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Research Article

Salinity-Induced Variability Assessment in Wheat based on Morphological and Yield Performance

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ABSTRACT

Salinity stress is a major abiotic factor that adversely affects wheat growth and productivity. This study aimed to evaluate the impact of salinity stress (6 dSm⁻¹ NaCl) on yield and yield-related morphological traits of ten wheat genotypes. A pot experiment was conducted using a completely randomized factorial design with three replications. Analysis of variance (ANOVA) revealed that salinity stress significantly affected all studied traits, with genotypes exhibiting differential responses. Genotype × treatment interactions were also highly significant, indicating the negative impact of salinity. Heat maps illustrated overall performance variations under control and stress conditions. Among the genotypes, AAS-11, Jauhar-16, and Faisalabad 2008 showed relatively higher tolerance, exhibiting better grain yield and related traits under stress conditions. Correlation analysis indicated a strong positive association between grain yield per plant and traits such as number of grains per spike, spike length, number of tillers per plant, peduncle length, and 1000 grain weight under salinity stress. Conversely, days to heading exhibited a negative correlation with grain yield under normal conditions. These findings suggest that selecting genotypes with favorable yield-related traits can enhance wheat productivity under saline conditions.

Keywords: Wheat, salinity, heat map, correlation, tolerance.

INTRODUCTION

Over 20% of soils globally experience salt stress, which is exacerbated by human activities and climate change (Corwin, 2021). Abiotic stresses pose a severe threat to the world's food supply, with agricultural output dropping by 50%. Food production must increase by 70% by 2050 to feed the world's growing population. Wheat is the most significant food crop and the world's largest grain producer. It provides 20% of total calories and 55% of total carbohydrates, making it the primary source of nourishment for about 36% of the global population (Erenstein *et al.*, 2022). Moreover, a significant concentration of macro and micronutrients necessary for human health may be found in wheat.

Wheat crop productivity is reduced by salt stress. Salinity stress values of 6–8 dS m⁻¹ reduce wheat crop yields (Jiang *et al.*, 2012). Global food security is seriously threatened by the detrimental effects of salt stress on 397 million hectares of wheat crops (Mustafa *et al.*, 2019). When plants are exposed to salt stress, ion damage



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and imbalances in nutrition significantly reduce yield and interfere with physiological functions (Pour-Aboughadareh et al., 2021). Salinity stress affects seed germination at first, but because it alters growth and reproductive activity over time, it causes significant output losses (Rani et al., 2019). Additionally, salt stress results in oxidative stress, which impacts nutrition, photosynthesis, enzyme function, cell membrane structure, hormone balance, and water and food intake (Saddiq et al., 2021). The polygenic character of salt stress is controlled by a wide range of genes. Plants must control osmotic pressure, maintain a suitable K⁺/Na⁺ ratio, boost antioxidant system activity, and remove Na⁺ while holding onto K⁺ in order to withstand salt stress (Miransari and Smith, 2019). Gene insertions, genotype screening, traditional breeding approaches, and genotype selection are among the numerous procedures that have been implemented globally to enhance crop productivity in the presence of salinity stress. These processes are costly and time-consuming, though. In this situation, salt stress can be controlled by hormones, osmoprotectant therapy, seed priming, and nutritional management (Miransari and Smith, 2019; Zhu et al., 2016). An essential phase of the plant life cycle, germination affects subsequent growth, development, and yield. Wheat crop output is greatly decreased by salinity stress since it prevents seeds from germinating. By interfering with the regular activity of enzymes necessary for metabolism, salt stress affects ultimate stand establishment and yield. Moreover, the osmotic potential is decreased by sodium stress. Additionally, the number of spikelets, biomass production, grain weight, and productive tillers are all impacted by saline stress. Salt stress can affect plant seedlings, which are especially vulnerable to stress (Negrão et al., 2017). Thus, salt stress drastically lowers growth and yield by disrupting the metabolic pathways.

MATERIALS AND METHODS

In order to evaluate the effects of salinity stress on wheat yield and yield-related morphological characteristics, a pot experiment was performed. The ten wheat genotypes described below were assessed.

