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Research Article

Screening Wheat Genotypes for Growth and Yield-Related Traits Under Normal and Salt Stress Conditions

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ABSTRACT

Salinity stress is a major abiotic factor limiting wheat (Triticum aestivum L.) growth and productivity worldwide. A pot experiment was conducted at the Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad, using a completely randomized design (CRD) with three replications. The wheat genotypes were evaluated under normal and saline (8 dSm-1) conditions for key agronomic traits. Analysis of variance (ANOVA) revealed significant variations among genotypes, treatments, and their interactions, indicating that salinity stress significantly influenced all measured traits. Principal Component Analysis (PCA) identified plant height, peduncle length, flag leaf area, and grain yield per plant as the most influential traits under stress conditions. Among the tested genotypes, Markaz-19, Ghazi-19, and Subhani-21 demonstrated superior performance under salinity stress, suggesting their potential as salt-tolerant candidates for future breeding programs.

Keywords: Salinity stress, wheat, CRD, PCA, tolerance.

INTRODUCTION

In recent years, the frequency and intensity of certain stresses have increased due to climate change, thereby affecting the quality and output of agriculture (Malhi *et al.*, 2021). Wheat, rice, and maize are among the important staple commodities globally, as they provide substantial daily protein and calorie intake. Wheat is the most significant cereal among these essential cereals, as it is the primary staple food crop worldwide and has been domesticated. Even though it occupies 38.8% of arable land, its production remains low. It is possible that it will continue to decline due to the abiotic stressors induced by climate change (Corwin, 2021). Several climate models predict that the yield of wheat will decrease by 6% in the presence of challenging conditions (Asseng *et al.*, 2019).

In response to human activities and climate change, salt stress is rapidly increasing, affecting 20% of the world's arable land (Corwin, 2021). The effects of environmental factors like salt are responsible for around half of output losses. Moreover, global food security is threatened by the ongoing expansion of the human population. Wheat is a fundamental sustenance for approximately 36% of the global population. Wheat growth and production is diminished by salinity (Saddiq *et al.*,

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2021). Salinity stress induces ion toxicity by increasing Na+ absorption and decreasing the Na+/K+ ratio in plant roots. Additionally, it disrupts the proper functioning of plants by disrupting the assimilation and movement of other essential ions in target cells (Rani *et al.*, 2019).

Salinity has a negative impact on agricultural output by reducing seedling establishment, stunting plant development, and altering reproductive development. Additionally, salt hinders crop development and output by altering cell ultrastructure, which disrupts photosynthetic apparatus and damages the membrane (Miransari and Smith, 2019). The persistence of plants in salinity is a polygenic trait that is influenced by a variety of genetic factors (Hasanuzzaman *et al.*, 2017). Wheat is more susceptible to salinity than other crops, which can result in the stunting of plant development and growth, a decrease in output, or, in severe cases, the collapse of the crop. Understanding the physiological underpinnings of plant stress tolerance can be beneficial in the development of breeding strategies and selection criteria (Marone *et al.*, 2021). Variations in the morphological characteristics of the leaves and stems of wheat genotypes are critical for salinity stress adaptation. The primary research on the physiological changes that occur because of specific conditions during leaf senescence has concentrated on the re-absorption of mineral nutrients, protein degradation, and the loss of photosynthetic pigments (Saddiq *et al.*, 2021). Additionally, plants frequently accumulate secondary metabolites, such as anthocyanins, flavones, phenolics, and specific phenolic acids, when they are stressed by numerous elicitors or signal molecules.

Morphological characteristics that are associated with stress tolerance can be identified and utilized as a selection criterion (Pour-Aboughadareh *et al.*, 2021). Additionally, the anthesis and grain filling phases have been identified as the primary constraints on global wheat production, as they are highly susceptible to salt stress (Zhu *et al.*, 2016). An understanding of the impact of salt stress on wheat yield enhancement, as well as the implementation of mitigating techniques, is essential for the preservation of output and the establishment of long-term food security. The objective of the current study was to identify some morphological traits involved in tolerance of salt stress.

MATERIALS AND METHODS

The current study was conducted in the wire-house. The following strategy was taken.

Collection of Germplasm

Experimental germplasm consisting of ten wheat genotypes was collected from the wheat research institute. The genotypes names along with their codes are represented in table 1.

Table 1. Detail of germplasm used in the experiment.

Codes	Genotype
G1	Anaj-17
G2	Dilkash-20
G3	Akbar-19
G4	Subhani-21
G5	Arooj-2022
G6	Ghazi-19
G7	Markaz-19
G8	Barani-17
G9	Ujala 2016
G10	Galaxy 2013

Experimental Design

Fertile soil from the experimental fields was collected. Following air drying, the soil was pulverized and passed through a 4 mm garden sieve. The air-dried dirt was collected in pots with bottom drain holes. Three replicas of the pots were set up in CRD.

Preparation of Saline Soil

An artificial saline soil treatment was created by mixing salt and water. The amount of salt needed to make the saline soil treatment (8dSm-1) was determined using the method outlined by (Rowell, 1994).

Observations

The following agronomic observations were recorded at maturity:

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Days to Heading
Plant Height (cm)
Number of Tillers per Plant
Flag Leaf Area (cm)
Spike Lenght (cm)
Peduncle Length (cm)
Number of Grains per Spike
Spikelet per Spike
1000 Grain Weight (g)
Grain Yield per Plant (g)

Statistical Analysis

Data was subjected to ANOVA using Statistix 8.1 statistical package to evaluate the significance. Mean performance graphs under normal and saline environment were made using Microsoft Excel. PCA analysis was applied using XLSTAT.

RESULTS

Assessment of Genetic Variability and Mean Performance Analysis of Wheat Genotypes Under Salinity Stress

Plant breeding is an intentional and ongoing effort to develop new plant varieties (Louwaars, 2018). For the development of new and better varieties, it integrates desired traits with genetic variation among individuals within a plant species (Mueller and Flachs, 2022). In plant breeding, genetic variability is essential, and fresh variation is needed to add new features to breeding programs (Kochupillai and Kochupillai, 2016). Results of ANOVA showed that all the genotypes were highly significant for all the traits under study (table 2). Treatments were also highly significant, which showed that salinity stress significantly influenced all the traits under study. The interaction effects of genotypes and treatment also showed significant results which indicated that the performance of all the genotypes was also impacted by salinity stress.

Table 2. Mean sum of squares of yield and yield related traits under normal and salinity stress.

