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Evaluation of some bread wheat genotypes for low nitrogen fertilization using different stress tolerance indices

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THIS STUDY was conducted for evaluation of some promising Egyptian cultivars to identify low-N-tolerant wheat genotypes by integrating stress indices (STI, GMP) with GGE-biplot analysis, offering a dual approach for breeding programs. The study was conducted as two field experiments at the experimental farm of El Gemmeiza research station. The two growing seasons 2021/2022 and 2022 / 2023 under four rates of nitrogen fertilizer (60, 120, 179 and 239 kg N / ha.). The experiment was designed in split plot. with three replications. Results showed that, the mean square of genotypes, nitrogen and their interactions showed high significance of all studied traits. Nitrogen stress shortened the heading duration The nitrogen stress caused a shorter duration to heading in the 1st season by an average of 14.22% and 13.41 % in the 2nd season and by an average of 8.45% and 7.77% and average of 3.46% and 3.83% under 1st, 2nd and 3rd nitrogen fertilizer rates, respectively, compared with the normal rate (N=75 kg nitrogen) under both conditions, Misr1 and G3 displayed the shortest plants, while Sakha 95 and G1 genotypes exhibited the earliest heading and maturity dates. Under both circumstances, Misr 2 was the best genotype overall in terms of the number of kernels per spike, 1000-kernel weight, and grain yield ton/ha . According to the GGE-biplot, Misr 3, G5, G6, and Giza 171 were the most stable cultivars across all eight environments. The correlation coefficients between grain yield under normal and low nitrogen conditions and stress tolerance indices show that the optimum yield indices in low and normal nitrogen circumstances can include the stress tolerance index (STI), mean productivity (MP), geometric mean productivity (GMP), and harmonic mean (HM).

Keywords: Wheat, grain yield, low N, stress tolerance indices and GGE-biplot modelling.

1. Introduction

Wheat (Triticum spp. L) is one of the earliest domesticated food crops and considers the basic staple food of the major civilizations of the world. Bread wheat (Triticum asetivum L) is the dominant wheat type produced in Egypt and the most major food grain source for Egyptians **(Said *et al*., 2021; Sayed *et al*., 2021 and Esmail et al., 2023).** Among the strategic cereals crops, wheat is the most staple cereal crop in Egypt with total annual production of about 10 million tons in 2021-2022 growing season from an average of 1.5 million hectares, which represents about 50% of the amount sufficient for local needs **(Economic Affairs Sector, MALR,2023 and Elkot et al., 2023).** The local consumption of wheat is increasing each year due to the continuous increase of population. So, this gap should be narrowed numerous environmental stresses affect its production in different ways. Nitrogen deficiency is one of the most significant abiotic stressors limiting crop productivity. The rate of increase in yield is still too slow to keep up with the 70% increase in wheat. Nitrogen (N) affects metabolic processes necessary for plant development and crop yield. Farmers tended to increase N fertilization to augment crop yield due to environmental costs like pollution, high input costs **(Hirel *et* 2007), Fouad (2018), El-gammal *et al* (2023) and Abd El- Aty *et al* (2024).**

Selection for nitrogen deficiency stress has been done using a variety of yield-based stress measures. Tolerance indices have been employed in numerous research to choose stable genotypes based on their

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performance in both stress and favourable environments (Insert References). These indices were divided into two categories: tolerance indices; mean productivity (MP), geometric mean productivity (GMP) and stress tolerance index (STI), and susceptibility; indices stress susceptible index (SSI) and Tolerance index (TOL). This study identifies low-N-tolerant wheat genotypes by integrating stress indices (STI, GMP) with GGE-biplot analysis, offering a dual approach for breeding programs.

2. Materials and Methods

Location, experimental site and environments

A field experiment was conducted in the Experime ntal Farm of Wheat Research Department, El Gem meiza Agricultural Research Station, Elgharbia Go v., Egypt, which is
in the center of the Delta (30.97°N, 30° 30.97 E), during the two wheat-growing seasons of 2021–2022 and 2022–2023.
The monthly highest and lowest temperatures for th e two growing seasons are summarized in table (1).

Table 1. Meteorological data in 2021 / 2022 and 2022 / 2023 growing season.

Month	2021/2022 season				2022/2023 season			
	Temperature (c°)		Rain (mm)	Relative humidity (%)	Temperature (c°)		Rain (mm)	Relative humidity (%)
	Min	Max			Min	Max		
November	**16.57**	**25.57**	**-**	**77.10**	**18.18**	**26.91**	**1.57**	**78.78**
December	**14.68**	**23.20**	**0.03**	**80.52**	**15.15**	**22.902**	**0.72**	**78.76**
January	**12.75**	**20.92**	**0.35**	**79.81**	**11.91**	**20.87**	**0.09**	**76.05**
February	**10.28**	**18.16**	**1.23**	**75.68**	**12.18**	**20.32**	**1.15**	**79.24**
March	**14.88**	**23.60**	**1.43**	**72.35**	**14.22**	**23.80**	**0.47**	**73.18**
April	**17.32**	**26.71**	**0.77**	**67.70**	**20.00**	**28.17**	**0.06**	**70.77**
May	**20.02**	**29.12**	**0.08**	**69.60**	**21.58**	**30.86**	**-**	**69.45**
June	**23.64**	**31.23**	**-**	**69.80**	**23.07**	**35.47**	**-**	**73.30**