AARI 2011	Fatehjang-16
Punjab 2011	Jauhar-16
Millat 2011	NARC-11
Faisalabad 2008	Millet-11
Lasani 2008	AAS-11

The experiment involved three replications and a completely randomized factorial design. Each pot contained seven seeds. Following seed germination and seedling thinning, three healthy seedlings were maintained in each pot. The salinity stress (6 dSm⁻¹ of NaCl) was applied after 2 weeks to germination up to maturity. The control plants were irrigated with normal tap water. At maturity, data related to the following traits were recorded:

Days to Heading; DTH	Peduncle Length (cm); PDL
Plant Height (cm); PH	Number of Grains per Spike; NG/S
Number of Tillers per Plant; NT/P	Number of Spikelet per Spike; NS/S
Flag Leaf Area (cm); FLA	1000 Grain Weight (g); GW
Spike Length (cm); SPL	Grain Yield per Plant (g); GY/P

Statistical Analysis

To test the significance of data, two-way ANOVA was applied by using STATISTIX 8.1. Mean performance of wheat genotypes were represented in the form of radar graphs and heat maps under normal and stress conditions with the help of Microsoft excel. To find out the relationship of important agronomic traits with grain yield under salinity, correlation analysis was performed by using STATISTIX 8.1.

RESULTS

Results of ANOVA are presented in table 1 which showed that salinity stress significantly affected all the traits under study as treatments showed highly significant results. Genotypes were also highly significant for all the traits.

Table 1. Mean sum of squares of ten wheat genotypes for all studied traits under normal and salinity stress conditions.

Source	DF	DTH	PH	NT/P	FLA	SPL	PDL	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	76.97**	322.3**	16.35**	244.7**	3.80**	71.18**	469.0**	7.37**	165.8**	79.52**
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										

Genotypes × treatment interaction was also highly significant showing the negative impact of salinity on the performance of genotypes. The overall depiction of performance of wheat genotypes under normal and salinity stress conditions is represented in the form of heat maps in figure 1 and figure 2 respectively.

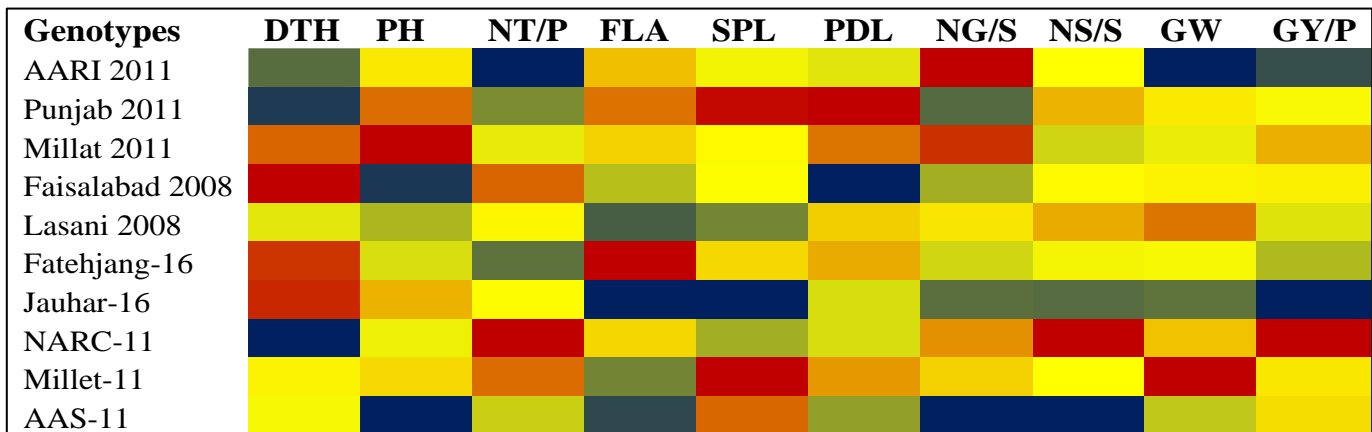


Figure 1. Heat map exhibiting mean performance of ten wheat genotypes under normal conditions (■ high; ■ medium; ■ low).

