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# Assessment of Yield Performance for Bread Wheat Genotypes Under Saline-Calcareous Soils

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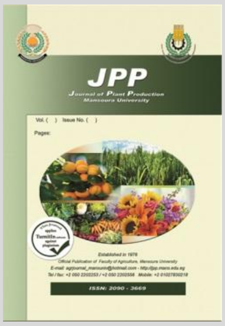


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## ABSTRACT

Soil salinity severely limits wheat production in Egypt and globally. This study evaluated twenty bread wheat genotypes from the Wheat Research Department breeding program under both non-saline and saline soil conditions during the 2021/2022 and 2022/2023 cropping seasons, in Nubaria, Egypt. The wheat genotypes were tested in an alpha lattice design to assess yield and yield components, physiological traits, and salinity tolerance. Measured traits included heading, plant height, days to maturity, flag leaf area, canopy temperature, stress tolerance indices, harvest index, biological yield, grain yield, and their components. The environments, genotypes, and genotype-by-environment interaction effects varied significantly for agronomic and physiological traits. The genotype + genotype-by-environment interaction effect (GGE) graphic identified line 1 and line 2 as superior under saline conditions, and line 7 performed best under non-saline conditions. Genotypes 9 and 11 were identified as stable and highly adapted across environments and were superior in genotype by salinity tolerance index (GSTI). Additionally, these genotypes demonstrated consistent yield and salinity tolerance and are recommended as promising candidates for cultivar release and use in a breeding program targeting saline calcareous soils.

***Keywords:*** Wheat, Soil Salinity, Canopy Temperature, SPAD, Stress Tolerance Indices

## INTRODUCTION

Wheat (*Triticum aestivum, L.*) is one of the most important crops in Egypt and globally, and serves as primary food source for over 35% of the world's population (Jing & Chang, 2003). It contributes approximately 20% of daily caloric intake in many developing countries. However, The global demands for wheat is expected to surpass production, a gap further exacerbated by climate change (Reynolds *et al.*, 2021). To meet projected demands by 2050, global wheat productivity must increase by nearly 70% (Said *et al.*, 2022). In Egypt, the total wheat production in the 2024 season was 9.44 million tons from 3.25 million feddans averaging 2.90 tons/fed.(Economic Affairs Sector, 2024). Meanwhile, national consumption of wheat was about 20.6 million tons, necessity the imported of 10.6 million tons (FAO, 2023). Thus, the gap between production and consumption is almost 50%. Wheat imports increased due to the growing population and increasing local consumption. Many efforts are continuously made to close that gap through increasing wheat production from the cultivated area. This included vertical and/or horizontal expansion. The horizontal expansion can be achieved by enhancing the wheat-cultivated area in the new reclaimed lands. On the other hand, the vertical expansion can be achieved by breeding and improving new wheat cultivars and applying proper agricultural practices.

Several biotic and abiotic stresses influence wheat production and productivity. Among abiotic stresses, salinity is a major constraint on wheat production (Al-Ashkar *et al.*, 2019). In arid and semiarid climates, particularly salinity is a key abiotic stress limiting crop production. The authors (Abedi *et al.*, 2021; Hailu & Mehari, 2021) reported that the main reason for soil degradation and global food productivity losses is salinity. Additionally, approximately 10% of saline areas worldwide are expanding every year (Zare *et al.*, 2014). Saline agricultural land is currently affected by more than 20%, and it hectarage about 954 million hectares of the total arable world land (Hafeez *et al.*, 2021; Zaman *et al.*, 2018). Hence, it is an increasing continuous refers to the change in climate and human activities (Arora, 2019). These saline areas are distributed through several countries with different zones/climates. The definition of saline and sodic soils by high electrical conductivity (EC) in terms of several ionic species in the soils' solutions (Hailu & Mehari, 2021). In Egypt, around 30 to 40% of the soils of the Nile delta and the newly reclaimed areas were classified as salt-affected soils (Elfanah *et al.*, 2023; Yassin *et al.*, 2019). In the desert and newly reclaimed areas, increased salinity levels are caused by saline irrigation water and improper management.

Wheat possesses wide genotypic differences in salinity tolerance (Saqib *et al.*, 2005). It is classified as a moderately salt-tolerant crop without yield losses at 6 $dSm^{-1}$ (Hafeez *et al.*, 2021; Maas & Hoffman, 1977; Munns *et al.*, 2006), and recorded about 50% of yield reduction at 13 $dSm^{-1}$ (Maas & Hoffman, 1977). To address these challenges, wheat breeders are adopting salt-tolerant wheat genotypes. Breeding for salt-tolerant wheat varieties is crucial to sustaining yield under saline conditions (Kotula *et al.*, 2024). Various breeding strategies for salt-tolerant wheat varieties have been employed, and a multi-faceted approach involving conventional breeding and screening for new promising lines to identify salt-tolerant genotypes (Munns *et al.*, 2006). Some wheat genotypes naturally possess soil salinity tolerance (Genedy & Eryan, 2022; Moustafa *et al.*, 2021). Thus, evaluating agronomic and physiological indices under salinity soil conditions has been crucial for identifying traits associated with salt-tolerance, guiding selection in breeding

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programs (Asadi & Naserian-Khiabani, 2007; Ashraf *et al.*, 2023; Farhat *et al.*, 2020).

Salinity stress has a negative impact, such as growth reduction and stunted plants (Akbarimoghaddam *et al.*, 2011), days to maturity, days to heading, plant height, flag leaf area (Said *et al.*, 2022), canopy temperature (Sohail *et al.*, 2020) and biomass due to reducing water uptake, cell expansion, and hormone metabolism (Hailu & Mehari, 2021). Wheat yield components like the number of spikes per square meter, 1000 kernel weight, and the number of kernels per spike are crucial traits in wheat that significantly affect final grain yield (El-Hendawy *et al.*, 2005; Shahbaz & Ashraf, 2013). Thus, wheat genotypes with high yield and low reduction under salinity stress are salt-tolerant (Phougat *et al.*, 2023; Ragab & S Kheir, 2019).

