16.45 | 2.83 |
| | | 210 days | E6 | 1.44 | 2.24 | 2.04 | 1.46 | 18.93 | 3.99 |
| | Sinnuris, El-Fayoum | 180 days | E7 | 1.23 | 2.17 | 2.03 | 1.40 | 13.71 | 2.25 |
| | | 195 days | E8 | 1.33 | 2.40 | 2.23 | 1.48 | 15.02 | 2.36 |
| | | 210 days | E9 | 1.47 | 2.53 | 2.49 | 1.57 | 17.34 | 3.42 |
| 2022/2023 | Nubaria, El-Buhira | 180 days | E10 | 1.49 | 1.94 | 1.47 | 1.35 | 17.43 | 4.25 |
| | | 195 days | E11 | 1.71 | 2.28 | 1.84 | 1.50 | 18.46 | 4.23 |
| | | 210 days | E12 | 1.57 | 2.41 | 2.05 | 1.52 | 20.39 | 5.93 |
| | Malawi, El-Minya | 180 days | E13 | 1.42 | 1.68 | 1.60 | 1.31 | 16.54 | 3.57 |
| | | 195 days | E14 | 1.84 | 2.03 | 1.97 | 1.52 | 17.67 | 3.61 |
| | | 210 days | E15 | 2.04 | 1.85 | 2.22 | 1.58 | 19.76 | 5.13 |
| | Sinnuris, El-Fayoum | 180 days | E16 | 2.12 | 2.44 | 2.27 | 1.69 | 15.01 | 3.03 |
| | | 195 days | E17 | 2.19 | 2.72 | 2.50 | 1.78 | 16.18 | 3.12 |
| | | 210 days | E18 | 2.32 | 2.84 | 2.74 | 1.86 | 17.84 | 4.15 |
| LSD $_{0.05}$ | | | | 0.06 | 0.36 | 0.23 | 0.08 | 0.50 | 0.17 |

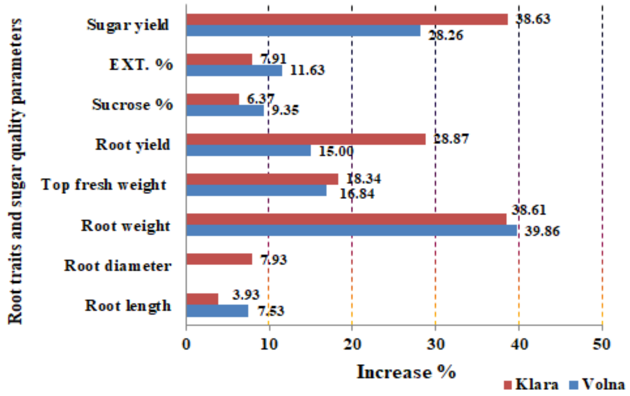

**Fig. 2.** The increase percentage for Volna and Klara varieties over the other varieties regarding root traits and juice quality parameters

highest values of all root traits and sugar quality parameters except for juice impurities characteristics. The plants of Volna and Klara varieties were 7.53 and 3.93% longer than the grand mean of the other varieties in terms of root length, respectively while the Klara variety recorded 8.5% as an increase percentage in root diameter over the other varieties. Also, the maximum root weight was produced by the two varieties; Volna and Klara which recorded significant increase rates of 39.86 and 38.61%, respectively over the root weight average of the others. These results indicate that Volna and Klara varieties have a strong root system, which supports their ability to cultivate in the new reclamation lands. Regarding top fresh weight, it is found that Volna and Klara varieties gave considerable increase rates of 16.84 and 18.34% compared to the average of the rest varieties. As a biological rule, when the top fresh weight increases, both the chlorophyll content and the photosynthesis process increase which positively reflects on the sugar storage in the roots. It is exhibited that Volna and Klara varieties significantly surpassed all other varieties in terms of root yield, sucrose%, sugar extractable %, and sugar yield (Table 5). They recorded meaningful increase percentages being 28.87 and 15 % for root yield, 9.35 and 6.37% for sucrose%, 11.63 and 7.91 for sugar extractable%, and 28.26 and 38.63% for sugar yield, respectively. The aforementioned results were graphically summarized in Fig. 2.

Considering juice impurities characteristics, the mean values of K, Na, and SLM% for Volna and Klara varieties were significantly decreased over the other sugar beet varieties recording reduction percentages being 25.36% for K, 31.18 and 26.16% for Na and 11.76 and 7.84% for sugar lost to molasses percentage (SLM%), respectively as outlined in Fig. 3. Although results confirmed that Volna and Klara varieties are the best ones regarding root and sugar yield, and juice quality parameters, but if the G x E interaction effect is significant, then the using of grand mean across environments as a measure of genotype behavior is a matter of doubt. Consequently, it is important to run a combined analysis to ensure the existence of significant or insignificant interaction effects and identify the stable varieties using stability methods (Elwan and Helmy 2018; Abu-Ellail et al. 2019 ; Abu-Ellail and Sasy 2021).