Source	DF	DH	PH	NT/P	FLA	SL	PL	NG/S	NS/S	GW	GY/P
Treatment (t)	1	49.14**	40.83**	0.6**	18.15**	3.60**	80.04**	58.80**	31.53**	75.93**	4.37**
Genotype (g)	9	38.93**	700.3**	45.48**	178.42**	2.19**	143.1**	516.6**	10.98**	60.08**	184.1**
t × g	9	0.68*	0.61*	0.01*	0.09*	0.13*	0.60*	1.08*	0.28*	0.43*	0.04*
Error	40	1.62	2.25	0.01	0.49	0.09	4	4	0.81	1.69	0.01
Total	59										

Salinity affects crop plant development and output because excessive concentrations of salt and chloride ions harm plants and decrease soil moisture availability (Hailu and Mehari, 2021; Safdar *et al.*, 2019). All of wheat's phenological stages are triggered by salinity stress, which also lowers the number of fertile tillers and spikelets per spike (Grieve *et al.*, 2001). It also has a detrimental effect on grain production (Kamkar *et al.*, 2004). For instance, salt stress can alter the number of grains per spike, 1,000-grain weight, and seed production, reducing wheat yields by up to 45% in sensitive varieties (Hasan *et al.*, 2015). For days to heading, Ujala 2016 showed maximum values under normal (108.06) and saline conditions (107.06) while Barani-17 showed lowest values under both conditions (101 under normal conditions and 98.4 under saline conditions) as presented in figure 1. For plant height, Dilkash-20 showed maximum values (121.66cm) while Arooj-2022 showed minimum values (85.76cm) under salinity (figure 2). Subhani-21 showed maximum number of tillers per plant (12.2) followed by Dilkash-20 (12.13) and Galaxy 2013 (10.05) under salt stress (figure 3). Ghazi-19 showed maximum mean performance for flag leaf area followed by Akbar-19 under both conditions (figure 4). Markaz-19 showed maximum spike length under saline conditions (14.1 cm) followed by Galaxy 2013 (13.93cm) and Ujala 2016 (13.53cm) (figure 5). Dilkash-20 also showed maximum peduncle length (49.66cm) under salt stress conditions followed by Ghazi-19 (42.9cm) (figure 6). Figure 7 shows that Markaz-19 showed the maximum number of grains per spike under salt stress (65.12) followed by Galaxy 2013 (64.86) and Anaj-17 (63.63). Salt stress also significantly reduced the number of spikelets per spike in all genotypes as presented in figure 8. Salt stress also reduced the 1000 grain weight of all genotypes. Ghazi-19 showed maximum grain weight (48.62g) under saline stress (figure 9). Markaz-19 showed maximum grain yield per plant (21.19g) followed by Ghazi-19 (21.05g) and Subhani-21 (20.86g) as showed in figure 10.

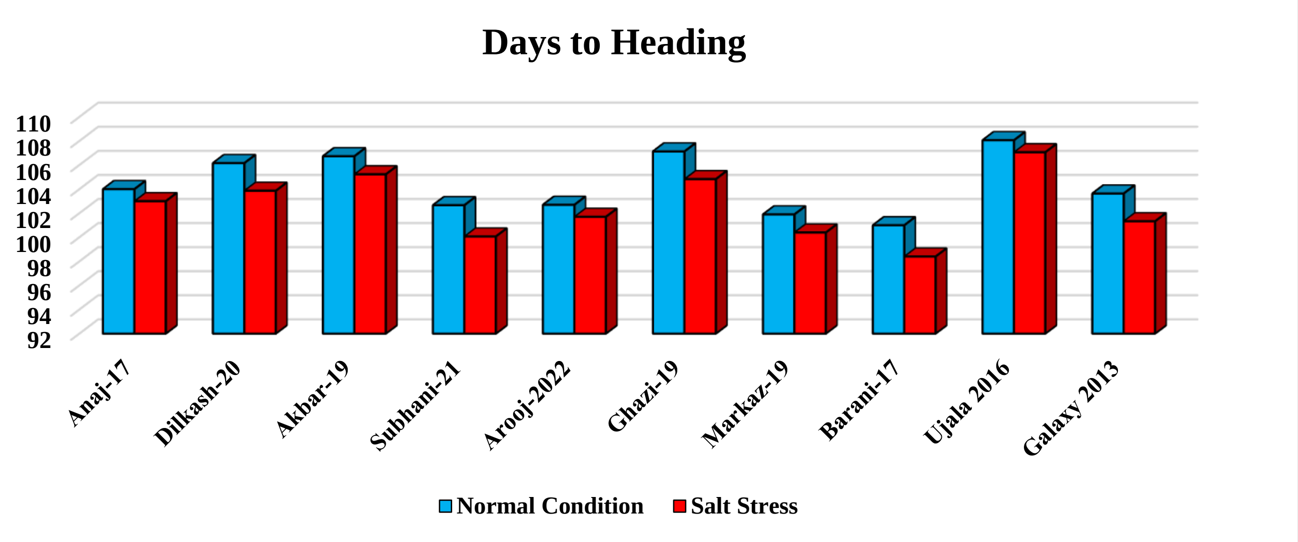

Figure 1. Impact of salt stress on days to heading of ten wheat genotypes.

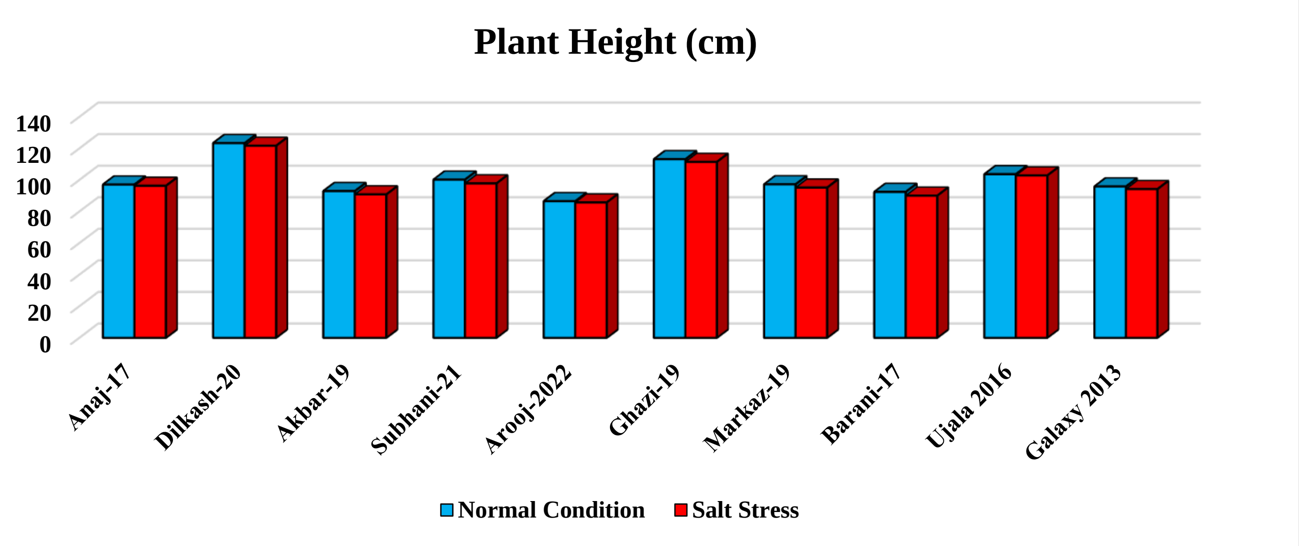

Figure 2. Impact of salt stress on plant height of ten wheat genotypes.