Experimental Materials

The experimental materials were consisted of thirteen bread wheat genotypes (*Triticum aestivum* L.). Seven genotypes of bread were provided by the National Gene Bank named (G1, G2, G3, G4, G5, G6 and G7) as well as six commercial cultivars was released by Wheat Research Department, Agriculture Research Center, Egypt. These wheat cultivars named (Sakha 95, Misr 1, Misr 2, Misr 3, Giza 171 and Sids 14). Name and pedigree of the wheat genotypes are presented in (Table 2).

Table 2. Name, pedigree and source of location of 13 wheat genotypes used in this investigation.

No.	genotype	Name	History of selection and pedigree
1	**1**	Sakha 95	PASTOR//SITE/MO/3/CHEN/AEGILOPSSQUARROSA (TAUS)//BCN/4/WBLL1.CMSA01Y00158S-040P0Y-040M-030ZTM-040SY26M-0Y-0SY- 0S
2	**2**	Misr 1	OASIS/SKAUZ//4*BCN/3/2*PASTOR. CMSS00Y01881T -050M-030Y-030M-030WGY-33M-0Y-0EGY
3	**3**	Misr 2	SKUAUZ/BAV92.CMSS96M03611S-1M-0105Y-8M-0Y- 010M-010SY-8Y-0S
4	**4**	Misr 3	ATTILA *2/PBW65*2/KACHU.CMSS06Y00582T099TOPM-099Y099ZTM099Y099M-10WGY-0B0- 0EGY
5	**5**	Giza 171	Sakha 93/Gemmeiza 9. S.6-1GZ-4GZ-1GZ-2GZ-0Sddf
6	**6**	Sids 14	Bow"s"/Vee"s"//Bow's'/ Tsi /3/BANI SUEF1. SD293-1SD-2SD-4SD-0SD
Genotypes		**Bar code**	**Source of location**
7	**G1**	112544	Giza
8	**G2**	112498	Egypt
9	**G3**	112659	Egypt
10	**G4**	112535	Egypt
11	**G5**	111068	Sohag
12	**G6**	112637	Giza
13	**G7**	112717	Egypt

Experimental design and treatments.

Two field experiments were carried out under four rates of nitrogen fertilizer used at rate of 60, 120, 179 and 239 kg N / ha. in the form of Urea (46.5% N). The experiment design was a randomized complete block design (RCBD) with a split plot arrangement with three replications. Nitrogen fertilizer rates are related to main plots and 13 bread wheat genotypes are related to sub-plots. Each experiment plot size was 4.8 m2 . Each plot included 6 rows at a distance of 20 cm between each other and with 4 meters long. In growing seasons, wheat was preceded by maize.

Table 3. Some chemical and physical properties of investigated soil.

Soil properties		2021/2022	2022/2023
physical analysis			
Sand %		22.06	21.14
Silt %		30.03	28.73
Clay %		47.91	50.13
Texture class		clay	clay
Chemical analysis			
pH		7.92	7.23
E.C. (dsm^{-1})		0.65	0.50
Soluble cations (meq/l)	Ca^{++}	1.55	1.49
	Mg^{++}	2.05	1.85
	Na^{+}	2.52	2.09
	K^{+}	0.41	0.49
Soluble anions (meq/l)	HCO_3^-	3.09	2.54
	Cl^-	1.90	0.84
	SO_4^-	1.41	0.89
Available nutrients (ppm)	N	33.06	35.89
	P	5.81	5.90
	K	463.15	465.78

Studied traits

Days to heading and maturity dates, plant height, nu mber of spikes/m2, number of kernels/spike,1000 - kernels weight and grain yield ton/ha.
straw ton/ha.. and harvest index .

Statistical analysis

Analysis of variance was used to all of the gathered data in accordance with **Steel et al. (1997).** The combined analysis over the two years was carried out when the error of variance was homogeneous. (Bartlett, 1937). The various sources of variance and their interactions were compared using the LSD test.

Calculation of nitrogen stress Tolerance Indices

Grain yield under high (N= 239) and low (N= 60) nitrogen fertilization circumstances has been screened for tolerance to nitrogen deficit genotypes using a number of stress tolerance metrics. For example, mean productivity (MP), the geometric mean productivity (G M P) (Fernandez, 1992), the harmonic mean (HM) (**Bidinger and Mahalakshmi,**

1987), the tolerance index (TOL) (**Roselle and Hamblin, 1981**), the yield index (YI) (**Gavuzzi et al., 1997**), the yield stability index (YSI) **(Bouslam and Schapaugh, 1984**), the stress susceptibility index (SSI) (**Fischer and Maurer, 1978**), the stress tolerance index (STI) (**Fernandez, 1992**), and the relative stress index (RSI) (**Bouslam and Schapaugh, 1984**). Grain yield for each genotype under low N conditions (Ys) and normal N conditions (Yp) was used to compute the yield reduction ratio (YR) and yield index (YI), respectively. The mean yields of all genotypes under low and normal nitrogen are denoted by s and p, respectively.

