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RESEARCH ARTICLE

Biplot analysis for yield and quality traits and comprehensive evaluation of sugar beet varieties treated by abscisic acid under water deficit stress.

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Abstract

Two field experiments were carried out during two growing seasons at the private farm located in the Kafr El Sheikh governorate, North Nile Delta, Egypt (31° 07' N latitude and 30° 05 E longitude). The purpose of the study was to examine the effects on the yield and quality of the five sugar beet varieties, namely BTS 970, Husam, Karam, Sandor, and Shantala-KWS, of two irrigation intervals, namely control (2-week interval) and water stress (4-week interval), as well as three rates of ABA (control = water, 1000, and 3000 ppm).

The results showed that the five sugar beet varieties differed significantly in how they responded to the three ABA concentrations under water deficit stress in terms of root length, root diameter, number of leaves, root yield, sucrose%, total soluble solids percentage (TSS%), sugar lost to molasses percentage (SLM%), extractable sugar percentage (EXT%), and sugar yield. In both seasons, the Husam and Karam varieties recorded the lowest mean values of these traits, while the Shantala-KWS variety had the highest mean values.

The sugar beet roots with ABA concentrations up to 3000 ppm also showed an increase in root yield, number of leaves, root diameter, root length, sucrose%, and TSS%. These traits also showed the highest mean values. The control treatments (water spray) showed the lowest mean values. On the other hand, the two seasons differed significantly in water deficit stress (4 weeks). The study recommends using the GT biplot analysis method to evaluate the adaptability of varieties across various environments.

Keywords: Beta vulgaris; Water deficit stress; ABA; Sugar Yield; GT biplot analysis.

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Introduction

Sugar consumption has increased over the last ten years, leading to a need to increase sugar production by expanding the cultivated area and improving root yield. Sugar beet (*Beta vulgaris L.*) is a major crop for sugar production and can be successfully grown in recently reclaimed soils due to its long root, high sugar yields under water deficit stress, and lower water requirements compared to sugarcane (Abu-Ellail et al. 2021; Galal et al. 2022; Ibraheim et al. 2024). According to the Council of Sugar Crops (2023), sugar beet is currently regarded as the primary source of sugar production in Egypt, accounting for approximately 63.8% (1.71 million tons) of the country's total sugar production, but 27.3% (0.678 million tons) from sugarcane.

One of the worst abiotic conditions that can reduce plant productivity is water deficit stress. Plant growth and development are stunted by water deficit stress, which negatively affects agriculture globally by lowering crop yield (Ahmed et al. 2023; Verma and Deepti 2016). Water deficit stress and crop losses caused by abiotic stresses such as water deficit stress are two of the most important environmental factors that restrict crop species' ability to grow in arid and semi-arid regions of the world.

Low water levels can impede plant growth and development, primarily through reduced transpiration rates, photosynthesis, and leaf turgor (Tahi et al. 2007). Sugar beet is a cash crop whose yield falls off quantitatively. Abiotic stressors and other unfavorable environmental conditions drastically reduce sugar beet productivity.

Abscisic acid (ABA) is vital for plant development and aids in plant adaptation to environmental stress, particularly water deficit stress (Chaves et al. 2003; Wani and Kumar 2015). ABA can reorganize a variety of physiological and biochemical signal transduction cascades in plants. The concentration of the plant hormone abscisic acid increases endogenously in plants as a defense against water scarcity.
It is important because it takes part in different processes of plant growth that allow plants to adapt to water deficit stress.

Cecilia et al. (2020) suggest that this ABA was a regulator in response to biological stress and enhanced plant resistance to water deficit stress. Under conditions of water deficit stress, transpiration water loss is prevented by ABA-mediated stomatal conductance (Kim et al. 2010). When there is little water available, the ABA stops the leaves from losing more water. ABA helps plants adapt to water deficit stress by synchronizing a variety of physiological processes (Wani and Kumar 2015). Also known as, a vital messenger, ABA mediates signals and regulates how plants respond to different environmental stressors. The purpose of this study is to evaluate five sugar beet varieties and examine the effects of abscisic acid (ABA) on the growth, yield, quality, and impurity traits under water deficit stress. Additionally, using traits to differentiate genotype GT biplot analysis.

Materials and methods

A field trial was conducted at the private farm (31° 07' N latitude and 30° 05 E longitude), Kafr El-Sheikh governorate, North Nile Delta, Egypt, in two successive seasons of 2021–2022 and 2022–2023. The treatments included five sugar beet varieties (BTS 970, Husam, Karam, Sandor, and Shantala-KWS), obtained from the Sugar Crop Research Institute Agricultural Research Center, Giza, to study the effects of water deficit stress and abscisic acid concentration on growth, physiological, yield and quality traits of sugar beet varieties under clay soil conditions. The experimental design was a split-split plot design in three replications used in both seasons, where the main plots were allocated by the five sugar beet varieties, while the sub-plots were occupied by two irrigation intervals (control (2 weeks), and water deficit stress (4 weeks). Each experimental basic unit included a plot area of 28 m2 (distance between rows: 50 cm; between hills: 20 cm). In the meantime, the sub-sub plots were occupied by the three rates of Abscisic Acid (ABA) (control = water, 1000, and 3000 ppm) as foliar application one time after thinning and a second time after the month from the first, in both seasons.

The sowing date was September 15th in the first and second seasons, respectively. After 40 days of sowing, seedlings thinned to one plant per hill. Nitrogen fertilizer level at the rate of 100 kg N/fed in the form of ammonium nitrate (33.5%) was applied in two equal portions; the first was applied after thinning, and the other was applied a month after the first application. All other agronomic practices, including surface irrigation and fertilizer application, are carried out according to recommended guidelines. During land preparation, phosphorus fertilizer was added at a rate of 45 kg P2O5/fed in the form of calcium superphosphate (15.5% P2O5).

Along with the second dose of nitrogen fertilizer, a potassium fertilizer rate of 36 kg K2O/fed was applied in the form of potassium sulfate (48% K2O). As advised by the Agricultural Research Center and the Sugar Crop Research Institute, other cultural customs followed. Following the methodology of Richards (1954), Table 1 presents the physical and chemical analysis of the experimental soil. The city of Kafr El-Sheikh experiences a subtropical desert climate with an annual temperature of 23.78ºC, which is -1.12% colder than the average for Egypt. Kafr El-Sheikh experiences 13.37 rainy days and 4.42 millimeters (0.17 inches) of precipitation on average each year.

Table 1. Physical and chemical analysis of the experimental sites of the two seasons.

Physical analysis	2021/2022	2022/2023	Soluble anions (meq/L)	2021/2022	2022/2023
Sand %	22.77	20.89	SO4-	5.06	6.87
Silt%	23.74	21.26	CO3-	2.00	2.14
Clay%	53.49	57.85	HCO3-	3.43	3.19
Texture class	Clay	Clay	Cl-	11.31	8.60
Chemical analysis			Soluble cations (meq/L)		
pH (1:2.5)	7.30	7.00	Ca++	2.17	3.65
EC (m. mhos/cm)	2.18	2.00	Mg++	8.74	7.12
Organic matter%	1.30	2.10	Na+	10.34	9.29
Available N ppm	17.00	16.00	K+	0.56	0.64
Available P ppm	9.30	9.20	Available K ppm	275.74	252.54

At harvest (210 days from sowing), the three guarded rows of each subplot harvested, cleaned, topped, and weighed, and the following characteristics were determined in both seasons:

Productivity traits

•Root length (cm), Root diameter (cm).
•Root yield (ton/fed): was calculated based on weight experimental plot.
•Sugar yield (ton/fed.): was determined according to the method described by Mc Ginnus (1971), Yield of clean roots were determined from the three guarded rows for each treatment: Sugar yield = root yield (ton/fed) x extractable sugar %
•Top yield (ton/fed): was calculated based on weight experimental plot.

Quality traits

•Sucrose percentage was determined according to Le-Docte (1927).
•Extractable white sugar percentage (EXT %) was determined according to Reinefeld et al. (1974).
•Sugar loss to molasses percentage (SLM %), was determined as described by Carruthers et al., (1962).
•Total soluble solids percentage (TSS %) it was calculated in juice of fresh roots by using Hand Reflectometer.

Impurities traits

•Potassium and sodium concentrations (meq/100 g beet) in roots were determined using "flame photometer" according to Brown and Lilliland (1964).
•Alpha amino nitrogen concentration determined using Hydrogenation method according to Pergel (1945).

Photosynthetic pigments

•Chlorophyll a, b, and carotenoids were calorimetrically determined in the leaves of sugar beet plants at 120 days after thinning according to methods described by Wettstein (1957) and calculated as mg/g fresh weight.

Total phenolic compounds

•Total phenolic compounds were determined using UV/Vis. Spectrophotometer, Jenway England at wavelength 750 nm as described by Singleton et al., (1999)

Statistical analysis

The collected data was statistically analyzed according to Gomez and Gomez (1984) by using the SAS computer software package. Revised L.S.D. at the 5% level was used to compare the means, according to Waller and Duncan (1969). Yan and Rajcan (2002) used the genotype by trait (GT) biplot, which is an application of the GGE biplot, to study the genotype by trait data. Because the traits were measured in different units, the biplot procedure was generated using the standardized values of the trait means.