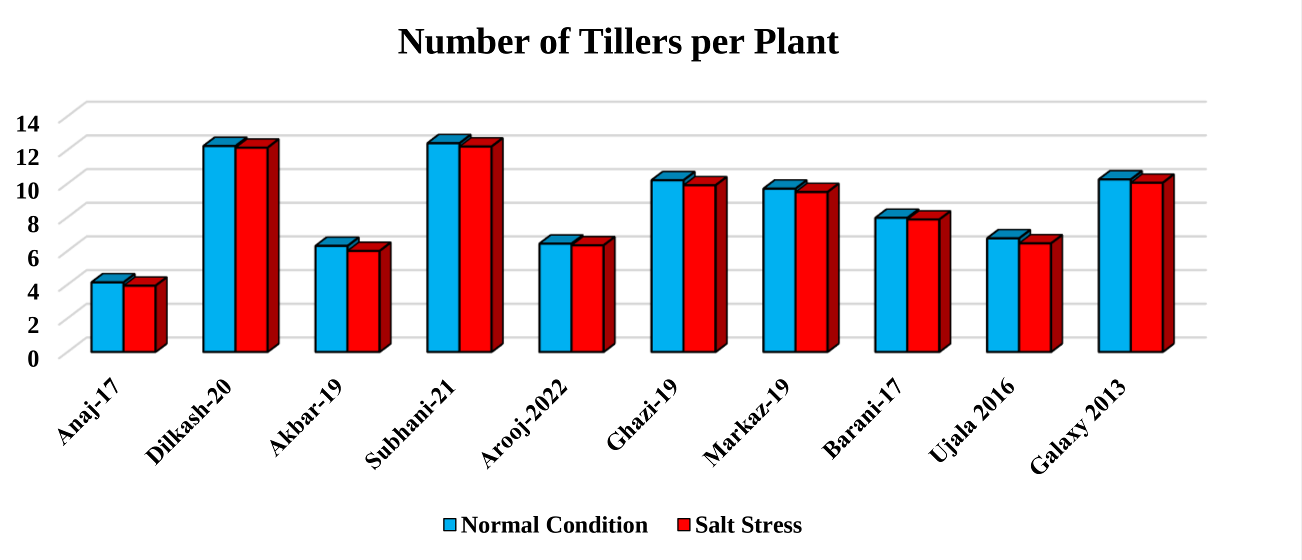

Figure 3. Impact of salt stress on number of tillers per plant of ten wheat genotypes.

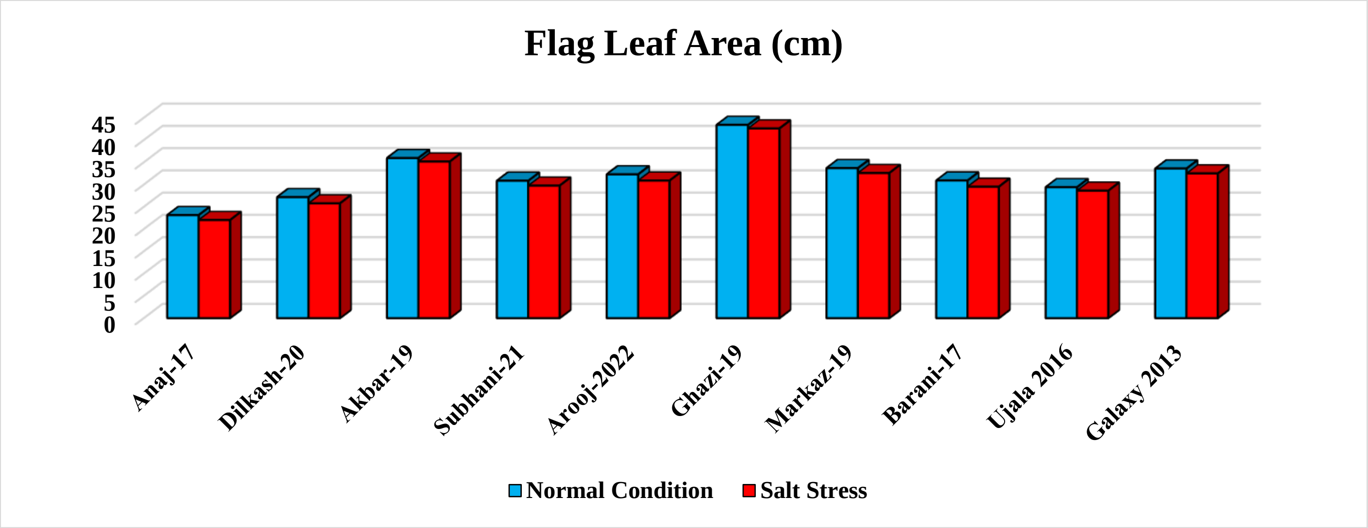

Figure 4. Impact of salt stress on flag leaf area of ten wheat genotypes.

