Utilizing GGE biplot analysis to evaluate Sugar Beet Varieties for yield and quality traits under Salicylic Acid Levels in Newly Reclaimed Soil

Farrag F.B. Abu-Ellail*, Arafat S.A. Saadan, Karam A. Sadek and Samar A.M. Helmy[1]

ABSTRACT

Two field experiments were conducted during the 2022/2023 and 2023/2024 seasons at a private farm in Mongaar Elmagabra village, Wadi El-Natrun, El-Beheira Governorate, Egypt, to evaluate the effect of salicylic acid (SA) rates (0, 100, 150, and 200 ppm/l) on yield and quality traits of four sugar beet varieties (Afendra-KWS, Shantala-KWS, BTS 8935, and BTS 7245) under sandy soil and drip irrigation conditions. The experimental design used a randomized complete block design (RCBD) with split-plot distribution and three replications. The results showed that root and sugar yields yield (ton/fed) increased with rising SA levels from 100 to 200 ppm/l during the both seasons. In contrast, molasses-forming substances decreased significantly at 100 ppm/l compared to 200 ppm/l. Sucrose and refined sugar content also increased with higher SA concentrations. Significant varietal differences were observed, with BTS 7245 and BTS 8935 outperforming the other varieties in both seasons for proline content, root yield, and sugar yield. Moreover, the interaction between SA rates and varieties had a significant effect on root yield, sugar yield, and related traits across both seasons. GGE biplot analysis was employed for multiple trait comparisons, and the GGE biplot visualization effectively illustrated trait relationships. In conclusion, applying 200 ppm/l of salicylic acid proved to be the most effective treatment for enhancing root and sugar yields of sugar beet in sandy soils.

Keywords: sandy soil, sugar beet, salicylic acid, sugar quality, growth traits, GGE biplot analysis.

INTRODUCTION

In Egypt, sugar beet (*Beta vulgaris* L.) is considered a major source of sugar production. Its high sugar recovery rate and adaptability to newly reclaimed lands highlight its economic importance. Moreover, sugar beet is often cultivated as a key cash crop (Abu-Ellail et al., 2021). According to the Council of Sugar Crops (2024), sugar beet accounted for 63.8% (1.79 million tons) of Egypt's total sugar production.

Mongaar Elmagabra Village's sandy soils are known for their low fertility and inadequate ability to retain water (Abu-Ellail et al., 2024; Goa et al., 1998). These soils provide chances for agricultural growth, but they also pose serious hydrological problems. The sugar industry could be strengthened and local production could rise if sugar beets are grown on reclaimed land (El-Kady et al., 2021). In order to maximize yield potential in such environments, careful evaluation and selection of appropriate varieties are necessary. Limited soil fertility and infrequent rainfall significantly lower crop productivity, especially for sugar beet, in arid and semi-arid regions like Egypt. Soil conditions and sugar beet variety interact to greatly affect crop performance (Benlhabib et al., 2014).

Salicylic acid (SA) plays a critical role in plant responses to abiotic stress (Koo et al., 2020). Numerous studies have reported its beneficial effects in enhancing tolerance to stressors such as salinity, heat, and drought (Bukhat et al., 2020; Ashraf et al., 2010). Through its regulation of several physiological processes, such as photosynthesis, transpiration, ion uptake, and chloroplast structure, appropriate concentrations of SA can mitigate abiotic stress and minimize oxidative damage (Ahmad et al., 2018; Sakhabutdinova et al., 2003). SA, a naturally occurring phytohormone and benzoic acid derivative, is essential for plant growth, nutrient uptake, and membrane stability. It also plays a part in systemic acquired resistance (Stevanato et al., 2019). It has been demonstrated that foliar SA application improves growth traits, increases antioxidant enzyme activity, and improves stress tolerance, all of which contribute to increased root and shoot biomass in sugar beet plants (Merwad, 2015). The relationship between SA application, water deficit, and sugar beet varieties in field settings is still not well understood, though. Factors like variety selection, nutrition management, and water stress are crucial because the main objective of sugar beet cultivation is to maximize sugar yield and extraction quality (Abu-Ellail et al., 2023; Singh and Usha, 2003). SA can be used externally to activate biochemical pathways that support tolerance to biotic and abiotic stresses because it is an endogenous growth regulator with potent antioxidant qualities (Janda et al., 2007; Hayat and Ahmed, 2007).

Programs for breeding sugar beets have made remarkable use of the biplot GGE graphical technique (Yan and Kang 2003). A genotype-trait (GT-biplot) can be created using a modified biplot GGE graphical method for any kind of two-way (Yan 2001 and Yan

---

DOI: 10.21608/esm.2025.452574
[1]Sugar Crops Research Institute, Agricultural Research Center, Giza 12619, Egypt.
***** Corresponding author: farrag_abuellail@yahoo.com
Received August 10, 2025, Accepted, September 14, 2025.

and Hunt 2002). To explain the relationship between the traits under study, the principal component analysis method was employed. Principal Component Analysis (PCA) is commonly applied in experimental research, as it simplifies complex datasets by reducing the number of variables and clarifying the relationships among them (Ghareeb et al., 2014). The GGE analysis method was used to describe the relationship between the studied traits. In addition, several studies have indicated that multivariate statistical methods, including PCA, GGE provide greater efficiency in evaluating genetic diversity across genotypes (Mundaragi, 2017). Therefore, this study aims to evaluate the effects of salicylic acid on sugar beet growth, yield, and quality in sandy soils, and to analyze root, sugar yield and related traits using GGE analysis.

MATERIALS AND METHODS

Two field experiments were carried out at a private farm in Mongaar Elmagabra village, Wadi El-Natrun, El-Beheira Governorate, Egypt (17.98 m above sea level; 30º 23’ 19.89’’ N, 30º 21’ 41.06’’ E) over the course of two consecutive seasons (2022/2023 and 2023/2024). Under sandy soil conditions, the trial sought to determine how salicylic acid (SA) affected sugar beet (*Beta vulgaris L.*) productivity and quality. In the experimental treatments, four SA levels (0 as control, 100,150 and 200 ppm/l). Also, four multigerm sugar beetvarieties (Afendra-KWS, Shantala-KWS, BTS 8935,and BTS 7245) were provided by the Sugar Crops Research Institute, Agricultural Research Center, Giza. A split-plot arrangement within a randomized complete block design (RCBD) was adopted, with three replications. Salicylic acid solutions were applied twice by spraying both the soil surface and plant foliage: the first application occurred 30 days after sowing (following thinning), and the second one month later. SA treatments were allocated to main plots, while sugar beet varieties were assigned to subplots. Irrigation was applied through a drip system equipped with GR drippers delivering 4 liters/hour. Each experimental plot covered 10.5 m² (equivalent to 1/400 feddan), comprising five rows of 3.5 m length, with 60 cm between rows and 20 cm between plants. In the first season, sugar beet seeds were sown on October 18; in the second season, they were planted on October 22. Plants were thinned to a density of two per hill at 30 days after sowing (DAS), followed by a final thinning to one plant per hill at 45 DAS. The recommended guidelines were followed in all agronomic practices. The physical and chemical properties of the soil were analyzed following the methods described by Page (1982), and the results are presented in Table 1.