Results and discussion

Productivity traits

Regarding the findings shown in Table 2, it was possible to see that, at the 5% probability level, water deficit stress significantly affected root length and diameter. With increasing times of irrigation (4 weeks), root diameter and length decreased. In comparison to other environmental stresses, water deficit stress has been studied most in beets, and these results tend to corroborate the findings of Yolcu et al. (2021), who found that they are important abiotic stresses that restrict crop growth and productivity. The findings presented here are consistent with those of Abu-Ellail and El-Mansoub (2020), who found that significant reductions in the root diameter of sugar beet plants caused by postponed irrigation days. According to Ibrahim et al. (2002), roots that are stressed by moisture grow longer. The Shantala-KWS variety outperformed the other varieties in terms of root length, diameter, and other varieties, as shown in Table 2. In terms of root length, the Husam and Karam varieties produced the lowest mean value, but the Karam variety also produced the lowest value throughout the two seasons. The results aligned with those of Alice et al. (2019), who discovered notable variations in root length and plant diameter among sugar beet varieties.

Table 2 demonstrates the impact of applying abscisic acid. It showed that increasing the concentration of ABA up to 3000 ppm resulted in longer and more robust roots. The highest mean values of these traits were recorded at 1000 ppm of ABA, and the lowest ones were recorded with control treatments during the two seasons.

These outcomes are in line with Cecilia et al. (2020), who showed the importance of abscisic acid (ABA) as a plant hormone and its well-known capacity to raise concentrations in plants quickly and dramatically in response to environmental stressors. Research by Harris (2015), Sah et al. (2016), and Li et al. (2017), has shown that abscisic acid regulates the growth of primary roots and the branching of lateral roots in plants. These results are in line with those of Awadalla et al. (2022), who discovered that during the two seasons, the tested sugar beet cultivars significantly influenced the root diameter trait.

Table 2 revealed that the interaction effect of water deficit stress × varieties x abscisic acid (ABA) was significant on all investigated traits of sugar beet varieties. In the first season, the sugar beet variety Sandor recorded the highest values of root length (35.66 and 29.66 cm under 2-week intervals and 4-week intervals, respectively) when plants were treated with 3000 ppm of ABA. In the second season, the sugar beet variety Shantala-KWS gave the highest values of root diameter (19.33 and 10.00 cm under 2-week intervals and 4-week intervals, respectively), followed by the variety Sandor (18.00 cm at 3000 ppm of ABA under a 2-week interval).

Table 2. Effect of irrigation intervals and abscisic acid (ABA) on root length and diameter of five sugar beet varieties during the two growing seasons 2021/2022 and 2022/2023.

Sugarbeet Varieties	Season one Root length (cm)								Season one Root diameter (cm)							
	2-week Irrigation interval Abscisic acid (ABA)			Mean	4-week Irrigation interval Abscisic acid (ABA)			Mean	2-week Irrigation interval Abscisic acid (ABA)			Mean	4-week Irrigation interval Abscisic acid (ABA)			Mean
	Zero	1000 ppm	3000 ppm		Zero	1000 ppm	3000 ppm		Zero	1000 ppm	3000 ppm		Zero	1000 ppm	3000 ppm	
BTS970	23.00	30.00	34.33	29.11	13.33	20.33	23.33	19.00	15.33	16.33	18.00	16.55	7.66	8.00	9.00	8.22
Husam	25.66	26.67	29.66	27.33	16.00	20.66	26.66	21.11	14.33	15.00	17.00	15.44	10.00	11.33	12.50	11.28
Karam	21.33	29.66	32.67	27.89	17.66	19.66	28.66	21.99	11.33	12.66	13.66	12.55	6.00	7.33	8.33	7.22
Sandor	23.00	28.00	35.66	28.89	18.33	21.66	29.66	23.22	12.66	13.00	16.00	13.89	11.00	12.00	13.66	12.22
Shantala	27.67	30.33	32.33	30.11	15.00	18.33	24.33	19.22	15.00	17.00	19.33	17.11	8.33	9.66	10.00	9.33
Mean	24.13	28.93	32.93	28.66	16.06	20.13	26.53	20.91	13.73	14.80	16.80	15.11	8.67	9.86	10.43	9.65
LSD at 5%																
Stress (S)								2.18								1.22
ABA (A)								2.29								1.60
Variety (V)								1.52								1.01
SxVxA								2.55								1.82
	Season two								Season two							
BTS970	29.66	31.00	32.00	30.89	14.66	18.00	26.00	19.55	13.66	14.33	16.33	14.77	9.66	10.00	10.33	10.00
Husam	28.33	30.00	31.00	29.78	16.00	17.66	18.00	17.22	14.33	15.66	17.33	15.77	10.00	11.00	12.33	11.11
Karam	26.33	28.00	30.00	28.11	15.66	18.00	22.33	18.66	12.00	14.00	15.00	13.67	7.66	8.33	9.33	8.44
Sandor	29.66	31.00	33.33	31.33	18.33	19.66	21.33	19.77	15.00	16.00	18.00	16.33	8.00	9.00	10.00	9.00
Shantala	29.66	30.00	36.00	31.89	17.33	20.33	23.66	20.44	13.66	15.00	16.33	15.00	5.00	6.66	7.66	6.44
Mean	23.46	24.40	26.47	24.78	13.86	14.86	17.46	15.40	11.33	12.60	13.20	12.38	6.60	7.40	7.93	7.31
LSD at 5%																
Stress (S)								1.33								1.65
ABA (A)								1.28								1.18
Variety (V)								1.44								1.00
SxVxA								2.21								1.70

However, the variety (Shantal-KWS) registered the highest significant value of root length (30.33 and 20.33 cm in 2-week intervals in the first season and 4-week intervals in the second season, respectively) when the plant was treated with 1000-ppm abscisic acid.

The largest root diameter was recorded by variety (Sandor) in the first season (13.66 cm at 3000 ppm ABA under a 4-week interval) and the second season (16.00 cm at 1000-ppm ABA under a 2-week interval).

The Husam variety came in second (12.33 cm at 3000 ppm and 11.00 cm at 1000 ppm of ABA under a 4-week interval) in the second season. In contrast, the variety Shantala-KWS, when treated with 1000 ppm of ABA, had the largest root diameter (17.00 cm under a 2-week interval) in the first season. Researchers Cecilia et al. (2020) came to similar conclusions.

Root and top yields

Means of top yield and root yield (ton/fed) as affected by water deficit stress treatments and abscisic acid (ABA) are shown in Table 3. The obtained results show that, under water deficit stress, the number of leaves per plant and root yield (ton/fed) significantly decreased. Under a 4-week interval had the lowest mean values of top yield (ton/fed) of sugar beet (8.61 and 7.91 ton /fed) in the first and second seasons and the lowest mean values of root yield (22.27 and 24.52 tons/fed) in both seasons.

This means that extending irrigation intervals from two to four weeks decreased the top yield and root yield (ton/fed). The decrease in the top yield (ton/fed) in the plant may be due to the reduction of water movement from the xylem to the different cells, which controls cell division and elongation.

Concerning water deficit stress and its effect on sugar yield, it is observed from the illustrated data in Table 3 that there is a significant reduction in the values of root yield (ton/fed) with the increased irrigation intervals. Similar results were reported by Abdelaal et al. (2020), who stated that water deficits led to significant decreases in the number of leaves. Abu-Ellail et al. (2021) found that delayed irrigation intervals (4 weeks) led to a marked decrease in root yield in both seasons, and yield and its attributes decreased under water deficit stress conditions. Nourjou (2008) stated that increasing the irrigation interval decreased sugar beet root yield.

Data in Table 3 indicate that sugar beet varieties differed significantly in top yield and root yield (ton/fed) traits, with the highest mean values of top yield (ton/fed) recorded by variety Karam, followed by Shantala-kws, and the highest mean values of root yield in the first and second seasons registered by Shantala-kws and Sandor varieties.

Alice et al. (2019) clearly shows that there is a significant difference among sugar beet cultivars for root yield. Gobarah et al. (2019) obtained the variations among sugar beet varieties. Regarding number of leaves per plant and root yield (ton/fed), the results in Table 3 showed clearly that increasing ABA concentration up to 3000 ppm increased top yield and root yield (ton/fed), which recorded the highest mean values of these traits, followed by 1000 ppm. While the lowest ones recorded with control treatments (water spray) in the two seasons.

This increase in the studied characters may be due to the role of ABA in the quality of plants.

