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Phenotypic and Physiological Evaluation of Wheat Genotypes under Non-Saline and Saline Soil Conditions

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Authors' contributions

This work was carried out in collaboration among all authors. Author HA collected the phenotypic data, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MZD and HMA reviewed the final version of the manuscript and managed the analyses of the study. Authors ISEB design the work, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript and managed the correspondence between the reviewers and the coauthors. All authors read and approved the final manuscript.

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ABSTRACT

This study was conducted to assess the effect of soil salinity on leaf area (LA), the number of days to flowering (DF), plant height (PH), and grain yield. Overall, 60 wheat genotypes were used, including 49 CIMMYT elite lines and 11 commercially grown Egyptian wheat cultivars. During two growing seasons (2017 and 2018), the genotypes were grown in non-saline (S_0) and saline (S_1) soils. A randomized complete block design with three replicates was used in a split-plot arrangement. Salinity levels were randomly assigned to the main plots, while genotypes were randomly assigned to the subplots. The obtained results showed that the saline soil adversely affected the evaluated genotypes. Furthermore, a highly significant effect of genotypes × salinity was observed on grain yield and its attributed traits. Based on salinity indices results, some of the imported wheat genotypes outperformed the Egyptian cultivars in grain yield under salinity stress

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conditions. The results further indicated that Sakha-93, C-31, and C-40 were the most salt-tolerant genotypes. The best performing line among the CIMMYT lines was C-31, which recorded the highest grain yield under none-saline and saline soil in the two seasons of study.

Keywords: Stability; grain yield; stress tolerance index.

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is the most important cereal crop in the world. Egypt suffers from a 49% gap between wheat consumption and production [1]. There are two obstacles expected to confront filling that gap: population growth and climate change. In 2030, the Egyptian population is expected to reach 125,870,736 persons, which will require producing more wheat grains [2]. Therefore, it is expected that the wheat production gap will be enlarged in 2030 unless serious efforts and investments are allocated to solve the main problems of wheat production in Egypt, i.e., abiotic and biotic stresses [3]. Wheat is cultivated over a wide range of environmental conditions [4]. Thus wheat plants are exposed to several biotic and abiotic stresses such as drought, heat, and salinity stress [5]. Salinity stress is considered major abiotic stress affecting wheat production [6].

Plant tolerance to salinity stress is a complex trait controlled by several minor genes of small effect on this quantitative trait [7]. Consequently, to understand the complexity of plant responses to salinity, it is vital to account for this response's morphological and physiological [8]. Additionally, understanding the recently developed wheat yield stability might help improve yield under salinity conditions [9]. The deleterious effect of salinity on several physiological and biochemical traits was observed by several authors [10,11,12]. These harmful effects caused overall grain yield reduction. That grain yield reduction in saline-affected lands was as high as 30% [13].

The two key points in identifying salinity stress-tolerant genotypes are 1- having access to sufficient genetic variability to select from, 2- exposing the plant materials to salinity stress to distinguish the tolerant genotypes [14]. Evaluating for salinity stress under the open field conditions during the reproductive stage was a more reliable approach than that conducted under the controlled conditions [15,12]. Stress tolerance (TOL) is the differences in yield between the stressed (Ys) and non-stressed (Yp) genotypes [16]. Stress susceptibility index (SSI) as a measurement of yield stability was also used to identify salinity stress-tolerant genotypes [17]. Based on these two criteria, selection favors genotypes with low yield potential under non-stress conditions and high yield under stress conditions. Moreover, SSI > 1 was suggested to select tolerant genotypes [18]. A new advanced index (STI= stress tolerance index) can identify genotypes that produce high yield under both stress and non-stress conditions [19]. The geometric mean productivity (GMP) is often used by breeders interested in relative performance [20] Selection based on STI and geometric mean productivity (GMP) has resulted in genotypes with higher stress tolerance and grain yield potential [19]. The yield index (YI) was used to evaluate genotypes' stability in both stressed and non-stressed conditions [21].

The salinity problem is of great concern in Egypt which, constitutes about 33% of the total cultivated land [22]. This problem results from the irrigation with saline water, poorly drained soils which cause too much evaporation from the soil surface, especially during the hot summer (35 to 45 C°), increase of the water table, and the low precipitation (<25 mm annual rainfall) [23]. The Salinity problems occur when water remains near the surface and evaporates and when salts are not dissolved and carried below the root zone. Irrigation and rainfall leach out the salinity from the soil. Therefore, soils naturally high in soluble salts are usually found in arid or semi-arid regions [24]. Salts often accumulate because there is not enough rainfall to dissolve and leach them out of the root zone [25]. Furthermore, the projected global warming and higher temperatures in Egypt will also increase soil surface evaporation, increasing soil salinization [26].

The present investigation's objective was to compare the response of the commercially grown Egyptian wheat cultivars and CIMMYT elite lines under saline and non-saline soil conditions to identify potentially salinity stress-tolerant genotypes.

2. MATERIALS AND METHODS

2.1 Plant Materials and Field Experimental Design

During two consecutive growing seasons, 2016/2017and 2017/2018, a panel of 60 spring wheat genotypes were grown, including 49 CIMMYT elite selection wheat yield trial (*ESWYT*) (Table 1) as well as 11 commercially grown Egyptian wheat cultivars (Table 2). The Egyptian cultivars were obtained from the Agricultural Research Center, Egypt (ARC). The panel was evaluated under saline ($S_{1:}$ EC = 8.76 dsm^{-1}) and non-saline (S_0 : EC = 0.78 dsm^{-1}) soil in Elbostan experimental farm, faculty of agriculture, Damanhur University, Egypt, (30°45'19.4"N, 30°29'04.8"E). Before planting, soil samples were collected from S_0 and S_1. Soil analysis was conducted according to [27], and the main physical and chemical properties of the soil are presented in (Table 3). Due to the limited seed amount during the first growing season, the experiment was conducted in a split-plot arranged in an augmented incomplete block design, in which each incomplete block contended 20 CIMMTY lines and the Egyptian cultivars. Thus, all the CIMMTY lines were planted in a single replicate. In contrast, the Egyptian cultivars were planted in three replicates, the soil salinity was arranged as main plots, and the genotypes were allocated as subplots.