Grain yield is the final product of various physiological and biochemical processes, and soil salinity significantly reduces wheat yield by affecting agronomic and physiological traits and yield components (Sen *et al.*, 2022; Shabala & Munns, 2017). Moreover, Soil salinity is increasing osmotic stress, nutritional imbalance, and ion toxicity, or these factors' combination affecting plant growth, i.e., influencing physiological and biochemical metabolism in the wheat crop and reducing the biological and grain yield (Al-Ashkar *et al.*, 2019; Ashraf & Harris, 2004; Ashraf *et al.*, 2023; El-Ramady *et al.*, 2022; Genedy & Eryan, 2022). Osmotic stress makes water uptake difficult for wheat plants, leading to dehydration, while the accumulation of toxic ions like sodium ($Na^+$) and chloride ($Cl^-$) disrupts nutrient balance, affecting metabolic processes. In addition, stunted growth and reduced tillering are common due to hormonal imbalances caused by salinity, and leaves may become chlorotic (yellowish) or necrotic (brown and dead) due to nutrient deficiencies and toxicity (Chinnusamy *et al.*, 2006; Pessarakli & Szabolcs, 1999). To ensure high wheat yield under saline conditions, breeding efforts for improving salinity tolerance of wheat cultivars are one of the most important breeding targets, especially with increasing reclaim and cultivate new lands of agricultural land by establishing mega projects nationally, e.g., the new delta (Ragab & S Kheir, 2019; Volkov & Beilby, 2017). Wheat genotypes recorded the lowest grain yield reduction due to better osmotic regulation, higher fertility, and improved photosynthesis, possibly salt-tolerant wheat varieties**.**

The objectives of this investigation were to 1) evaluate the twenty bread wheat genotypes' yield and yield traits. 2) Determined wheat salt-tolerant genotypes appropriate to saline calcareous soil cultivation. 3) Identify a bread wheat source for improving salinity tolerance in the national breeding programs.

## MATERIALS AND METHODS

Two field experiments were conducted during the 2021/2022 and 2022/2023 winter seasons at the Experimental Farm of Nubaria Agricultural Research Station, Agricultural Research Center (ARC), Egypt, located at 29°58′01″E longitude and 30°52′56″N latitude. The trials aimed to evaluate the performance of twenty bread wheat (Triticum aestivum L.) genotypes under contrasting soil conditions: saline calcareous soil and non-saline calcareous soil. The evaluated genotypes included sixteen promising lines and four commercial Egyptian cultivars. These genotypes were selected from the national breeding program and international sources (CIMMYT), based on their superior performance in terms of grain yield and agronomic traits. Detailed information on Name, pedigree, and source of the twenty genotypes is shown in Supplemental Table S1.

**Sites, Design, and layout of the experiment:**

A randomized alpha-lattice design with three replications was employed for each environment (saline and non-saline conditions). Each experimental unit consisted of six rows, each 3 meters in length, with 20 cm spacing between rows, giving a plot area of 3.6 m². Wheat grains were manually sown at a density of 400 seeds m². Sowing was performed on November 25th in both growing seasons. Flood irrigation was used, and all recommended agronomic practices (fertilization, pest control, and weed management) were applied uniformly across all plots throughout the growing period. Soil samples were collected before planting from surface and subsurface soil layers (0-30 and 30-60 cm) to determine some chemical and physical characteristics of the experimental soil sites during the two growing seasons of 2021/2022 and 2022/2023 (Page, 1982) are shown in Table 1.

**Table 1. Soil chemical and physical characteristics of the experimental site during the two seasons of 2021/2022 and 2022/2023.**

| Chemical and physical properties | | Non-saline soil | | | | Saline soil | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2021-2022 | | 2022-2023 | | 2021-2022 | | 2022-2023 | |
| Soil depth | | 0-30 cm | 30-60 cm | 0-30 cm | 30-60 Cm | 0-30 cm | 30-60 Cm | 0-30 cm | 30-60 cm |
| EC ($dSm^{-1}$) | | 2.13 | 1.98 | 2.07 | 1.89 | 10.73 | 9.76 | 8.95 | 7.93 |
| PH | | 8.27 | 8.33 | 8.11 | 8.24 | 8.01 | 8.18 | 7.96 | 8.08 |
| $CaCo_3$% | | 22.73 | 23.82 | 21.45 | 22.64 | 23.55 | 24.25 | 23.64 | 25.00 |
| Cations meq/L | $Ca^{+2}$ | 6.77 | 7.05 | 6.48 | 6.89 | 20.27 | 22.24 | 27.15 | 28.02 |
| | $Mg^{+2}$ | 1.98 | 1.68 | 1.81 | 1.56 | 9.34 | 9.73 | 10.63 | 9.52 |
| | $Na^+$ | 10.13 | 8.79 | 10.02 | 8.45 | 58.61 | 46.31 | 65.81 | 57.65 |
| | $K^+$ | 2.42 | 2.28 | 2.37 | 1.99 | 1.27 | 1.04 | 3.7 | 2.42 |
| Anions meq/L | $CO_3^{-2}$ | - | - | - | - | - | - | - | - |
| | $HCO_3^-$ | 4.11 | 3.81 | 4.06 | 3.45 | 2.53 | 2.06 | 2.7 | 2.22 |
| | Cl- | 11.82 | 10.32 | 10.46 | 10.03 | 50.97 | 47.91 | 60.05 | 55.19 |
| | $SO_4^{-2}$ | 5.37 | 5.67 | 6.15 | 5.41 | 36.01 | 29.33 | 44.53 | 40.18 |
| Organic M. | % | 0.26 | 0.34 | 0.31 | 0.42 | 0.28 | 0.31 | 0.4 | 0.36 |
| Distribution of particle size | Sand, % | 53.13 | 51.45 | 47.95 | 45.07 | 34.1 | 32.22 | 38.34 | 29.11 |
| | Silt, % | 10.44 | 11.97 | 16.21 | 18.47 | 16.27 | 24.12 | 18.77 | 26.14 |
| | Clay, % | 36.43 | 36.58 | 35.84 | 36.83 | 49.63 | 43.66 | 42.89 | 44.75 |
| Texture of Soil | | Sandy Clay Loam | Sandy Clay Loam | Sandy Clay Loam | Sandy Clay Loam | Clay loam | Clay loam | Clay loam | Clay loam |

Soil salinity levels (electrical conductivity: EC, $dSm^{-1}$) varied according to soil type. Non-saline soil showed EC values from 1.89-2.13 $dSm^{-1}$, whereas Saline soils recorded EC values ranging from 7.93-10.73 $dSm^{-1}$ in surface and sub-surface layers averaged over the two growing seasons, respectively. Soils with EC values reached around 2 $dSm^{-1}$ were calcified as moderately saline, whereas soils with EC values exceeding more than 4 $dSm^{-1}$ were calcified as extremely saline (Richards, 1954). The data showed pH values ranged from 8.11 to 8.33 for the non-saline soils on the surface and sub-surface soil layers, averaged over the two growing seasons, respectively. However, the pH value of saline soils ranged between 7.96 and 8.18, compared with values of non-saline soils. Soil pH values over 7.8 indicate moderately alkaline. Soil pH is a crucial parameter for plant growth. For most crops, soil pH levels higher than 7.5 lead to reductions in nutrient, microbial activity, crop yields, and soil health (USDA, 1981). Calcareous soils contain a high content of $CaCO_3$, and pH values ranging from 7.9 to 8.3. These factors are common and cause poor crop establishment and low grain yields compared to less hostile soils.