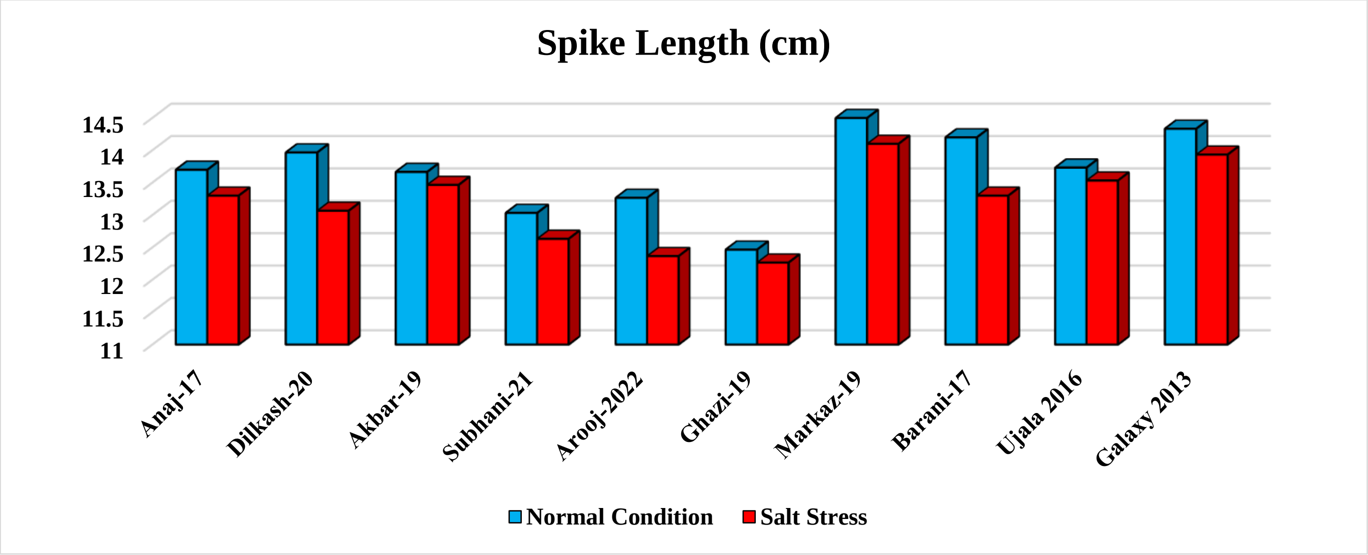

Figure 5. Impact of salt stress on spike length of ten wheat genotypes.

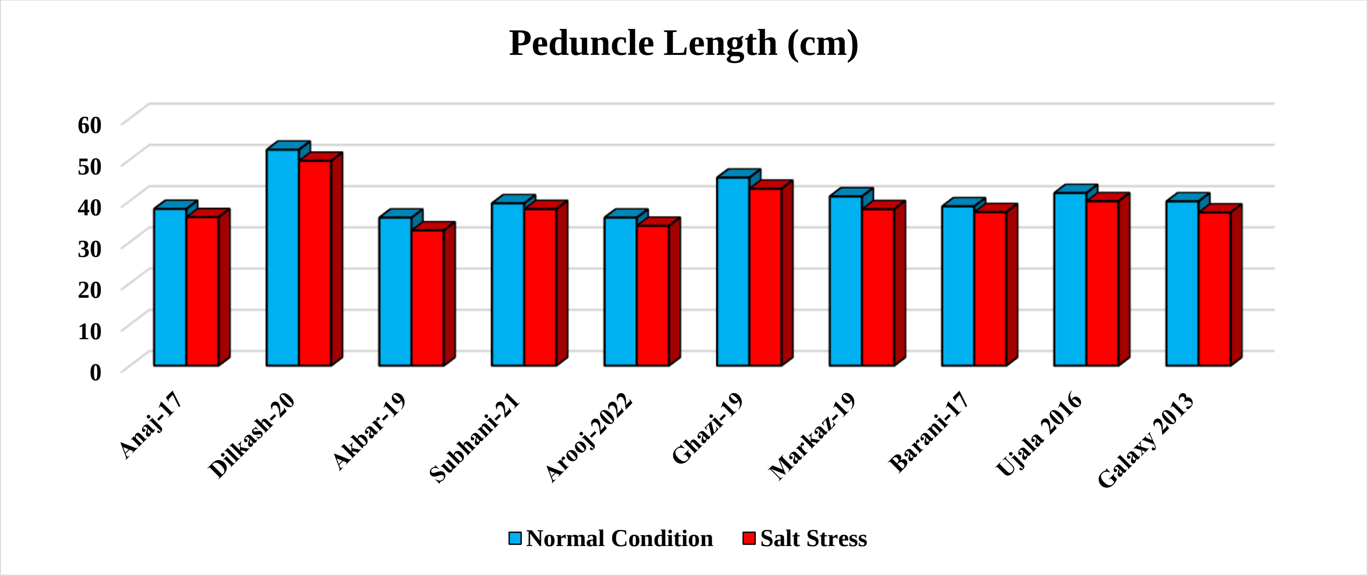

Figure 6. Impact of salt stress on peduncle length of ten wheat genotypes.

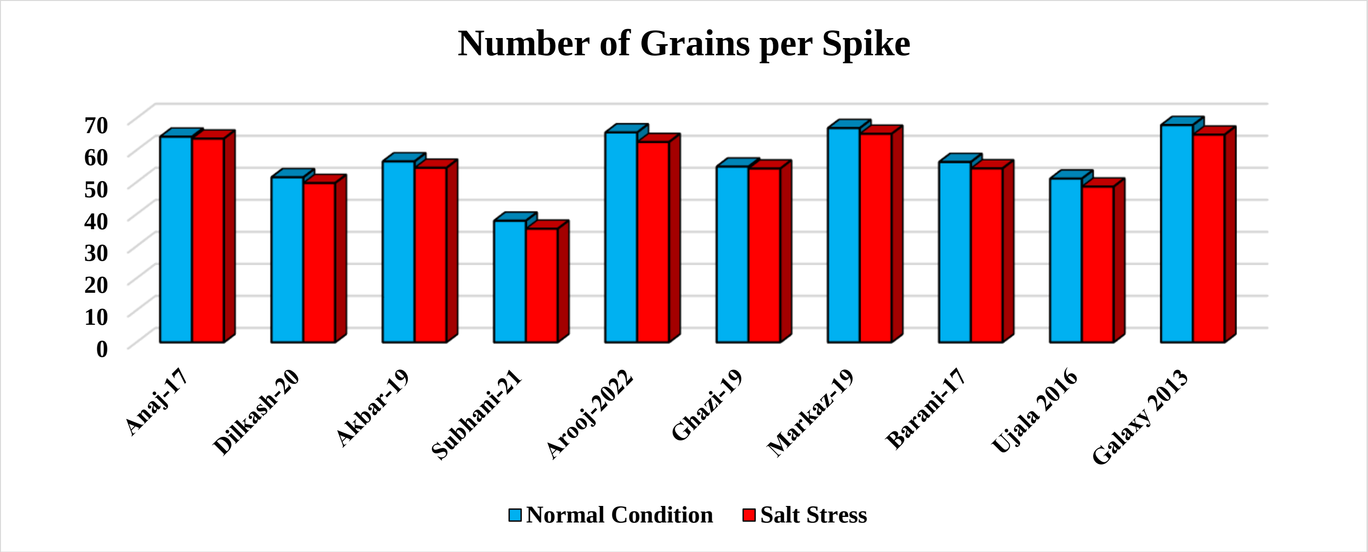

Figure 7. Impact of salt stress on number of grains per spike of ten wheat genotypes.