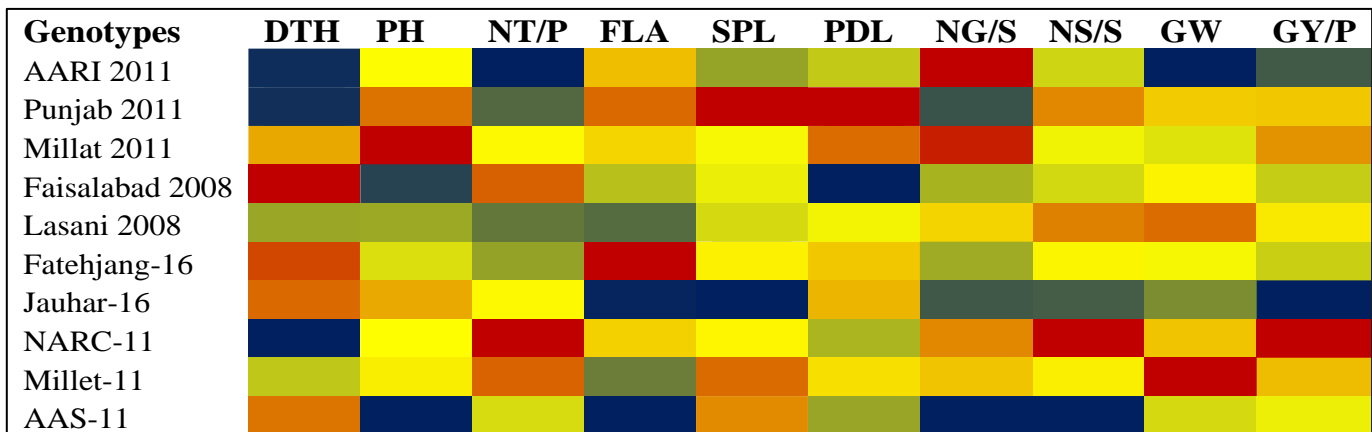


Figure 2. Heat map exhibiting mean performance of ten wheat genotypes under salinity conditions (■ high; ■ medium; ■ low).

Mean Performance of Wheat Genotypes Under Normal and Salinity Conditions

Mean performance of wheat genotypes for days to heading is presented in figure 3 which shows that AARI 2011, Punjab 2011 and NARC-11 showed maximum days to heading under salt stress. Faisalabad 2008 took minimum days for heading among all genotypes under stress conditions. AAS-11 showed maximum plant height followed by Faisalabad 2008 under both conditions (figure 4). For number of tillers per plant, AARI 2011 showed maximum values followed by Punjab 2011 and Fatehjang-16 under stressed conditions as presented in figure 5. Jauhar-16, AAS-11, Lasani 2008 and Millet-11 showed maximum values of flag leaf area under control and stress conditions (figure 6). Spike length and peduncle lengths were also significantly reduced by salinity stress as exhibited in figure 7 and figure 8. AAS-11 showed the highest number of grains per spike under stressed condition followed by Punjab 2011, Jauhar-16, Fatehjang-16 and Faisalabad 2008 (figure 9). Salinity stress also reduced number of spikelets per spike with AAS-11 and Jauhar-16 showing maximum values among all genotypes (figure 10). For 1000 grain weight, AARI 2011 and Jauhar-16 showed maximum values under both normal and stress conditions (figure 11). Jauhar-16 showed highest grain yield per plant under salinity stress followed by AARI 2011 while lowest values were observed in NARC-11 (figure 12).