Table 1. lists some of the soil's physical and chemical characteristics prior to planting over two seasons

Practical size distribution%		2022/2023	
		Soluble cations (meq/L)	
Sand%	59.12	Ca++	9.72
Silt%	15.35	Mg++	6.84
Clay%	25.53	Na+	10.91
Textural class	Sandy Loam	K+	0.83
pH	7.66	Soluble Anions (meq/ L)	
EC(ds/m)	2.83	HCO_3-	2.69
O.M (%)	0.49	CL-	15.34
CaCO3 (%)	2.51	SO4	10.27
	2023/2024		
		Soluble cations (meq/L)	
Sand%	57.31	Ca++	8.29
Silt%	16.48	Mg++	7.61
Clay%	26.21	Na+	10.41
Textural class	Sandy loam	K+	1.19
pH	7.84	Soluble Anions (meq/ L)	
EC(ds/m)	2.75	HCO3-	2.04
O.M%	0.67	CL-	14.31
CaCO3%	2.17	SO4	11.15

Table 2. Irrigation water chemical analysis at the experimental site

EC, dS m^{-1}	pH	Soluble cations (meq L^{-1})				Soluble anions (meq L^{-1})			SAR
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	
1.24	7.31	3.06	2.92	4.73	1.75	3.44	3.14	5.88	2.73
Abbreviations:	EC: Electrical Conductivity¸, dS m^{-1} : deciSiemens per meter , SAR: , Sodium Adsorption Ratio								

Studied traits

Harvesting was carried out manually 210 days after sowing for both seasons, to analysis the sugar beet plants, samples were randomly taken from each subplot after 105 days from sowing to determine Proline content (u moles/g leaf fresh weight) using the method of Bates *et al.* (1973).

At harvest, ten guarded plants were randomly selected from the middle ridges of each subplot to measure the following traits:

1.Root length /plant (cm)

2. Root diameter/plant (cm).

3. Root fresh weights/plant (g).

4. Root yield/fed (ton). where fed is equal to 4200 m².

5. Sucrose % was polarimetrically measured using the methods of A.O.A.C. (2005).

6. Sugar lost in molasses % (SLM) = 0.14 × (K + Na) + 0.25 × (α-amino – N) + 0.5, as described by Devillers (1988).

7. Extractable sugar % = Sucrose% - SLM - 0.6, as described by Dexter *et al.* (1967).

8. Sugar yield/fed (ton) = Root yield (ton) x Extractable sugar %.

9. Alpha amino N, potassium, and sodium impurity concentrations in roots were calculated as (meq/100 g beet), was determined Cook and Scott (1993).

Statistical Analyses

The SPSS statistical software package (version SPSS 21.0) was used to statistically analyze the data. The least significant difference (LSD) method was used to test differences between means at a 5% level of probability to compare between means as described by Gomez (1984), and analysis of variance (ANOVA) was carried out. The GGE biplot was constructed using the first two principal components (PC1 and PC2) derived using environment-centered yield data (Yan, 2001).

RESULTS AND DISCUSSION

Root yield and its related traits

The root length, diameter, weight, and root yield (tons/fed) for each variety in both seasons are clearly different, as shown in Tables 3 and 4. The highest values for every measured root trait were produced by the varieties BTS 7245 and BTS 8935, which continuously outperformed the others. In both seasons, BTS 7245 was the best performer in terms of yield. It maintained its lead with 27.98 tons/fed of roots in the second season after producing 29.55 tons/fed of roots in the first. In contrast, Shantala-KW recorded the lowest yields in the second season (24.64 tons/fed), while The same variety produced the lowest yields in the first season (25.04 tons/fed of roots). Their genetic composition and the ways in which each genotype responds to environmental factors are probably responsible for the observed variations among the sugar beet varieties under study. Previous researchers have reported similar variability in root traits; for example, Abd El-Aal et al. (2010) and Abu-Ellail et al. (2021) both reported significant differences in root weight among sugar beet varieties.

The results presented in Tables 3 and 4 demonstrate that during the 2022–2023 and 2023–2024 seasons, both root length and root diameter (cm) increased significantly as salicylic acid concentrations were raised from 0 to 200 ppm/l. The mean values were consistently lowest for the control treatment, while the highest application rate (200 ppm/l) produced the highest mean values. Furthermore, there was a noticeable rise in root yield (ton/fed) when salicylic acid concentrations were raised to 200 ppm/l. The positive effects of salicylic acid on plant performance may be due to a variety of physiological processes, including enhanced chlorophyll synthesis, growth-related hormone simulation, decreased respiration, enhanced membrane permeability, increased nutrient uptake, and increased accumulation of dry matter. These results align with those of Ashraf et al. (2010) and Bukhat et al. (2020), who discovered that the application of salicylic acid improved plant growth parameters under stress. In a similar vein, Ahmad et al. (2018) attributed the growth-promoting qualities of salicylic acid to enhanced respiration and photosynthesis, improved phosphorus and oxygen absorption by roots, and increased cell membrane permeability.

As shown in Tables 3 and 4, the relationship between sugar beet varieties and foliar salicylic acid application rates significantly affected root yield, root length, root diameter, and root weight in both seasons. When treated with the highest concentration of salicylic acid (200 ppm/l), the variety BTS 7245 consistently produced the highest values for root diameter (17.28 and 16.63 cm) and root length (38.46 and 38.63 cm) in the first and second seasons, respectively. In contrast, the variety Shantala-KWS recorded the lowest root dimensions under several salicylic acid treatments. Under the highest concentration (200 ppm/l), the Shantala-KWS produced the lowest root diameter (15.11 cm) and root length (34.08 cm) in the first season. While in the second season, a similar pattern for the same variety was observed (14.11 and 35.72 cm for root length and diameter, respectively) among the same treatment. These findings are in line with previous studies. Stevanato et al. (2019) reported that salicylic acid enhances growth traits by improving nutrient solubilization and uptake. Similarly, Janda et al. (2007) observed that salicylic acid application (250 ppm/l) significantly improved root traits and highlighted a strong interaction between genotype and salicylic acid levels on root length and diameter in sugar beet.

The interaction between salicylic acid concentrations and sugar beet varieties significantly affected root fresh weight per plant and root yield per feddan in both seasons (Tables 3 and 4). In the first season, the multi-germ variety BTS 7245 treated with 200 ppm/l salicylic acid produced the highest values of root weight/plant and root yield (1.39 kg/plant and 31.79 tons/fed, respectively). Also recorded (1.22 kg/plant and 30.29 tons/fed for root weight and yield, respectively) under the second season. A similar trend was observed, where BTS 7245 and BTS 8935 outperformed the other varieties, recording the greatest values for these traits. These results may be explained by the role of salicylic acid in enhancing plant tolerance through increased phenolic and proline compound production, in addition to inherent genetic differences among varieties and the influence of the soil’s chemical properties at the experimental site. Comparable findings were reported by Makhlouf et al. (2021), Abu-Ellail et al. (2023), and Singh and Usha (2003), who also confirmed the positive effects of salicylic acid on sugar beet growth and yield.