Similar findings were reported by Abdelaal et al. (2020), who noticed that application of ABA at 250 ppm led to significant increases in top yield (ton/fed). With respect to the interaction effect between water deficit stress, the examined varieties, and ABA, it could be noticed that top yield and root yield (ton/fed) were statistically affected by this interaction. The highest number leaves per plant was recorded with the Sandor variety with A3 (3000 ppm) under 2-week interval in the first season, BTS970 under 2-week interval in the second season, and Shantala-kws under water deficit stress for 4 weeks in seasons one and two. and the highest root yield (ton/fed) were produced from Shantala-kws when sprayed at 3000 or 1000 ppm under 2-week interval in the two seasons; Sandor at 3000 ppm under water deficit stress in first season; and Husam in second season.

Quality traits

Data illustrated in Table 4 showed that water deficit stress had a significant effect on sucrose and TSS percentages ($P < 0.05$). Results showed that mean values of sucrose% under 4-week intervals were (17.07 and 17.89%, respectively) in the first and second seasons lower than 2-week intervals (recommended irrigation times), (19.49 and 19.40%, respectively) in both seasons, and total soluble solids percentage (TSS%) was decreased to 21.60 and 20.99%, respectively, in the first and second seasons under 4-week intervals (water deficit stress) compared to normal irrigation (22.87 and 22.75, respectively) in the first and second seasons. These results tended to support the findings of Abdelaal et al. (2020), who found the increasing period between planting and first irrigation scheduling led to significant differences in sucrose percentage.

Table 3. Effect of irrigation intervals and abscisic acid (ABA) on top yield (ton/fed) and root yield (ton/fed) of five sugar beet varieties during the two growing seasons 2021/2022 and 2022/2023.

Sugarbeet Varieties	Season one Top yield (ton/fed)								Season one Root yield (ton/fed)							
	2-week Irrigation interval Abscisic acid (ABA)			Mean	4-week Irrigation interval Abscisic acid (ABA)			Mean	2-week Irrigation interval Abscisic acid (ABA)			Mean	4-week Irrigation interval Abscisic acid (ABA)			Mean
	Zero	1000 ppm	3000 ppm		Zero	1000 ppm	3000 ppm		Zero	1000 ppm	3000 ppm		Zero	1000 ppm	3000 ppm	
BTS970	7.79	8.92	10.25	8.99	6.45	7.45	9.87	7.92	27.10	29.76	34.02	30.29	20.19	23.94	27.24	23.79
Husam	8.45	9.56	10.14	9.38	7.12	7.54	8.84	7.83	23.40	28.63	32.94	28.32	17.03	21.96	23.57	20.85
Karam	8.88	9.99	11.87	10.25	7.54	8.12	10.87	8.84	27.64	28.23	30.29	28.72	16.12	20.45	25.12	20.56
Sandor	9.78	10.89	12.72	11.13	8.94	8.87	9.42	9.08	28.76	31.60	34.72	31.69	20.38	26.62	27.51	24.84
Shantala	8.81	10.32	12.38	10.50	7.99	9.21	10.87	9.36	32.23	38.38	41.42	37.34	18.41	20.74	24.73	21.29
Mean	8.74	9.94	11.47	10.05	7.61	8.24	9.97	8.61	25.14	28.79	33.07	29.00	18.43	22.74	25.63	22.27
LSD at 5%																
Stress (S)								1.14								1.90
ABA (A)								0.61								1.88
Variety(V)								1.16								1.18
SxVxA								2.40								2.43
	Season two								Season two							
BTS970	6.45	9.11	10.98	8.85	5.41	7.42	9.21	7.35	34.11	36.61	40.69	37.14	22.2	31.27	32.29	18.1
Husam	6.94	9.34	11.98	9.42	6.87	6.54	7.87	7.09	34.55	35.43	38.55	36.18	14.4	28.11	34.18	26.9
Karam	7.08	9.62	12.23	9.64	5.74	7.54	9.45	7.58	30.65	38.97	41.02	36.88	17.6	24.62	30.60	27.4
Sandor	7.88	10.19	10.65	9.57	7.71	8.21	8.45	8.12	32.18	37.50	37.90	35.86	15.8	23.15	31.77	26.0
Shantala	9.45	10.35	11.22	10.34	8.18	9.94	10.11	9.41	38.03	39.80	46.08	41.30	16.6	27.99	33.38	27.2
Mean	7.56	9.72	11.41	9.56	6.78	7.93	9.02	7.91	27.77	29.87	32.64	30.10	13.8	22.10	26.32	24.5
LSD at 5%																
Stress (S)								1.12								1.70
ABA (A)								0.39								1.12
Variety(V)								1.10								1.17
SxVxA								2.15								2.36

The lowest value of TSS % (18.60%) was obtained under irrigation every 15 days (water deficit stress). Results showed significant differences among sugar beet varieties on all traits in both seasons. The sugar beet Shantala-KWS variety recorded the highest values of sucrose % and TSS%, as did the Husam variety in TSS%. Awadalla et al. (2022) found that the tested sugar beet cultivars, varieties, or genotypes had a significant effect on the sucrose trait in both seasons. Concerning the effect of ABA, the result in Table 4 revealed that the highest values of sucrose % and TSS% of sugar beet root were recorded with ABA at 3000 ppm, while the lowest ones were recorded with control treatments (water spray).

Results are in agreement with those obtained by El-Safy et al. (2020), who stated that increasing ABA concentration up to 3000 ppm increased TSS (%), sucrose (%), and sugar beetroots, which recorded the highest mean values of these traits, followed by 2000 ppm. These results tended to support the findings of Ofosu and Shohei (1994), who found that ABA content had a significantly positive correlation with sucrose content (percentage) and a highly significant positive correlation with the soluble sugar content of storage roots. Vreugdenhil (1983) suggested that ABA exerts an effect on the phloem loading of sucrose by enhancing the efflux of sucrose.

The interaction effect between water deficit stress, varieties, and ABA was significant for quality traits with increasing irrigation times. Sugar beet variety Shantala-KWS recorded the highest value of sucrose percentage with ABA 3000 ppm under water deficit stress at 4-week intervals in both seasons and with 3000 ppm under 2-week intervals in the first season compared with other varieties.In addition, Shantala-KWS had the highest TSS percentage value when spraying with ABA 3000 ppm under a 2-week interval in both seasons, followed by the Husam variety with ABA 3000 ppm in the first season, followed by the Sandor variety in the second season. Irrigation regime treatments had a significant effect on sugar beet yield and quality traits (Mahmoodi et al. 2008).

Data in Table 5 showed that water deficit stress from a 2-week interval (recommended irrigation times) to a 4-week interval (water deficit stress) was accompanied by a substantial and significantly decreased sugar lost to molasses percentage (SLM%) and extractable sugar percentage (EXT%), in the first season, as counted by (0.9 and 1.43%) and (0.76 and 1.55) in the second season compared to the 2-week interval (control).

These findings follow those found by El-Sayed (2018), who noted that water deficit stress increased sucrose loss to molasses (SLM) by up to 70%. Awadalla et al. (2021) showed that increasing the irrigation rate from 60 to 100% of IWR significantly affected the extractable sugar (EXT%), and sugar loss to molasses percentage (SLM%) was significantly affected by the examined irrigation rates.

The effects of the sugar beet varieties on SLM% and EXT% showed significant differences between the two seasons, as shown in Table 5. The highest mean values of SLM% and EXT% were recorded by variety (BTS970 and Sandor) compared to the mean values of the previously mentioned characters for the Husham, Karam, and Shantala-kws varieties. These results may be due to the differences between the studied varieties in gene expressions, Awadalla et al. (2021) showed that extractable sugar was significantly affected by tested sugar beet varieties in the two seasons. Concerning the results presented in Table 5, it could be observed that the application of Abscisic Acid (ABA) had no significant effect on SLM% and EXT% traits in the first and second seasons. The means of SLM% and EXT% were significantly affected by the interaction between water deficit stress, varieties, and ABA. When plants were treated with 3000 ppm of ABA, the sugar beet variety (Sandor) recorded the highest values of SLM% (2.42% under a 2-week interval) in the first season, followed by the BTS970 variety (2.37) in the second season, and the BTS970, Sandor varieties (1.53% under a 4-week interval) in the first season, but the Shantala-KWS variety (1.73% under a 4-week interval) in the second season. With ABA 3000 ppm, the sugar beet variety (Shantala-KWS) gave the highest values of EXT% (16.98 and 16.31 under 2-week intervals and 4-week intervals, respectively) in the first season, followed by variety (BTS970) (17.91 and 15.44% under 2-week intervals and 4-week intervals) in the second season.

However, when the plant was treated with 1000-ppm abscisic acid, the varieties (BTS970, Husam, and Karam) registered the highest significant value of SLM% under a 2-week interval in both seasons. Varieties BTS970 and Sandor registered the biggest SLM% (at 1000 ppm ABA under 4-week interval) in the first and second seasons, respectively, and the biggest EXT% at 1000 ppm ABA under 2-week interval by Sandor and Shantala-KWS varieties in the first and second seasons, respectively. Nevertheless, the 4-week interval varieties (Shantala-KWS and Husam) recorded the highest values in the first and second seasons, respectively.

Table 4. Effect of irrigation intervals and abscisic acid (ABA) on TSS% and sucrose% of five sugar beet varieties during the two growing seasons 2021/2022 and 2022/2023.