**Studied traits and parameters:**

1. Morphological and physiological characters: number of days to heading (DH, days), plant height (PH, cm), days to maturity (DM, days), Flag leaf area (FLA, $cm^2$), Leaf chlorophyll content (SPAD, unit) and Canopy Temperature (CT, $^oC$).
2. Yield and its components: number of spikes/$m^2$ (NS/$M^2$), 1000-kernel weight (1000KW, g), biological yield (BY, ton/fad.), harvest index (HI, %), number of kernels per spike (NK/S), and grain yield (GY, ard. /fad.)
3. Leaf chlorophyll content was performed using a portable SPAD 502 meter (Minolta, Osaka, Japan). The measurements were taken during anthesis, with average readings of 10 measurements from the leaf tip to the leaf base. Calibration of SPAD output readings into units of leaf chlorophyll concentration and interpretation of the relationship between these two parameters is not entirely straightforward

**Salinity tolerance parameters**

The averages of twenty genotypes' grain yield, both non-saline (Yp) and two salt-affected soils (Ys), over both seasons were used to compute salinity tolerance indices (STI). Utilizing these means, the STIs were estimated by the *i*PASTIC online toolkit (Pour-Aboughadareh *et al.*, 2019). Table 2 shows salinity tolerance/sensitivity indices and their equations.

**Table 2. Salinity tolerance indices' names and equations**

| Index's name | Abbreviation and Equation | Reference |
|---|---|---|
| Tolerance | $TOL = Yp - Ys$ | (Rosielle & Hamblin, 1981) |
| Stress susceptibility | $SSI = \frac{1-(Ys/Yp)}{1-(\bar{Y}s/\bar{Y}p)}$ | (Fischer & Maurer, 1978) |
| Geometric mean productivity | $GMP = \sqrt{Yp \times Ys}$ | (Fernandez, 1992) |
| Stress tolerance | $STI = \frac{Ys \times Yp}{(\bar{Y}s)^2}$ | (Fernandez, 1992) |
| Harmonic mean | $HM = \frac{2(Ys \times Yp)}{Ys + Yp}$ | (Bidinger *et al.*, 1987) |
| Mean productivity | $MP = \frac{Yp + Ys}{2}$ | (Rosielle & Hamblin, 1981) |
| Yield | $YI = \frac{Ys}{\bar{Y}s}$ | (Gavuzzi *et al.*, 1997) |
| Yield stability | $YSI = \frac{Ys}{Yp}$ | (Bouslama & Schapaugh Jr, 1984) |
| Relative stress | $RSI = \frac{(Ys/Yp)}{(Ys/Yp)}$ | (Fischer & Wood, 1979) |
| Stress susceptibility percentage | $SSPI = \frac{Yp - Ys}{2(Xp) \times 100}$ | (Mousavi *et al.*, 2008) |
| Mean relative performance | $MRP = \frac{Ys}{Xs} + \frac{Yp}{Xp}$ | (Ramirez-Vallejo & Kelly, 1998) |

**Where Xp and Xs are the twenty genotypes' means in non-saline and saline conditions, respectively.**

The STI parameters differed in their desirable values for genotype selection. For some indices, lowed values were preferred, such as the Tolerance Index (TOL), yield index (YI), stress susceptibility index (SSI), and Stress Susceptibility Percentage Index (SSPI). However, the maximum value was desirable for Mean Productivity (MP), geometric mean productivity (GMP), Stress, Tolerance Index (STI), yield stability index (YSI), harmonic mean (HM), and relative stress index (RSI).

**Statistical analysis**

Analyses of variance (ANOVA) were performed for estimated traits of saline and non-saline soils over both seasons 2021/22 and 2022/23 (four environments). The predicted/adjusted grain yield means of each experiment (over two sites and two seasons) were utilized to produce GGE biplots over environments suggested by (Yan *et al.*, 2000; Yan *et al.*, 2007). The GenStat 21st Edition (VSN International Ltd, Hemel Hempstead, UK) was utilized for analyses.

To produce salinity tolerance indices, the adjusted means of grain yield averaged from both non-stressed sites compared with means generated from salinity sites. Hence, in this calculation, the STIs Table 4 is subjected to represent genotype by salt-tolerance-indices (GSTI) biplots proposed by (Yan & Frégeau-Reid, 2008). The data normalization is as follows:

$$Y_{ij} = \frac{T_{ij} - \bar{T}_j}{S_j}$$

**Where** **$Y_{ij}$ is the normalized value of genotype *i* for STI *j*, $T_{ij}$ is the original entry value *i* for STI *j*, $\bar{T}_j$ genotype's mean *i* for STI *j*, $S_j$ is the standard deviation for STI *j*.**

**The Yield Reduction equation**

$$Yr = 1 - \frac{Ys}{Yp}$$

**Where** **non-salt-affected sites (Yp) and saline soils (Ys) (Golestani Araghi & Assad, 1998)**

# RESULTS AND DISCUSSION

**Results**

**Analysis of variance:**

Analysis of variance (combined data analysis) for the studied characteristics under normal and soil salinity conditions, both seasons, is presented in Table 3. The sites' effect varied significantly from site to another for all studied attributes. Wheat genotypes' component showed significant and highly significant differences for all studied traits under normal and soil salinity conditions in two studied seasons (environments), except biological yield (BY) and harvest index (HI). In addition, the interaction between environments and genotypes recorded significant variation for agronomic and physiological traits except for BY.

The twenty genotypes mean yield in non-stressed conditions (Yp) and means in salinity sites over two seasons subjected to produce stress tolerance indices such as STI, TOL, SSI, SSPI, MP, GMP, HM, YSI, YI, RSI, and MRP (Table 4). The lowest value of indices, e.g., TOL, SSI, YSI, RSI, and SSPI were recorded by genotypes 1 and 2. This reflected their salinity tolerance, as they maintained high performance under stress conditions, with grain yield reached 17.57 and 17.21 ardeb/fad, respectively. On the other hand, genotype 7 had the highest value of the same STIs and was considered the salinity susceptible genotype because of the high difference between the normal and stress conditions and increased the overall means of $GY_E$. From the tolerance indices' view of GMP, STI, MP, HM, and MRP, the superior genotypes were 1, 2, 7, 9, and 11; in contrast, the inferior genotypes were 4 and 13.