Table 1. Description of the wheat genotypes

No	Code	Pedigree
1	C-02	PBW343
2	C-03	PRL/2*PASTOR
3	C-04	MUNAL #1
4	C-05	SUPER 152
5	C-06	SITE/MO//PASTOR/3/TILHI/4/WAXWING/KIRITATI
6	C-07	ATTILA*2/PBW65*2//KACHU
7	C-08	REEDLING #1
8	C-09	KACHU#1/4/CROC_1/AE.SQUARROSA(205)//BORL95/3/2*MILAN/5/KACHU
9	C-10	SAUAL/3/ACHTAR*3//KANZ/KS85-8-4/4/SAUAL
10	C-11	BECARD/KACHU
11	C-12	ALTAR84/AE.SQUARROSA(221)//3*BORL95/3/URES/JUN//KAUZ/4/WBLL1/5/ MUTUS
12	C-13	NAC/TH.AC//3*PVN/3/MIRLO/BUC/4/2*PASTOR/5/ KACHU/6/KACHU
13	C-14	CHIBIA//PRLII/CM65531/3/SKAUZ/BAV92/4/MUNAL
14	C-15	KACHU//WBLL1*2/BRAMBLING
15	C-16	KACHU/KIRITATI
16	C-17	KACHU #1//WBLL1*2/KUKUNA
17	C-18	KIRITATI/WBLL1//FRANCOLIN #1
18	C-19	SUP152/BAJ #1
19	C-20	SUP152//WBLL1*2/BRAMBLING
20	C-21	SUP152/BECARD
21	C-22	BAJ #1/3/KIRITATI//ATTILA*2/PASTOR
22	C-23	WBLL4/KUKUNA//WBLL1/3/WBLL1*2/BRAMBLING
23	C-24	ITP40/AKURI
24	C-25	KIRITATI/WBLL1//MESIA/3/KIRITATI/WBLL1
25	C-26	KIRITATI/WBLL1//2*BLOUK #1
26	C-27	FRNCLN*2/TECUE #1
27	C-28	SUP152/AKURI//SUP152
28	C-29	MUTUS*2/TECUE #1
29	C-30	WBLL1*2/VIVITSI//AKURI/3/WBLL1*2/BRAMBLING
30	C-31	MUTUS*2/AKURI
31	C-32	BAJ #1*2/WHEAR
32	C-33	TACUPETO F2001*2/KIRITATI//VILLA JUAREZ F2009
33	C-34	KACHU/KINDE
34	C-35	PBW343*2/KUKUNA/3/PASTOR//CHIL/PRL/4/GRACK
35	C-36	VILLA JUAREZ F2009/CHYAK
36	C-37	WBLL1*2/BRAMBLING//QUAIU
37	C-38	BECARD/QUAIU #1
38	C-39	BECARD/QUAIU #1
39	C-40	BECARD/FRNCLN
40	C-41	WBLL1*2/BRAMBLING//CHYAK

Continued Table 1. Pedigree of the studied imported wheat genotypes

Serial No	Code	Pedigree
41	C-42	BECARD//ND643/2*WBLL1
42	C-43	ATTILA/3*BCN*2//BAV92/3/KIRITATI/WBLL1/4/DANPHE
43	C-44	FRET2*2/BRAMBLING//BECARD/3/WBLL1*2/BRAMBLING
44	C-45	KAUZ*2/MNV//KAUZ/3/MILAN/4/BAV92/5/AKURI/6/MUTUS
45	C-46	KACHU/BECARD//WBLL1*2/BRAMBLING
46	C-47	KAUZ/PASTOR//PBW343/3/KIRITATI/4/FRNCLN
47	C-48	SUP152*2/TECUE #1
48	C-49	FRANCOLIN #1/AKURI #1//FRNCLN
49	C-50	ND643/2*TRCH//MUTUS/3/SUP152

Table 2. Identification and pedigree of the studied Egyptian cultivars

Serial No	Cultivars	Pedigree
1	Misr-1	OASIS/SKAUZ//4*BCN/3/2*PASTOR
2	Misr-2	SKAUZ/BAV 92
3	Gemmiza-9	ALD'S'/HUAC'S'//CMH74.630/5X
4	Gemmiza-11	BOW"S"/ KVS"S"// 7C/ SERI 82/3/ GIZA 168/ SAKHA 61
5	Sids-12	BUC//7C/ALD/5/MAYA74/ON//1160.147/3/BB/GLL/4/CHAT"S" /6/MAYA/VUL//CMH74A.63014*SX
6	Sids-13	ALMAZ.19=KAUZ"S"// TSI/ SNB"S"
7	Shandaweel-1	SITE/ MO/4/ NAC/ TH.AC// 3*PVN/3/ MIRLO/ BUC.
8	Giza-168	MIL/BUC//SERI
9	Giza - 171	Sakha 93 / Gemmiza 9 S.6-1GZ-4GZ-1GZ-2GZ-0S
10	Sakha- 93	Sakha 92/TR 810328 S 8871-1S-2S-1S-0S
11	Sakha- 94	OPATA/RAYON/3/JUP/BJY//URES

Table 3. Physical and chemical properties of the non-saline (S_0) and saline soil (S_1)

Location	S_0	S_1
Physical properties		
Clay%	1.1	0.9
Silt%	1.4	1.5
Sand%	97.5	97.6
Soil texture	sand	Sand
Chemical properties	**value**	**value**
PH	8.5	9.7
EC(dsm^{-1})	0.78	8.76
$Caco_3$	6	0.73
Organic matter %	0.05	0.04
Soluble cations meq100^{-1} g soil	**value**	**value**
Ca^{++}	0.9	6.1
Mg^{++}	0.8	13
Na^{++}	6	29.5
K^{+}	0.21	0.95
Soluble anions meq100^{-1} g soil	**value**	**value**
HCO_3	0.8	11
Cl^{-}	1	77
SO_4	6	17

Furthermore, during the second growing season, the experiment was conducted in a split-plot arrangement in a randomized complete block design (RCBD) with three replicates. The soil salinity was arranged as main plots, and genotypes were allocated as subplots. The size of the experimental unit (plot size) was four rows wide $\times$ 1.5 m long with 20 cm between rows within each replicate and growing season. Standard agronomic practices, including recommended fertilization and irrigation schedules, were followed.