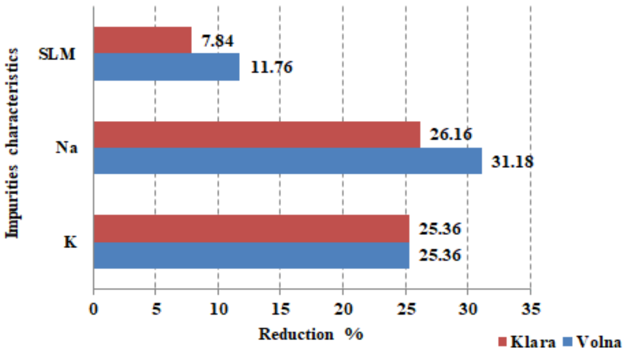

**Fig. 3.** The reduction percentage of Volna and Klara varieties over the other varieties regarding impurities parameters

## *Stability analysis*

### The AMMI model

Principal components analysis (PCA) is a multivariate analysis method that describes data patterns regarding similarities/dissimilarities among variables (genotypes or environments) based on various mathematical methods. The PCA scores of genotype may be positive or negative values that express its fluctuating performance across the environments (Yan and Hunt 2001). Consequently, near zero PCA scores of genotype represent its phenotypic expression is less fluctuating and more stable across environments. The AMMI model is statistically dependent on the PCA approach but it does not provide a quantitative measure to test genotypes for stability (Gauch 1992; Gauch and Zobe 1996). Accordingly, the AMMI Stability Value (ASV) was proposed by Purchase et al. (2000) to quantify and rank genotypes for stability where a genotype had the lowest ASV score is the most stable one. Stability proper itself is not enough as a selection parameter for the elite genotype because the stable genotype may not give the best mean performance; therefore, there was a need to find a measure that combines stability and good performance of the genotype in a single index (Farshadfar 2008). In this respect, the genotype selection index (GSI) is another stability parameter calculated by ranking the mean trait of genotypes across environments and ranking of AMMI stability value. Bearing in mind that the lowest ASV value is ranked one, while the highest trait mean is ranked one, the ranks are then summed in a single simultaneous selection index being (GSI) where the lowest value of this parameter shows a stable genotype with a high mean trait.

Estimates of mean rank, AMMI stability value (ASV) and its rank, and GSI for sugar beet varieties are summarized in Table 6. Results indicated that Carma and Fantazia varieties revealed an average stability in terms of root length trait

**Table 5.** Mean values of root traits and sugar quality parameters as affected by sugar beet varieties across eighteen environments

| Sugar beet varieties | Studied traits | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Root Length (cm) | Root Diameter (cm) | Root Weight (g) | Top fresh weight (g) | Root Yield (tons/fed) | Sucrose % | N | K | Na | SLM% | EXT. % | Sugar Yield (tons/fed) |
| Carma | 23.47 | 10.43 | 576.63 | 141.80 | 19.99 | 18.76 | 1.51 | 2.29 | 2.12 | 1.49 | 16.66 | 3.37 |
| Fantazja | 23.75 | 10.68 | 563.17 | 155.71 | 19.72 | 19.01 | 1.56 | 2.46 | 2.24 | 1.55 | 16.87 | 3.38 |
| FD18B4018 | 22.75 | 9.77 | 517.13 | 150.85 | 19.64 | 18.86 | 1.56 | 2.46 | 2.20 | 1.54 | 16.72 | 3.35 |
| SV2173(desert) | 22.39 | 10.18 | 566.30 | 153.30 | 20.06 | 18.59 | 1.65 | 2.35 | 2.19 | 1.55 | 16.44 | 3.35 |
| Vangelis | 23.10 | 10.50 | 648.11 | 156.94 | 20.50 | 18.65 | 1.60 | 2.23 | 2.22 | 1.52 | 16.53 | 3.43 |
| Volna | 24.83 | 10.16 | 803.17 | 177.27 | 22.98 | 20.53 | 1.58 | 1.76 | 1.51 | 1.35 | 18.58 | 4.33 |
| Klara | 24.00 | 11.13 | 795.98 | 179.54 | 25.75 | 19.97 | 1.75 | 1.76 | 1.62 | 1.41 | 17.96 | 4.68 |
| $LSD_{0.05}$ | 0.55 | 0.43 | 43.47 | 8.40 | 0.74 | 0.40 | 0.04 | 0.11 | 0.12 | 0.03 | 0.41 | 0.15 |

where they occupied middle-ranking positions for both ASV value the grand mean of root length. Regarding root diameter and root weight, Vangelis variety was considered the more stable variety because it recorded the lowest ASV values but it was ranked the third one among the varieties in terms of the grand mean of these two traits. Also, the Vangelis variety was the desirable one for the selection of top fresh weight, root yield, and sugar yield where it was ranked the first or second in terms of ASV values with medium grand mean values of these traits.

With regard to juice impurities, the good variety must achieve the lowest values, or in other words, the highest rank. In the same context, the Vangelis variety recorded somewhat low values of K and sugar lost to molasses percentage (SLM %) as well as it was average stable across the environments because it is ranked the third one in terms of stability parameter (ASV).

Concerning sucrose % and extractable sugar percentage (EXT %), Fantazja and FD18B4018 varieties would be adapted to be relatively stable since they ranked the third and second ones respecting ASV value but their mean values ranked the third and fourth ones in terms of these traits, respectively. For the N component, Fantazja variety was considered the highest stable one because it recorded the lowest ASV value and also it was ranked the sixth one recording low mean value of the N component while Carma variety was relatively stable and had the low mean values of Na and SLM components (Table 6). The other sugar beet varieties gave a high average value and less stability, and vice versa.

Yan and Tinker (2005) mentioned that the elite genotypes are expected to have high mean performance and stability across various environments but practically this elite genotype is rarely encountered. So, high mean performance and relatively stable genotypes could be used as the best alternative solution. Taleghani et al. (2023) used a modern set of stability parameters based on the AMMI and GGE biplot approaches to obtain a high degree of reliability in estimating the performance and stability of sugar beet varieties. It could be concluded from the previous results that the Vangelis variety was adapted to different environments and reflected good performance for most root and sugar yields and juice impurities traits, compared to the rest varieties.