Table 3. Mean performance of sugar beet varieties for root length and diameter traits treated by salicylic acid levels during the 2022/2023 and 2023/2024 seasons

Varieties	2022/ 2023									
	Root length (cm/plant)					Root diameter (cm/plant)				
	Salicylic acid levels (SA) (ppm/l)									
	Zero	**100 ppm**	**150 ppm**	**200 ppm**	**Mean**	**Zero**	**100 ppm**	**150 ppm**	**200 ppm**	**Mean**
Afendra-KWS	27.63	32.08	35.60	36.56	32.97	11.00	13.41	14.18	15.43	13.51
Shantala-KWS	26.16	30.06	32.35	34.08	30.66	10.37	11.9٢	13.96	15.11	12.84
BTS 8935	30.16	32.76	36.23	37.19	34.09	12.05	13.05	14.81	15.93	13.96
BTS 7245	32.09	36.14	37.50	38.46	36.05	13.06	14.88	16.13	17.28	15.34
Mean	29.01	32.76	35.42	36.57	33.44	11.62	13.32	14.77	15.94	13.91
LSD at 0.5%										
SA					2.03					0.67
Var.					1.15					1.12
SA xVar.					1.56					0.71
	2023 / 2024									
Afendra-KWS	29.46	33.96	35.57	36.85	33.96	11.60	13.11	14.1١	14.61	13.36
Shantala-KWS	29.37	33.54	34.53	35.72	33.29	10.51	12.71	13.48	14.11	12.70
BTS 8935	30.95	34.72	36.12	37.34	34.78	11.92	13.82	14.63	15.12	13.87
BTS 7245	32.48	35.43	37.41	38.63	35.99	12.02	13.9٣	15.09	16.63	14.42
Mean	30.57	34.41	35.91	37.14	34.51	11.51	13.39	14.33	15.12	13.59
LSD at 0.5%										
SA					1.47					1.00
Var.					1.63					0.98
SA xVar.					1.24					0.56

Table 4. Mean performance of sugar beet varieties for root weight and root yield traits treated by salicylic acid levels during the 2022/2023 and 2023/2024 seasons

Varieties	2022/ 2023									
	Root weight (kg/plant)					Root yield(ton/fed)				
	Salicylic acid levels (SA) (ppm/l)									
	Zero	100 ppm	150 ppm	200 ppm	Mean	Zero	100 ppm	150 ppm	200 ppm	Mean
Afendra-KWS	0.69	0.84	1.06	1.23	0.96	21.96	26.98	29.05	29.66	26.91
Shantala-KWS	0.64	0.82	1.00	1.14	0.90	21.25	24.34	26.97	27.58	25.04
BTS 8935	0.76	0.93	1.23	1.28	1.05	24.49	28.13	30.36	31.01	28.50
BTS 7245	0.87	0.98	1.34	1.39	1.15	26.52	28.69	31.18	31.79	29.55
Mean	0.74	0.89	1.16	1.26	1.01	23.56	27.04	29.39	30.01	27.50
LSD at 0.5%										
SA					0.23					1.42
Var.					0.21					1.06
SA xVar.					0.15					1.21
	2023 / 2024									
Afendra-KWS	0.73	0.89	1.09	1.14	0.96	21.49	25.95	27.47	27.73	25.66
Shantala-KWS	0.70	0.84	1.08	1.11	0.93	20.86	24.72	26.38	26.59	24.64
BTS 8935	0.76	0.89	1.16	1.16	0.99	22.34	26.35	28.39	28.13	26.30
BTS 7245	0.82	0.90	1.24	1.22	1.05	23.57	27.83	30.07	30.29	27.94
Mean	0.75	0.88	1.14	1.16	0.98	22.07	26.21	28.08	28.19	26.14
LSD at 0.5%										
SA					0.18					2.04
Var.					0.18					1.00
SA xVar.					0.13					1.16

Sugar yield and its related traits

The findings in Tables 5 and 6 showed that the sugar beet varieties differed significantly in terms of sucrose percentage, extractable sugar percentage, and sugar yield (ton/fed). However, the variation in sugar lost to molasses percentage (SLM%) was not statistically significant. Across both seasons, the variety BTS 7245 consistently recorded the lowest SLM% values (1.48 and 1.53%, respectively). This reduction in SLM% and associated impurities contributed to its superior performance in sucrose content, extractable sugar percentage, and sugar yield. The observed differences in these quality traits among the tested varieties may be attributed to genetic factors, which play a key role in determining plant morphology and physiological efficiency. In support of these findings, Hayat and Ahmed (2007) reported that sucrose percentage and refined sugar yield differed significantly among sugar beet varieties and were positively influenced by salicylic acid application compared with the untreated control.

As shown in Tables (5 and 6), foliar application of salicylic acid significantly enhanced sucrose percentage, extractable sugar, and sugar yield (ton/fed), while reducing SLM% compared with the control treatment in both seasons. The best performance was obtained with the 200 ppm/l treatment, followed by 150 ppm/l, during both study seasons. Across all application rates (50–200 ppm/l), salicylic acid consistently increased sucrose content and extractable sugar compared to the control. These findings are consistent with earlier reports. Khodary (2004) demonstrated that sugar beet quality traits improved significantly with higher salicylic acid application rates, while Tasgin et al. (2003) found that sugar yield markedly increased with salicylic acid treatment compared to untreated plants.

In both seasons, the interaction between sugar beet varieties and salicylic acid levels had a significant impact on sucrose percentage, extractable sugar, and sugar yield, according to the results in Tables 5 and 6. The variety BTS 7245, when treated with 200 ppm/L salicylic acid, achieved the highest values for sucrose percentage (21.35 and 20.34%), extractable sugar percentage (19.70 and 18.65%), and sugar yield (6.26 and 5.65 tons/fed) in the first and second seasons, respectively, which contributed to its superior performance relative to the other varieties. Conversely, the multi-germ variety Shantala-KWS recorded the lowest values of the above quality traits under the same treatment (200 ppm/l). Overall, the results suggest a positive relationship between the frequency and concentration of salicylic acid application and improvements in sucrose and refined sugar content. This may be attributed to reduced levels of juice impurities. Supporting evidence was reported by Merwad (2015), who found that salicylic acid decreased juice impurities, and by Abu-Ellail et al. (2023) and El-Kady et al. (2021), who observed significant varietal differences in quality traits when sugar beet was cultivated in newly reclaimed soils and treated with salicylic acid.

Impurities traits

The results in Tables (7 and 8) revealed significant differences among the tested varieties in the concentrations of impurities, namely N%, Na%, and K%. Among them, the variety BTS 7245 consistently recorded the lowest of the most impurity traits. This reduction in impurities is likely linked to their superior performance in sucrose percentage and sugar extraction efficiency, which ultimately translated into higher sugar yield. These results are most likely related to genetic factors that influence juice quality. Similar findings were reported by Abu-Ellail et al. (2024) and Benlhabib et al. (2014), who observed significant varietal differences in impurity components—potassium, sodium, and α-amino-N.