2.2 Data Collected

Number of days to flowering (DF) was recorded when 50% of spikes in a plot have extruded anthers (noted as days from January 1st). Plant height (PH) was measured on a random sample of five plants in each plot as the length from the soil surface to the tip of the spike at harvest time. A random sample of ten spikes was collected from each plot, and the mean number of grains per spike (NG/S) for each plot was calculated. 1000 kernels were taken randomly from each genotype and weighed. The grain yield (GY) was determined by harvesting the four rows of each plot and expressed as tons/ha. Leaf area (LA) was estimated, according to the following equation suggested by [28], as follows:

$$\text{Leaf area(LA)} = \text{L}\times\text{W}\times 0.75$$

Where L and W are the length and width of the flag leaf, respectively.

2.3 Salinity Indices

The high values of the following indices indicated salinity stress tolerance [29] as follows:

1-Mean productivity (MP):

$$\text{MP} = (Y_S + Y_P) / 2$$ [16].

2- Geometric mean productivity (GMP):

$$\text{GMP} = (\text{Y}_\text{P} \times \text{Y}_\text{S})^{0.5}$$ [19].

3- Stress tolerance index (STI):

$$\text{STI} = (\text{Y}_\text{P}) \times (\text{Y}_\text{S}) / (\bar{\text{Y}}_\text{P})^2$$ [19].

The low values of the following indices indicated salinity stress tolerance [29] as follows:

4- Tolerance index (TOL):

$$\text{TOL} = \text{Y}_\text{P} - \text{Y}_\text{S}$$ [16].

5- Stress susceptibility index (SSI)

$$\text{SSI} = [1 - (\text{Y}_\text{S} / \text{Y}_\text{P})] / [1 - (\bar{\text{Y}}_\text{S} / \bar{\text{Y}}_\text{P})]$$ [17].

Where, $\mathbf{Y_P}$, $\mathbf{Y_S}$, and $\bar{\mathbf{Y}}_\mathbf{P}$ were yield under normal, yield under salinity stress, and yield means of all genotypes under normal condition, respectively.

2.4 Statistical Analysis

Analysis of variance was carried out using SAS 9.2 (SAS v9.2; SAS Institute Inc., Cary, NC, USA), by fitting the following linear model:

$$Y_{ijk} = \mu + S_i + k_{(i)k} + G_j + SG_{iJ} + {}_{ijlm}$$

Where Y_{ijk} is the response measured on the $_{ijk}$ plot, μ is the overall mean, $S_i$is the effect of the i^{th} salinity stress, $\eta k_{(i)k}$ the whole plot error, G_j is the effect of j^{th} genotype SG_{ij} is the interaction effect among i^{th} salinity stress, and j^{th} genotype, and ε_{ijlm} is the experimental error.

Means were compared using the least significant difference test (*Lsd*, at *P-value* < *0.05*), according to [30]. The Pearson correlation coefficient was used to test the correlation between salinity indices.

3. RESULTS

3.1 Analysis of Variance

The variance analysis for all the studied traits as affected by salinity stress, genotypes, and genotypes × salinity stress interaction is presented in (Table 4) across the two growing seasons 2017 and 2018. Salinity stress significantly affected the number of days to flowering, plant height, number of grains /spike, and grain yield during the two growing seasons. On the other side, salinity stress had no significant effect on the 1000-grain weight during the first season, but it was significant in the second season. The genotypes had a significant impact on all studied traits during the two growing seasons; except for the 1000-grain weight and grain yield, there was a non-significant effect in the first season.

During the first growing season, the interaction between genotypes × salinity stress significantly affected the number of days to flowering. Moreover, during the second growing season, the interaction between genotypes × salinity stress significantly affected the number of days to flowering, number of grains / spike, and the 1000-grain weight.

3.2 Performance of Genotypes Under Non-saline and Saline Soils

During the first season, the earliest genotype in DF, was Giza-168, where it recorded 48.33 days, while the latest genotype in flowering was C-27, where it recorded 74 days. In the second season, the earliest genotype was C-32, where it recorded 51.83 days; and the latest genotype in flowering was C-02, where it recorded 62 days. According to the relative reduction, the highest reduction in number of days to flowering belonged to C-09 (58.30%), in contrast with Gemmiza-9, C-12, C-18, C-28, C-50, and C-49, which had the lowest reduction in number of days to flowering (0%), in the first season. In respect to the second season, the highest reduction belonged to Sakha-94 (16.77%), while Shandaweel-1 was the lowest genotype having a relative reduction in number of days to flowering (0%). During 2017/2018 season, C-19 and Sakha-94 were the earliest under salinity stress condition (48) days, while C-32 and C-43 were the earliest under non-stress conditions. on contrast, C-09 and C-02 were the latest genotypes in number of days to flowering under non-stress, and salinity stress condition and they recorded 56 days. (Supporting Information, Table S1). Furthermore, the leaf area was decreased from 49.05 cm^2 under the non-stress condition to 40.50 cm^2 under salinity stress conditions. Similar results were obtained in the second season (2017/2018), where the leaf area was decreased from 24.83 cm^2 under the non-stress condition to 19.88 cm^2 under salinity stress condition. The reduction in the leaf area across the two seasons under salinity stress was 17.16% and 18.45%, respectively.