Correlation :Pearson correlation among indices and grain yield in two conditions was performed by SPSS Ver. 20.

3. **Results**

Analysis of Variance.

Mean squares in each condition indicated significant differences for yield among the studied genotypes which may be due to variation in genotypes response to nitrogen deficiency. Table 4.

Table 4. Mean squares for all the studied traits of 13 wheat genotypes (G) under four nitrogen (N) over the two growing seasons.

Source of Variation	DF	Days to Heading	Days to maturity	Plant Height	No.of spikes / m2	No. of kernels / spike	1000-kernel weight	Grain yield ton/ ha	Straw yield ton/ ha	Harvest Index
Years (y)	1	2331.4**	0.55	325.32**	962.1**	31.97**	9.02**	33.41**	44.41	100.35**
Y / rep.	3	8.73	8.65	33.51	1034.1	33.73	0.91	0.4	1.32	4.6
Nitrogen (N)	3	2815.5**	1340.2**	1599.3**	106348.9**	2848.51**	640.71**	101.31**	63.42**	435.52**
Y x N	3	15.51**	9.51**	32.02**	211.2**	17.42**	2.48**	2.5644**	3.3055**	27.65**
Error (a)	12	2.5	2.54	2	158.27	6.27	0.47	0.22	1.11	7.49
Geno. (G)	12	242.9**	351.4**	156.8**	24731.9**	347.21**	147.31**	8.01**	12.66**	49.13**
Y x G	12	76.07**	43.98**	28.98**	559.9**	32.58**	4.26	1.44**	11.38**	57.43**
G x N	36	15.42**	9.44**	8.41**	1408.9**	44.51**	7.89**	1.33**	3.93**	23.41**
Y x G x N	36	2.85**	5.06**	2.46**	102.5*	9.84**	2.01**	0.41**	1.73**	15.09**
Pooled Error (b)	192	2.37	2.48	2.34	106.1	6.25	0.6	0.22	0.93	4.3

* and ** Significant and highly significant at 0.05 and 0.01, respectively.

The interaction of years' × nitrogen fertilizers (Y× N) differed significantly for all traits referring to the influences of season on the response to nitrogen fertilizers. Also, highly significant interactions between years × genotypes (Y× G) were observed for all the studied traits, indicating that growing season affects the relative trait genotypic potential. Similar results were obtained by **(Le Gouis and Pluchard 1996; Gallais and Coque 2005; An et al. 2006)** who reported that, genotypes exhibited different behaviour with different N levels growing seasons. Moreover, the results showed highly significant interactions between genotypes and nitrogen fertilization levels (G x N) for all characters. For (y× G × N) interaction, there were a different response among genotypes to seasons and nitrogen fertilizer treatment for the studied traits. Indicating, the effects of nitrogen fertilizer levels on genotype performance and significant genetic variation with the possibility of selection for favorable genotypes. Similar results were obtained **Tammam and Abd El Rady (2010)** , **Tawfelis et al. (2011) Ali, M. M. A.(2017) Fouad (2018), El-gammal *et al* (2023) and Abd El- Aty *et al* (2024).**

There were notable variations in the responses of wheat genotypes under both conditions for every variable examined, as indicated by the mean performance and reduction percentage of thirteen genotypes of bread wheat (Triticum aestivum L.) for all the traits under study (Table 5). Days to heading varied from 83 days for G1 to 95 days for G5 genotypes under mild nitrogen deficit treatment, and from 99 days for G1 to 107 days for G6 genotypes under normal nitrogen. Under both circumstances, the earliest values were found in the genotypes (G1) and Gemmiza12

Table 5. Means and reduction percentage of studied traits of 13 wheat genotypes grown under normal (N) and low nitrogen (L) over the two growing seasons.

Genotypes	Days to heading		Red%.	Plant Height		Red. %	No. of Spikes/m^2		Red%.
	N	L		N	L		N	L	
Sakha 95	100	84	16.0	119	109	8.40	477	359	24.7
Misr 1	101	85	16.8	117	103	11.9	456	356	21.9
Misr 2	100	86	14.0	117	109	6.84	466	351	24.6
Misr 3	102	94	9.8	116	105	9.48	417	343	17.7
Giza 171	102	90	13.7	119	109	8.40	358	328	8.38
Sids 14	101	86	15.8	118	107	9.32	471	421	10.6
G1	99	83	15.1	117	112	4.27	459	384	16.3
G2	101	84	17.8	117	106	9.40	452	366	19.0
G3	104	89	18.4	112	102	8.93	453	381	15.8
G4	104	92	15.5	118	105	11.0	461	387	16.0
G5	106	95	16.3	119	107	10.0	459	369	19.6
G6	107	91	21.9	121	108	10.7	484	381	21.2
G7	106	86	24.8	121	107	11.5	484	378	21.99
Grand mean	102.53	88.07	14.10	117.76	106.84	9.27	453.61	369.54	18.53

Table 5b. Means and reduction percentage of studied traits of 13 wheat genotypes grown under normal (N) and low nitrogen (L) over the two growing seasons.