**Table 3. Analysis of variance for all characteristics of twenty genotypes evaluated in calcareous salt-affected and non-salt-affected sites during 2021/22 and 2022/23 seasons.**

| SOV | DF | DH | DM | PH | FLA | SPAD | CT |
|---|---|---|---|---|---|---|---|
| Environment | 3 | 2069** | 10324** | 7900** | 3226** | 1981.8** | 1151** |
| Rep. Environment | 8 | 4.846 | 8.608 | 69.67 | 59.09 | 55.99 | 42.957 |
| Rep. Block. Environment. | 48 | 5.925 | 10.815 | 70.46 | 65.79 | 30.44 | 5.17 |
| Genotype | 19 | 26.7** | 13** | 93.8** | 173** | 82.9** | 3.17** |
| Environment. Genotype | 57 | 9.3** | 8.7** | 50.9** | 54.6** | 26** | 3.2** |
| Experimental Error | 104 | 2.33 | 2.562 | 21.8 | 21.73 | 12.38 | 1.513 |
| CV % | | 1.75 | 1.14 | 4.86 | 12.5 | 6.46 | 6.12 |
| SOV | DF | 1000 KW | NK/S | NS/M2 | GY | BY | HI |
| Environment | 3 | 1260** | 2049** | 138750** | 930** | 121** | 839** |
| Rep. Environment | 8 | 8.13 | 15.72 | 456.2 | 7.988 | 1.705 | 2.393 |
| Rep. Block. Environment. | 48 | 30.52 | 48.03 | 1592.7 | 8.136 | 1.221 | 5.864 |
| Genotype | 19 | 84** | 97** | 3354** | 24.9** | 1.17NS | 8.6NS |
| Environment. Genotype | 57 | 32** | 69** | 3391** | 6.5** | 1.65NS | 9.6* |
| Experimental Error | 104 | 12.9 | 17.19 | 863.7 | 2.64 | 1.416 | 6.669 |
| CV % | | 7.01 | 10.14 | 9.84 | 9.76 | 13.59 | 9.14 |

**DF= degrees of freedom, DH = Days to Heading, PH = Plant Height, DM = Days to Maturity, SPAD = chlorophyll content, FLA = Flag Leaf Area, CT = Canopy Temperature, 1000KW = 1000 kernels weight, NS/$M^2$ = Number of spikes/$M^2$ BY = Biological Yield,, GY = Grain Yield, NK/S = Number of kernels/spike, HI = Harvest Index, * and ** = significant level of P≤ 0.05 and P≤ 0.01 probability levels of probability, respectively and ns= no significant difference.**

Genotype selection based on STI parameters differed for desirable value; some of them preferred with minimum value, such as the stress susceptibility index (SSI), Tolerance Index (TOL), and Stress Susceptibility Percentage Index (SSPI). However, the desirable value is maximum for Mean Productivity (MP), harmonic mean (HM), Stress Tolerance Index (STI), geometric mean productivity (GMP), yield stability index (YSI), yield index (YI), and relative stress index (RSI).

**Table 4. The yield performance of twenty genotypes evaluated under non-saline sites (Yp), salt-affected soil sites (Ys), and salinity tolerance indices, and their combined means of sites-seasons ($GY_E$, four environments).**

| Geno. | Yp | Ys | TOL | MP | HM | YSI | GMP | SSI | STI | YI | RSI | SSPI | MRP | $GY_E$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 19.29 | 17.57 | 1.73 | 18.43 | 18.39 | 0.91 | 18.41 | 0.30 | 0.89 | 1.28 | 1.30 | 4.41 | 2.27 | 18.43 † abc |
| 2 | 18.82 | 17.21 | 1.61 | 18.01 | 17.98 | 0.91 | 17.99 | 0.29 | 0.85 | 1.25 | 1.30 | 4.10 | 2.22 | 18.01 abcde |
| 3 | 20.16 | 15.67 | 4.49 | 17.91 | 17.63 | 0.78 | 17.77 | 0.75 | 0.83 | 1.14 | 1.11 | 11.47 | 2.17 | 17.91 abcde |
| 4 | 16.51 | 12.03 | 4.49 | 14.27 | 13.92 | 0.73 | 14.09 | 0.91 | 0.52 | 0.88 | 1.04 | 11.47 | 1.72 | 14.26 hi |
| 5 | 17.56 | 11.96 | 5.60 | 14.76 | 14.23 | 0.68 | 14.49 | 1.07 | 0.55 | 0.87 | 0.97 | 14.31 | 1.77 | 14.76 ghi |
| 6 | 20.20 | 12.44 | 7.76 | 16.32 | 15.39 | 0.62 | 15.85 | 1.29 | 0.66 | 0.91 | 0.88 | 19.85 | 1.94 | 16.32 cdefgh |
| 7 | 24.26 | 14.46 | 9.80 | 19.36 | 18.11 | 0.60 | 18.72 | 1.36 | 0.92 | 1.05 | 0.85 | 25.06 | 2.29 | 19.35 a |
| 8 | 18.34 | 11.37 | 6.97 | 14.85 | 14.03 | 0.62 | 14.44 | 1.28 | 0.55 | 0.83 | 0.88 | 17.83 | 1.77 | 14.85 ghi |
| 9 | 21.78 | 15.59 | 6.20 | 18.68 | 18.17 | 0.72 | 18.42 | 0.96 | 0.89 | 1.13 | 1.02 | 15.84 | 2.25 | 18.68 ab |
| 10 | 19.25 | 12.87 | 6.39 | 16.06 | 15.42 | 0.67 | 15.74 | 1.12 | 0.65 | 0.94 | 0.95 | 16.33 | 1.92 | 16.06 efghi |
| 11 | 21.58 | 15.70 | 5.88 | 18.64 | 18.17 | 0.73 | 18.40 | 0.92 | 0.89 | 1.14 | 1.04 | 15.04 | 2.25 | 18.64 ab |
| 12 | 17.87 | 12.75 | 5.12 | 15.31 | 14.88 | 0.71 | 15.09 | 0.96 | 0.60 | 0.93 | 1.02 | 13.09 | 1.84 | 15.3 fghi |
| 13 | 17.47 | 10.81 | 6.67 | 14.14 | 13.35 | 0.62 | 13.74 | 1.28 | 0.49 | 0.79 | 0.88 | 17.05 | 1.68 | 14.14 i |
| 14 | 16.85 | 12.74 | 4.11 | 14.79 | 14.50 | 0.76 | 14.65 | 0.82 | 0.56 | 0.93 | 1.08 | 10.51 | 1.79 | 14.79 ghi |
| 15 | 18.46 | 13.72 | 4.74 | 16.09 | 15.74 | 0.74 | 15.91 | 0.86 | 0.66 | 1.00 | 1.06 | 12.11 | 1.94 | 16.09 defghi |
| 16 | 18.34 | 11.64 | 6.70 | 14.99 | 14.24 | 0.63 | 14.61 | 1.23 | 0.56 | 0.85 | 0.90 | 17.14 | 1.78 | 14.99 ghi |
| 17 | 20.39 | 16.11 | 4.28 | 18.25 | 18.00 | 0.79 | 18.12 | 0.71 | 0.86 | 1.17 | 1.12 | 10.93 | 2.22 | 18.25 abcd |
| 18 | 22.10 | 14.21 | 7.90 | 18.15 | 17.29 | 0.64 | 17.72 | 1.20 | 0.82 | 1.03 | 0.91 | 20.19 | 2.16 | 18.15 abcd |
| 19 | 20.55 | 12.89 | 7.67 | 16.72 | 15.84 | 0.63 | 16.27 | 1.25 | 0.69 | 0.94 | 0.89 | 19.60 | 1.99 | 16.72 bcdefg |
| 20 | 21.29 | 13.10 | 8.19 | 17.20 | 16.22 | 0.62 | 16.70 | 1.29 | 0.73 | 0.95 | 0.88 | 20.95 | 2.04 | 17.2 bcdef |