The highest genotype for leaf area was C-06, which recorded 65.98 cm^2 and Giza-171, which recorded 30.47 cm^2, in the first growing season and second growing, respectively. On the other hand, the lowest genotype was C-19, which recorded 26.13 cm^2 in the first season, while C-05 was the lowest genotype in the second season, which scored 16.65 cm^2. During the first seasons, the highest reduction in leaf area was recorded in C-50 (41.40%), in contrast with C-10, which had the lowest reduction in leaf area (0.14%). In the second season, the highest reduction was recorded in C-09 (46.87%). C-22 was the lowest genotype having a relative reduction in leaf area (0.10%) (Supporting Information, Table S2). Moreover, in the first season, the average plant height across all genotypes was decreased from 90.32 cm under the non-stress condition to 81.79 cm under the salinity stress condition. The average plant height across all genotypes decreased from 74.09 cm under the non-stress condition to 55.77 cm under the second season's salinity stress condition. In the first growing season, the tallest genotype was C-43, where it recorded 102.50 cm, whereas the shortest genotype was C-09, where it recorded 70.50 cm. In the second season, the tallest genotype was C-22, where it recorded 75.33cm, while the shortest genotype was Sakha-94, where it recorded 53.33 cm (Supporting Information, Table S3).

Table 4. Analysis of variance for the number of days to flowering (DF), plant height (PH), leaf area, 1000- grain weight (g), number of grains/spike, and grain yield during 2016 / 2017 and 2017 / 2018 seasons

Trait	Source of variance	D.f	Mean squares	
			2017	**2018**
Number of days to flowering	Stress (S)	1	194.85***	2295.23 **
	Genotypes (G)	59	51.30***	27.05 **
	G x S	59	54.80***	12.16 **
Leaf area	Stress (S)	1	39.50 ns	1544.53 ns
	Genotypes (G)	59	212.24**	71.39 **
	G x S	59	90.96 ns	37.05 ns
Plant Height	Stress (S)	1	1721.65***	30213.34 **
	Genotypes (G)	59	166.87**	103.62 **
	G x S	59	95.70 ns	51.60 ns
Number of grains/spike	Stress (S)	1	5065.79***	3635.38 **
	Genotypes (G)	59	208.88**	190.68 *
	G x S	59	77.19 ns	149.30 **
1000-grain weight	Stress (S)	1	11.39 ns	3252.01 *
	Genotypes (G)	59	35.26 ns	74.81 **
	G x S	59	41.71ns	81.22 **
Grain yield	Stress (S)	1	249647.14 *	717.12 *
	Genotypes (G)	59	97382.82 ns	384.86 *
	G x S	59	89918.68 ns	902.17 ns

*ns: non-significant, *: Significant at P-value = 0.05 and **: Significant at P-value = 0.01*

Number of grains/spikes was decreased from 12.44 grains/spike under the non-stress condition to 11.05 grains/spike under the salinity stress condition. Similar results were obtained in the second season, where the number of grains/spikes was decreased from 51.36 grains/spike under the non-stress condition to 42.25 grains/spike under the salinity stress condition. The reduction in the number of grains/spikes across the two seasons under salinity stress was 11.03 % and 16.75 %, respectively.

The highest genotypes for the number of grains/spikes was C-22, which recorded 13.75 and Sakha-93, which scored 60.67 grains/spike, in 2016/2017 and 2017/201y. On the other hand, the lowest genotype was C-19, which recorded 9.75 grains/spike in the first season. C-40 was the lowest genotype in the second season, which recorded 32.50 grains/spike. The highest reduction in NG/S was recorded in C-40 (42.30%). In contrast C-11, C-23, C-38, Sakha-94, and Sids-12 had the lowest reduction in NG/S (0%), in the first season. In the second season, the highest reduction was recorded in C-33 (45.04%), while C-14 was the lowest genotype having a relative reduction in NG/S (0.66%) (Supporting Information, Table S4). Data in (Table S5) indicated a significant reduction in the thousand-grain weight with increased salinity stress during the first season. The thousand-grain weight significantly decreased from 52.45 g under non-stress conditions to 41.36 g under salinity stress. In the second season, the thousand-grain weight was significantly reduced from 57.98 g under the non-stress condition to 50.62 g under the salinity stress condition. The reduction in thousand-grain weight across the two seasons under salinity stress was 20.66% and 12.75%, respectively.

The imported genotypes exceeded the Egyptian cultivars in thousand-grain weight, where the highest imported genotypes were C-31 with (72.50 g) and (64.27 g) in the first and second seasons, respectively. Moreover, the highest Egyptian cultivar was Sakha-93 (51.00 g) and (55.47 g) in both seasons, respectively. On the other hand, the lowest genotypes were C-11 and C-23, where they recorded (30 g) in the first season. C-12 recorded (45.67 g) in the second season. During the first season, the highest reduction in thousand-grain weight belonged to C-39 (38%); in contrast, C-17, had the lowest reduction in thousand-grain weight (2.38%). In the second season, the highest reduction belonged to C-41 (39.10%), while Gemmiza-11 was the lowest genotype having a relative reduction in thousand-grain weight (0.24%). (Supporting Information, Table S5). Table S6 indicated a decrease in grain yield with increased salinity stress. In the first growing season, grain yield was decreased from 2.63 tons/ha, under the non-stress condition to 1.59 tons/ha under salinity stress conditions. Similar results were obtained in the second season, where grain yield was decreased from 2.59 tons/ha under the non-stress condition to 1.98 tons/ha under the salinity stress conditions. The reduction in grain yield across the two environments was 37.34 % and 22.69% in the first and second seasons, respectively.

The imported genotypes exceeded the Egyptian cultivars in grain yield (GY); where the highest imported genotypes were C-31 with 4.01 and 4.26 tons/ha in both seasons, respectively. Moreover, the highest Egyptian cultivar was Sakha-93 (3.05 tons/ha) and (3.38 tons/ha) in the first and second seasons, respectively. On the other hand, the lowest genotypes were C-09, where it recorded 0.48 and 0.93 tons/ha in the first and second seasons, respectively. The highest reduction in grain yield belonged to C-26 (89.29%); in contrast, C-22 had the lowest reduction in grain yield (0.57%) in the first season (Supporting Information, Table S6).