Genotypes	No. of kernels /spike		Red%.	1000 kernel weight		Red. %	Grain Yield ton/ha		Red%.
	N	L		N	L		N	L	
Sakha 95	64	45	29.6	49.15	41.67	16.83	8.05	4.59	42.95
Misr 1	61	45	26.2	50.85	43.07	15.62	6.91	4.90	29.16
Misr 2	65	56	13.8	53.23	49.04	11.46	8.75	5.14	41.22
Misr 3	56	45	24.4	50.95	43.84	12.94	8.39	5.77	31.29
Giza 171	62	47	24.1	51.18	40.87	16.57	7.51	5.18	31.05
Sids 14	59	40	32.2	46.37	42.86	10.49	7.69	4.75	38.30
G1	57	45	21.0	47.67	43.81	9.79	6.42	4.18	34.89
G2	59	45	23.7	49.09	42.45	11.7	7.33	5.04	31.26
G3	58	40	31.0	56.07	50.52	9.36	6.21	4.73	23.85
G4	57	38	33.3	46.79	44.65	13.03	8.29	5.21	37.18
G5	51	42	17.6	56.91	44.36	17.08	8.29	5.75	30.60
G6	53	44	16.9	48.59	44.25	11.73	7.61	6.20	18.47
G7	58	44	24.1	51.13	43.65	14.63	7.85	4.83	38.47
Grand mean	58.46	44.31	24.6	50.65	44.03	13.0	7.64	5.10	32.98

For plant height, the lowest mean values were recorded for (G3) under normal and low nitrogen treatments (112 and 102 cm), respectively. Regarding the no. of spikes/ m2, three genotypes (G6, Sakha 95 and Sids 14) and (Sids 14, G4 and G6) had the highest no. of spikes / m2; (484, 477 and 471), and (421, 387 and 381) under normal and low nitrogen treatments, respectively, on the other hand, two genotypes; Sids 14 and G6 had the highest no. spikes / m2 under both conditions.

With regard to no. of kernels / spike three genotypes namely; Sakha 95, Misr 2 and Giza 171 had the highest no. of kernels/ spike; (64, 65 and 62) and (45, 56 and 47) under normal and low nitrogen, respectively.

Regarding 1000 kernel weight the results showed that, under both normal and low nitrogen treatments the highest mean values were observed for genotypes; Misr2 and G2 (53.32 and 52.23) and (47.21 and 46.93), respectively. As for grain yield three genotypes namely; Misr2, Misr3 and G4 had the highest values under normal nitrogen (24.48, 23.49 and 23.34) while, the three genotypes Misr3, G5 and G6 exhibited the highest values under low nitrogen treatment (16.14, 16, 71 and 16.48), respectively. The genotype Misr3 had the highest values of grain yield under both conditions. Nitrogen deficiency caused reductions in these traits by 14.10, 9.27, 18.53, 24.20, 13.07 and 33.47 % respectively. These results are in agreement with those obtained by **Abd El- Aty *et al* (2016)**, **Fouad (2018), El-gammal *et al* (2023)** and **Abd El- Aty *et al* (2024).**

Screening of promising cultivars based on nitrogen selection indices

Identifying donor parents with high yields under low nitrogen (LN) conditions is essential for developing high-yielding wheat varieties appropriate for low nitrogen conditions.

Selection indices were calculated for grain yield (ton/ha.) of 13 wheat genotypes under normal (Yp) and low nitrogen (Ys) conditions over two seasons, Table 6. Genotype estimated indices showed wide range of variations, the stress tolerance index (STI) ranged from 0.46. to 0. 83. The lowest value of STI was obtained from the genotype G1 and the highest value from the Misr 3. Genotypes Misr 3, G5 and G6 showed the highest STI rate with values of 0.83, 0.81 and 0.81, respectively and had high yield under normal and low nitrogen rate indicating a high stress tolerance. While, both genotypes G 3 and G1 had the lowest STI rate with values of 0.50 and 0.46. Regarding GMP, it was the same trend with MP where the highest value of GMP belonged to Misr 3, while G1 had the lowest value of GMP (Table 6). As water stress-tolerant genotypes, geometric mean productivity (GMP) and mean productivity (MP) can be chosen. Furthermore, under both stress and non-stress conditions, genotypes with high HM and low TOL values would be more stable. The TOL index shows the differences between the YP and YS treatments; G3 and G6 have the lowest TOL values, at 4.14 and 3.93, respectively. For selection genotypes, a lower TOL value is preferred **(Zangi, 2005).** Low drought susceptibility (high yield stability) is indicated by stress sensitivity index (SSI) values less than 1, whereas high drought susceptibility (poor yield stability) is indicated by values more than 1.