**†Same letters are not significantly different among means according to the least significant difference (LSD) at P ≤ 0.05, GYE combined data; RSI = relative stress index; SSPI = stress susceptibility percentage index, and MPR = mean relative performance.**

Table 5 reveals the grain yield performance and reduction affected by normal and soil salinity conditions across the 2021/22 and 2022/23 seasons separately, and their combined two normal sites and both salinity sites of twenty wheat genotypes. The measured trait, generally, showed a marked decrease in genotype means under soil salinity conditions compared to normal conditions in the two seasons and the combined data.

The highest GY values were recorded by line 7 (24.2 ardab/fadan), followed by genotype 18 (Sakha95, 23.00 ardab/fadan) and line 9 and Sids 14 (21.8 ardab/fadan) in the first season under normal conditions. Whereas line 7 displayed the highest GY value (24.04 ardab/fadan) in the second season, followed by line 11 (23.9 ardab/fadan) and Misr3 (22.38 ardab/fadan). Additionally, the highest average of both normal sites over seasons was recorded by line 7, followed by line 9. In contrast, the lowest values were achieved by line 4 in the normal first season and the combined data, while line 14 had the lowest value in the second season.

Under soil salinity conditions, the highest GY values were achieved by line 1 and line 2 (16.2 and 15.3 ardab/fadan) in the 2021-2023 season and (18.9 and 19.1 ardab/fadan) in the 2022-2023 season, respectively, followed by line 3 (18.0 ardab/fadan) and line 9 (17.7 ardab/fadan) in the 2022-2023 season. Additionally, lines 1 and 2 achieved the highest means in the stressed combined data, followed by Misr 2 (genotype 17).

The evaluated genotypes showed different behavior in saline and non-saline conditions, and a reduction in grain yield. Based on the genotype rank, lines 1 and 2 recorded the lowest yield reduction with 15 % and 13.4 % in the 2021/22 season and (3.0 and 4.2 %) in the 2022/23 season. However, the same lines in the combined data recorded 8.9% and 8.5% in the 2021/22 and 2022/23 seasons, followed by 17 (Misr 2) and line 3.

**Table 5. Mean performance and yield reduction (YR%) percentage of grain yield (GY) affected by normal (Yp) and salinity stress (Ys) for 20 bread wheat genotypes across 2021/22 and 2022/23 seasons.**

| Geno. | Season 2021/2022 | | | | Season 2022/2023 | | | | Seasons 2021/2022 and 2022/2023 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Yp | Ys | YR% | Rank | Yp | Ys | YR% | Rank | Yp | Ys | YR% | Rank |
| 1 | 19.1 | 16.2 | 15.0 | 2 | 19.5 | 18.9 | 3.0 | 1 | 19.3 | 17.6 | 8.9 | 2 |
| 2 | 17.7 | 15.3 | 13.4 | 1 | 20.0 | 19.1 | 4.2 | 2 | 18.8 | 17.2 | 8.5 | 1 |
| 3 | 19.1 | 13.3 | 30.4 | 5 | 21.2 | 18.0 | 14.9 | 8 | 20.2 | 15.7 | 22.3 | 4 |
| 4 | 14.6 | 8.4 | 42.8 | 9 | 18.4 | 15.7 | 14.7 | 7 | 16.5 | 12.0 | 27.2 | 7 |
| 5 | 17.2 | 8.4 | 51.2 | 16 | 17.9 | 15.5 | 13.3 | 6 | 17.6 | 12.0 | 31.9 | 11 |
| 6 | 19.1 | 9.6 | 49.5 | 14 | 21.3 | 15.2 | 28.5 | 18 | 20.2 | 12.4 | 38.4 | 18 |
| 7 | 24.2 | 13.3 | 44.8 | 10 | 24.4 | 15.6 | 36.0 | 20 | 24.3 | 14.5 | 40.4 | 20 |
| 8 | 17.3 | 8.3 | 52.0 | 17 | 19.4 | 14.4 | 25.6 | 17 | 18.3 | 11.4 | 38.0 | 16 |
| 9 | 22.8 | 13.5 | 40.6 | 7 | 20.8 | 17.7 | 15.2 | 11 | 21.8 | 15.6 | 28.4 | 9 |
| 10 | 19.4 | 10.5 | 45.9 | 11 | 19.1 | 15.2 | 20.3 | 13 | 19.3 | 12.9 | 33.2 | 12 |
| 11 | 19.3 | 14.5 | 24.8 | 3 | 23.9 | 16.9 | 29.3 | 19 | 21.6 | 15.7 | 27.3 | 8 |
| 12 | 18.5 | 9.7 | 47.6 | 12 | 17.2 | 15.8 | 8.2 | 4 | 17.9 | 12.7 | 28.7 | 10 |
| 13 | 16.9 | 6.3 | 62.9 | 20 | 18.1 | 15.4 | 15.1 | 10 | 17.5 | 10.8 | 38.2 | 17 |
| 14 | 17.5 | 10.4 | 41.0 | 8 | 16.2 | 15.1 | 6.4 | 3 | 16.8 | 12.7 | 24.4 | 5 |
| 15 | 18.9 | 11.6 | 38.5 | 6 | 18.0 | 15.8 | 12.3 | 5 | 18.5 | 13.7 | 25.7 | 6 |
| 16 | 17.5 | 8.8 | 49.6 | 15 | 19.2 | 14.5 | 24.6 | 16 | 18.3 | 11.6 | 36.5 | 14 |
| 17 | 21.6 | 16.0 | 26.0 | 4 | 19.2 | 16.2 | 15.3 | 12 | 20.4 | 16.1 | 21.0 | 3 |
| 18 | 23.0 | 11.9 | 48.5 | 13 | 21.2 | 16.6 | 21.9 | 14 | 22.1 | 14.2 | 35.7 | 13 |
| 19 | 19.6 | 9.2 | 52.9 | 18 | 21.5 | 16.5 | 23.1 | 15 | 20.6 | 12.9 | 37.3 | 15 |
| 20 | 22.8 | 9.4 | 58.8 | 19 | 19.8 | 16.8 | 15.0 | 9 | 21.3 | 13.1 | 38.5 | 19 |