## GGE biplot graph

The main effect of the genotype (G) plus G×E interaction (GGE Biplot) approach is based on the graphical presentation of a two-way table representing G x E interaction data. This method generates different types of graphs aimed at various goals. In our investigation, attention is focused on the selection of good performance and stable genotypes; hence the graph namely "genotype evaluation" or "mean vs. stability" would be only carried out and discussed. The view (mean vs. stability) is an efficient tool to visually assess genotypes based on their average performance and stability in different environments where the origin point of the graph represents the grand mean of a trait. The details and concepts of (the average vs. stability) graph may be summarized as follows: the line with a single arrow (abscissa) passing through the origin point is called the Average Environmental Coordinate (AEC). The direction of the arrow indicates a genotype with a higher average performance. The small circles on this line represent the average of the $PC_1$ and $PC_2$ scores for the environments. However, the line (ordinate) passes through the biplot origin and is perpendicular to the AEC line reflecting stability. In accordance, genotypes that are closer to the AEC line in both directions would be stable, and vice versa. Undoubtedly, GGE biplot graph becomes more understandable when a few genotypes and environments are used. When many genotypes and environments are used, the graph becomes crowded, making it difficult to interpret. Reddy et al. (2022)

**Table 6.** Estimates of mean rank, AMMI stability value (ASV) and its rank, and Genotype Selection index (GSI) for sugar beet varieties

| Genotype | Mean rank | ASV | ASV rank | GSI | Mean rank | ASV | ASV rank | GSI | Mean rank | ASV | ASV rank | GSI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Root length | | | | Root diameter | | | | Root weight | | | |
| Carma | 4 | 3.09 | 3 | 7 | 4 | 2.46 | 4 | 8 | 4 | 46.47 | 5 | 9 |
| Fantazja | 3 | 3.28 | 4 | 7 | 2 | 3 | 5 | 7 | 6 | 46.1 | 4 | 10 |
| FD18B4018 | 6 | 2.9 | 2 | 8 | 7 | 2.34 | 3 | 10 | 7 | 23.59 | 2 | 9 |
| SV2173(desert) | 7 | 2.62 | 1 | 8 | 5 | 1.01 | 2 | 7 | 5 | 31.81 | 3 | 8 |
| Vangelis | 5 | 3.52 | 5 | 10 | 3 | 0.68 | 1 | 4 | 3 | 19.52 | 1 | 4 |
| Volna | 1 | 7.27 | 6 | 7 | 6 | 3.6 | 6 | 12 | 1 | 86.23 | 7 | 8 |
| Klara | 2 | 7.31 | 7 | 9 | 1 | 3.6 | 7 | 8 | 2 | 73.94 | 6 | 8 |
| | Top fresh weight | | | | Root yield | | | | Sucrose % | | | |
| Carma | 7 | 6.89 | 1 | 8 | 5 | 4.36 | 2 | 7 | 5 | 2.58 | 4 | 9 |
| Fantazja | 4 | 28.32 | 4 | 8 | 6 | 6.39 | 5 | 11 | 3 | 2.1 | 3 | 6 |
| FD18B4018 | 6 | 30.51 | 5 | 11 | 7 | 6.32 | 4 | 11 | 4 | 1.88 | 2 | 6 |
| SV2173(desert) | 5 | 16.72 | 3 | 8 | 4 | 5.39 | 3 | 7 | 7 | 0.88 | 1 | 8 |
| Vangelis | 3 | 7.63 | 2 | 5 | 3 | 2.53 | 1 | 4 | 6 | 3 | 5 | 11 |
| Volna | 2 | 37.64 | 7 | 9 | 2 | 12.51 | 7 | 9 | 1 | 4.81 | 6 | 7 |
| Klara | 1 | 36.95 | 6 | 7 | 1 | 11.55 | 6 | 7 | 2 | 4.88 | 7 | 9 |
| | N | | | | K | | | | Na | | | |
| Carma | 7 | 0.77 | 4 | 11 | 4 | 2.7 | 2 | 6 | 5 | 7.177 | 2 | 7 |
| Fantazja | 6 | 0.38 | 1 | 7 | 2 | 2.12 | 1 | 3 | 1 | 4.674 | 1 | 2 |
| FD18B4018 | 5 | 0.51 | 3 | 8 | 1 | 5.15 | 5 | 6 | 3 | 7.865 | 3 | 6 |
| SV2173(desert) | 2 | 0.48 | 2 | 4 | 3 | 4.69 | 4 | 7 | 4 | 8.568 | 4 | 8 |
| Vangelis | 3 | 0.82 | 5 | 8 | 5 | 2.72 | 3 | 8 | 2 | 9.016 | 5 | 7 |
| Volna | 4 | 1.18 | 6 | 10 | 6 | 8.6 | 6 | 12 | 7 | 20.89 | 7 | 14 |
| Klara | 1 | 1.19 | 7 | 8 | 7 | 8.6 | 6 | 13 | 6 | 16.34 | 6 | 12 |
| | Sugar lost to molasses percentage (SLM %) | | | | Extractable sugar percentage (EXT %) | | | | Sugar yield | | | |
| Carma | 5 | 8.15 | 2 | 7 | 5 | 3.264 | 4 | 9 | 5 | 2.88 | 1 | 6 |
| Fantazja | 2 | 4.83 | 1 | 3 | 3 | 2.843 | 3 | 6 | 4 | 4.75 | 5 | 9 |
| FD18B4018 | 3 | 9.45 | 4 | 7 | 4 | 2.691 | 2 | 6 | 7 | 3.7 | 4 | 11 |
| SV2173(desert) | 1 | 9.53 | 5 | 6 | 7 | 1.443 | 1 | 8 | 6 | 3.59 | 3 | 9 |
| Vangelis | 4 | 8.26 | 3 | 7 | 6 | 4.114 | 5 | 11 | 3 | 3.17 | 2 | 5 |
| Volna | 7 | 21 | 7 | 14 | 1 | 6.986 | 7 | 8 | 2 | 9.67 | 7 | 9 |
| Klara | 6 | 19.2 | 6 | 12 | 2 | 6.855 | 6 | 8 | 1 | 8.16 | 6 | 7 |