Data in table (6) showed that the lowest values of this index were the genotypes G6 followed by G3 its value less than one indicated high tolerance to stress. For SSI and YSI the desirable low nitrogen tolerant genotypes were G6, G3, Misr 1, Misr 3 and Giza 171 respectively. SSI appeared to be a suitable selection index to distinguish resistant genotypes. However, SSI was evaluated based on yield ratio of each variety in stressed conditions to non-stressed conditions as compared with the proportion in the total varieties. According to yield index (YI) G6 recorded the highest value of (YI) followed by Misr 3 and G5, respectively. These results are in agreement with those obtained **by Abd El-Aty *et al* (2016). Fouad *et al* (2018) and Abd El-Aty *et al* (2024)**.

Table 6. Means and selection indices for grain yield (ton /ha.) of 13 wheat genotypes under normal (Yp) and low nitrogen (Ys) condition over two seasons.

Genotypes	YP	YS	TOL	MP	HM	SSI	GMP	STI	YI	YSI	YR
Sakha 95	8.05	4.59	3.46	6.32	5.85	1.29	6.08	0.63	0.90	0.57	0.43
Misr 1	6.91	4.90	2.02	5.90	5.73	0.88	5.82	0.58	0.96	0.71	0.29
Misr 2	8.75	5.14	3.61	6.94	6.47	1.24	6.70	0.77	1.01	0.59	0.41
Misr 3	8.39	5.77	2.63	7.08	6.83	0.94	6.95	0.90	1.13	0.69	0.31
Giza 171	7.51	5.18	2.33	6.34	6.13	0.93	6.23	0.79	1.02	0.69	0.31
Sids 14	7.69	4.75	2.95	6.22	5.87	1.15	6.04	0.69	0.93	0.62	0.38
G1	6.42	4.18	2.24	5.30	5.06	1.05	5.18	0.52	0.82	0.65	0.35
G2	7.33	5.04	2.29	6.18	5.97	0.94	6.07	0.63	0.99	0.69	0.31
G3	6.21	4.73	1.48	5.47	5.36	0.72	5.41	0.50	0.93	0.76	0.24
G4	8.29	5.21	3.08	6.75	6.39	1.12	6.57	0.74	1.02	0.63	0.37
G5	8.29	5.75	2.54	7.02	6.79	0.92	6.90	0.89	1.13	0.69	0.31
G6	7.61	6.20	1.41	6.90	6.83	0.56	6.87	0.81	1.22	0.82	0.18
G7	7.85	4.83	3.02	6.34	5.98	1.16	6.16	0.65	0.95	0.62	0.38

Ys = grain yield under low nitrogen (60 kg N/ ha.), **Yp** = grain yield under normal nitrogen (239 N/ ha.), Tolerance index **(TOL)**, Harmonic Mean (**HM)**, stress susceptible index (SSI**),** geometric mean productivity (GMP), mean productivity (MP**),** stress tolerance index (STI**)**, yield stability index **(YSI**), Yield Stability Index (**YSI)** and Yield reduction ratio (**YR)**.

Estimates of the correlation coefficients between each nitrogen selection index and grain yield under normal (YP) and low (YS) nitrogen.

Table 7 displays estimates of the correlation coefficients between grain yield under normal (YP) and low (YS) nitrogen as well as each nitrogen selection index to identify the best tolerance criterion for choosing the superior genotypes under low nitrogen fertilization. All indices showed highly significant positive associations with grain yield under normal nitrogen conditions (YP): TOL (0.721), MP (0.911), HM (0.800), GMP (0.866), and STI (0.786). Additionally, grain yield under nitrogen stress conditions (YS) had highly significant positive correlations with all indices, with the exception of the tolerance index, which had values of STI (0.838), MP (0.815), HM (0.921), GMP (0.874), and TOL (-0.236). The measure with a relatively high correlation with grain yield under stress and non-stress circumstances is the most suitable indicator for identifying genotypes with stress tolerance, according to Farshadfar et al. (2001). As a result, under both circumstances, genotypes with high yield can be identified using STI, MP, HM, GMP, and STI as the superior ones. Additionally, a genotype might be deemed nitrogen tolerant if it has low SSI under stress conditions and high GMP and STI values. Combining various indices is therefore believed to yield valuable information for identifying and choosing the genotypes most suitable for stress and non-stress situations. These findings were consistent with those published **by Sio-Se Mardeh et al. (2006), Talebi et al. (2009), EL Shal, M. H. et al. (2022) and Abd El-Aty et al (2024).**

Table 7. **coefficients of correlations among grain yield under normal (YP) and low (YS) nitrogen and each of nitrogen selection indices.**