**Genotype plus genotype-by-environment interaction (GGE) biplots.**

Figure 1 visualizes the which-won-where of the GGE biplot of twenty genotypes evaluated under salt-affected and non-saline soils during the 2021/22 and 2022/23 cropping seasons (four Environments). The lines extended from the origin of the biplot, the biplot's eight sectors were split, and the tested environments were categorized into two main groups/sectors. Genotypes 1, 2, and 17 (Misr 2) are the winners in the saline soil in both seasons. However, genotype 7 is situated on the polygon's vertex, thus, it was the best in the sector's non-saline soil in the two cropping seasons. The principal components (PC1, 63.75 plus PC2, 22.31) accounted recorded about 86% of the environments and genotypes and the G×E interaction of total variation.

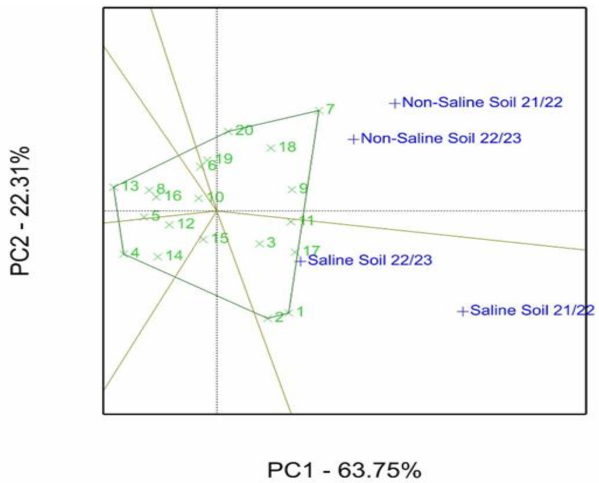


**Figure 1. Which-won-where GGE biplot of four environments, non-saline and saline affected conditions during 2021/22 and 2022/23 seasons, for grain yield of 1-20 entries/genotypes.**

Figure 2 shows the mean vs stability of the GGE biplot of twenty genotypes and four Environments, under normal and stressed soil conditions in the 2021/22 and 2022/23 growing seasons. The genotypes were ranked in descending order from line 7 (the best performance) to line 13 (the worst performance). Furthermore, genotypes 11, 9, and 17 are more stable because it had short projection or their close to the average tester coordinator line (ATC, the line with an arrow and perpendiculars on the overall mean), but genotypes 7, 1, and 2 possess long projections, which indicates unstable performance from stressed and non-stressed conditions.

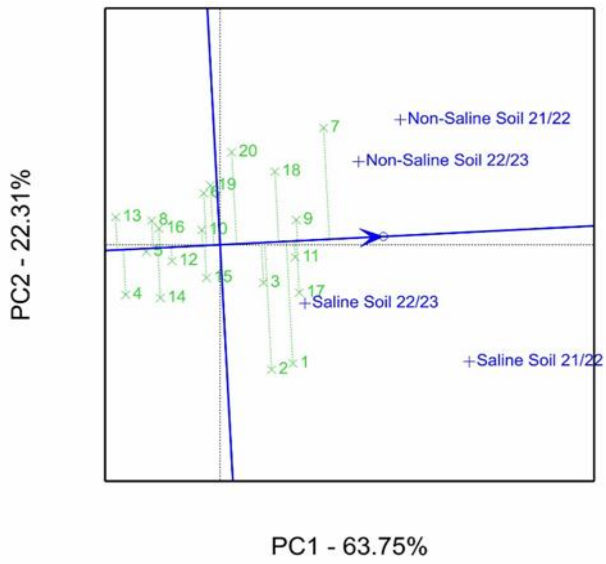


**Figure 2. Mean vs stability GGE biplot of the grain yield in four environments, during the 2021/22 and 2022/23 seasons for 20 evaluated genotypes.**

The ideal genotype should perform as high-yielding and stable as possible in all environments, which falls into the central circle of the biplot, i.e., ideal genotypes in terms of higher yielding ability and stability, compared with the other genotypes. Figure 3 reveals that genotypes 9 and 11 were the ideal genotypes with the best performance and stability across saline and non-saline sites during both seasons. Furthermore, genotype 17 falls in the second circle, which means it is a desirable genotype. The principal components (PC1, 63.75 plus PC2, 22.31) recorded 86% of the total environmental variation.

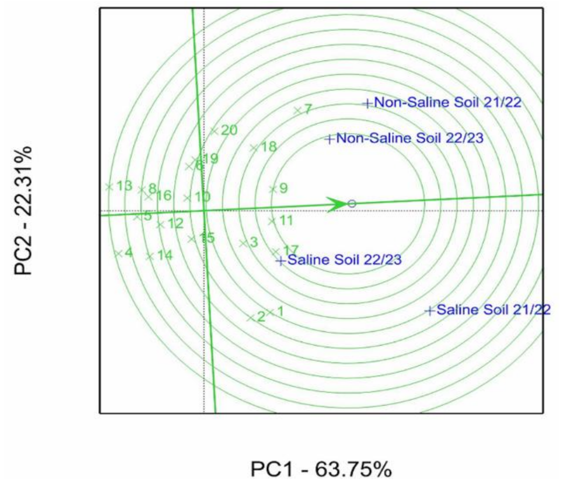


**Figure 3. The ideal genotype GGE biplot of the grain yield in the four environments, during the 2021/22 and 2022/23 seasons for 20 evaluated genotypes.**

Scatter plot of GSTI biplot view of 20 genotypes evaluated in the normal and stressed conditions during 2021/22 and 2022/23 seasons (Figure 4). The grain yield means (Yp and Ys) and STIs values in Table 4 were used to generate the GSTI biplots of twenty genotypes after normalizing the data. The relationship between the index and the resting indices reflected the correlation between them; for example, the acute angle between MP and STI represented a positive correlation. However, the wide angle between SSI and RSI indicates a negative correlation relationship. Accordingly, genotypes 9 and 11 recorded the best and stable genotypes from the point of view of indices, such as STI, MP, GMP, HM, and situated in the higher positive PC1 value and low positive value of PC2. Hence, these genotypes are considered to have salinity tolerance. However, lines 1 and 2 recorded high values of PC1 and negative PC2 and close to YSI and RYI. Genotypes 20, 19, and 6 from TOL, SSI, and SSPI views are susceptible because they recorded the low value of PC1 and high score of PC2.