Table 5. Mean performance of sugar beet varieties for sugar lost to molasses (SLM%) and sucrose% under salicylic acid influence during the 2022/2023 and 2023/2024 seasons

Varieties	2022/ 2023									
	Sugar lost to molasses (SLM%)					Sucrose%				
	Salicylic acid levels (SA) (ppm/l)									
	Zero	100 ppm	150 ppm	200 ppm	Mean	Zero	100 ppm	150 ppm	200 ppm	Mean
Afendra-KWS	1.97	1.69	1.28	1.04	1.50	14.14	16.92	19.56	19.12	17.44
Shantala-KWS	2.02	1.69	1.31	1.06	1.52	12.93	15.91	18.19	18.66	16.42
BTS 8935	2.05	1.78	1.31	1.07	1.55	14.22	17.63	20.48	21.01	18.34
BTS 7245	1.91	1.64	1.30	1.05	1.48	15.36	18.05	20.73	21.35	18.87
Mean	1.99	1.70	1.30	1.06	1.51	14.16	17.13	19.74	20.04	17.77
LSD at 0.5%										
SA					0.27					1.57
Var.					NS					0.59
SA xVar.					NS					0.87
2023 / 2024										
Afendra-KWS	2.01	1.71	1.32	1.07	1.53	15.71	17.76	18.99	19.68	18.04
Shantala-KWS	2.04	1.69	1.32	1.08	1.53	15.54	17.64	18.72	19.26	17.79
BTS 8935	2.06	1.81	1.31	1.07	1.56	16.36	18.01	19.72	20.31	18.60
BTS 7245	1.95	1.73	1.33	1.09	1.53	16.79	18.63	20.48	20.34	19.06
Mean	2.02	1.74	1.32	1.08	1.54	16.10	18.01	19.48	19.90	18.37
LSD at 0.5%										
SA					0.66					1.38
Var.					NS					0.67
SA xVar.					NS					0.68

Table 6. Mean performance of sugar beet varieties for extractable sugar% and sugar yield (ton/fed) under Salicylic acid influence during the 2022/2023 and 2023/2024 seasons

Varieties	2022/ 2023									
	Extractable sugar%					Sugar yield (ton/fed)				
	Salicylic acid levels (SA) (ppm/l)									
	Zero	**100 ppm**	**150 ppm**	**200 ppm**	**Mean**	**Zero**	**100 ppm**	**150 ppm**	**200 ppm**	**Mean**
Afendra-KWS	11.57	14.63	17.68	17.48	15.34	2.54	3.95	5.14	5.18	4.20
Shantala-KWS	10.31	13.62	16.28	17.00	14.30	2.19	3.31	4.39	4.69	3.65
BTS 8935	11.57	15.25	18.57	19.34	16.18	2.83	4.29	5.64	6.00	4.69
BTS 7245	12.85	15.81	18.83	19.70	16.80	3.41	4.54	5.87	6.26	5.02
Mean	11.58	14.83	17.84	18.38	15.66	2.74	4.02	5.26	5.53	4.39
LSD at 0.5%										
SA					1.14					0.24
Var.					0.13					0.14
SA xVar.					0.64					0.35
	2023 / 2024									
Afendra-KWS	13.10	15.45	17.07	18.01	15.91	2.81	4.01	4.69	4.99	4.13
Shantala-KWS	12.90	15.35	16.80	17.58	15.66	2.69	3.80	4.43	4.68	3.90
BTS 8935	13.70	15.60	17.81	18.64	16.44	3.06	4.11	5.06	5.24	4.37
BTS 7245	14.24	16.30	18.55	18.65	16.94	3.36	4.54	5.58	5.65	4.78
Mean	13.49	15.68	17.56	18.22	16.23	2.98	4.12	4.94	5.14	4.29
LSD at 0.5%										
SA					0.89					0.26
Var.					0.41					0.16
SA xVar.					0.74					0.48

During two seasons, increasing salicylic acid concentrations from 0 to 200 ppm/l significantly reduced the percentages of N, Na, and K (Tables 7 and 8). At the highest application level (200 ppm/l), the lowest mean values were recorded: N% (0.52 and 0.55), Na% (1.02 and 1.02), and K% (2.03 and 2.11) in the first and second seasons, respectively. In contrast, the control treatment produced the highest impurity levels, with mean values of N% (1.63 and 1.66), Na% (3.33 and 3.39), and K% (4.39 and 4.48) in the first and second seasons, respectively. The reduction in these impurities corresponded with improvements in juice quality, which reached its maximum when salicylic acid was applied at 200 ppm/l. This effect may be attributed to the regulatory role of salicylic acid in enhancing sugar properties and improving physiological parameters. These findings are consistent with those of Bukhat et al. (2020), Ashraf et al. (2010), and Abu-Ellail et al. (2023), who reported that higher salicylic acid application rates significantly enhanced sugar beet quality traits by reducing juice impurities and improving overall sugar quality.

The interaction between sugar beet varieties and salicylic acid levels shown in Tables 7 and 8 significantly impacted N% and Na% impurities in both seasons. The variety Afendra-KWS recorded the lowest N% values (0.54 and 0.43% in the first season and 0.60 and 0.49% in the second season) when treated with 150 and 200 ppm/l salicylic acid, respectively. Also, the same variety recorded the lowest Na% under the highest concentration of salicylic acid (200 ppm/l) in the first season (0.97%). While, the variety Shantala-KWS recorded the lowest value in the second season (0.97%). Additionally, when the concentration of salicylic acid (200 ppm/l) increases, the K% values decrease. However, in both the first and second seasons, the variety BTS 8935 had the lowest value (1.85% and 1.93%, respectively). Overall, impurity levels declined progressively with increasing salicylic acid rates, suggesting a strong positive relationship between salicylic acid application and reduced concentrations of Na, K, and α-amino nitrogen in sugar beet roots. Similar trends were reported by Merwad (2015), who observed that salicylic acid application significantly influenced nutrient composition (N, P, and K) in sugar beet roots, and by Bukhat et al. (2020) and Ashraf et al. (2010), who found that increasing salicylic acid up to 200 ppm/l decreased sodium, potassium, and amino-nitrogen contents in sugar beet varieties.

As shown in Table 8, there was a significant interaction between varieties and salicylic treatments on proline accumulation (µmoles/g leaf fresh weight) in both seasons. In the first season, there was no significant difference in the proline accumulation of the varieties; however, in the second season, there was a significant difference in this trait. However, there is a noteworthy interplay between salicylic acid levels during both seasons and variance. A positive correlation was found between the level of stress tolerance and the rise in proline content. These patterns of findings led us to conclude that proline contributed to the stress tolerance of these sugar beet varieties (Ghoulam et al., 2002). In sugar beet, proline was accumulated to a high level and played the main role in osmotic adjustment under osmotic stress. Proline accumulation in stressed tissues has been suggested to serve additional purposes, such as protecting membranes and enzymes (Bandurska, 1993).

GGE biplot analysis

1. Comparison biplot for Genotype by traits (GT)

GGE biplot analysis based on GT (genotype and traits) was performed using standardized data to eliminate unit differences among traits. The analysis allowed for the visualization of relationships among traits, their associations with cultivars, and the genetic diversity among sugar beet varieties (Fig. 1). Root length, sucrose percentage, sugar yield, and root yield were the traits contributing most to the variation explained by the first principal component (PC1). These findings highlight the complex interactions between measured traits and genotypes (Yan and Tinker 2005).