3.3 Salinity Indices

The maximum mean yield under non-stress condition (Yp) was 4.50 ton/ha for C-31 genotype, in contrast with C-09, which produced (0.71 ton/ha). The highest grain yielding genotype under stress conditions (Ys) was Sakha-93 (3.48 ton/ha), whereas C-09 (0.19 ton/ha) had the lowest grain yield (Table 5). Furthermore, C-31 had the highest MP value, whereas the lowest MP value belonged to C-09, which also, as mentioned earlier, had the lowest yield under both non-stress and stress conditions (Table 5). With respect to GMP, C-31 (3.56 ton/ha) had the highest value of GMP followed by C-40 (3.54 ton/ha), while C-09 (0.37 ton/ha) had the lowest value of GMP. The obtained results in Table 5 showed that Sakha93 (0.01) followed by C-31(0.02), had the lowest TOL value, so they were recognized as the best genotypes based on this index. The results indicate that the lowest value of SSI belonged to Sakha-93 (0.01) followed by C-31 (0.02), whereas C-26 (2.45) and C-09 (2.28) had the highest SSI value, as shown in Table 5.

Genotypes with high STI values also showed high values for MP and GMP indices and low SSI and TOL indices values. According to this index, C-31 had the highest value (1.54) followed by C-15 (1.52) (Table 5). However, the lowest value was C-09 (0.02).

3.4 Correlation Among Salinity Tolerance Indices

A positive, highly significant correlation was observed between Yp and Ys (r = 0.55), which means that high-yielding genotypes can be selected based on them under both stress and non-stress conditions. According to this study findings, a general linear model regression of grain yield under stress condition on yield under non-stress condition revealed that a positive correlation has existed between Yp and Ys indices with a coefficient of determination (R^2 = 0.297) (Fig.1). There were robust positive significant correlations between Yp and all salinity tolerance indices except for SSI.

Ys was highly significantly positively correlated with MP (r = 0.87), GMP (r = 0.93) and STI (r = 0.92). As well table 6 shows, a highly negative significant correlations between Ys and SSI (r = -0.72) and TOL (r = -0.41).

Also, correlation analysis indicated that grain yield under both stress (Ys) and non-stress conditions (Yp) were positively correlated with STI, GMP, and MP. A linear model regression based on STI for grain yield under non-stress condition(Yp) and grain yield under drought stress (Ys) revealed a positive correlation between these criteria with a coefficient of determination (R^2= 0.6272 and R^2= 0.833) for STI on YP and STI on Ys, respectively, (Figs.2 and 3).

There was a highly positive significant correlation between MP with GMP as value (0.99) and with STI as value (0.97) that indicate any criteria of them could be used for selection of genotype, while a correlation with SSI was negative significant as value (- 0.30), and there was a non-significant correlation between MP with TOL.

There was a high correlation between STI and GMP (r = 0.98). Also, linear regression for GMP on STI showed that there was a very strong correlation between the two indices with a coefficient of determination (R^2= 0.958) (Fig.4). It can be concluded that yield under stress conditions was dependent on yield under non-stress conditions. Furthermore, STI, GMP, and MP were able to identify genotypes with high yielding in both environments

It appears from the aforementioned investigations that MP, GMP, and STI indices are appropriate criteria for the selection of tolerant cultivars. Consequently, genotypes; Sakha-93, C-31, and C-40 were identified as the most salt-tolerant genotypes.

4. DISCUSSION

Salinity stress significantly affected the number of days to flowering during the first and second growing seasons. Early flowering is one of the mechanisms that plants use to escape the damage effects caused by salinity stress [31]. Additionally, the genotypes × salinity stress interaction had a significant impact on the number of days to flowering during the two growing seasons, which agrees with previous reports [32,33,34,29,22] (Table 4).

Salinity stress had a significant effect on the plant height during the two growing seasons in which it reduced plant height. That reduction could be attributed to the salts uptake by plants and the changes in the cell wall's metabolic activities, due to which the cell wall elasticity was greatly decreased [11,35]. Furthermore, genotypes had a significant effect on leaf area and plant height during the two growing seasons due to the shrinkage of the cell contents, reduced development and differentiation of tissues, unbalanced nutrition, damage of membrane, and disturbed avoidance mechanism [36,37,11].

Salinity stress had a significant effect on the number of grains/spike during the two seasons. Further, salinity stress has a substantial impact on the number of grains/spike, 1000-grain weight, and grain yield. Salinity stress hinders photosynthetic efficiency and assimilates translocation ability from the vegetative organ to the reproductive organ; for these reasons, fewer grains were developed in spike. Additionally, salts concentrations may limit the reproductive development and spikelet initiation during spike emergence. Ultimately the number of grains /spike is reduced [38]. Under salinity stress, plants produced fewer tillers and fewer spikes due to reduced assimilation through photosynthesis [39,35].

In the present study, several indices such as SSI, MP, TOL, GMP, and STI were used. According to MP, GMP and STI indices, our results indicated that several imported wheat genotypes were superior to Egyptian cultivars in salinity stress tolerance. On the other hand, the Egyptian cultivars outperformed the imported genotypes for TOL index and SSI index. MP is expressed as the mean performance under both stress and non-stress conditions. We can use MP to maximize yield in stressed and non–stressed environments and used the MP in moderate stress conditions [40]. Moreover, to identify high yielding and salinity tolerant lines, the MP index was more favorable, as reported by Singh et al., [41] . STI index, STI was a more useful index in order to select the best cultivars under stress and non-stress conditions. Genotypes with high STI values also showed high MP and GMP indices and low values of SSI and TOL. Therefore, selection based on STI will result in high-yielding and tolerant genotypes [42,43].

Table 5. Salinity tolerance indices for 11 Egyptian genotypes and 49 imported genotypes in two seasons (2017 and 2018)