and Yadawad et al. (2023) automated the biplot graph method to select the stable and high-yielding genotypes of pearl millet and sugar cane, respectively. They stated that using AMMI and GGE to interpret the GxE interaction is an excellent tool in guiding the selection of stable and superior varieties. It is obvious from Figs. 4, 5 and 6 that GGE biplot graphs for all studied traits show validity and goodness of fit where the percentages of total variation explained by the first two principal components ($PC_1$ and $PC_2$) were more than 75 %. Considering root length; Fig. 4A shows that the varieties that had above-average root lengths were descending ranked as follows: Volna > Klara > Fantazia, where they are located to the right side of the origin point (grand mean), but the three varieties were unstable because they placed away from AEC abscissa. However, the Vangelis variety was almost located on AEC line reflecting its above

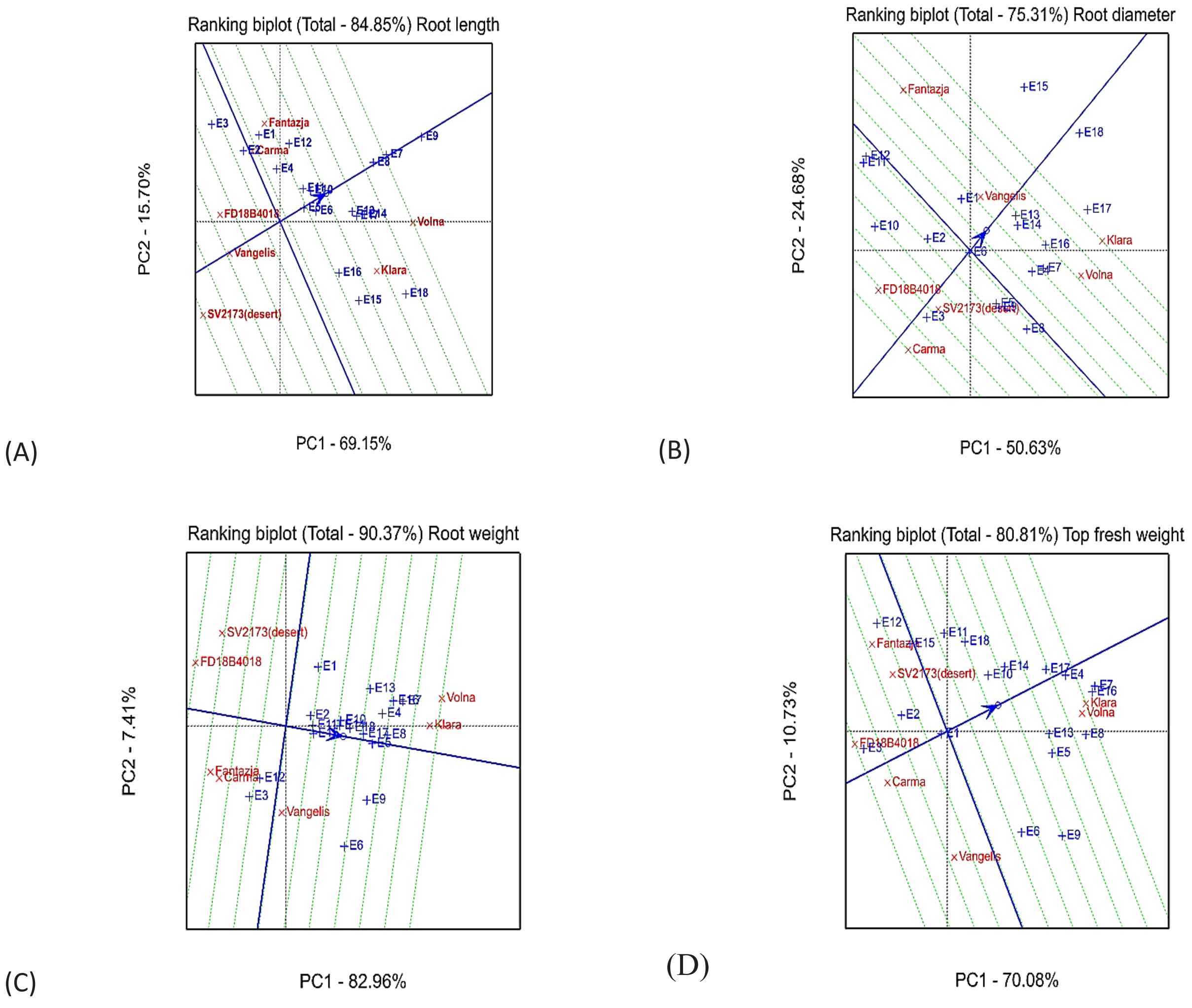

**Fig. 4.** The mean vs. stability view of the GGE biplot for root length, root diameter, root weight and top weight

stability in spite of its low root length.