In the first season, PC1 and PC2 accounted for 71.75% and 19.60% of the total variation, respectively, while in the second season, they explained 80.59% and 15.27%, giving a cumulative variation of 95.86%. According to Yan and Kang (2003), a GGE biplot is considered reliable when the first two principal components explain more than 60% of the total variation, a condition satisfied in this study. The polygon view of the biplot provided a useful tool for exploring genotype–trait interactions. Consistent with Shojaei et al. (2022), genotypes located closer to the biplot origin were more stable, while those farther from the origin showed greater variability.

Table 7. Impact of salicylic acid foliar application on key impurity traits (α-Amino N % and Sodium%) in sugar beet varieties during the 2022/2023 and 2023/2024 seasons

Varieties	2022/ 2023									
	α-Amino N %					Na%				
	Salicylic acid levels (SA) (ppm/l)									
	Zero	100 ppm	150 ppm	200 ppm	Mean	Zero	100 ppm	150 ppm	200 ppm	Mean
Afendra-KWS	1.58	1.25	0.54	0.43	0.95	3.34	2.29	1.11	0.97	1.93
Shantala-KWS	1.67	1.36	0.63	0.52	1.05	3.45	2.34	1.18	1.04	2.00
BTS 8935	1.63	1.36	0.75	0.64	1.10	3.54	2.45	1.20	1.06	2.06
BTS 7245	1.62	1.22	0.58	0.47	0.97	2.97	2.00	1.14	1.00	1.78
Mean	1.63	1.30	0.63	0.52	1.02	3.33	2.27	1.16	1.02	1.94
LSD at 0.5%										
SA					0.11					0.91
Var.					NS					NS
SA xVar.					0.09					0.13
	2023 / 2024									
Afendra-KWS	1.67	1.34	0.60	0.49	1.03	3.36	2.37	1.18	1.04	1.99
Shantala-KWS	1.69	1.44	0.68	0.57	1.10	3.50	2.10	1.11	0.97	1.92
BTS 8935	1.63	1.42	0.73	0.62	1.10	3.54	2.44	1.16	1.02	2.04
BTS 7245	1.64	1.37	0.64	0.53	1.05	3.16	2.29	1.19	1.05	1.92
Mean	1.66	1.39	0.66	0.55	1.07	3.39	2.30	1.16	1.02	1.97
LSD at 0.5%										
SA					0.16					0.83
Var.					NS					NS
SA xVar.					0.05					0.08

Table 8. Impact of salicylic acid foliar application on key impurity trait (K%) and praline accumulation in sugar beet varieties during the 2022/2023 and 2023/2024 seasons

Varieties	2022/ 2023									
	K%					Proline (u moles/g)				
	Salicylic acid levels (SA) (ppm/l)									
	Zero	100 ppm	150 ppm	200 ppm	Mean	Zero	100 ppm	150 ppm	200 ppm	Mean
Afendra-KWS	4.34	4.01	3.52	2.11	3.50	5.21	6.05	6.32	6.62	6.05
Shantala-KWS	4.40	3.76	3.46	2.05	3.42	5.25	6.18	6.54	6.74	6.18
BTS 8935	4.62	4.26	3.26	1.85	3.50	5.32	6.26	6.62	6.85	6.26
BTS 7245	4.19	3.94	3.52	2.11	3.44	5.21	5.62	5.69	6.23	5.69
Mean	4.39	3.99	3.44	2.03	3.46	5.25	6.03	6.29	6.61	6.04
LSD at 0.5%										
SA					0.26					0.46
Var.					NS					NS
SA xVar.					NS					0.15
	2023 / 2024									
Afendra-KWS	4.46	3.91	3.59	2.18	3.54	5.00	5.34	5.41	5.62	5.34
Shantala-KWS	4.50	3.80	3.54	2.13	3.49	5.23	5.32	5.69	6.51	5.69
BTS 8935	4.68	4.3	3.34	1.93	3.56	5.45	5.62	5.97	6.85	5.97
BTS 7245	4.29	4.08	3.6	2.19	3.54	5.32	6.33	6.45	7.21	6.33
Mean	4.48	4.02	3.52	2.11	3.53	5.25	5.65	5.88	6.55	5.83
LSD at 0.5%										
SA					0.17					0.33
Var.					NS					0.23
SA xVar.					NS					0.26

Variety BTS 7245 recorded the highest sugar yield (SY) and root yield (RY), with BTS 7245 and BTS 8935 clustering in the same sector, indicating similar performance for yield-related traits. The positive associations among these traits were reflected in the acute angles between them, whereas Afendra-KWS and Shantala-KWS, separated by obtuse angles, exhibited the lowest values for SY and RY. The grouping of varieties in the biplot corresponded closely with their mean performance, confirming the reliability of this method. Yan (2001) demonstrated that specific genotypes were representative, stable, and able to distinguish between different traits for the performance of the evaluated sugar beet varieties.

Overall, PCA proved to be a robust and effective approach for identifying superior varieties based on multiple traits. The analysis demonstrated that yield-related traits such as root and sugar yield per feddan, sugar extraction coefficient, and extractable sugar percentage were the most discriminating factors among genotypes. These results are consistent with the findings of Yan and Kang (2003), Korshid (2016), Ghareeb et al. (2014), and Abbasi et al. (2014), who reported high variation between varieties in traits represented by shorter vectors and explained the interaction between the genotype and the traits. This relatively high percentage demonstrates the complexity of the relationships between the measured correlated traits and the genotypes.

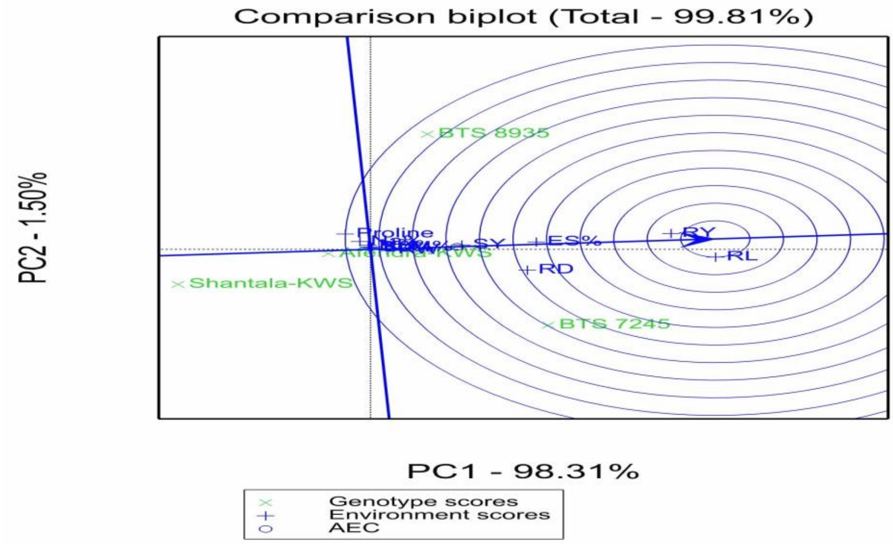
1. Relationship between genotypes and treatments (GTr)

The scaling values of the first two principal components (PC1 and PC2) were symmetrically distributed between trait and variety scores. Figures 2 and 3 present the polygon view of the genotype × treatment (GTr) biplot, which was constructed to evaluate diversity among sugar beet cultivars using twelve characters. Together, PC1 and PC2 explained up to 89.4% of the total variation across traits (Yan and Hunt ,2002). The visualizing graphic of genotype means and treatments shows different highly desirable traits, which are high yield and high stability.