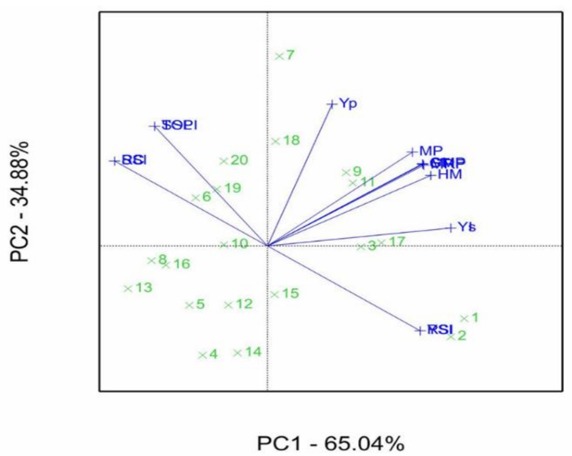


**Figure 4. Scatter plot of GSTI biplot view of salinity tolerance indices (STI), and the grain yield Yp and Ys of 20 genotypes evaluated in normal and stressed conditions during 2021/22 and 2022/23 seasons.**

Figure 5 represents the average tester coordination of the GSTI biplot view for the STIs of 20 evaluated genotypes in the normal and stressed conditions during the 2021/22 and 2022/23 seasons. Based on the STIs values in Table 4, after normalizing the data, were used to generate the GSTI biplots of twenty genotypes. Genotype 7 scored the highest performance in comparison with genotype 4 recorded the lowest rank. Genotypes 7 and 11 recorded higher performance and stability based on the STIs, i.e., genotypes 11 and 9 were stable in saline and non-saline soils, because it's located on the line average tester coordinator line (ATC, the line with an arrow and perpendiculars on the overall mean). In contrary, lines 7, 1, and 2 recorded high performance but were unstable to be sown in a stressed environment, because of the long projection from the ATC line.

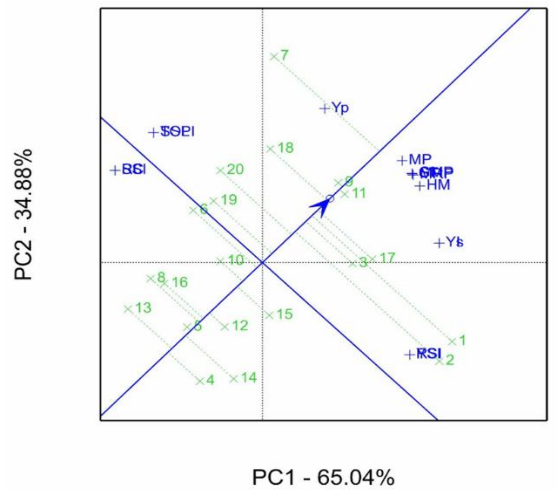


**Figure 5. The average tester coordination view of GSTI biplot view of salinity tolerance indices (STI), and the grain yield (Yp) and (Ys) of 20 genotypes evaluated in normal and stressed conditions during 2021/22 and 2022/23 seasons.**

Ideal genotype based on the GSTI biplot view of STIs for 20 evaluated genotypes in non-saline and salt-affected conditions during the 2021/22 and 2022/23 seasons, utilizing salinity tolerance indices (Figure 6).

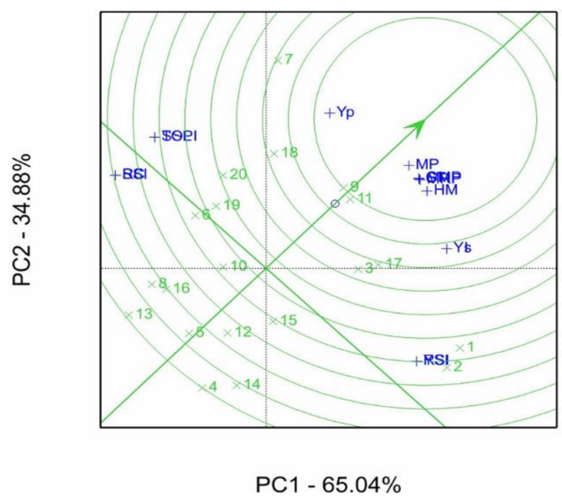


**Figure 6. Ideal genotype based on the GSTI biplot view of salinity tolerance indices (STI), and the grain yield (Yp) and (Ys) of 20 genotypes evaluated in normal and stressed conditions during 2021/22 and 2022/23 seasons.**

The ideal genotype should perform as high-yielding and stable as possible in all environments/STIs, which falls into the central circle of the biplot, i.e., ideal genotypes in terms of higher performance and stability, compared with the rested genotypes. Figure 6 reveals that genotype 9 was the ideal genotype with the best performance and stability across saline and non-saline sites during both seasons, according to the STIs' estimated values. Furthermore, genotype 11 falls in the second circle, which means it is a desirable genotype.

**Discussion**

In the present study, notable variations were identified among the twenty wheat genotypes in the following attributes: DH, DM, PH, FLA, CT, SPAD, NS/M2, 1000-grain weight, NK/S, GY, and HI. There were clear differences in the response of wheat genotypes under calcareous saline and non-saline soils, influenced by the higher electrical conductivity, as shown in Table 1. This pattern of evaluation is suitable for screening and selecting salt-tolerant genotypes. The analysis of variance displayed that the genotypes behave differently under those conditions (Table 3), which was confirmed by the reduction of all characteristics, particularly grain yield. There are significant variations of environments, genotypes, and their interaction effects for most studied attributes. Similar findings were reported by (Darwish *et al.*, 2017; Darwish *et al.*, 2023; Elfanah *et al.*, 2023; Ragab & S Kheir, 2019).

Grain yield is the final product of various physiological and biochemical processes, and soil salinity significantly reduces wheat yield by affecting agronomic and physiological traits and yield components (Sen *et al.*, 2022; Shabala & Munns, 2017). Moreover, Soil salinity is increasing, ion toxicity, osmotic stress, nutritional imbalance, or these factors' combination affecting plant growth, i.e., affecting physiological and biochemical metabolism in the wheat crop, and reducing the biological and grain yield(Al-Ashkar *et al.*, 2019; Ashraf & Harris, 2004; Ashraf *et al.*, 2023; El-Ramady *et al.*, 2022; Genedy & Eryan, 2022). We performed the grain yield adjusted means of 20 genotypes generated from the alpha lattice design (individual four environments) to produce the genotype plus genotype by environment (GGE biplots) as a graphical selection technique. The results showed that genotypes 9 and 11 are stable and ideal genotypes, i.e., the best performing across all different saline and non-saline soil conditions (Figures 2 and 3). Despite genotypes 1, 2, 17and genotypes 7 and 20 being the winners for saline and non-saline conditions, respectively (Figure 1). These findings align with the results reported by researchers (Elfanah *et al.*, 2023). They evaluated 40 genotypes in the Sakha station under clay saline and non-saline sites.