On the other hand, Volna, Klara, and Fantazia varieties were unstable across environments in terms of root diameter in spite of their averages surpassing the grand mean (Fig. 4B). Vangelis variety was average stable (located close to Abscissa) and its root diameter was more than the grand mean. Results are in agreement with the findings of Taleghani et al. (2023) who concluded that the application of different stability analysis methods not only helps to evaluate different aspects of G x E interaction properties but also allows for a more accurate selection of stable genotypes. They added that the multi-trait stability index (MTSI) may be useful because of its ability to simultaneously select stable genotypes based on multiple traits. It is shown in Fig. 4C that Klara variety had above-average root weight, as well as it was located near the Average Environmental Coordinate (AEC) indicating its average stability while the other varieties were unstable. Moreover, Klara, Volna, Carma and FD18B4018 varieties showed average stability in terms of top fresh weight but only Klara and Volna varieties recorded top fresh weight averages surpassed the grand mean (Fig.4D).

Data in Fig. 5 shows the mean vs. stability view of the GGE biplot for root yield, sucrose%, N, and K. With regard to root yield and sucrose % traits, it was found that Klara was an ideal variety characterized by above-averages for the two traits and a high degree of stability while Volna variety reflected average stability. Biplot graphs charts allow genotypes to be grouped based on their similarity in performance in different environments (Oroian et al. 2023).

In the case of juice impurities contents, it is axiomatic that the elite variety must contain the lowest percentage of these impurities contents (below-average that is located on the left side of the origin point in the GGE biplot graph). Carma and Klara varieties can be judged to be more stable ones across different environments in addition they had the

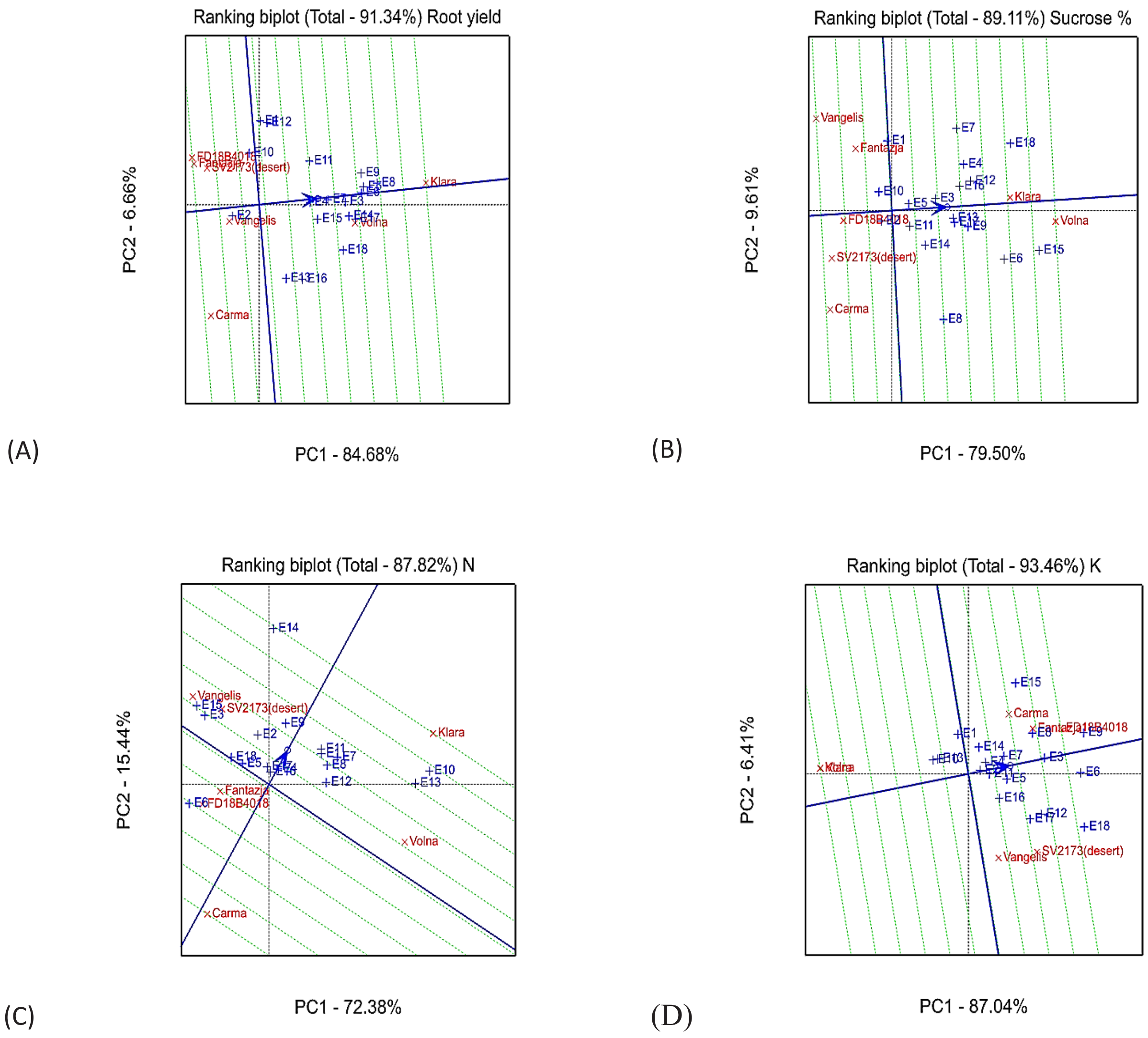

**Fig. 5.** The mean vs. stability view of the GGE biplot for root yield, sucrose %, N and K

lowest mean values in terms of N and K contents (Figs. 5C and D). These results are in agreement with those obtained by Korshid (2016) who found that biplot analysis was a good statistical tool for screening salinity-tolerant genotypes of sugar beet lines.