	YP	YS	TOL	MP	HM	SSI	GMP	STI	YI	YSI	YR
YP	1	0.504*	0.721**	0.911**	0.800**	0.462	0.860**	0.786**	0.499*	-0.453	0.453
YS		1	-0.236	0.815**	0.921**	-.530-*	0.874**	0.838**	1.000**	0.538*	-0.538
TOL			1	.371	.161	.945**	.267	.212	-.242	-.942-**	0.942**
MP				1	0.976**	.057	0.994**	0.928**	0.811**	-.048	.048
HM					1	-.159	0.994**	0.942**	0.918**	.167	-.167
SSI						1	-.052	-.076	-.536-*	-.999-**	0.999**
GMP							1	.940**	0.870**	.061	-.061
STI								1	0.836**	.077	-.077
YI									1	0.543*	-.543-*
YSI										1	-1.000-**
YR											1

* **and** ** significant and highly significant at 0.05 and 0.01, respectively.

Grain yield normal N (239 N/ha.) is represented by Yp, while grain yield under low N conditions (60 N/ha) is represented by Ys. Geometric mean productivity (GMP), mean productivity (MP), tolerance index (TOL), harmonic mean (HM), stress susceptible index (SSI), stress tolerance index (STI), yield stability index (YSI), yield stability index (YSI), and yield reduction ratio (YR).

Means and reduction percentage relative to normal nitrogen (179 N/ fed) for all the studied traits under eight environments.

Means and reduction percentage relative to normal nitrogen (N3) for all the studied traits under different eight environmental conditions (two seasons and four nitrogen levels; Y1N1, Y1N2, Y1N3, Y1N4, Y2N1, Y2N2, Y2N3, Y2N4) are presented in table 8. Severe nitrogen fertilization (Y1N1 and Y2N1) reduced studied traits.

The nitrogen stress (N1) shortened the duration to heading (in days) by an average of 11.76 % and 9.47 % in the 1st and the 2nd seasons respectively. And, by an average of 5.88 % and 4.21 % for (N). While, there was a delay in days to heading by an average of 2.85 % and 4.21 % under (N4), in the 1st and the 2nd seasons respectively, compared with the (N3) (the normal).

Table 8. Means and reduction percentage relative to normal nitrogen (70 kg N/ fed) for all the studied traits under eight environments.

Env.	**Treat**	**Days to Heading**		**Plant Height**		**No. of Spikes/m^2**		**No. of kernels/spike**		**1000 kernel weight**		**Grain Yield (ton/ha)**	
		Mean	**Red. %**	**Mean**	**Red. %**	**Mean**	**Red. %**	**Mean**	**Red. %**	**Mean**	**Red. %**	**Mean**	**Red. %**
E1	Y1N1 25kg.N	90	11.76	109	5.21	368	11.17	44	20.20	44.23	10.86	5.53	28.51
E2	Y1N2 50kg.N	96	5.88	113	1.74	409	6.83	51	7.27	48.09	2.89	6.83	11.73
E3	Y1N3 70kg.N	102	---	115	--	439		55		49.52		7.56	2.25
E4	Y1N4 100kg.N	105	-2.85	118	2.6	449	2.28	57	3.50	50.62	2.27	7.74	31.01
E5	Y2N1 25kg.N	86	9.47	105	7.89	370	16.28	44	21.42	43.69	11.86	5.20	2.25
E6	Y2N2 50kg.N	91	4.21	110	3.51	411	7.01	51	8.92	47.34	4.50	5.81	31.01
E7	Y2N3 70kg.N	95		114		442	3.39	56		49.57		7.03	22.84
E8	Y2N4 100kg.N	99	-4.21	117	2.63	457		59	5.08	50.50	1.84	7.24	6.73

For plant height, nitrogen deficiency stress reduced plant height, the reduction percentages were 5.21 % and 7.89 % in the 1st and 2nd seasons under (N1) and 1.744 % in the 1st and 3.51 % in the 2nd season for (N2). While there was an average increase of 2.60 % and 2.63 % under(n4), in the 1st, 2nd seasons, respectively, compared with the (N3) (the normal). The decrease percentage for no. of spikes /m^2 in the 1st season by an average of 11.17 % and 16.28 % in the 2nd season, and by an average of 6.83 % and 7.01 % for (N2). Also, there was an average increase of 2.28 % and 3.39 % under (N4), in the 1st, 2nd seasons, respectively, compared with the (N3) (normal).

For no. of kernels/ spike there was a decrease in its number with an average of 20.00 % and 21.43 % in the 1st and the 2nd seasons under (N1), respectively. And by an average of 7.27 % and 8.92 % for (N2) and 3.50 % and 3.39 % in the 1st and 2nd seasons under (N4) respectively, compared with the (N3) (the normal).

Percentages of decrease for 1000-kernel weight were 10.68% and 11.86 % in the 1st and the 2nd seasons under (N1) and 2.89 % and 4.50 % in the 1st and 2nd seasons for (N2) and 2.12 % and 1.84 % in the 1st and 2nd seasons, under (N4) respectively, compared with the (N3) (the normal).