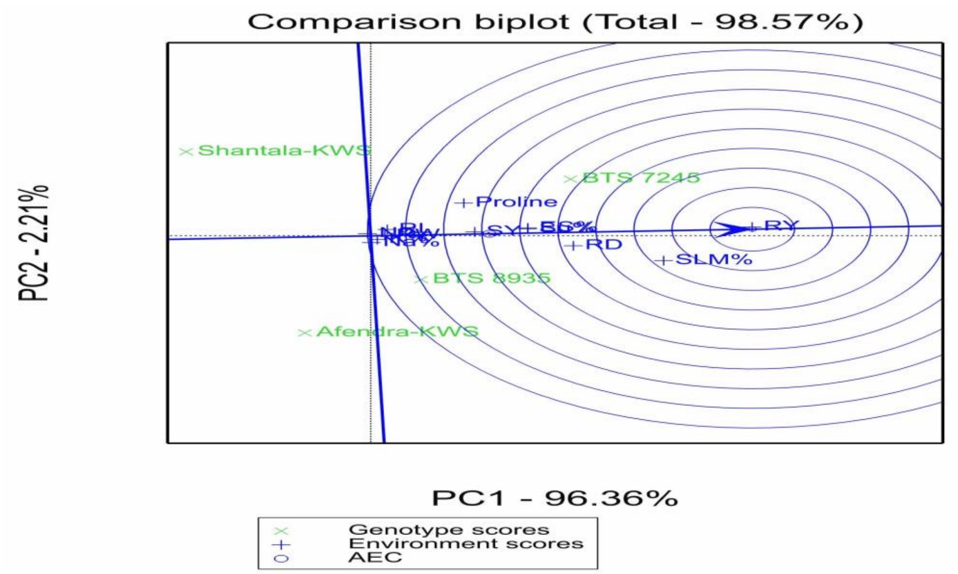
For the root yield dataset (Fig. 2), the GGE biplot accounted for 98.82% and 99.77% of the total variation in the first and second years, respectively. In the first season, PC1 and PC2 explained 75.22% and 23.60% of the variance, while in the second season, they accounted for 87.01% and 12.75%, respectively. Similarly, for the sugar yield dataset (Fig. 3), the GGE biplot captured 99.77% and 98.82% of the variation in the first and second years, respectively. These high proportions demonstrate the reliability of the biplot in describing the contributions of sugar beet varieties to yield-related traits, in agreement with Yan and Rajcan (2002) and Al-

Naggar et al. (2018), who emphasized the utility of biplots for interpreting trait–environment relationships.

The polygon view also facilitated the identification of superior genotypes. BTS 7245 consistently exhibited the highest root and sugar yields across most treatments in both seasons, followed by BTS 8935, Afendra-KWS, and Shantala-KWS. Such findings highlight the potential of GGE biplots as tools for indirectly selecting cultivars suited to sandy soil environments. These results are in line with Hu et al. (2016), Korshid (2016), and Ober et al. (2005), who reported that GGE biplots effectively distinguish genotypes expressing favorable combinations of traits. Furthermore, the analysis suggested that root weight and water use efficiency can serve as key indicators for identifying elite sugar beet varieties. The GGE biplot is most appropriate for multi-environment analysis, test environments that offer discriminating power vs. representativeness, and genotype evaluation (Yan and Tinker ,2006) .

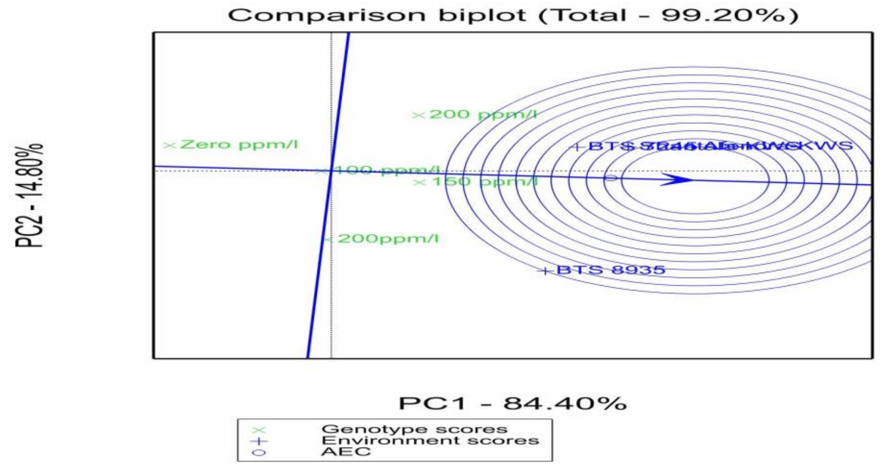


First season

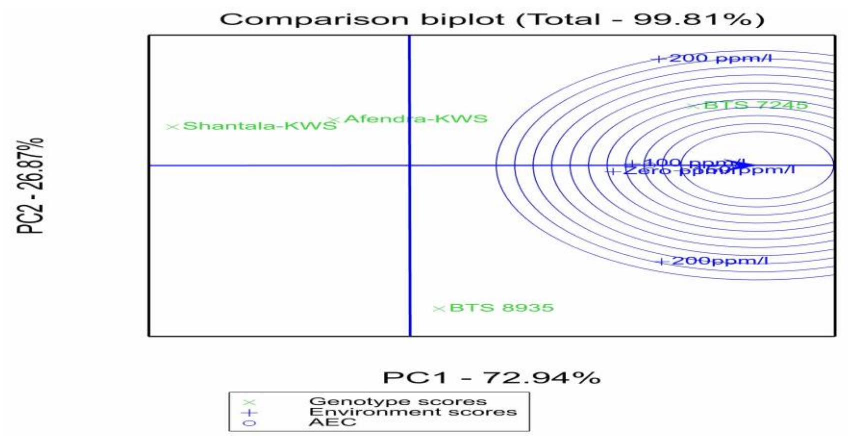


Second season

Fig.1. GGE-biplot based on GT (genotype and traits) for a comparison graph displaying the traits and varieties with the highest values for four sugar beet varieties during the first and second seasons