Genotypes	Yp	Ys	MP	GMP	TOL	SSI	STI
C-02	2.26 (49)	1.95 (31)	2.11 (44)	2.10 (39)	0.29 (50)	0.43 (50)	0.53 (39)
C-03	3.61 (9)	2.03 (29)	2.83 (15)	2.72 (16)	1.56 (13)	1.54 (19)	0.90 (16)
C-04	1.82 (56)	1.51 (45)	1.67 (55)	1.66 (52)	0.31 (49)	0.53 (43)	0.33 (52)
C-05	2.51 (43)	1.88 (32)	2.19 (38)	2.17 (35)	0.63 (34)	0.78 (33)	0.57 (35)
C-06	4.00 (4)	2.16 (23)	3.08 (9)	2.94 (10)	1.84 (7)	1.44 (15)	1.05 (10)
C-07	3.95 (6)	2.93 (5)	3.44 (5)	3.40 (5)	1.00 (23)	0.81 (32)	1.41 (5)
C-08	3.48 (14)	2.55 (11)	3.43 (6)	3.43 (4)	0.09 (57)	0.08 (57)	1.43 (4)
C-09	0.71 (60)	0.19 (60)	0.45 (60)	0.37 (60)	0.52 (39)	2.28 (2)	0.02 (60)
C-10	3.88 (7)	1.45 (46)	2.67 (22)	2.37 (30)	2.43 (2)	1.95 (5)	0.68 (30)
C-11	1.95 (53)	1.06 (54)	1.51 (57)	1.44 (57)	0.88 (28)	1.41 (17)	0.25 (57)
C-12	2.96 (28)	1.58 (41)	2.27 (34)	2.14 (37)	1.38 (15)	1.45 (14)	0.55 (37)
C-13	2.16 (50)	1.81 (34)	1.98 (46)	1.98 (42)	0.35 (46)	0.51 (45)	0.47 (42)
C-14	3.19 (20)	1.55 (42)	2.37 (31)	2.22 (33)	1.64 (12)	1.60 (12)	0.60 (33)
C-15	4.42 (2)	2.79 (7)	3.65 (4)	3.36 (6)	1.71 (11)	1.19 (24)	1.52 (2)
C-16	3.26 (18)	2.24 (22)	2.75 (17)	2.70 (17)	0.96 (25)	0.98 (30)	0.88 (18)
C-17	1.51 (59)	0.95 (58)	1.23 (59)	1.20 (59)	0.56 (38)	1.16 (25)	0.17 (59)
C-18	2.99 (27)	1.44 (47)	2.22 (36)	2.08 (40)	1.54 (14)	1.61 (11)	0.52 (40)
C-19	3.60 (10)	1.60 (40)	2.60 (23)	2.40 (28)	2.00 (4)	1.73 (9)	0.70 (28)
C-20	2.94 (29)	1.97 (30)	2.45 (29)	2.42 (27)	0.93 (26)	1.04 (28)	0.71 (27)
C-21	3.63 (8)	2.31 (18)	2.97 (12)	2.90 (13)	1.32 (18)	1.13 (26)	1.02 (13)
C-22	2.54 (42)	2.40 (16)	2.47 (27)	2.47 (25)	0.14 (54)	0.17 (55)	0.74 (25)
C-23	2.07 (51)	1.62 (38)	1.85 (50)	1.83 (46)	0.45 (41)	0.68 (36)	0.41 (46)
C-24	2.89 (31)	1.09 (51)	1.99 (45)	1.77 (49)	1.80 (9)	1.94 (6)	0.37 (49)
C-25	2.86 (32)	1.05 (55)	1.96 (47)	1.73 (50)	1.81 (8)	1.97 (4)	0.36 (50)
C-26	3.49 (13)	0.75 (59)	2.12 (43)	1.62 (53)	2.74 (1)	2.45 (1)	0.32 (53)
C-27	1.78 (57)	1.77 (36)	1.78 (51)	1.78 (48)	1.87 (6)	1.32 (20)	0.38 (48)
C-28	3.02 (25)	1.61 (39)	2.31 (33)	2.21 (34)	1.37 (16)	1.43 (16)	0.59 (34)
C-29	3.08 (23)	2.04(28)	2.57 (25)	2.52 (23)	0.98 (24)	1.03 (29)	0.76 (24)
C-30	3.00 (26)	1.28 (50)	2.14 (41)	1.96 (43)	1.72 (10)	1.79 (7)	0.45 (43)
C-31	4.50 (1)	3.39 (2)	3.94 (1)	3.56 (1)	0.02 (59)	0.02 (59)	1.54 (1)
C-32	2.76 (36)	2.30 (19)	2.53 (26)	2.50 (24)	0.46 (40)	0.52 (44)	0.77 (23)
C-33	3.27 (17)	2.69 (9)	2.98 (11)	2.97 (9)	0.58 (36)	0.55 (42)	1.07 (9)
C-34	1.73 (58)	1.39 (49)	1.56 (56)	1.55 (56)	0.34 (47)	0.61 (39)	0.29 (56)
C-35	2.45 (44)	1.43 (48)	1.94 (48)	1.87 (45)	1.02 (22)	1.30 (22)	0.43 (45)
C-36	2.42 (46)	2.05 (27)	2.24 (35)	2.23 (32)	0.36 (45)	0.46 (48)	0.61 (32)
C-37	1.88 (54)	1.52(44)	1.71 (54)	1.70 (51)	0.33 (48)	0.56 (41)	0.35 51)

The parentheses' numbers refer to the genotypes rank, Yp = yield under non-stress condition, Ys = yield under stress condition, MP=mean productivity, GMP= geometric of mean productivity, TOL= tolerance index, SSI= stress susceptibility index, STI=stress tolerance index

Continued Table 5.