Sugarbeet Varieties	Season one TSS%								Season one Sucrose%							
	2-week Irrigation interval Abscisic acid (ABA)			Mean	4-week Irrigation interval Abscisic acid (ABA)			Mean	2-week Irrigation interval Abscisic acid (ABA)			Mean	4-week Irrigation interval Abscisic acid (ABA)			Mean
	Zero	1000 ppm	3000 ppm		Zero	1000 ppm	3000 ppm		Zero	1000 ppm	3000 ppm		Zero	1000 ppm	3000 ppm	
BTS970	21.89	22.52	23.63	22.68	20.65	21.24	21.86	21.25	17.41	18.88	19.77	18.69	16.05	17.06	18.97	17.36
Husam	20.08	21.97	22.01	21.35	22.53	23.00	23.75	23.09	18.17	19.63	20.08	19.29	15.53	16.38	17.22	16.38
Karam	22.45	23.48	24.71	23.55	21.75	21.97	22.56	22.09	19.07	20.29	21.33	20.23	14.77	16.05	16.67	15.83
Sandor	20.43	22.66	23.63	22.24	19.19	20.76	21.54	20.50	16.81	18.44	19.87	18.37	15.05	17.33	18.85	17.08
Shantala	23.69	24.08	25.86	24.54	20.62	20.86	21.78	21.09	19.68	20.26	22.64	20.86	17.86	18.92	19.36	18.71
Mean	21.71	22.94	23.97	22.87	20.95	21.57	22.30	21.60	18.23	19.50	20.74	19.49	15.85	17.15	18.21	17.07
LSD at 5%																
Stress (S)								0.14								0.35
ABA (A)								0.13								0.89
Variety (V)								0.46								0.74
SxVxA								1.21								1.79
	Season two								Season two							
BTS970	20.55	23.27	23.98	22.60	20.12	21.36	21.28	20.92	19.57	20.19	20.94	20.23	17.37	17.86	18.49	17.91
Husam	21.29	22.66	23.88	22.61	21.13	21.87	22.74	21.91	18.78	19.32	20.13	19.41	16.25	17.04	17.98	17.09
Karam	20.01	21.6	22.06	21.22	20.59	21.03	21.39	21.00	17.75	18.37	19.33	18.48	15.2	16.12	17.3	16.21
Sandor	22.9	23.45	24.38	23.58	19.81	22.05	22.82	21.56	16.42	17.9	18.28	17.53	17.44	18.33	18.84	18.20
Shantala	21.21	24.27	25.8	23.76	18.48	19.9	20.34	19.57	19.04	19.74	20.88	19.89	18.44	20.18	21.58	20.07
Mean	21.192	23.05	24.02	22.75	20.02	21.242	21.714	20.99	18.312	19.644	20.23	19.40	16.94	17.906	18.838	17.89
LSD at 5%																
Stress (S)								0.19								0.46
ABA (A)								0.87								0.48
Variety (V)								0.18								0.75
SxVxA								1.28								1.46

Table 5. Effect of irrigation intervals and abscisic acid (ABA) on SLM% and EXT% of five sugar beet varieties during the two growing seasons 2021/2022 and 2022/2023.

Sugar beet Varieties	Season one SLM%								Season one EXT%							
	2-week Irrigation interval Abscisic acid (ABA)			Mean	4-week Irrigation interval Abscisic acid (ABA)			Mean	2-week Irrigation interval Abscisic acid (ABA)			Mean	4-week Irrigation interval Abscisic acid (ABA)			Mean
	Zero	1000 ppm	3000 ppm		Zero	1000 ppm	3000 ppm		Zero	1000 ppm	3000 ppm		Zero	1000 ppm	3000 ppm	
BTS970	2.01	2.45	2.39	2.28	1.30	1.36	1.53	1.40	16.80	15.82	16.78	16.47	16.56	15.69	15.42	15.89
Husam	2.17	2.45	2.20	2.27	1.34	1.29	1.47	1.37	17.39	16.57	16.27	16.74	14.59	16.48	14.14	15.07
Karam	2.17	2.45	2.32	2.31	1.24	1.35	1.45	1.35	16.29	17.24	16.63	16.72	13.93	16.44	15.25	15.21
Sandor	2.26	2.16	2.42	2.28	1.39	1.24	1.53	1.39	16.94	17.79	16.85	17.19	14.05	16.48	14.72	15.08
Shantala	2.32	2.12	2.05	2.16	1.30	1.22	1.45	1.32	16.75	17.53	16.98	17.09	13.95	17.09	16.31	15.78
Mean	2.19	2.33	2.28	2.26	1.31	1.29	1.49	1.36	16.83	16.99	16.70	16.84	14.62	16.44	15.17	15.41
LSD at 5%																
Stress (S)								0.34								0.45
ABA (A)								NS								NS
Variety (V)								0.08								0.05
SxVxA								0.48								0.12
	Season two								Season two							
BTS970	2.42	2.56	2.37	2.45	1.50	1.59	1.45	1.51	16.55	17.38	17.91	17.28	15.27	15.27	15.44	15.33
Husam	2.42	2.42	1.88	2.24	1.46	1.57	1.40	1.48	15.75	17.10	17.84	16.90	14.18	16.86	15.28	15.44
Karam	2.44	2.37	1.91	2.24	1.50	1.44	1.43	1.46	15.70	16.35	16.86	16.30	15.09	15.07	15.27	15.14
Sandor	2.42	2.32	2.09	2.28	1.60	1.60	1.68	1.63	17.39	17.35	16.20	16.98	16.23	15.12	14.56	15.30
Shantala	2.32	2.37	2.12	2.27	1.53	1.59	1.73	1.62	17.11	17.90	16.02	17.01	15.30	15.98	15.25	15.51
Mean	2.40	2.41	2.07	2.30	1.52	1.56	1.54	1.54	16.50	17.22	16.97	16.89	15.21	15.66	15.16	15.34
LSD at 5%																
Stress (S)								0.23								0.38
ABA (A)								NS								NS
Variety (V)								0.04								0.07
SxVxA								0.93								0.42

Sugar yield and impurities traits

Increasing water deficit stress significantly decreases sugar yield (ton/fed) and Na%, as shown in Table 6. In this respect, the lowest sugar yield (ton/fed) was recorded under a 4-week interval (water deficit stress) compared with a 2-week interval (recommended irrigation times). Peyman (2012) found that the results showed significant differences between irrigation treatments for white sugar yield. Gizem and Hamit (2020) recorded a similar conclusion, and Awadalla et al. (2021) cleared that the impurity percentage (sodium percentage) was significantly affected by the irrigation rate in both seasons. Sadeghian et al. (2000) found that under severe water deficit stress, sugar yield and white sugar yield decreased to 59% and 60%, respectively.

The sugar yield is the product of the total amount of dry matter accumulated in the plant during growth, the percentage allocated to the storage root, and the proportion of accumulated dry matter (Bell et al. 1996). In this study (Table 6), mean sugar yield (ton/fed) was significantly affected by sugar beet varieties in both seasons.

The resistant varieties showed the highest values, i.e., BTS970 and Sandor, obtained under water deficit stress treatments compared to the other susceptible varieties, i.e., Husam, Karam, and Shantala-KWS. Meanwhile, it could be observed that the effect of the varieties had no significant effect on the Na% trait. The investigator reported similar results, Sadeghian et al. (2000).

The ranges of white sugar yield demonstrated that genotypes respond differently to water deficit stress. Regarding the effect of the application of Abscisic acid, Table 6 revealed that increasing ABA concentration up to 3000 ppm decreased sugar yield (ton/fed), which recorded the lowest mean values of these traits followed by 1000 ppm, while the highest ones recorded with control treatments, however, noticed that application of Abscisic acid had no significant effect on Na% trait. Ofosu and Shohei (1994) noticed that ABA at 10–5 M restricted the release of sugars from the discs, primarily the rate of release across the plasma membrane. Concerning the effect of interaction between water deficit stress, varieties, and Abscisic Acid (Table 6), it showed a significant effect on sugar yield (ton/fed) but no significant effect on the Na% trait. whereas the highest mean values of sugar yield (ton/fed) of sugar beet were recorded when sprayed by ABA at a rate of 3000 ppm with Shantala-KWS and BTS970 varieties under a 2-week interval under the first and second seasons, respectively, and variety BTS970 under a 4-week interval in both seasons.

Results in Table 7 showed that water deficit stress from a 2-week interval (recommended irrigation times) to a 4-week interval (water deficit stress) was accompanied by a substantial increase in N% in the first season, which was counted at 0.01 percent and decreased by 0.03% in the second season compared to the 2-week interval (control), but water deficit stress did not have a have a significant effect on the K% trait.

These results are in full agreement with those reported by Mahmoodi et al. (2008), who found that potassium concentration was not significantly affected by irrigation treatments. Awadalla et al. (2021) clarified that the impurity percentages (α- amino nitrogen percentages) were significantly affected by the irrigation rate in both seasons.

Table 7 clarifies that the effect of varieties, abscisic acid, and the interaction between them and water deficit stress had no significant effect on the N% and K% traits.