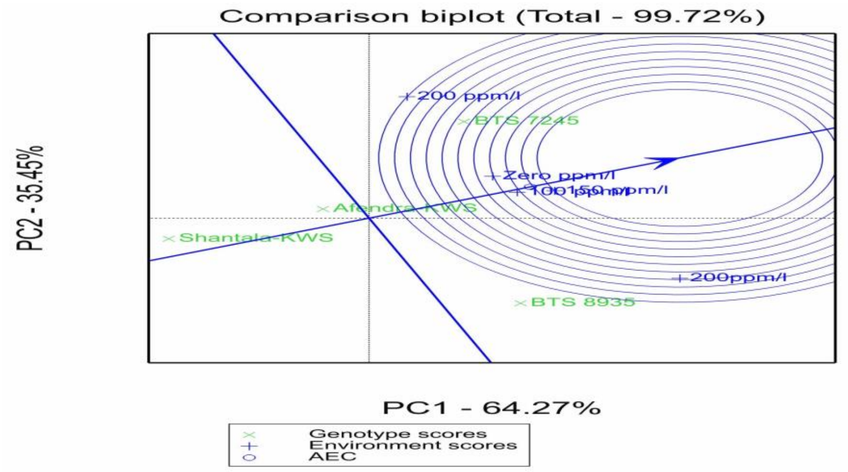


First season

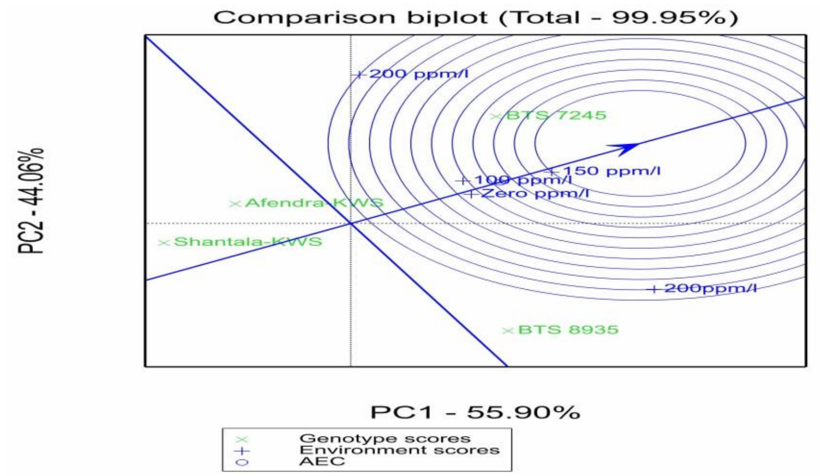


Second season

Fig.2 .GGE-biplot based on GTr (genotype and treatments) displays the relationship between the four sugar beet varieties and treatments with respect to root yield in the first and second growing seasons



First season



Second season

Fig.3. GGE-biplot based on GTr (genotype and treatments) displays the relationship between the four sugar beet varieties and treatments with respect to sugar yield in the first and second growing seasons

CONCLUSION

The results demonstrated that salicylic acid application enhanced root yield and juice quality of sugar beet under sandy soil conditions. The highest juice quality, with the lowest impurity levels, was obtained with 150 and 200 ppm/l of salicylic acid. Overall, salicylic acid showed a positive impact on sugar beet varieties, confirming its potential as a low-cost approach for producing high-quality roots and supporting profitable sugar production in reclaimed soils.

The GGE biplot analysis effectively illustrated trait relationships, providing results consistent with mean performance and offering a simple yet informative tool for evaluating multiple traits. Among the tested varieties, the multigerm BTS 7245, along with BTS 8935 and Shantala-KWS, recorded the best performance across most yield and quality traits. In contrast, proline and SLM % were not reliable indicators for selecting superior genotypes when considering root and sugar yield combinations. GGE biplot analysis further indicated that root diameter and root weight at harvest were the key contributors to root yield variation.

REFERENCES

A.O.A.C. 2005. Association of Official Analytical Chemists. Official methods of analysis, 26th Ed. A.O.A.C., Int., Washington, D.C; USA.

Abd El-Aal, A. M., A. I. Nafie and M.R. Abdel Aziz. 2010. Response of some sugar beet genotypes to nitrogen fertilization under newly reclaimed land conditions. Egypt. J. Appl. Sci., 25 (6B) 194-208.

Abu-Ellail, F.F.B., Arfat S. A. Sadan and Ahmed E. Attia .2023. Salinity Tolerant Indices Based on Yield Performance of Some Sugar Beet Varieties as Treated by Potassium Silicate to Mitigate Saline Soil Stress. *Egypt. J. Agric. Sci., 2023, 74 (3):61-75*. Doi: 10.21608/ejarc.2024.339448.

Abu‑ Ellail, F.F.B., Eman M. A. Hussein and T. M. Attafy .2024. Categorization of Sugar Beet Varieties for Water Saving in Sandy Soils Using Factor Analysis Scores. Sugar Tech, https://doi.org/10.1007/s12355-024-01359-3

Abu-Ellail, F.F.B., I.S.H. El-Gamal, S. M.I. Bachoosh and N.K. El- Safy. 2021. Influence of Water Stress on Quality, Yield and Physiological Traits of Some sugar beet Varieties. *Egypt. J. of Appl. Sci., 36 (3):35-50*,DOI: 10.21608/EJAS.2021.163194.

Ahmad, P., M.N. Alyemeni, M.A. Ahanger, D. Egamberdieva, L. Wijaya, P. Alam .2018. Salicylic acid (SA) induced alteations in growth, biochemical attributes and antioxidant enzyme activity in faba bean (*Vicia faba* L.) seedlings under NaCl toxicity. Russ. J. Plant Physiol. 65, 104–114.

Al-Naggar, A.M.M., R.M. Abd El-Salam and W.Y.S. Yaseen .2018.'Yield Adaptability and Stability of Grain Sorghum Genotypes across Different Environments in Egypt using AMMI and GGE-biplot Models' *Annual Research & Review in Biology* 23(3): pp.1-16.

Ashraf, M., N.A. Akram, R.N. Arteca, M.R. Foolad .2010. The physiological, biochemical and molecular roles of brassinosteroids and salicylic acid in plant processes and salt tolerance. Crit. Rev. Plant Sci. 29, 162–190.

Bandurska, H. 1993. In vivo and in vitro effect of proline on nitrate reductase activity under osmotic stress in barley. *Acta. Physiol. Plant*, 15: 83-88.

Bates, L.S., R.P. Waldren and I.D. Teare .1973. Rapid determination of free proline for water stress studies. Plant Soil, 39:205–207.

Benlhabib, O., A. Yazar, M. Qadir, E. Louren'o, S.E. Jacobsen .2014. How can we improve Mediterranean cropping systems, J. Agron. Crop Sci., 200: 325-332.

Bukhat, S., H. Manzoor, H.U.R. Athar, Z.U. Zafar, F. Azeem, S. Rasul .2020. Salicylic acid induced photosynthetic adaptability of Raphanus sativus to salt stress is associated with antioxidant capacity. J. Plant Growth Regul. 39, 1–14.

Cooke, D.A. and R.K. Scott .1993. The Sugar Beet Crop. Science into Practice Published by Chapman and Hall, London, pp: 262-265.

Council of sugar crops, Ministry of Agriculture and Land Reclamation .2024. Sugar crops and sugar production in Egypt, Cairo pp.140

Devillers, P. 1988. Prevision du sucre melasse sucrerie franases 190-200. (C.F. The Sugar Beet Crop. Book).

Dexter, S.T., M.G. Frankes and F.W. Snyder .1967. A rapid and practical method of determining extractable while 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.

El-Kady, M.S., F.F.B. Abu-Ellail and E.H.S. El-Laboudy .2021. Evaluation of some sugar beet varieties under water salinity stress in new reclaimed land. J. of Plant Production, Mansoura Univ., 12 (1):63–72.

Ghareeb, Zeinab E., Hoda E.A. Ibrahim, S.R.E. Elsheikh and S.M.I. Bachoash .2014. 'Genotype × environment Interaction for characteristics of some sugar beet genotypes' *J. Plant Production, Mansoura Univ.*, Vol. 5 (5), pp. 853-867.