Genotype plus genotype by environment interaction (GGE) biplot graphs are commonly used to explain two-way data, based on principal components (PC1 and PC2). To assess the adaptability or stability range between evaluated genotypes and environments, this method was employed to explain the relationship in the same figure (Yan & Kang, 2002). The GGE biplot technique demonstrates concurrently the grain yield superiority and relative tolerance of cultivars to reduced salinity stress, with the most stability under the studied environments. In this method (Figure 2), a line with a single arrow passing across the biplot origin is named the average tester coordinator (ATC). The higher genotype's performance or top-ranked, situated in the direction of the arrow. The line perpendicular to ATC and passing through the biplot origin points to higher performance or lower performance on both sides (grand mean) (Yang *et al.*, 2009). A longer projection from the mentioned line, whether located up or down, represents a greater amount of variation G by E, i.e., means that the genotype is more variable and less stable across environments and vice versa (Kaya *et al.*, 2006). GGE biplot offers a key method for analyzing yield stability and adaptability of the mega-environment. Thereby, genotypes 9 and 11 possessed the best adaptability and stability. Similar results were reported by (Farhat *et al.*, 2020; Kendal, 2019).

The STI parameters differed for genotype selection based on the desirable value; some of them preferred with minimum value, such as the Tolerance Index (TOL), stress susceptibility index (SSI), and Stress Susceptibility Percentage Index (SSPI). However, the maximum value was desirable for yield stability index (YSI), Mean Productivity (MP), Stress Tolerance Index (STI), geometric mean productivity (GMP), harmonic mean (HM), yield index (YI), and relative stress index (RSI). These STIs were produced from the genotypes' means of both normal against two stressed sites over two seasons, hence, to produce the GSTI biplots, Table 4 was employed to facilitate the genotype selection and identify the resilient and salinity-tolerant entries (Darwish *et al.*, 2023; Elfanah *et al.*, 2023). Accordingly, genotypes 9 and 11 are the best genotypes from this point of view (Figures 4, 5, and 6). Similar results were reported by (Singh *et al.*, 2015; Yassin *et al.*, 2019). genotypes that recorded low values of stress susceptibility index (SSI) less than 1 would be more tolerant to salt stress, which is supported by (Darwish *et al.*, 2017; Elfanah *et al.*, 2023; Farhat *et al.*, 2020; Ragab & S Kheir, 2019).

The harmony of the studied genotypes between the studied seasons was not achieved under soil salinity conditions. This is due to the difference in the electrical conductivity (EC) between the experimental sites in the two seasons. This is considered one of the problems of saline soil, as they are usually not constant and change with many environmental factors. Such problems can be taken into consideration when evaluating other varieties in similar environments, as well as evaluating at different levels of salinity to determine the appropriate salinity level for each genetic composition.

## CONCLUSION

Significant differences were observed among the experimental sites for all evaluated traits. Wheat genotypes' component showed significant differences variation in all studied traits under both normal and soil saline conditions across two seasons, except for biological yield (BY) and harvest index (HI). Furthermore, genotype x environment interaction effects were significant for most agronomic and physiological traits, except for biological yield. Genotype plus genotype-by-environment interaction (GGE) biplot analysis revealed show that lines 9 and 11 were the most adaptable and stable under salt-affected and non-saline conditions in both seasons. Additionally, the same advanced lines were recorded superior from the GSTI biplots view. These findings highlight the potential of lines 9 and 11 as valuable genetic resources for developing salt-tolerant wheat cultivars in breeding programs targeting saline-calcareous soils.

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# تقدير المحصول ومكوناته لبعض التراكيب الوراثية من قمح الخبز تحت ظروف الإجهاد الملحي في الأراضي الجيرية

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## الملخص

تعد ملوحة التربة من أبرز العوائق التي تحد من إنتاجية القمح في الأراضي الجيرية وشمال الدلتا بمصر. لذلك تم تقييم عشرين تركيب وراثياً من قمح الخبز منتخبة من برنامج التربية تحت ظروف الأراضي الطبيعية والملحية خلال موسمي الزراعة ٢٠٢٢/٢٠٢١ و٢٠٢٣/٢٠٢٢ بالنوبارية. نفذت التجربة باستخدام تصميم القطاعات غير الكاملة (استخدام التصميم الشبكي alpha lattice) في ثلاث مكررات بهدف تقدير المحصول ومكوناته ودراسة بعض الصفات المورفولوجية والفسيولوجية لهذه التراكيب الوراثية وذلك لاستنباط تراكيب وراثية متحملة لظروف الأراضي الملحية. كانت الصفات التي تمت دراستها هي عدد الأيام حتى طرد السنابل، وعدد الأيام حتى النضج الفسيولوجي، وارتفاع النبات، ومساحة ورقة العلم، ومحتوي الكلوروفيل، ودرجة حرارة المظلة النباتية، ومعامل الإجهاد، ودليل الحساسية للإجهاد، والمحصول البيولوجي، ودليل الحصاد، ومحصول الحبوب، ومكوناته. أظهرت التراكيب الوراثية سلوكاً مختلفاً ومعنوياً في صفاتها المدروسة تحت ظروف الأراضي الطبيعية والأراضي الملحية في كل من موسمي التقييم. انخفضت متوسطات جميع قيم الصفات المدروسة لجميع التراكيب الوراثية تحت الظروف الملحية عنها في الأراضي الطبيعية ويرجع ذلك لتأثير الملوحة على صفات النبات مثل عدد الأفرع ومحصول القش وامتلاء الحبوب. كما ان تأثير البيئات والاصناف والتفاعل بنهما كان معنويا جدا لمعظم الصفات. كما اوضح تحليل التركيب الوراثي والتفاعل البيئي الوراثي GGE Biplot تفوق السلالة٧ في الظروف الطبيعية والسلالات رقم١ و٢ تحت ظروف الإجهاد الملحي في كل من موسمي الزراعة وبالرغم من ذلك كانت السلالات ٩ و١١ أفضل التراكيب الوراثية من حيث الاقلمة الواسعة وكذلك الثبات الوراثي من بيئة لأخرى وكذألك من منظور GSTI Biplot ذا يمكن التوصية بأنها سلالات واعدة يمكن تقييمها في تجارب مقارنة المحصول بالبرنامج القومي لبحوث القمح في الأراضي الجيرية المتأثرة بالأملاح.