Fig. 6 depicts the mean vs. stability view of the GGE biplot for Na, SLM, extraction%, and sugar yield. In light of the same previous rules, it was evident that Volna and Klara varieties had the lowest Na content averages, as well as they reflected average stability across the environments as shown by their points located close to Abscissa (Fig. 6A). For sugar lost to molasses percentage (SLM%), it is proved that there was no sugar beet variety that could combine the lowest SLM% content and the phenomenon of stability (Fig. 6B). Indeed, both Volna and Klara varieties gave the lowest values of SLM% content, but they were positioned far from the AEC line indicating instability. Pour-Aboughaddareh et al. (2022) revealed eight practical merits of the GGE Biplot graphs when used in the stability study. Figures 6C and 6D show that Klara and Volna varieties produced high mean values of extractable sugar percentage and sugar yield but Klara variety was almost placed on AEC line reflecting its perfect stability while Volna variety was average stable because its point fell near AEC line. Mostafavi et al. (2018) showed that AMMI and GGE Biplot methods were highly efficient in demonstrating the sugar beet varieties' behavior across different environments and provided useful information for sowing adequate varieties in specific environments. They added that it must avoid resource waste and increase the biological gain by sowing the appropriate variety for each region. It can be concluded that Klara and Volna varieties are considered very promising and out of the competition

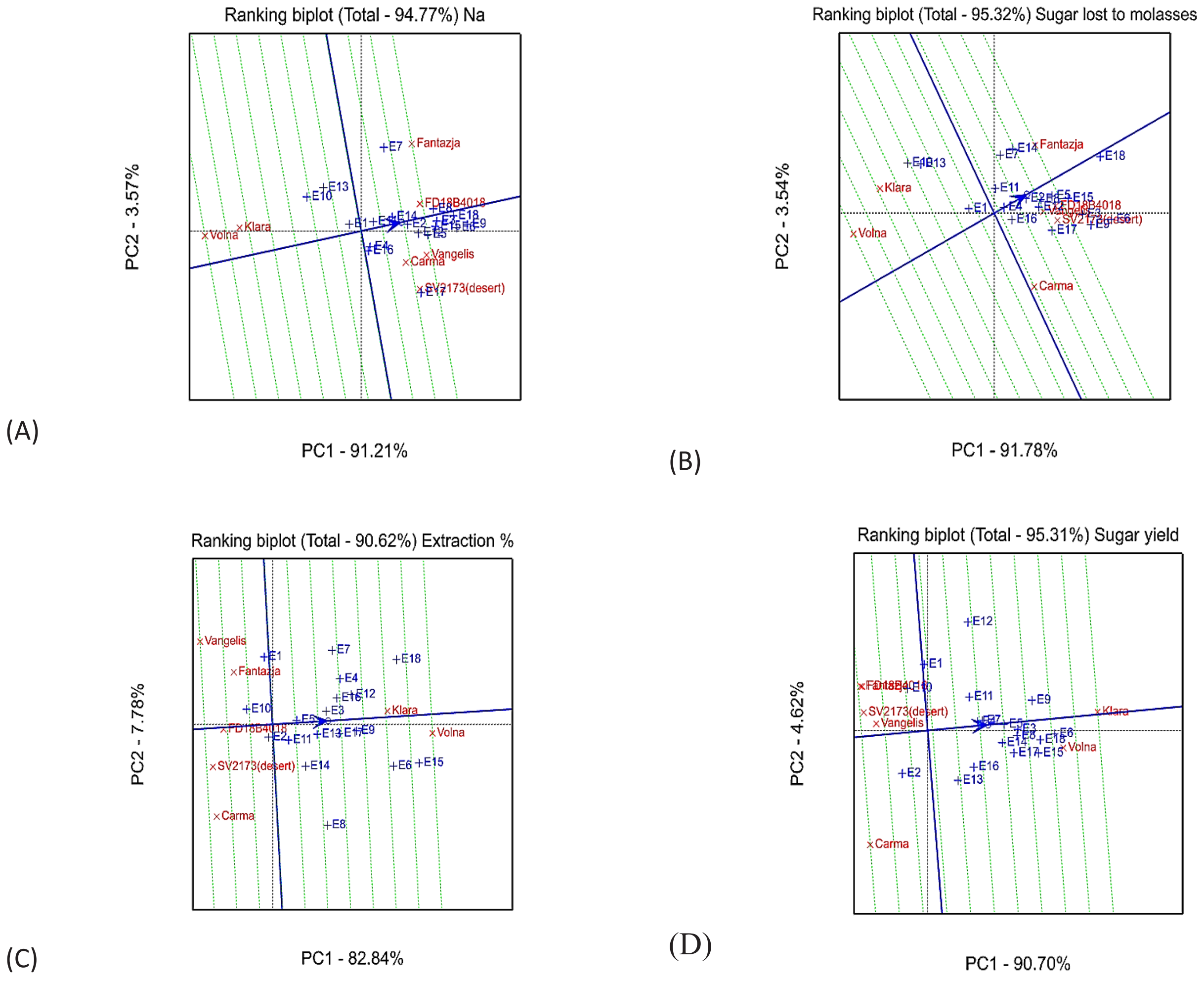

**Fig. 6.** The mean vs. stability view of the GGE biplot for Na, SLM, extraction % and sugar yield

because they showed remarkable stability, and at the same time they gave a good mean performance for the most important root traits and sugar quality parameters such as root yield, sucrose %, extractable sugar percentage and sugar yield. Therefore, Klara and Volna varieties might be incorporated in the future plans for sugar beet commercial cultivation in Egypt after further evaluation in other regions.