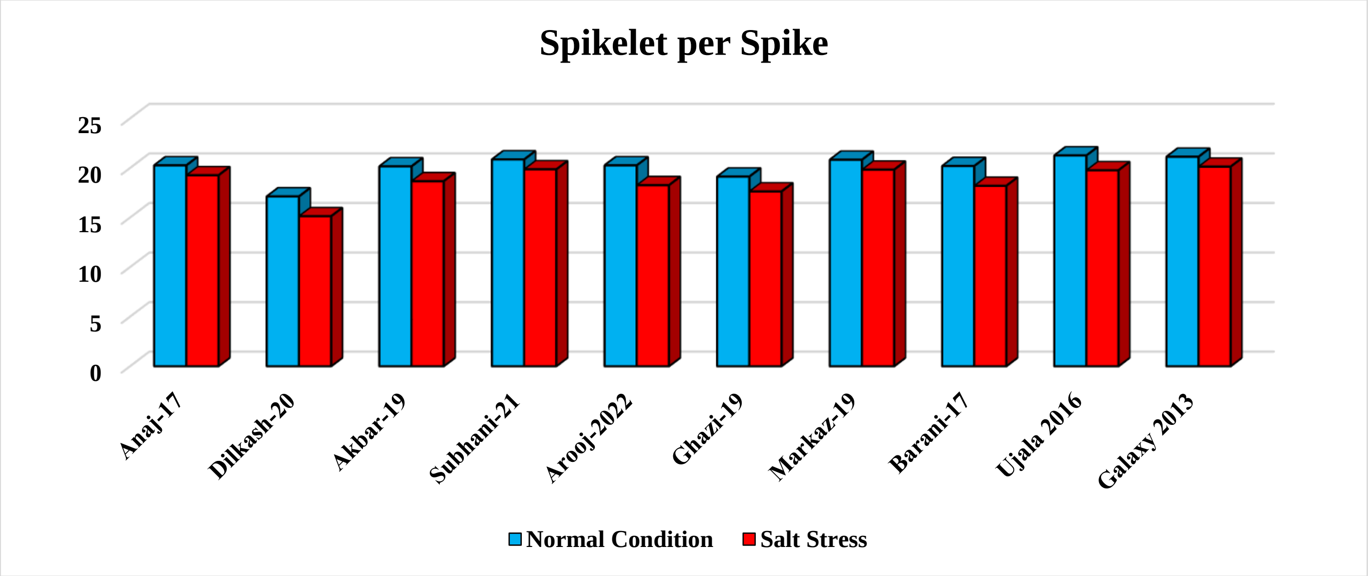

Figure 8. Impact of salt stress on spikelets per spike of ten wheat genotypes.

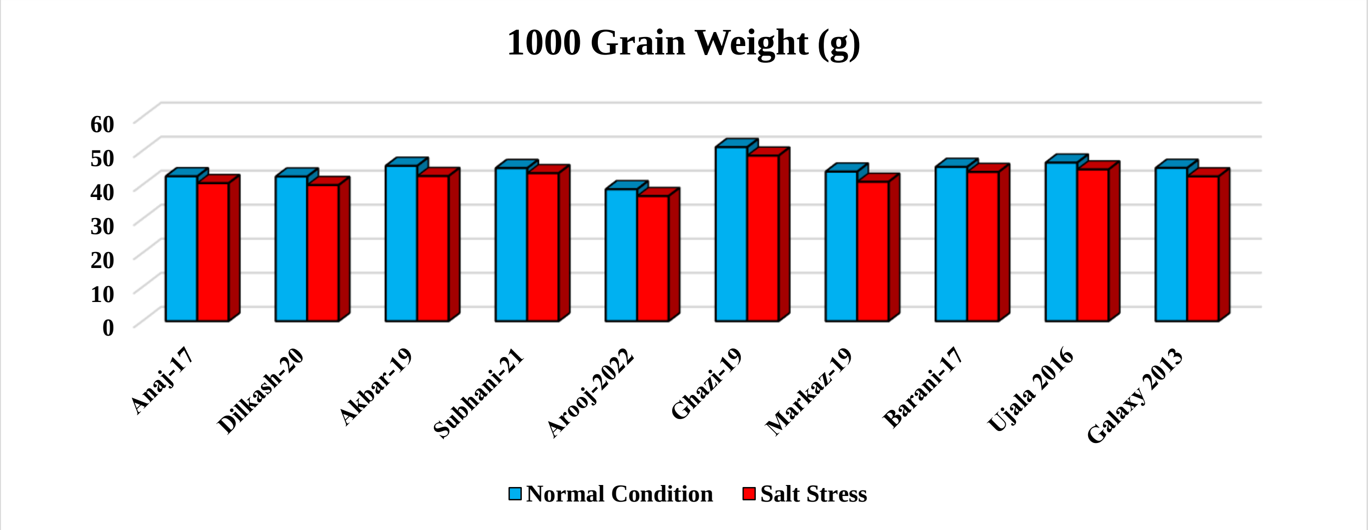

Figure 9. Impact of salt stress on 1000 grain weight of ten wheat genotypes.

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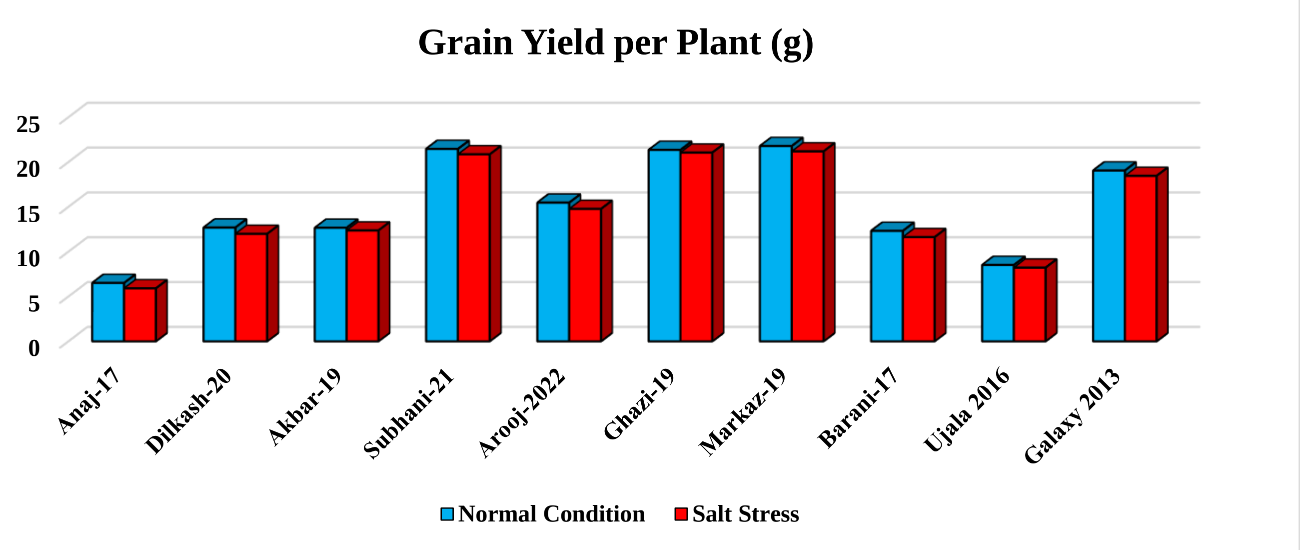

Figure 10. Impact of salt stress on grain yield per plant of ten wheat genotypes.