Photosynthetic pigments and total phenolic compounds

Concerning the results presented in Table 8, it could be observed that water deficit stress had a significant effect on T- Phenol and T- Chlorophyll A+B at 5% probability level. T- Phenol and T- Chlorophyll A+B increased by increasing irrigation times (4 weeks) in both seasons except in the second season T- Chlorophyll A+B decreased. Chlorophyll breakdown under stress is a typical response for limiting photo-inhibition, which decreases leaf chlorophyll accumulation under stress.

Under water deficit stress conditions, the decrease in chlorophyll content could be considered a typical symptom of oxidative stress because of pigment photo-oxidation and chlorophyll degradation (Ashraf and Harris 2013). These results tended to support the findings of Abu-Ellail and El-Mansoub (2020) who found that total chlorophyll in leaves decreased significantly by increasing water deficit stress. Meanwhile, the highest total chlorophyll was produced by using moderate stress compared with normal irrigation treatment and increasing water deficit stress significantly increased the total phenolic content. Niazi et al. (2004) and Islam et al. (2020) found that Chlorophyll a, chlorophyll b, and total chlorophyll, significantly decreased ($p < 0.05$) in water deficit stress compared to the control condition. Chlorophyll a, b, total chlorophyll significantly decreased in all the genotypes under water deficit stress conditions. Water deficit stress has also a negative impact on different chlorophyll fluorescence parameters and total polyphenol scavenging activity were remarkably increased under water deficit stress condition.

Table 6. Effect of irrigation intervals and abscisic acid (ABA) on sugar yield (ton/fed) and Na % of five sugar beet varieties during the of two growing seasons 2021/2022 and 2022/2023.

Sugar beet Varieties	Season one Sugar yield (ton/fed)								Season one Na %							
	2-week Irrigation interval				4-week Irrigation interval				2-week Irrigation interval				4-week Irrigation interval			
	Abscisic acid (ABA)			Mean	Abscisic acid (ABA)			Mean	Abscisic acid (ABA)			Mean	Abscisic acid (ABA)			Mean
	Zero	1000 ppm	3000 ppm		Zero	1000 ppm	3000 ppm		Zero	1000 ppm	3000 ppm		Zero	1000 ppm	3000 ppm	
BTS970	5.71	4.70	4.89	5.10	4.51	3.17	3.69	3.79	4.77	4.13	3.49	4.13	2.78	2.19	1.83	2.27
Husam	5.72	4.74	4.63	5.03	4.02	2.80	3.10	3.31	4.32	3.96	2.01	3.43	2.33	2.24	1.15	1.91
Karam	4.94	4.86	4.59	4.80	3.49	2.65	3.11	3.08	4.34	3.72	1.81	3.29	2.41	1.36	0.79	1.52
Sandor	5.88	5.62	4.84	5.45	3.73	4.53	3.00	3.75	4.78	3.34	2.84	3.65	2.82	2.43	1.83	2.36
Shantala	6.46	7.25	5.48	6.40	3.88	3.15	3.41	3.48	4.61	3.49	2.88	3.66	2.63	1.47	1.18	1.76
Mean	5.74	5.43	4.89	5.35	3.93	3.26	3.26	3.48	4.56	3.73	2.61	3.63	2.59	1.94	1.36	1.96
LSD at 5%																
Stress (S)								0.22								0.28
ABA (A)								0.17								ns
Variety (V)								0.03								ns
SxVxA								0.42								ns
	Season two								Season two							
BTS970	5.98	6.37	7.27	6.54	4.76	3.40	4.98	4.38	5.21	4.34	3.84	4.46	2.78	2.30	2.06	2.38
Husam	6.07	6.06	6.16	6.10	4.84	2.43	4.29	3.85	5.38	4.10	3.41	4.30	2.72	2.63	2.45	2.60
Karam	6.11	6.73	5.16	6.00	4.62	2.66	3.75	3.68	4.82	4.32	3.81	4.32	2.35	2.33	2.03	2.24
Sandor	6.59	6.50	5.21	6.10	5.16	4.81	3.35	4.44	4.78	4.11	3.03	3.97	3.00	2.43	1.83	2.42
Shantala	6.80	8.24	6.09	7.04	5.11	2.67	4.30	4.03	4.26	3.01	2.84	3.37	2.48	2.07	1.78	2.11
Mean	6.31	6.78	5.98	6.36	4.90	3.19	4.13	4.08	4.89	3.98	3.39	4.08	2.67	2.35	2.03	2.35
LSD at 5%																
Stress (S)								0.31								0.07
ABA (A)								0.13								ns
Variety (V)								0.41								ns
SxVxA								0.52								ns

Table 7. Effect of irrigation intervals and abscisic acid (ABA) on N% and K% of five sugar beet varieties during the two growing seasons 2021/2022 and 2022/2023.

Sugar beet Varieties	Season one N%								Season one K%							
	2-week Irrigation interval				4-week Irrigation interval				2-week Irrigation interval				4-week Irrigation interval			
	Abscisic acid (ABA)			Mean	Abscisic acid (ABA)			Mean	Abscisic acid (ABA)			Mean	Abscisic acid (ABA)			Mean
	Zero	1000 ppm	3000 ppm		Zero	1000 ppm	3000 ppm		Zero	1000 ppm	3000 ppm		Zero	1000 ppm	3000 ppm	
BTS970	2.91	2.23	0.99	2.04	1.94	1.07	0.77	1.26	5.19	4.65	4.12	3.97	2.29	1.50	1.31	1.70
Husam	2.69	1.96	1.42	2.02	1.72	0.80	0.68	1.07	5.04	4.46	4.08	3.27	2.14	1.80	1.19	1.71
Karam	2.48	2.31	1.81	2.20	1.51	1.15	0.70	1.12	4.91	4.72	3.02	2.26	2.01	1.72	1.24	1.82
Sandor	2.62	2.31	1.69	2.21	1.65	1.12	0.82	1.20	4.83	4.62	3.70	2.33	1.93	1.87	1.42	1.77
Shantala	2.82	2.38	2.16	2.45	1.85	1.22	0.73	1.27	4.87	4.15	2.52	2.07	1.97	1.43	1.24	1.55
Mean	1.75	1.69	1.80	1.75	1.75	1.77	1.75	1.76	4.97	4.52	3.49	2.78	2.07	1.66	1.28	1.71
LSD at 5%																
Stress (S)								NS								NS
ABA (A)								NS								NS
Variety (V)								NS								NS
SxVxA								NS								NS
	Season two								Season two							
BTS970	3.12	2.99	3.16	1.99	1.67	1.35	1.67	3.12	4.43	4.36	3.01	3.93	2.54	2.02	0.81	1.79
Husam	2.83	2.11	2.93	2.09	1.81	1.45	1.78	2.83	4.62	4.41	3.02	4.02	2.73	2.07	0.82	1.87
Karam	2.98	2.83	3.10	2.25	1.79	1.71	1.92	2.98	4.64	3.71	2.96	3.77	2.75	1.37	0.76	1.63
Sandor	2.41	1.97	2.51	2.43	1.79	1.54	1.92	2.41	4.84	4.7	4.75	4.76	2.95	2.36	1.88	2.40
Shantala	2.56	2.24	2.72	2.53	1.98	1.56	2.02	2.56	4.97	4.77	3.58	4.44	3.08	2.43	1.38	2.30
Mean	2.21	2.27	2.24	2.24	2.25	2.24	2.24	2.21	4.7	4.39	3.464	4.18	2.81	2.05	1.13	2.00
LSD at 5%																
Stress (S)								NS								NS
ABA (A)								NS								NS
Variety (V)								NS								NS
SxVxA								NS								NS

Table 8. Effect of irrigation intervals and abscisic acid (ABA) on T- Phenol and T- Chlorophel A+B of five sugar beet varieties during the two growing seasons 2021/2022 and 2022/2023.