It was expected that there would be differences in the results between the two methods of studying stability (AMMI and GGE biplot graph) due to the different mathematical philosophies of each. It is known that AMMI method partitioned G×E (genotype × environment) interaction component of combined ANOVA using principal component analysis, while GGE Biplot method used the two items i.e. genotype component + G×E (genotype × environment) interaction component, which makes GGE biplot method is more informative. One of the advantages of AMMI method is giving a single value measure AMMI stability value ASV for estimating the stability. However, one of the criticisms directed to ASV as a stability measure, there is no statistical test to determine the significance of ASV values. On the other hand, the effectiveness of the GSI as a stability parameter is questionable because it is based on ranks similar to non-parametric methods (Morsy et al. 2017). Yan et al. (2007) and Yan (2011) compared AMMI and GGE Biplot graphs as stability methods and decided that GGE biplot method is superior, more effective, and more informative than AMMI method.

## Authors' contribution

Conceptualization of research (FFBA, WMF); Designing of the experiments (FFBA, WMF); Contribution of experimental materials (FFBA, KAS, YMA); Execution of field/lab experiments and data collection (FFBA, KAS, YMA); Analysis of data and interpretation (FFBA, WMF); Preparation of the manuscript (FFBA, WMF).

## References

A.O.A.C. 2012. Official methods of analysis, Association of official analytical chemist 19th edition, Washington D.C., USA.

Abbasi Z. and Bocianowski J. 2021. Genotype by environment interaction for physiological traits in sugar beet (*Beta vulgaris* L.) parents and hybrids using additive main effects and multiplicative interaction model. Euro. Food Rese. Technol., **247**: 3063–3081.

Abu-Ellail F.F.B. and Sasy A. H. 2021. GT Biplot analysis for yield and related traits in some sugar beet, as affected by compost under saline soil. 2021. Egypt. J. Appl. Sci., **36**(3): 66-83. https://doi.org/10.21608/ejas.2021.163587.

Abu-Ellail F.F.B., Sadek K.A. and El-Bakary H.M.Y. 2019. Broad sense heritability and performance of ten sugar beet varieties for growth, yield and juice quality under different soil salinity levels. Egypt. J. Agric. Sci., **70**: 327–339. https://doi.org/10.21608/ejarc.2019.211070.

Abu-Ellail F.F.B., Salem K.F.M., Saleh M.M., Alnaddaf L.M. and Al-Khayri J.M. 2021. Molecular Breeding Strategies of Beetroot (*Beta vulgaris* ssp. *vulgaris* var. *conditiva* Alefeld). In: Al-Khayri J.M., Jain S.M., Johnson D.V. (eds) Advances in Plant Breeding Strategies: Vegetable Crops. Springer, Cham. pp 157–212. https://doi.org/10.1007/978-3-030-66965-2_4.

Alami L., Terouzi W., Otmani M., Abdelkhalek O., Salmaoui S. and Mbarki M. 2021. Effect of sugar beet harvest date on its technological quality parameters by exploratory analysis. J. Food Quality, https://doi.org/10.1155/2021/6639612.

Al-Sayed H.M., Abd El-Razek U.A., Sarhan H.M. and Hayam S. F .2012. Effect of harvest dates on yield and quality of sugar beet varieties. Aust. J. Basic Appl. Sci., **6**(9): 525-529.

Altunbay S.G. and Kıllı F. 2022. Cultivar and harvesting date effect on yield, yield components and some technological characteristics of sugar beet (*Beta vulgaris* L.). Inter. J. Sci. Engine. Sci., **6**(8): 34-37.

Annonymous 2022. Annual Report of the Sugar Crops Council, December 2022, Egypt

Bayomi K.E.M., El-Hashash E.F., Ghura N.S.A. and El-Absy K.M. 2022. Genotype by Environment interaction effects on the crop of sugar beet (*Beta vulgaris* L.) using multivariate analysis. Asian J. Res. Crop Sci., **7**(4): 135-149.

Browen J.D. and Lilliand D.1964. Rapid determination of potassium and sodium in plant materials and soil extracts by flame photometric. In: Proc. Amer. Soc. Hort. Sci., 341–346.

Cooke D.A. and Scott R. K. 1993. The sugar beet crop. Chapman and Hall London, pp. 262-265.

Curcic Z., Ciric M., Nagl N. and Taski-Ajdukovic K. 2018. Effect of sugar beet genotype, planting and harvesting dates and their interaction on sugar yield. Front. Plant Sci., **9**: 1-9.

Devillers P. 1988. Prevision du sucre melasse. Scurries Fr., **129**: 190–200.

Dexter S.T., Frakes M.G. and Snyder F.W. 1967. A rapid and practical method of determining extractable white sugar as may be applied to the evaluation of agronomic practices and grower deliveries in the sugar beet industry. J. Am. Soc. Sugar Beet Technol., **14**: 433–454. https://doi.org/10.1016/j.eja.2021.126262

Elwan A.M. and Helmy S.A.M. 2018. Yield and technological characteristics of sugar beet as affected by sowing date, nitrogen level and harvesting age. J. Plant Prod., Mansoura Univ., **9**(4): 345–352.