Principle Component Analysis Under Normal and Saline Conditions

Principal component analysis (PCA) is a multivariate analysis technique that employs a restricted number of independent components to ascertain the relationship between multiple variables (Abdi and Williams, 2010; Mishra *et al.*, 2017). This statistical method is used in salinity research to assess how a physiological or morphological trait influences the yield variable (Zulfiqar *et al.*, 2024). Several studies have used PCA to determine variability and whether a certain attribute or component contributes to yield (Rana *et al.*, 2015). To demonstrate the genotype x environment relationship, a biplot can be generated using the PCA components. A two-dimensional visualization of genotypes to environment variance is constructed using the first two PCA components in a biplot (Abdi and Williams, 2010). Under normal conditions, total variance was divided into 9 components. The first 4 PCs out of a total of 14 principal components displayed >1 eigen values PC1, PC2, PC3 and PC4 had a share of 38.47%, 22.108%, 16.618% and 10.20% to total variability respectively (Table 3).

Table 3. Eigen values and cumulative variability of PCs under normal conditions.

	F1	F2	F3	F4	F5	F6	F7	F8	F9
Eigenvalue	3.848	2.211	1.662	1.021	0.741	0.273	0.191	0.032	0.022
Variability (%)	38.479	22.108	16.618	10.207	7.413	2.730	1.907	0.320	0.219
Cumulative %	38.479	60.587	77.205	87.412	94.824	97.554	99.461	99.781	100.000

These 4 PCs imparted 87.41% to total variability among studied genotypes (figure 11). Rest of the PCs had <1 eigen value therefore should not be discussed further. While under saline conditions PC1, 2, 3 and 4 had a share of 35%, 22.36%, 15.17% and 11% to total variability respectively (Table 6). These 4 PCs imparted 83.52% total variability among the genotypes studied (figure 12). Under normal and saline conditions, PC1 was mainly related to plant height, peduncle length, number of tillers per plant and number of spikelets per spike while PC-II revealed higher and positive values for flag leaf area and grain yield per plant (table 4 and 7). The genotypes having higher values for PC-I included Ghazi-19, Dilkash-20, Arooj-2022 and Anaj-17 (table 5 and 8). To determine genetic diversity, measurement is done of the distance between the plot's point and the origin. The genotypes that was farthest from the origin is more variable than the others. In our study, Dilkash-20, Ghazi-19, Anaj-17 and Arooj-202 were farthest from the origin under both conditions (figure 13 and 14). The cosine angle of vectors represents the relationship between each character. There was a negative association between characters with cosine angles more than 90 degrees and a positive correlation between characters with angles less than 90 degrees. Flag leaf area showed a positive correlation with grain yield per plant. Peduncle length showed positive correlation with plant height. While days to heading showed negative correlation with peduncle length and plant height. In our study, the most effective traits are those with the longest arrows, such as grain yield per plant, flag leaf area and peduncle length. Genotypes Galaxy 2013 and Markaz-19 cluster together,

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meaning they have similar characteristics. Dilkash-20 and Ghazi-19 seem to be distinct from other genotypes, meaning they have unique traits.

Table 4. Contribution of traits to the PCs under normal conditions.

	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**
DH	7.92	2.04	28.25	4.85	1.17	38.45	8.47	5.04	0.00
PH	21.23	6.54	0.18	0.72	0.70	0.35	10.13	1.10	9.36
NT/P	12.77	2.02	23.71	2.84	2.11	3.85	1.85	5.66	44.39
FLA	3.93	28.13	1.19	13.63	3.37	0.90	17.97	19.58	0.23
SL	5.23	5.42	15.05	11.92	35.91	0.21	20.43	0.00	5.71
PL	18.32	7.68	3.72	3.28	0.49	0.24	6.67	41.07	0.20
NG/S	8.38	0.01	1.36	57.31	4.75	1.19	14.81	4.20	7.94
NS/S	10.79	12.07	1.40	2.26	25.52	19.56	13.30	10.99	0.60
GW	8.57	9.74	9.23	3.07	24.60	27.72	5.13	7.16	0.47
GY/P	2.86	26.35	15.92	0.12	1.38	7.52	1.24	5.20	31.11

Table 5. Contribution of genotypes to the PCs under normal observations.

	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**
Anaj-17	12.20	16.87	6.66	0.13	0.95	2.84	30.70	17.44	2.20
Dilkash-20	27.41	44.54	11.46	0.18	1.77	0.30	4.15	0.08	0.10
Akbar-19	1.02	1.07	15.50	1.28	0.05is	0.01	50.21	15.34	5.53
Subhani-21	2.79	9.23	3.36	67.80	0.58	1.32	0.34	4.16	0.41
Arooj-2022	13.43	0.31	0.13	0.36	50.49	8.13	0.50	13.87	2.78
Ghazi-19	34.73	17.16	9.23	7.83	6.58	4.78	9.41	0.24	0.05
Markaz-19	2.10	3.66	21.46	10.00	3.28	0.92	1.20	2.57	44.82
Barani-17	4.50	0.00	2.05	0.80	3.34	61.55	2.77	9.46	5.53
Ujala 2016	0.07	3.37	22.86	0.55	25.27	12.58	0.31	24.83	0.16
Galaxy 2013	1.76	3.80	7.28	11.07	7.69	7.56	0.42	12.01	38.40

Table 6. Eigen values and cumulative variability of PCs under salt stress.

	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**
Eigenvalue	3.50	2.24	1.52	1.10	0.98	0.39	0.23	0.02	0.02
Variability (%)	35.00	22.36	15.17	11.00	9.85	3.94	2.28	0.24	0.18
Cumulative %	35.00	57.35	72.53	83.52	93.37	97.31	99.59	99.82	100.00

Table 7. Contribution of traits in PCs under salt stress.

	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**
DH	1.98	8.58	37.85	1.37	0.62	36.11	0.25	2.16	1.51
PH	22.28	5.55	0.06	5.99	0.17	0.29	8.69	25.28	6.10
NT/P	15.61	6.70	15.56	2.64	1.07	3.55	1.45	27.35	26.03
FLA	2.73	22.46	13.93	0.12	16.33	0.00	11.93	2.13	5.81
SL	5.60	0.05	0.64	66.14	1.41	0.00	22.57	2.78	0.81
PL	21.62	4.77	2.37	6.33	0.39	1.04	5.56	10.86	45.52
NG/S	9.49	0.08	0.06	9.34	52.14	3.08	15.36	3.49	6.36
NS/S	11.21	10.92	2.26	4.79	17.78	7.71	30.53	3.95	1.86
GW	6.35	7.21	23.97	3.05	6.65	38.09	1.36	0.00	4.27
GY/P	3.13	33.69	3.32	0.23	3.45	10.12	2.30	22.00	1.73

Table 8. Contribution of genotypes in PCs under salt stress.