Grain yield decreased in the 1st season by an average of 28.51% and 2.25 % in the 2nd season for (N1) and by an average of 11.73 % and 31.01 % for (N2). Meanwhile, there was an average increase of 2.28 % and 3.39 % under (N4), in the 1st, and 2nd seasons, respectively, compared with the (N3) (the normal).

Generally, grain yield and other studied traits were severely diminished at the first (N=25kg N) and the second (N= 50kg N) nitrogen fertilizer rates, while there was a slight increase under fourth (N= 100N) nitrogen fertilizer rate for all the studied traits when compared with the third rate (N= 75 N) (normal). Similar results were reported **by Hamam and Khaled (2009)** and **Ali, (2017).**

The GGE-biplot analysis provides information about the effects of genotypes, environments and their interaction **kaya *et al* (2006).** Relationships between the 13 genotypes and the eight environments for grain yield according GGE-biplot method are presented in Fig. 1: crop production varies according to genotype-by-environment (G×E) interaction across environments. Genotypes located near to the origin of the GGE biplot indicate its low contribution to G × E interaction referring that these genotypes were stable. Accordingly, genotypes, Misr 3, G171, G5 and G6 genotypes were positioned to the right of the midpoint of the perpendicular line associated with high mean of the studied traits and vice versa for genotypes in the left side; G1, Sakha95 and Misr1. Variable crop production is mainly due to variation in the environmental circumstances, soil features, and genotypes' inherent potential (**Yan and Hunt 2001; Yan et al., 2002; Al-Naggar et al., 2020** and **Hussein et al.,2022.**

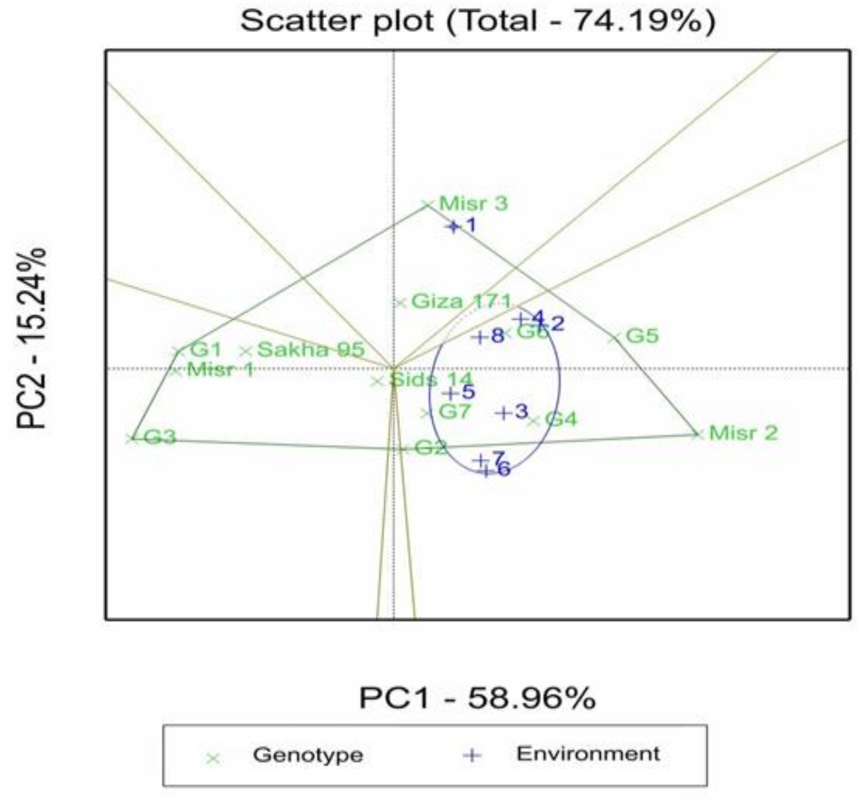

Fig. 1. Relationships between the 13; genotypes and the eight environments,1 = Y1N1, 2 = Y1N2, 3 = Y1N3, 4 = Y1N4, 5 = Y2N1, 6 = Y2N2, 7 = Y2N3 and 8 = Y2N4 for grain yield and Nitrogen levels; N1= 25kg, N2=50kg, N3=75kg and N4=100 kg according GGE-biplot method.

4. Discussion

All of the examined traits showed highly significant differences, suggesting that the bread wheat genotypes under study responded differently to the nitrogen shortage. These findings are comparable to those of **Belete et al. (2018)** and **Hussein et al. (2022)**

According to **Ullah et al. (2018)** and **Tyagi et al. (2020)**, increased nitrogen levels aid in cell division and aid in the uptake of other soil nutrients, resulting in longer plant shoots and more spikes m-2. This is because wheat plants can produce more tillers, spikes, and kernel spikes.