Farshadfar E. 2008. Incorporation of AMMI stability value and grain yield in a single non-parametric index (GSI) in bread wheat. Pak. J. Biol. Sci., **11**: 1791-1796.

Gauch H.G. 1988. Model selection and validation for yield trials with interaction. Biometrics, **44**: 705-715.

Gauch H.G. and Zobel R.W. 1996. AMMI analysis of yield trials. In: Kang M.S. and H. G. Gauch (eds) Genotype by environment interaction. CRC Press. Boca Raton, Florida, USA.

Gauch H.G. 1992. Statistical analysis of regional yield trials: AMMI analysis of factorial designs. Elsevier, Amsterdam, The Netherlands.

Ghareeb Z. E., Ibrahim H. E.A., Elsheikh S.R.E. and Bachoash S.M.I. 2014. Genotype × environment interaction for characteristics of some sugar beet genotypes. J. Plant Prod., Mansoura Univ., **5**(5): 853-867.

Korshid A. 2016. Biplot analysis of salinity tolerance indices in sugar beet breeding lines. Adv Plants Agric. Res., 5(2): 495–499.

Levene H. 1960. Robust tests for equality of variances. In Ingram Olkin, Harold Hotelling, Italia, Stanford, Univ. Press, PP. 278-292.

Mohamed H.Y. and Yasin M.A.T. 2013. Response of some sugar beet varieties to harvesting dates and foliar application of boron and zinc in sandy soils. Egypt. J. Agron., **35**(2): 227-252.

Morsy A.R., Abdel-Rahman R.A., Fares W.M., El Hosary A.A.A., Ibrahim M.A., El-Noby M.A. and Abou-Zied A.A. 2017. Interpretation of genotype x environment interaction for soybean cultivar trials using different stability procedures. Egypt. J. Plant Breed., **21**(5): 536–553.

Mostafavi K., Orazizadeh M., Rajabi A. and Ilkaei M.N. 2018. Stability and stability analysis in sugar beet varieties for sugar content using GGE-biplot and AMMI methods. Bulgarian J. Agric. Sci., **24**(1): 40–45.

Nagib S.R., Abd El-Azez Y.M. and Ali A.M.K. 2018. Evaluation of some new sugar beet varieties as affected by different harvest ages under conditions of Minia governorate. J. Plant Prod., Mansoura Univ., **9**(12): 1175–1180.

Oroian C., Ugrutan F., Muresan I.C., Oroian I., Odagiu A., Petrescu-Mag I.V. and Burduhos P. 2023. AMMI Analysis of Genotype × Environment Interaction on Sugar Beet (*Beta vulgaris* L.) Yield, Sugar Content and Production in Romania. Agronomy 2023, **13**: 2549. https://doi.org/10.3390/agronomy13102549.

Piper C.S. 1955. Soil and plant analysis. Univ. of Adelaide, Australia, P.178.

Pour-Aboughadareh A., Khalili M., Poczai P. and Olivoto T. 2022. Stability indices to deciphering the genotype-by-environment interaction (GEI) effect: an applicable review for use in plant breeding programs. Plants, **11**: 414. https://doi.org/10.3390/plants11030414.

Purchase J.L., Hatting H. and Vandenventer Cs. 2000. Genotype x environment interaction of winter wheat (*T. aestivum*) in South Africa: stability analysis of yield performance. South African J. Plant Soil, **17**: 101–107.

Reddy P.S., Satyavathi C. Tara., Khandelwal V., Patil H.T., Narasimhulu R., Bhadarge H.H., Iyanar K., Talwar A.M., Sravanthi K. and Athoni B. K. 2022. GGE biplot analysis for identification of ideal cultivars and testing locations of pearl millet (*Pennisetum glaucum* L.R. Br.) for peninsular India. Indian J., Genet. Plant Breed., **82**(02): 167–176.

Taleghani D., Rajabi A., Saremirad A. and Fasahat P. 2023. Stability analysis and selection of sugar beet (*Beta vulgaris* L.)

genotypes using AMMI, BLUP, GGE biplot and MTSI. Scientifc Rep., **13**: 10019, https://doi.org/10.1038/s41598-023-37217-7.

Yadawad A., Patil S.B., Kongawad B.Y., Kadlag A.D. and Hemaprabha G. 2023. Multi environmental evaluation for selection of stable and high yielding sugarcane clones based on AMMI and GGE biplot models. Indian J. Genet. Plant Breed., **83**(3): 389-397.

Yan W. 2001. GGE biplot - a Windows application for graphical analysis of multi-environment trial data and other types of two-way data. Agron. J., **93**: 1111–1118.

Yan W. 2011. GGE Biplot vs. AMMI graphs for genotype x environment data analysis. J. Indian Soc. Agic. Stat., **65**(2): 181-193.

Yan W. and Tinker N.A. 2005. An integrated system of biplot analysis for displaying, interpreting, and exploring genotype–by-environment interactions. Crop Sci., **45**: 1004-1016.

Yan W. and Hunt L.A. 2001. Interpretation of genotype – environment interaction for winter wheat yield in Ontario. Crop Sci., **41**: 19-25.

Yan W., Kang M.S., Ma B., Woods S., and Cornelius P.L. 2007. GGE biplot vs. AMMI analysis of genotype-by-environment data. Crop Sci., **47**: 643–655.

Zobel R.W., Wright M.J. and Gauch H.G. 1988. Statistical analysis of yield trials. Agron. J., **80**: 338-393.