	F1	F2	F3	F4	F5	F6	F7	F8	F9
Anaj-17	14.09	20.63	0.41	0.04	0.44	3.87	26.61	14.65	9.27
Dilkash-20	33.82	30.57	16.31	1.49	2.21	0.93	3.93	0.00	0.75
Akbar-19	3.86	0.01	16.08	0.44	0.32	3.36	48.41	8.37	9.15
Subhani-21	4.37	13.57	6.94	10.79	43.14	5.49	1.12	2.69	1.88
Arooj-2022	8.47	0.13	2.79	37.10	17.33	9.84	0.71	8.55	5.08
Ghazi-19	28.21	10.09	22.65	1.44	12.80	5.37	8.64	0.78	0.01
Markaz-19	2.89	8.91	7.27	22.72	4.02	1.92	0.07	19.64	22.57
Barani-17	1.69	0.25	3.51	1.48	2.15	64.66	9.03	3.07	4.15
Ujala 2016	0.00	7.97	22.51	5.02	16.63	4.17	0.44	12.70	20.56
Galaxy 2013	2.60	7.86	1.54	19.49	0.95	0.38	1.05	29.54	26.58

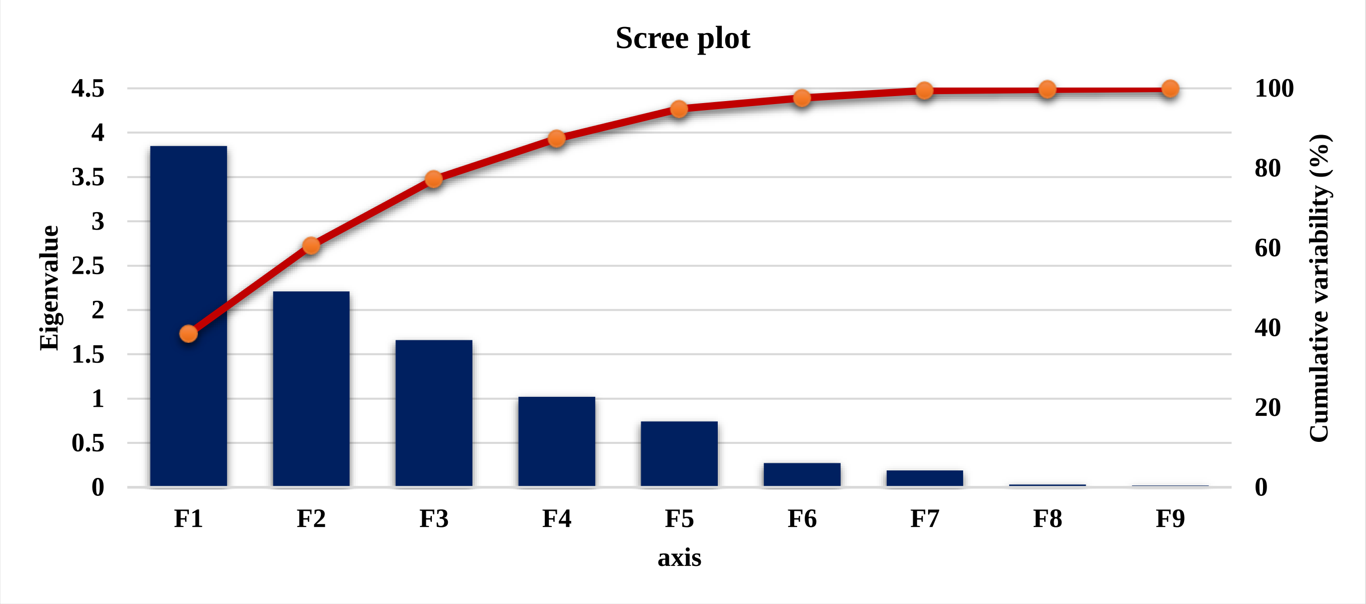

Figure 11. Scree plot under normal conditions.

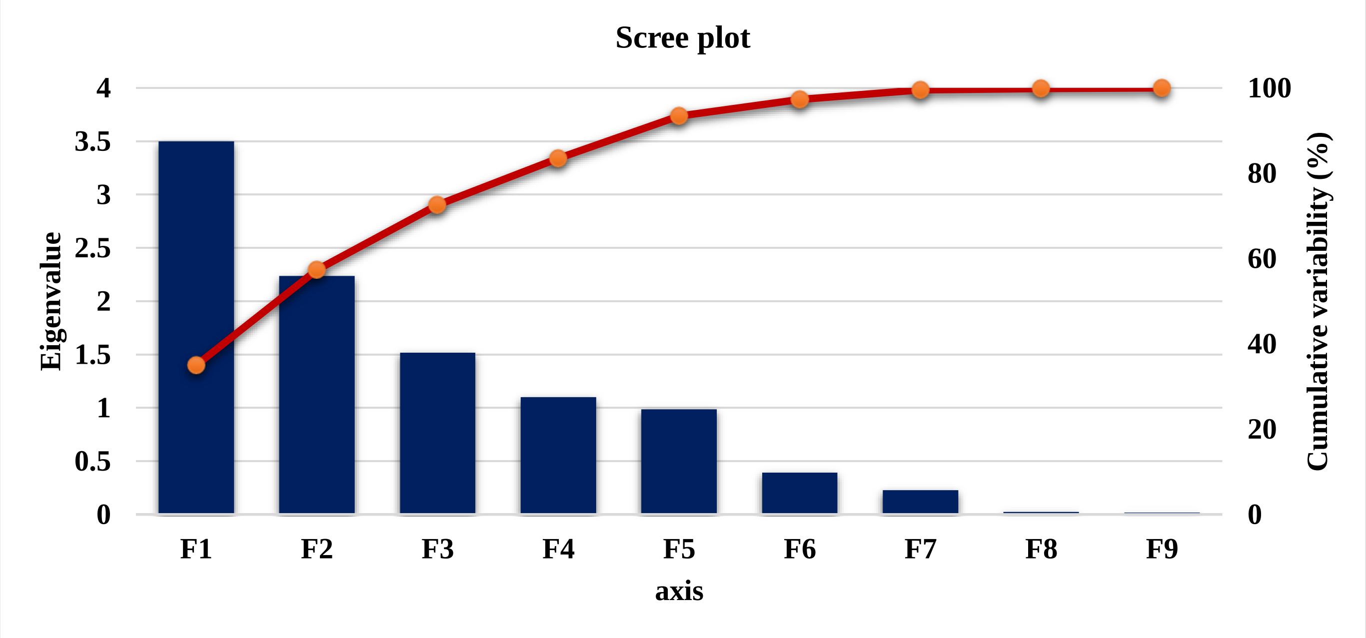

Figure 12. Scree plot under salt stress.