Genotypes	Yp	Ys	MP	GMP	TOL	SSI	STI
C-38	2.56 (41)	1.84 (33)	2.20 (37)	2.16 (36)	0.72 (33)	0.88 (31)	0.56 (36)
C-39	3.36 (15)	0.98 (57)	2.17 (39)	1.81 (47)	2.38 (3)	2.21 (3)	0.40 (47)
C-40	3.98 (5)	3.19 (3)	3.59 (2)	3.54 (2)	0.79 (31)	0.62 (38)	1.37 (6)
C-41	2.43 (45)	2.29 (20)	2.36 (32)	2.36 (31)	0.13 (55)	0.18 (56)	0.65 (31)
C-42	2.41 (47)	1.04 (56)	1.73 (53)	1.58 (55)	1.36 (17)	1.77 (8)	0.30 (55)
C-43	3.59 (11)	2.78 (8)	3.17 (8)	3.16 (8)	0.81 (29)	0.70 (35)	1.21 (8)
C-44	2.72 (37)	1.54 (43)	2.13 (42)	2.05 (41)	1.18 (21)	1.35 (18)	0.50 (41)
C-45	2.39 (48)	1.08 (52)	1.74 (52)	1.61 (54)	1.31 (19)	1.71 (10)	0.31 (54)
C-46	2.00 (52)	1.78 (35)	1.89 (49)	1.89 (44)	0.22 (53)	0.34 (51)	0.43 (44)
C-47	2.61 (40)	1.70 (37)	2.16 (40)	2.11 (38)	0.91 (27)	1.09 (27)	0.54 (38)
C-48	2.78 (34)	2.38(17)	2.58 (24)	2.57 (22)	0.40 (44)	0.45 (49)	0.80 (22)
C-49	4.07 (3)	2.08 (25)	3.06 (10)	2.91 (12)	1.99 (5)	1.53 (13)	1.03 (12)
C-50	1.87 (55)	1.07 (53)	1.48 (58)	1.42 (58)	0.77 (32)	1.31 (21)	0.23 (58)
Gemmiza-11	2.68 (39)	2.26 (21)	2.46 (28)	2.46 (26)	0.42 (43)	0.49 (46)	0.72 (26)
Gemmiza-9	3.18(21)	3.17 (4)	3.19 (7)	3.19 (7)	0.27 (51)	0.30 (52)	1.23 (7)
Giza-168	3.13 (22)	2.53 (13)	2.81 (16)	2.81 (15)	0.60 (35)	0.60 (40)	0.93 (15)
Giza-171	3.05 (24)	2.80 (6)	2.93 (13)	2.92 (11)	0.25 (52)	0.26 (53)	1.04 (11)
Misr-1	2.81 (33)	2.54 (12)	2.68 (21)	2.67 (20)	0.04 (58)	0.04 (58)	0.85 (20)
Misr-2	2.77 (35)	2.64 (10)	2.71 (18)	2.69 (18)	0.11 (56)	0.15 (56)	0.89 (17)
Sakha-93	3.52 (12)	3.48 (1)	3.50 (3)	3.50 (3)	0.01 (60)	0.01(60)	1.49 (3)
Sakha-94	2.70 (38)	2.13 (24)	2.42 (30)	2.39 (29)	0.57 (37)	0.66 (37)	0.69 (29)
Shandaweel-1	3.34 (16)	2.06 (26)	2.70 (19)	2.62 (21)	1.28 (20)	1.20 (23)	0.84 (21)
Sids-12	2.92 (30)	2.48 (14)	2.69 (20)	2.68 (19)	0.44 (42)	0.47 (47)	0.87 (19)
Sids-13	3.25 (19)	2.44 (15)	2.85 (14)	2.82 (14)	0.80 (30)	0.75 (34)	0.96 (14)

The parentheses' numbers refer to the genotypes rank, Yp = yield under non-stress condition, Ys = yield under stress condition, MP=mean productivity, GMP= geometric of mean productivity, TOL= tolerance index, SSI= stress susceptibility index, STI=stress tolerance index

Table 6. Correlation coefficients between salinity tolerance indices for 11 Egyptian genotypes and 49 imported genotypes over two seasons (2016/2017 and 2017/2018)

Variable	Yp	Ys	MP	GMP	TOL	SSI	STI
Yp	1.00						
Ys	0.55**	1.00					
MP	0.89**	0.87**	1.00				
GMP	0.82**	0.93**	0.99**	1.00			
TOL	0.54**	- 0.41**	0.09 ^{ns}	-0.04 ^{ns}	1.00		
SSI	-0.15 ^{ns}	- 0.72**	-0.30*	- 0.42**	0.88**	1.00	
STI	0.79**	0.92**	0.97**	0.98**	-0.06 ^{ns}	- 0.39**	1.00

*ns: not significant. * and ** Significant at the 5% and 1% level, respectively; Yp : mean yield under non-stress condition, Ys : yield under stress condition, MP : mean productivity, GMP : geometric of mean productivity, TOL : tolerance index, SSI : stress susceptibility index and STI : stress tolerance index*

The low value of Ys or high value of Yp leads to an increase in TOL value. Therefore, the smallest value of TOL is favored for the selection of the tolerant genotypes [21](Singh et al., 2014;). Genotypes with low SSI values were considered stress-tolerant because such genotypes showed a lower reduction in grain yield under stress conditions than non-stress conditions. Researchers have widely used SSI to identify sensitive and tolerant genotypes [43](Singh et al., 2014;).

There were highly positive significant correlations between Yp and all salinity tolerance indices, indicating that high yielding genotypes can be selected based on them under stress and non-stress conditions. Our results were similar to those of Farshadfar and Sutka, [40] . Ys was highly significant and positively correlated with MP, GMP, and STI. These results are in agreement with those reported by Reynolds and Trethowan, [44]. There were highly positive significant correlations between Yp and all salinity tolerance indices, indicating that high yielding genotypes can be selected based on them under stress and non-stress conditions. Our results were similar to those of Farshadfar and Sutka, [40]. Ys was highly significant and positively correlated with MP, GMP and STI. These results are in agreement with those reported by Reynolds and Trethowan, [44]. It can be concluded that yield under stress condition was dependent on yield under non-stress conditions. Furthermore, STI, GMP and MP identified genotypes with high yielding in both environments.

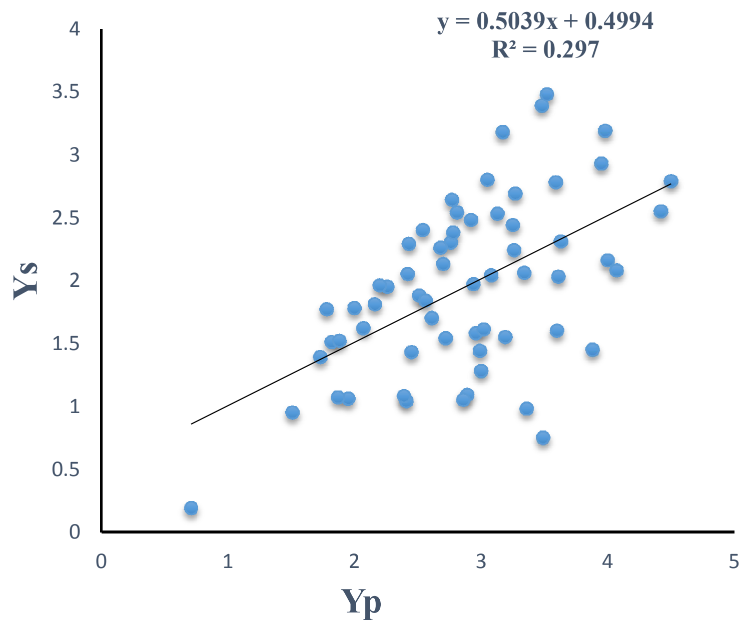

Fig. 1. Relationship between grain yield under salinity stress condition (Ys) and grain yield under non-stress condition (Yp)