Sugar beet Varieties	Season one T- Phenol								Season one T- Chlorophyll A+B							
	2-week Irrigation interval				4-week Irrigation interval				2-week Irrigation interval				4-week Irrigation interval			
	Abscisic acid (ABA)			Mean	Abscisic acid (ABA)			Mean	Abscisic acid (ABA)			Mean	Abscisic acid (ABA)			Mean
	Zero	1000 ppm	3000 ppm		Zero	1000 ppm	3000 ppm		Zero	1000 ppm	3000 ppm		Zero	1000 ppm	3000 ppm	
BTS970	158.47	199.87	226.93	195.09	164.93	178.43	234.60	192.66	3.53	5.46	5.59	4.86	2.61	2.96	7.42	4.33
Husam	127.00	175.43	221.93	174.79	146.87	196.20	199.87	180.98	3.48	5.07	6.17	4.90	3.42	4.07	5.32	4.27
Karam	146.73	167.23	227.83	180.60	161.30	175.43	223.50	186.74	3.55	5.24	5.62	4.80	2.65	3.93	7.29	4.63
Sandor	140.80	153.90	191.97	162.22	146.73	194.90	238.60	193.41	3.34	3.46	3.74	3.52	2.93	5.93	8.38	5.75
Shantala	124.17	167.63	222.27	171.36	140.80	170.80	254.13	188.58	2.49	3.28	3.81	3.19	3.56	6.84	7.19	5.86
Mean	139.43	172.81	218.19	176.81	152.13	183.15	230.14	188.47	3.28	4.50	4.98	4.26	3.03	4.75	7.12	4.97
LSD at 5%																
Stress (S)								3.59								1.33
ABA (A)								2.14								1.57
Variety (V)								1.32								0.89
SxVxA								4.78								2.01
	Season two								Season two							
BTS970	157.14	198.57	223.67	193.13	165.93	178.48	234.75	193.0	2.76	6.23	6.45	5.15	1.81	3.74	5.29	3.61
Husam	124.98	171.32	219.21	171.84	144.22	195.22	200.96	180.1	2.65	5.54	7.01	5.07	2.68	3.82	4.19	3.56
Karam	143.21	163.65	225.58	177.48	162.34	176.41	223.57	187.4	2.88	5.08	6.07	4.68	1.83	4.63	5.16	3.87
Sandor	137.54	153.52	188.67	159.91	146.71	184.68	242.85	191.4	2.51	4.25	4.54	3.77	2.12	3.68	6.25	4.02
Shantala	120.89	162.57	221.99	168.48	152.83	173.71	256.26	194.2	1.64	3.03	4.08	2.92	2.70	2.59	3.06	2.78
Mean	136.75	169.93	215.82	174.17	154.41	181.70	231.68	189.2	2.49	4.83	5.63	4.31	1.15	2.66	3.57	2.46
LSD at 5%																
Stress (S)								2.51								1.21
ABA (A)								2.32								1.06
Variety (V)								1.64								0.98
SxVxA								3.71								2.31

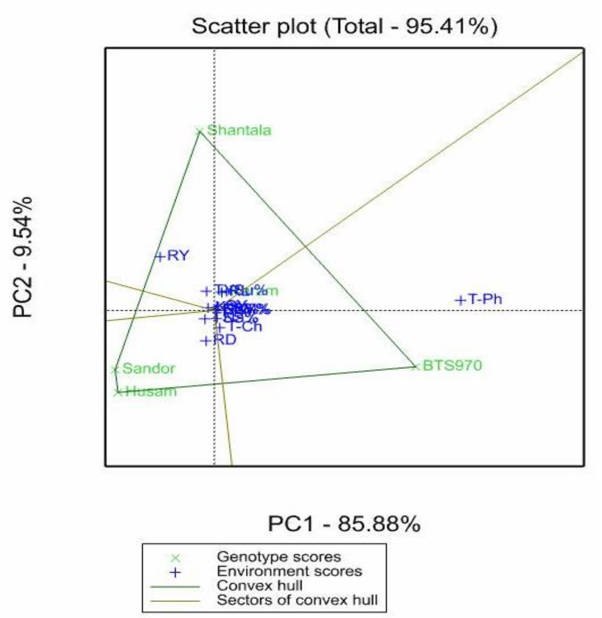
Regarding the varieties' effects in Table 8, it was noticed that T-phenol BTS970 and Sandor gave the highest value in the first season but the variety Shantala-kws in the second season. Meanwhile, in T-Chlorophyll A+B, the highest mean values were recorded by varieties (Husam and Shantala-KWS) in the first season, but varieties (BTS 970 and Sandor) scored the highest mean I the second season These findings were following those of Abu-Ellail and El-Mansoub (2020) found that a significant difference ($P < 0.05$) was also observed among varieties for the chlorophyll content. Respecting the effect of the application of Abscisic acid, Table 8 revealed that increasing ABA concentration up to 3000-ppm increase T- Phenol and T- Chlorophyll A+B in both seasons, which recorded the highest mean values of these traits followed by 1000 ppm, while the lowest ones recorded with control treatments. El-Safy et al. (2020) indicated that without ABA application, severe water deficit stress conditions increased the total phenol content compared to the irrigation condition, and application of ABA increased the total phenol content under moderate and severe water deficit stress conditions.

Concerning the effect of interaction between water deficit stress, varieties and Abscisic acid (Table 8) it showed a significant effect on T- Phenol and T- Chlorophyll A+B. whereas the highest mean values T- Phenol of sugar beet were recorded when sprayed by ABA at the rate of 3000 ppm with Karam variety under 2-week interval in first and second seasons while Shantala-kws under 4-week interval.

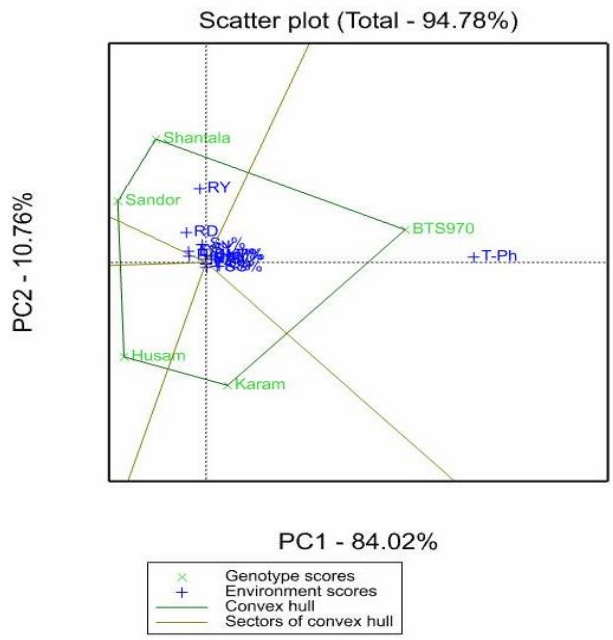
Meanwhile the highest values in Chlorophyll A+B were recorded with Husam variety when sprayed by 3000 ppm ABA under 2-week interval and Sandor variety under 4-week interval in both seasons.

Genotype by Trait biplot graph

A genotype-by-trait (GT) biplot graph's polygon view is a helpful tool for analyzing patterns of interaction between genotypes and traits, provided that the biplot accounts for a significant amount of the overall variation. The relationship between the targeted sugar beet genotypes is shown in the biplot graph (Fig. 1), which makes use of the root and sugar yields as well as associated characteristics. The first season's mean performance of the sugar beet data's GT biplot explained 94.78% of the variation in the standardized data overall. A total of 84.02% and 10.76% of the explanations were provided by the first and second principal components (PC1 and PC2). In the second season, the first and second principal components (PC1 and PC2) represented 85.88% and 9.54% of the total variation, respectively, which amounted to 95.41%. To attain the GT biplot model's goodness of fit, the first two PCs must reflect more than 60% of the total variation. A few indicators of distinct sugar beet varieties have been employed to assess sugar beet characteristics and identify different varieties (Hu et al., 2016). Furthermore, Ghareeb et al. (2014) used the PCA technique to perform extensive evaluations and analyses to ascertain the root and sugar yields of five distinct sugar beet varieties.



1st season



2nd season

Figure 1. The polygon view of Genotype by Trait (GT) biplot showing which varieties had the highest values for which traits for five sugar beet varieties at 1st and 2nd seasons.

The perpendicular lines to the polygon sides facilitate comparison between neighboring vertex varieties. The root yield (RY), root diameter (RD), and associated traits recorded high values for the variety Shantala-KWS. Furthermore, variety Sandor was found in the same sector and showed comparable traits in terms of root yield and root diameter. It is observed that these traits and variety points were grouped into a single sector, and the angles connecting them reflected their favorable correlations.

However, due to obtuse angles between the two varieties (Husam and Karam) and the two characters, the two varieties had the lowest values of root yield and sugar yield. According to Johnson (2012), the purpose of PCA is to convert a set of characters' total dissimilarity into linearly, independent composite characters that gradually increase the data variability. It is important to note that the variety of groups that are currently in place match the ones that the mean performance produced. As a result, choosing the ideal variety for multi-traits is thought to be a successful and effective use of the GT biplot graph. The GT biplot graph is the better choice because it is more readable and easier to understand. These findings are consistent with those of Ober et al. (2005), and Abu-Ellail et al. (2023), who discovered that a GT biplot demonstrated that traits related to yield (i.e., root and sugar yields/fed) and the extraction coefficient of sugar content and sugar extractable percentage had similar discriminating values for the genotypes. There was less variation in traits with short vectors between varieties.