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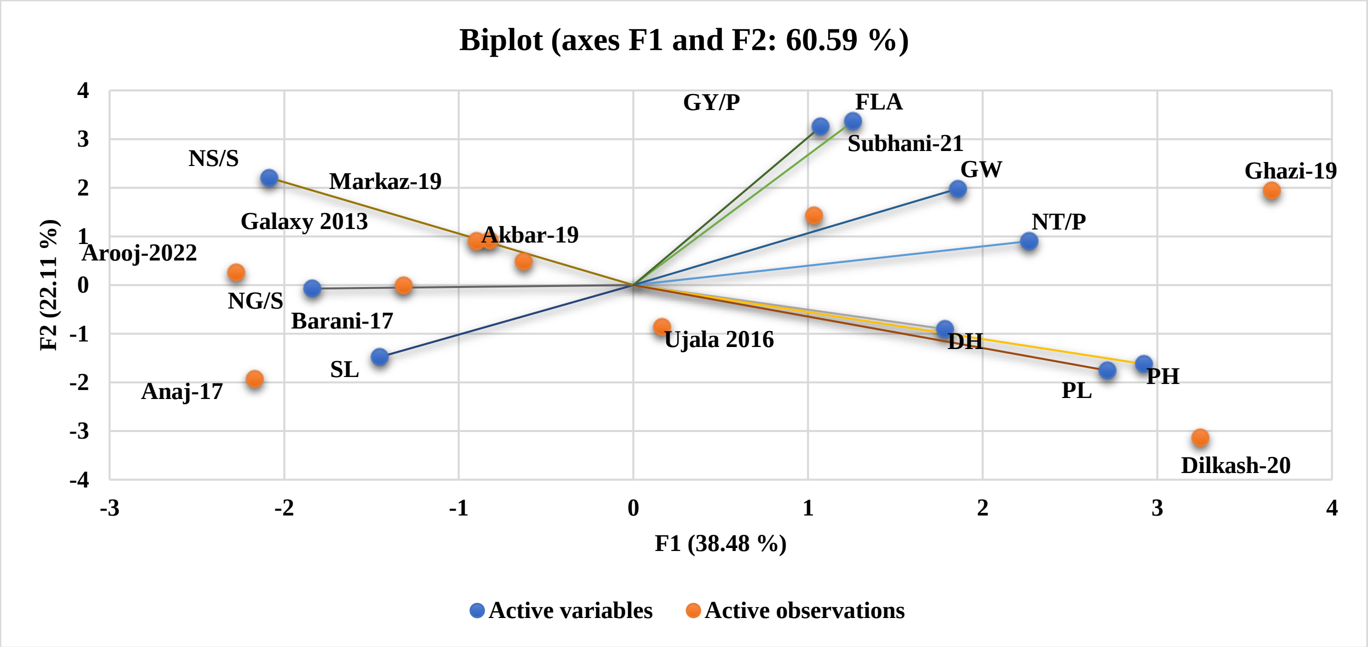

Figure 13. Biplot graph under normal conditions.

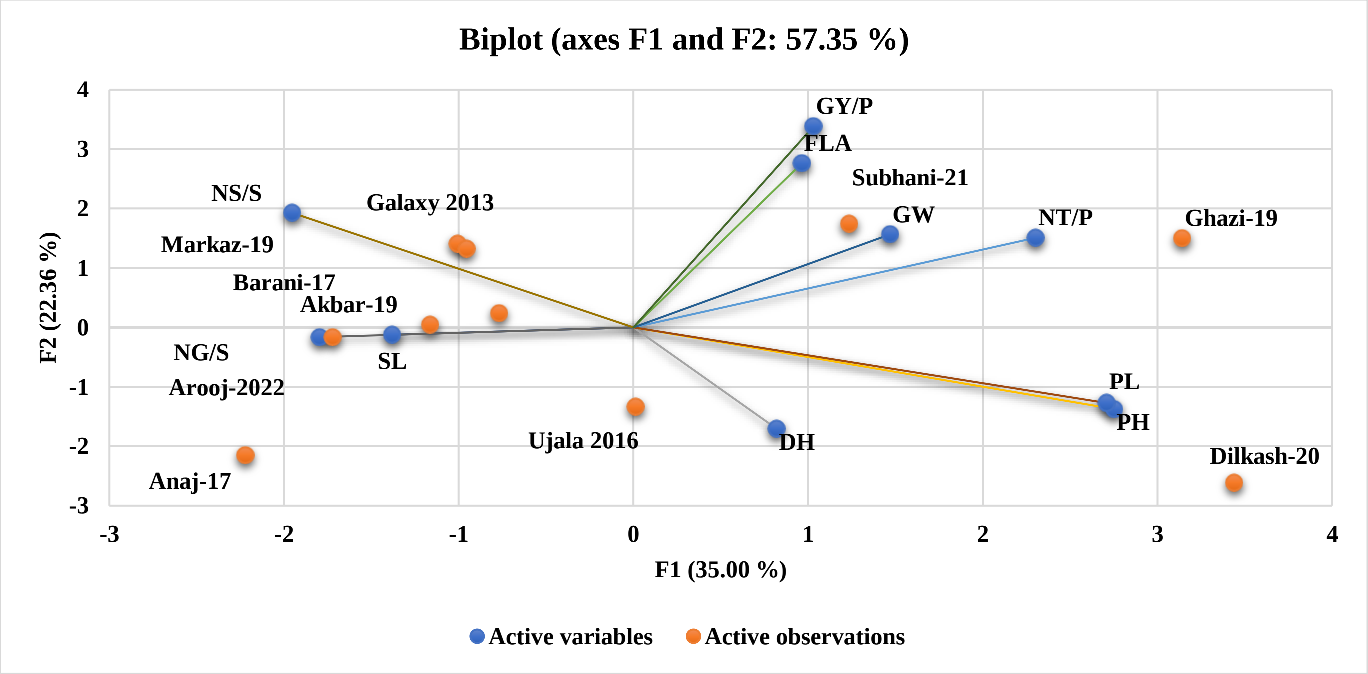

Figure 14. Biplot graph under salt stress conditions.

CONCLUSIONS

This study demonstrated the significant impact of salinity stress on wheat growth and yield-related traits. The results confirmed that salinity stress adversely affects plant development, reducing key agronomic traits such as plant height, number of tillers per plant, spike length, and grain yield perplant. However, the observed genetic variability among wheat genotypes suggests the possibility of selecting and breeding salt-tolerant cultivars.

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Not applicable.

AUTHOR CONTRIBUTIONS

All the authors contributed equally to this research.

COMPETING OF INTEREST

No conflicts of interest have been disclosed by the authors.

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