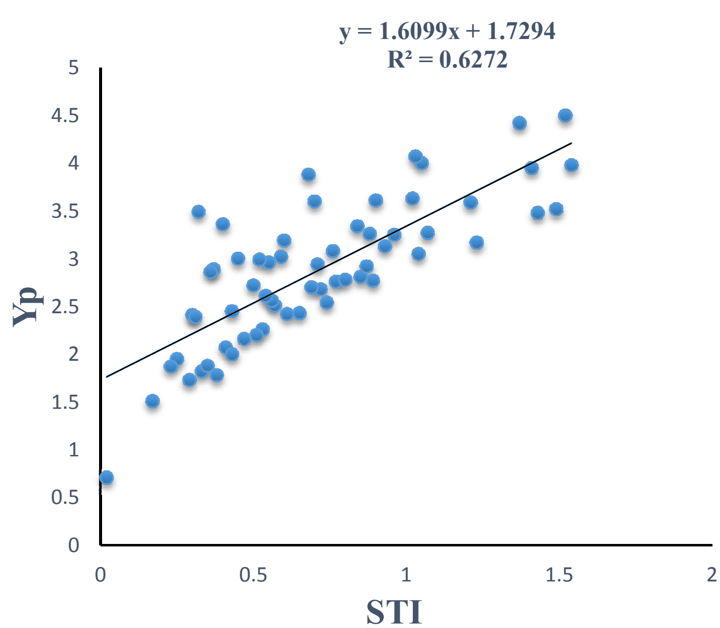

Fig 2. Relationship between grain yield under non-stress condition (Yp) and stress tolerance index (STI)

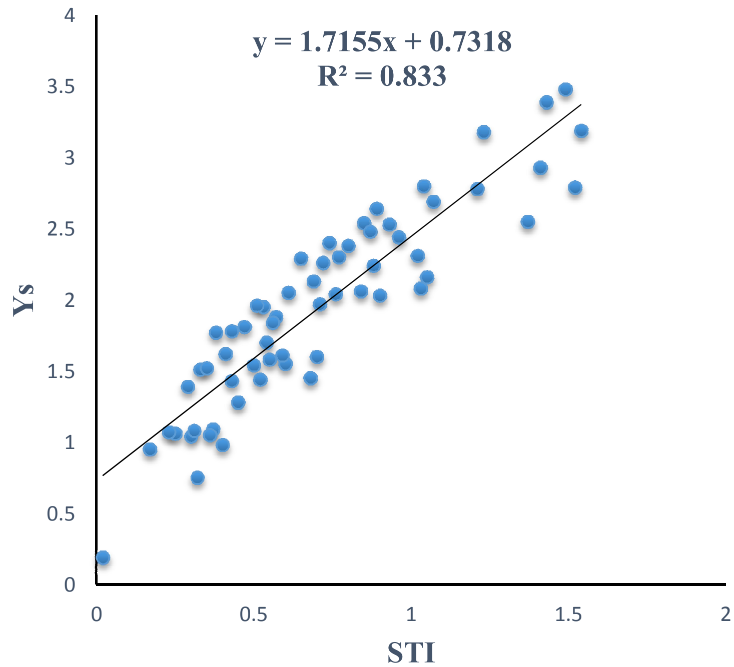

Fig. 3. Relationship between grain yield under stress condition (Ys) and stress tolerance index (STI)

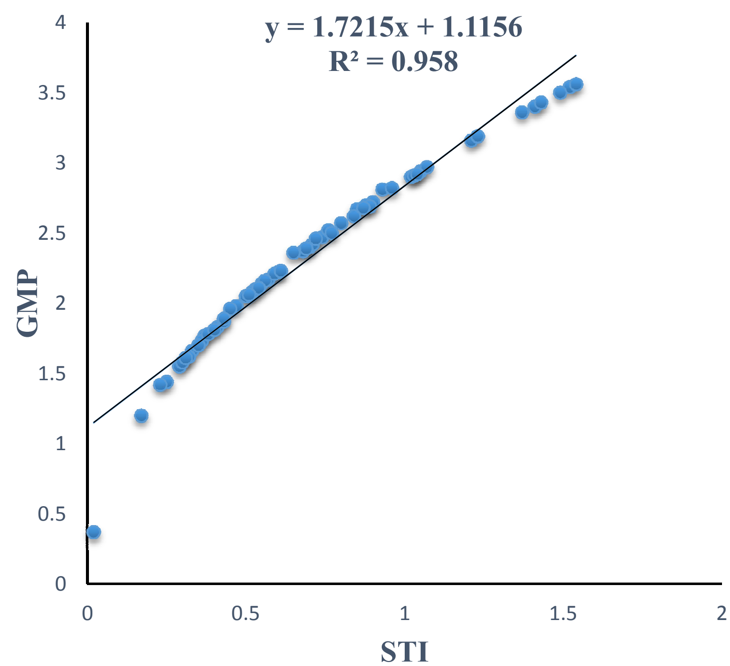

Fig. 4. Relationship between geometric mean productivity (GMP) and stress tolerance index (STI

5. CONCLUSION

The results of the present study enabled us to conclude that among the 60 wheat genotypes, Sakha-93, C-31, and C-40 were identified as suitable genotypes for saline soils. Sakha-93, C-31, and C-40 can be used in further breeding programs aimed to improve salinity stress tolerance. On the other hand, MP, GMP, and STI are useful indices to identify salinity stress tolerant wheat cultivars.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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