Genotypes by treatment biplot graph

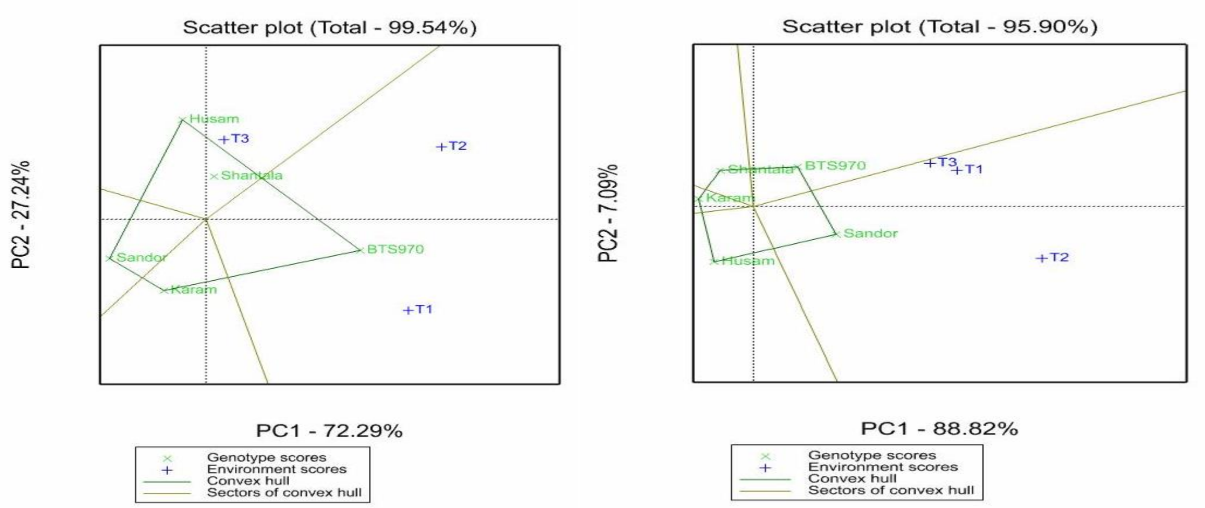
The data in Figures 2 and 3 were used to display the polygon view of a genotype-by-treatment (GT) biplot graph. In Figure 2, the GT biplot for the sugar beet root yield dataset accounted for 95.90 and 99.54% of the total variation in the first and second years, respectively. On the other hand, in the first and second seasons for root yield, the first two PCs (PC1 and PC2) explained (88.82 and 7.09%) and (72.29 and 27.24%), respectively.

According to Ghareeb et al. (2014) and Abu-Ellail et al. (2023), a high genotype and environment share of the total sum of squares percentages indicates that there is variation in both the productivity potential of different environments and the genetic potential of genotypes.

The biplot helps in the understanding of interrelationships among environments. Numerous studies have examined the characteristics of different sugar beet varieties using correlational PCA. According to Jia et al. (2015), varieties or environments located on the right side of the axis' midpoint yield more than those on the left do.

Figure 3 shows that for the sugar yield dataset, the GT biplot graph explained 97.31% and 97.63%, respectively, of the total variation in the first and second years. Regarding the overall variation, the first two PCs (PC1 and PC2) contributed approximately 72.10% and 25.53% in the first season and 77.67% and 19.64% in the second. This relatively high percentage shows how well the GT biplot graph interpreted the root and sugar yield treatments for each variety of sugar beet during both experimental years. The polygon view of the GT biplot helps to determine varieties with good responsibility for one or more treatments.

The variety Shantala-KWS produced the highest root and sugar yields under most or all treatments during the first and second seasons. It is concluded that BTS970 and Sandor varieties followed in order of importance. Our findings are consistent with those of Ober et al. (2005), who discovered that genotype × trait biplots (GT) demonstrated superior genotypes with comparatively higher expression of favorable trait combinations. Based on these findings, superior sugar beet varieties may be distinguished by root weight and irrigation patterns. This data ought to make it possible to create instruments for indirectly identifying varieties that are appropriate for demanding situations.



Root yield in 1st season **Root yield in 2nd season**

Figure 2. Polygon view of genotype × treatments biplot of five sugar beet varieties for root yield at the 1st and 2nd season.

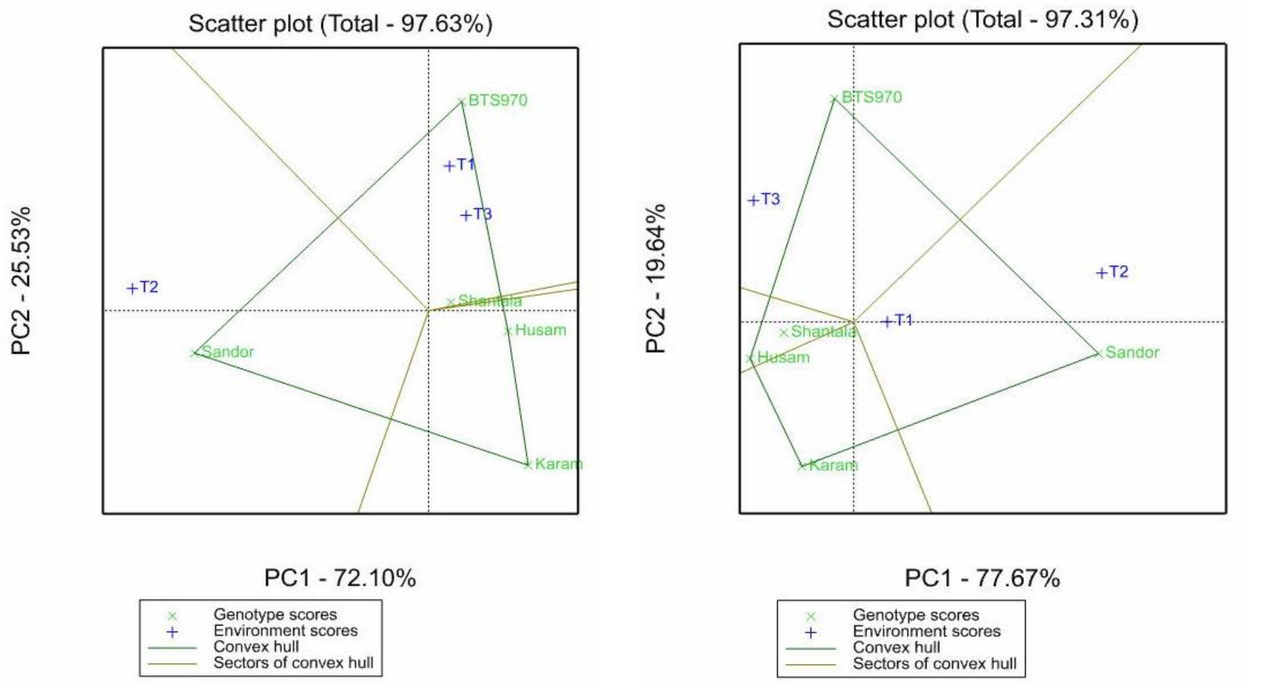


Figure 3. Polygon view of genotype × treatments biplot of five sugar beet varieties for sugar yield at the 1st and 2nd season.

Conclusions

The results concluded that water deficit stress significantly influenced and markedly decreased the root length, root diameter, number leaves per plant, sucrose %, TSS%, SLM%, EXT%, Na% root yield, sugar yield and T-Chlorophyll A+B (in the second season), in contrary N%, T-phenol and T-Chlorophyll A+B (in first season) increased. The studied varieties, as well, showed different reactions to water deficit stress and abscisic acid. Also increasing ABA concentration up to 3000 ppm increased root length and diameter, number leaves per plant, sucrose %, TSS%, root yield, T-phenol and T-Chlorophyll A+B, while decrease sugar yield. Sugar beet varieties i.e. the Shantala-kws variety recorded the highest mean values of these traits followed by Sandor variety hence, these varieties can be cultivated as commercial varieties in districts of deficit water deficit stress. The relationship between the traits under study was described using the principal component analysis method. The ultimate findings demonstrated that the best root and sugar yields, as well as the most consistent performance under water deficit stress, were produced by the elite varieties Shantal-KWS, Sandor, and BTS970. The GT method was utilized in the study to evaluate the adaptability of genotypes × traits and genotypes x treatments interaction across various environments.

Reference

Abdelaal Kh. AA, Sahar HR, Adel R, Akbar H and Ayman ES (2020) Yield and quality of two sugar beet (Beta vulgaris L. ssp. vulgaris var. altissima Döll) cultivars are influenced by foliar application of salicylic acid, irrigation timing, and planting density. 115.2.1159.

Abu-Ellail FFB and Sasy AH (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 FFB, Sadek KA, Abd El-Azez YM and Fares WM (2023) Simultaneous evaluation of yield and stability for some sugar beet (Beta vulgaris L.) varieties under Egyptian conditions using AMMI and GGE biplot approaches. Indian J. Genet. Plant Breed., 83(4): 587-601.

Abu-Ellail FFB and El-Mansoub MMA (2020) Impact of water deficit stress on growth, productivity and powdery Mildew disease of ten sugar beet varieties. Alexandria Science Exchange J., 41 :(2)165-179.

Abu-Ellail FFB, El-Gamal ISH, Bachoosh SMI and El-Safy NK (2021) Influence of water deficit stress on quality, yield and physiological traits of some sugar beet varieties. Egypt. J. of Appl. Sci., 36: (3) 35-50.