All the studied traits were significantly impacted by the nitrogen levels. These findings suggest that nitrogen plays a significant part in kernel grain growth and development. These findings are comparable to those published by **Belete et al. (2018) and Hussein et al. (2022).** Sakha 95 and G1 had the earliest heading and maturity dates under both conditions, according to the data in Table 7. In contrast, Misr1 and G3 displayed the shortest plants in both scenarios. As nitrogen levels rose, the plants took longer to mature, and vice versa. **Kutman et al. (2011) and Ullah et al. (2018)** both reported similar findings. Under both circumstances, Misr 2 outperformed genotypes in terms of the number of kernels per spike, 1000-kernel weight, and grain yield ton/ha. Grain yield and its constituents were higher in both seasons when nitrogen fertilizer levels were raised to 100 kg N fed-1 as opposed to when nitrogen levels were low. The findings published by **Ullah et al. (2018), Tyagi et al. (2020) and Hussein et al. (2022),** corroborate these findings.

The development of high-yielding wheat varieties appropriate for low nitrogen stress requires the identification of donor parents with high yields under low nitrogen (LN) circumstances. Table 6 shows the estimated selection indices for grain yield (ton/ha.) of 13 wheat genotypes for the two seasons under normal (Yp) and low nitrogen (Ys) circumstances. G5, G6, Misr 3, and Giza 171 were the preferred low nitrogen tolerant genotypes for SSI and YSI, respectively. In order to find tolerant genotypes, SSI seemed to be an appropriate selection index. However, the yield ratio of each variety under stressed versus non-stressed conditions, as opposed to the proportion in the total varieties, was used to evaluate SSI. G6 obtained the greatest yield index (YI) value, followed by Misr 3 and G5, in that order. These outcomes concur with the findings of **Abd El-Aty et al. (2016), Fouad et al. (2018)** and **Abd El-Aty et al. (2024)**

Identifying donor parents with high yields under low nitrogen (LN) conditions is necessary for developing high-yielding wheat varieties suitable for low nitrogen stress. Selection indices were estimated for grain yield (ton/ha.) of 13 wheat genotypes under normal (Yp) and low nitrogen (Ys) conditions over the two seasons, Table 6. For SSI and YSI, the desirable low nitrogen tolerant genotypes were G5, G6, Misr 3 and Giza 171 respectively. SSI appeared to be a suitable selection index to identify tolerant genotypes. However, SSI was evaluated based on yield ratio of each variety in stressed to non-stressed conditions as compared with the proportion in the total varieties. According to yield index (YI), G6 recorded the highest value of YI followed by Misr 3 and G5, respectively. These findings are consistent with those obtained by **Abd El-Aty *et al* (2016). Fouad *et al* (2018) and Abd El-Aty *et al* (2024)**.

Correlation coefficients among grain yield under normal (YP) and low (YS) nitrogen and each of nitrogen selection indices to determine the most desirable tolerance criteria to select the better genotypes under low nitrogen fertilization were estimated.

The measure that has a relatively high correlation with grain output under stress and non-tress circumstances is the most suitable index for identifying genotypes of stress tolerance, accordi ng to Farshadfar et al (2001)Additionally, a genotyp e that exhibits low SSI under stress and high GMP a nd STI values might be regarded as nitrogen tolerant. These findings were consistent with those published by **Sio Mardeh et al. (2006) Talebi et al. (2009)an dEL Shal, M. H. et al. (2022)** For each of the eight conditions under study, the percentage reduction fro m normal nitrogen (70 kg N/fed) was calculated. when compared to the third rate (N=75 N) (normal), grain yield and other traits were significantly reduced at the first (N=25 kg N) and second (N=50 kg N) nit rogen fertilizer rates. However, all the traits under stu dy showed a little rise under the fourth nitrogen fertil izer rate (N=100 N) **Hamam and Khaled (2009), Ali (2017) and Marko et al. (2021)**, all achieved comparable outcomes.

According to **Farshadfar *et al*. 2001** the best appropriate index to identify stress tolerance genotypes is the index that has a relatively high correlation with grain yield under stress and non-stress conditions. Therefore, STI, MP, HM, GMP, and STI can be detected as the better ones, used to identify genotypes with high yield under both conditions. Also genotype with high value of GMP and STI, and low value of SSI under stress condition can be considered as nitrogen tolerant. These results were in harmony with those reported by; **Sio-Se Mardeh *et al*., 2006; Talebi et al.,2009) and EL Shal , *et al*. (2022) .**

Reduction percentage relative to normal nitrogen (70 kg N/ fed) for all the studied traits under eight environments were estimated. Grain yield and other traits were severely diminished at the first (N=25kg N) and the second nitrogen fertilizer rates (N= 50kg N), while there was a slight increase under the fourth nitrogen fertilizer rate (N= 100N) for all the studied traits when compared with the third rate (N= 75 N) (normal). Similar results were obtained **by Hamam and Khaled (2009), Ali, (2017) and. Marko *et al* (2021).**

5. Conclusion:

The genotypes that were shown to be the most tolerant to low nitrogen fertilization were Misr 3, G4, G5, G6, Misr 2, and Misr 3. The strongest indicators of yield under low nitrogen conditions were stress tolerance index and productivity, geometric productivity, and harmonic means; these might be employed as selection tools for genotype screening.

Conflicts of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest

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