Ghoulam, C.; A. Foursy and K. Fares .2002. Effects of salt stress on growth, inorganic ions and proline accumulation in relation to osmotic adjustment in five sugar beet cultivars. *Environ. Exp. Bot.*, 47: 39-50.

Goa, S., W.L. Pan and R.T. Koeining .1998. Integrated root system age in relation to plant nutrient uptake activity. Agron. J. 90: 505-510.

Gomez, K. A. and A. A. Gomez .1984. Statistical procedures for agricultural Researches. 2nd Ed., John Wiley & Sons, New York U.S.A., 97-107.

Hayat, S. and A. Ahmed. 2007. *Salicylic Acid: A Plant Hormone.* Dordrecht, Netherlands: Springer.

Hu, X.H., Y.M. Wu, and X.W. Wang.2016. 'Principal component analysis and comprehensive evaluation of amino acid in different varieties of sugar beet' *Chinese Agricultural Science Bulletin*, 32(27), pp. 69-75.

Janda, T., E. Horvath, C. Szalai and E. Pald. 2007. Role of salicylic acid in the induction of abiotic stress tolerance. In: *Salicylic Acid: A Plant Hormone*, ed. S. Hayat and A. Ahmed, pp. 91-154. Dordrecht, Netherlands: Springer.

Khodary, S.F.A. 2004. Effect of salicylic acid on growth, photosynthesis and carbohydrate metabolism in salt-stressed maize plants. *Int. J. Agric. Biol.* 6: 5-8.

Koo, Y.M., A.Y. Heo, H.W. Choi.2020. Salicylic acid as a safe plant protector and growth regulator. Plant Pathol. J. 36, 1–10.

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

Merwad, A.M.A. 2015. Effect of Potassium Fertilisation and Salicylic Acid on Yield, Quality and Nutrient Uptake of Sugar Beet (*Beta vulgaris* L.) Grown in Saline Soil. *Malaysian Journal of Soil Science, 19,* 95-105.

Mundaragi, A., D. Thangadurai, S. Bhat, J. Sangeetha .2017. 'Proximate analysis and mineral composition of potential minor fruits of Western Ghats of India' *Scientific Papers Series A – Agronomy.* (60), *pp.* 340-6.

Page, A. L. 1982. "Methods of Soil Analysis". Chemical and Microbiological Properties. Soil Soc. Amer. Madison, Wisconsin, USA.

Sakhabutdinova A.R., D.R. Fatkhudinova, M.V. Bezrukova and F.M. Shakirova. 2003. Salicylic acid prevents the damaging action of stress factors on wheat plants. *Bulg. J. Plant Phsiol.* 2013: 314-319.

Shojaei, S. H., I. Ansarifard, K. Mostafavi, M. R. Bihamta, and M. Zabet .2022. GT biplot analysis for yield and related traits in some sunflower (Helianthus annuus L.) genotypes. *Journal of Agriculture and Food Research*, *10*, 100370.

Singh, B. and K. Usha. 2003. Salicylic acid induced physiological and biochemical changes in wheat seedlings under water stress. *Plant Growth Regul.* 39: 137- 141.

Stevanato, P., C. Chiodi, C. Broccanello, G. Concheeri, E. Biancardi, O. Pavli, G. Skaracis. 2019. Sustainability of the sugar beet crop. Sugar Tech. 21, 703–716.

Tasgin, E., O. Atici and B. Nalbantoghu. 2003. Effect of salicylic acid and cold on freezing tolerance in wheat leaves. *Plant Growth Regul*. 41: 231-236.4.

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. and L. Hunt 2002. Biplot analysis of diallel data. Crop Sci. 42:21-30.

Yan, W. and I.R. Rajcan .2002. Biplot analysis of test sites and trait relations of soybean in Ontario. Can. J. Plant Sci., 42:11–20.

Yan, W. and M.S. Kang .2003. GGE-biplot Analysis: A graphical Tool for Breeders, Geneticists and Agronomists, CRD Press, Boca Raton.

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

Yan, W. and N.A. Tinker .2006. Biplot analysis of multi-environment trial data: Principles and applications. Can. J. Plant Sci., 86(3): 623–645.

الملخص العربي

استخدام تحليل GGE ثنائي الأبعاد لتقييم أصناف بنجر السكر من حيث خصائص المحصول والجودة تحت مستويات حمض الساليسيليك في التربة المستصلحة حديثًا

فراج فرغل برعى أبو الليل، كرم عبد الصادق،عرفات سعد الدين عبد الرحيم سعدان و سمر عبد العاطي محمد حلمي

أُجريت تجربتان حقليتان في مزرعة خاصة بقرية منقار المجابرة بوادي النطرون، محافظة البحيرة، مصر، خلال موسمي ٢٠٢٢/٢٠٢٣ و٢٠٢٣/٢٠٢٤ لدراسة تأثير أربع معدلات من حمض الساليسيليك، وهي صفر (بدون حمض الساليسيليك كعينة ضابطة)، و١٠٠، و١٥٠، و٢٠٠ جزء في المليون/للتر، على صفات الجودة والمحصول لأربعة أصناف من بنجر السكر (أفندرا-KWS، وشانتالا-KWS، وBTS 8935، وBTS 7245) تحت ظروف التربة الرملية ونظام الري بالتنقيط.أُجريت باستخدام تصميم القطاعات العشوائية الكاملة (RCBD) بنظام القطع المنشقة وبثلاثة مكررات.

أظهرت النتائج زيادة في محصول الجذور والسكر (طن/فدان) عند رفع معدلات حمض الساليسيليك من ١٠٠ إلى ٢٠٠ جزء في المليون/لتر خلال الموسمين. وبالمثل، انخفضت كمية المواد المكونة المولاس بشكل أكبر في معاملة ١٠٠ جزء في المليون/لتر مقارنةً بمعاملة ٢٠٠ جزء في المليون/لتر. ومع ذلك، ارتبطت مستويات حمض الساليسيليك باتجاه ارتفاع محتوى السكروز والسكر المكرر. اختلفت الأصناف بشكل كبير، وفقًا للنتائج، حيث تفوق BTS 7245 وBTS 8935 على الأصناف الأخرى المختبرة في كلا الموسمين من حيث إنتاج الجذور والسكر. كان التفاعل بين معدلات حمض الساليسيليك والأصناف المختبرة ذا دلالة معنوية وأثر تفاعلي ملحوظ، خاصة في ما يتعلق بإنتاج الجذور والسكر والصفات المرتبطة بهما. وقد تم استُخدم تحليل GGE ثنائي الرسم البياني لمقارنة عدة صفات ، حيث أوضحت الرسوم GGE البيانية ثنائية البُعد العلاقات بين الصفات بشكل فعّال. يُعد استخدام حمض الساليسيليك بتركيز ٢٠٠ جزء في المليون/لتر المعاملة الأكثر كفاءة في تحسين إنتاجية الجذور والسكر لبنجر السكر المزروع في التربة الرملية.

الكلمات المفتاحية: التربة الرملية، بنجر السكر، حمض الساليسيليك، جودة السكر، صفات النمو.