Ahmed S, Bekeet M, Eissa M, Hussien H, Abou-Elwafa SF (2023) Effect of water deficit irrigation and bio-fertilizers on growth, yield and quality of sugar beet. Egyptian Sugar Journal, 19: 71-81. https://10.21608/esugj.2023.181138.1028

Alice TT, MM Tawfik, Eltham AB and Magda HM (2019) Yield and quality response of some sugar beet (*Beta vulgaris L.)* varieties to humic acid and yeast application in newly reclaimed soil. Middle East Journal of Agriculture Research, 08: (01) 56-65.

Ashraf M, Harris PJC (2013) Photosynthesis under stressful environments: an overview. Photosynthetica. 51 (2), 163–190.

Awadalla AO, Ahmed AZ and Mohammad M Sh (2021) Possibility of sugar beet production in Toshka Region. II- Effect of water deficit stress on some sugar beet varieties, Egypt. J. Agron. 43 (3):403-415.

Awadalla AOA, Ahmed SMM, Sakina RA and Esraa HAA (2022) Effect of planting date on productivity of some sugar beet varieties under Kom Ombo conditions. Aswan University Journal of Environmental Studies (AUJES). 3(2) 207-219.

Bell CI, Milford GFJ and Leigh RA (1996) Sugar beet. In: Zamski E., Schaffer A.A. (eds.): Photoassimilate distribution in plants and crops. Source-sink relationships. Marcel Dekker Inc., USA, New York, Pp: 691–707.

Brown JD and Lilliand O (1964) Rapid determination of potassium, sodium in plant material and soil extraction by flame photometry. Proc. Amer. Soc. Hort. Sci., 48:340-364.

Carruthers A, Oldifield JFT and Teague HJ (1962) Assessment of beet quality. Paper presented to the 15th Annual Technical Conference, Brtish Sugar Corporation Ltd. 28 PP.

Cecilia B, Tadeja S, Andrea N, Francesco L, Antonella G and Mauro C (2020) Changes in abscisic acid content during and after drought are related to carbohydrate mobilization and hydraulic recovery in poplar stems. Tree Physiology, 40 (8), 1043–1057.

Chaves MM, Maroco JP and Pereira JS (2003) Understanding plant responses to drought-from genes to the whole plant. Funct. Plant Biol. FPB, 30, 239–264.

El-Sayed AM, Mahmoud AH, Taha IB and Eman IRE (2018) Tolerance of some sugar beet varieties to water deficit stress. Agricultural Water Management Volume 201, 144-151.

El-Safy NK, El-Sharnoby HM and El-Sheikh AM (2020) Response of some sugar beet varieties to abscisic acid under different storage periods. Egypt. Acad. J. Biolog. Sci., 11(2):41- 51.

Galal A, El-Noury M, Essa M, Abou El-Yazied A, Abou-Elwafa SF (2022) Effect of algae extract foliar application and inter-row planting distances on the yield and quality of sugar beet. Egyptian Sugar Journal, 18: 16-31. https://10.21608/esugj.2022.125012.1004

Ghareeb Zeinab E1, Hoda EA Ibrahim, Elsheikh SRE and Bachoash SMI (2014) Genotype × environment Interaction for characteristics of some sugar beet genotypes. J. Plant Production, Mansoura Univ., Vol. 5 (5), pp. 853-867.

Gizem AKSU and ALTAY Hamit (2020) The effects of potassium application on drought stress in sugar beet: PART I. Sugar beet quality components. Journal of Scientific Perspectives, 4(2): 157-168.

Gobarah M, Hussein MM, Tawfik MM, Ahmed AG and Mohamed MF (2019) Effect of different sowing dates on quantity and quality of some promising sugar beet (beta vulgaris l.) varieties under North Delta, condition. Egyptian Journal of Agronomy, 41(3), 343-354.

Gomez KA and AA Gomez (1984) Statistical Procedures for Agriculture Research. John Wiley and Sons. Inc. New York, USA.

Harris J (2015) Abscisic acid: hidden architect of root system structure. Plants.;4:548–572.

Hu XH, Wu YM, Wang XW (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.

Ibraheim H, Eissa M, Galal A, Aboelyazied A, Abou-Elwafa SF (2024) Effect of sowing dates and geometrical distribution-based planting densities on the yield and quality of sugar beet. Egyptian Sugar Journal, 21: 19-31. https://10.21608/esugj.2024.259521.1047

Ibrahim MM, Khalifa MR, Korim MA, Zein FI and Omer EH (2002) Yield and quality of sugar beet crop as affected by mid to late season drought and potassium fertilization at north Nile Delta. Egypt. Journal of Soil Science, 42(1): 87-102.

Islam J, Kim JW, Begum K, Sohel AT and Lim YS (2020) Physiological and biochemical changes in sugar beet seedlings to confer stress adaptability under drought condition. Plants. 9, 1511.

Jia XF, Zhu SM, Wang Q, Long W, Zhang XL (2015) Principal component analysis and cluster analysis of the elements in sugar beet roots of different geographical origins in Xinjiang' Modern Food Science and Technology, (7), pp. 302-308.

Johnson DE (2012) 'Applied Multivariate Methods for Data Analysis' New York: Duxbury Press.

Kim TH, Böhmer M, Hu H, Nishimura N and Schroeder JI (2010) Guard cell signal transduction network: Advances in understanding abscisic acid, CO2, and Ca2+ signaling. Annu. Rev. Plant Biol. 61, 561–591.

Le-Docte (1927) Commercial determination of sugar beet in the beet root using the sacks. Le-Docte process. Int. Sugar. J., 29: 488- 492.

Li X, Chen L, Forde BG and Davies WJ (2017) The biphasic root growth response to abscisic acid in Arabidopsis involves interaction with ethylene and auxin signalling pathways. Front Plant Sci.; 8:1493.

Mahmoodi, R, Maralian H and Aghabarati A (2008) Effects of limited irrigation on root yield and quality of Sugar beet *(Beta vulgaris L.*). African. J. Biol. 7(24): 4475-4478.

McGinnus RA (1971). Sugar Beet Technology 2nd ed. Sugar Beet Development Foundation, Fort Collins, Coloimbia, USA.

Niazi, BH, Athar M and Rozema J (2004) Salt tolerance in fodder beet and sea beet: Analysis of biochemical relation. Bulgarian Journal of Plant Physiology 30: 78-88.

Nourjou A (2008) The effects of water deficit on yield and yield components of sugar beet and water productivity. Iranian Journal of Irrigation and Drainage 2:31-42.

Ober ES, Le Bloa M, Clark CJA, Royal A, Jaggard KW and Pidgeon JD (2005) Evaluation of physiological traits as indirect selection criteria for drought tolerance in sugar beet, Field Crops Research, 91 (2–3): 231-249.

Ofosu-A J and Shohei Y (1994) Sugar content, compartmentation, and efflux in Strawberry Tissue J. AMER. SOC. HORT. SCI. 119(5):1024–1028.

Pergel F (1945) Quantitative Organic Micro Analysis 4th Ed. J. and Churchill Ltd., London.

Peyman F, Eslam MH, Mohammad RB, Daryoush FT and Davood H (2012) Physiological Evaluation of sugar beet genotypes under drought stress. American-Eurasian J. Agric. & Environ. Sci., 12 (6): 820-826.

Reinefeld E, Emmerich A, Winner and Beiss U (1974) For the prediction of molasses sugar extraction analgesics. Zucke., 27:2-12.

Sadeghian SY, Fazli H, Mohammadian R, Taleghani DF and Mesbah M (2000) Genetic variation for drought stress in sugar beet. Journal of Sugar Beet Research, 37 (3):55-77.

Sah SK, Reddy KR and Li J (2016) Abscisic acid and abiotic stress tolerance in crop plants. Front Plant Sci.; 7:571.

Singleton VL, Orthofer R and Raventos RML (1999) Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteau reagent. Methods Enzymol. 299:152-178.

Tahi H, Wahbi S, Wakrim R, Aganchich B, Serraj R and Centritto M (2007) Water relations, photosynthesis, growth and water-use efficiency in tomato plants subjected to partial root zone drying and regulated deficit irrigation. Plant Bio systems – An International Journal Dealing with all Aspects of Plant Biology: Official Journal of the Societa Botanica Italiana, 141: 265–274.

Verma A and Deepti S (2016) Abiotic stress and crop improvement: current scenario, Adv. Plants Agric. Res. 4, 345–346.

Vreugdenhil D (1983) Abscisic acid inhibits phloem loading of sucrose. 57,4: 463-467

Waller RA and Duncan DB (1969) A Bayes rule for the symmetric multiple comparisons problem. Amer. Statist. Ass.,64: 1484–1503.

Wani SH and Kumar V (2015) Plant stress tolerance: Engineering ABA: A potent phytohormone. Transcriptomics 3, 1000113.

Wettstein D (1957) Chlorophyll-lethal and the submicroscopic change in form of the plastids. Exptl. Cell Res., 12: 427-433.

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

Yolcu S, Alavilli H, Ganesh P, Panigrahy M and Song K (2021) Salt and drought stress responses in cultivated beets (Beta vulgaris L.) and wild beet (Beta maritima L.). Plants, 10, 1843. https://doi.org/10.3390/plants1009184.