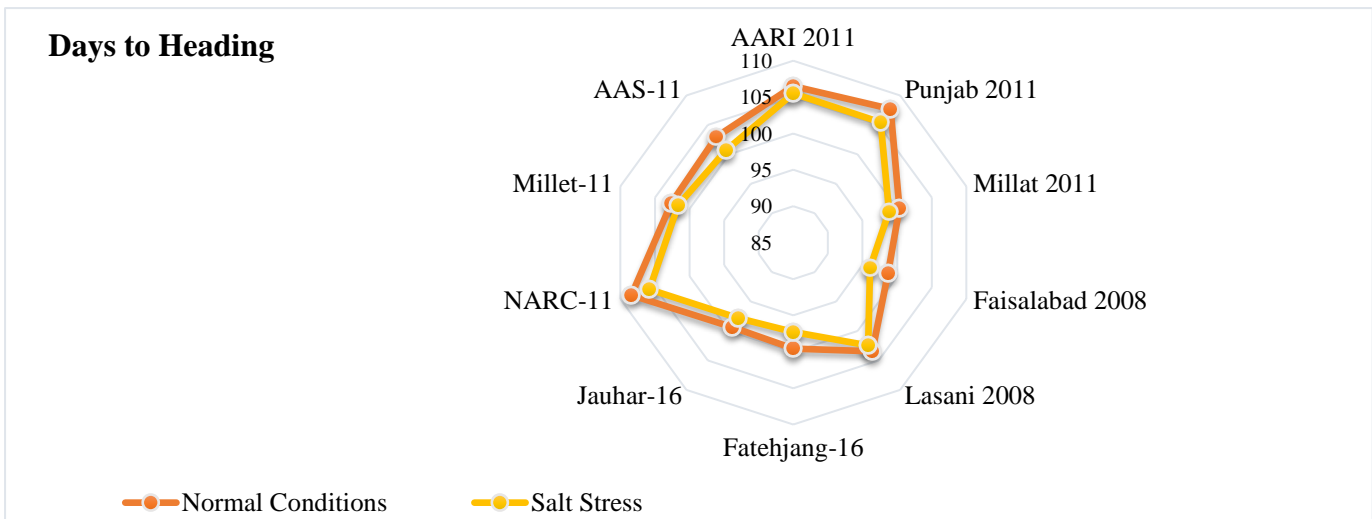


Figure 3. Impact of salinity on the performance of wheat genotypes for days to heading.

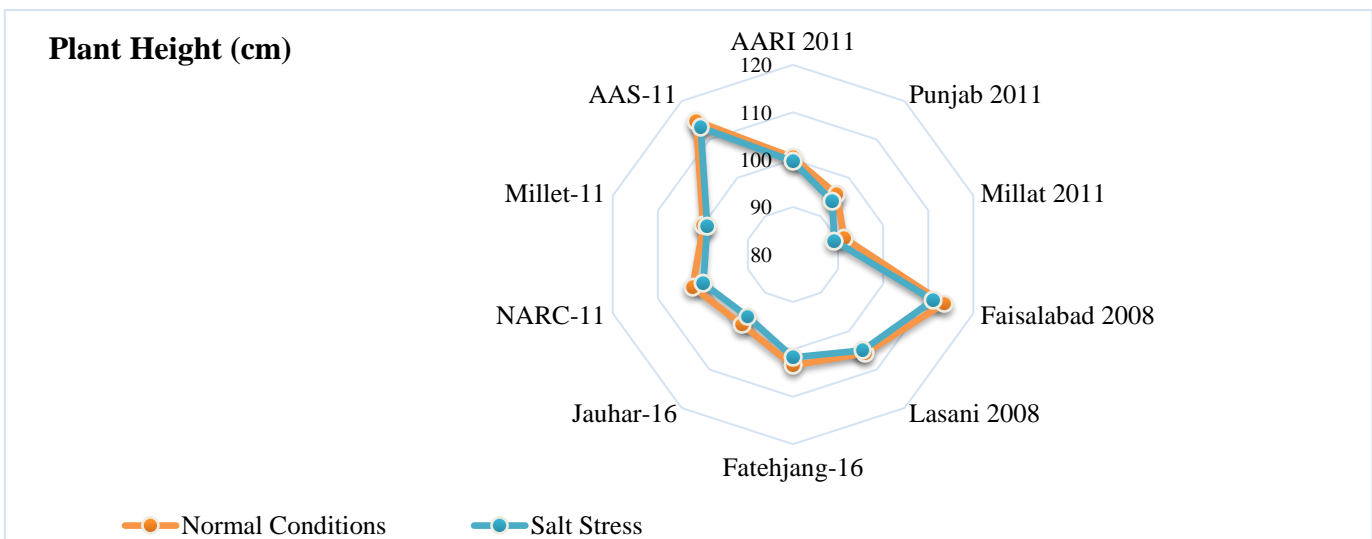


Figure 4. Impact of salinity on the performance of wheat genotypes for plant height.

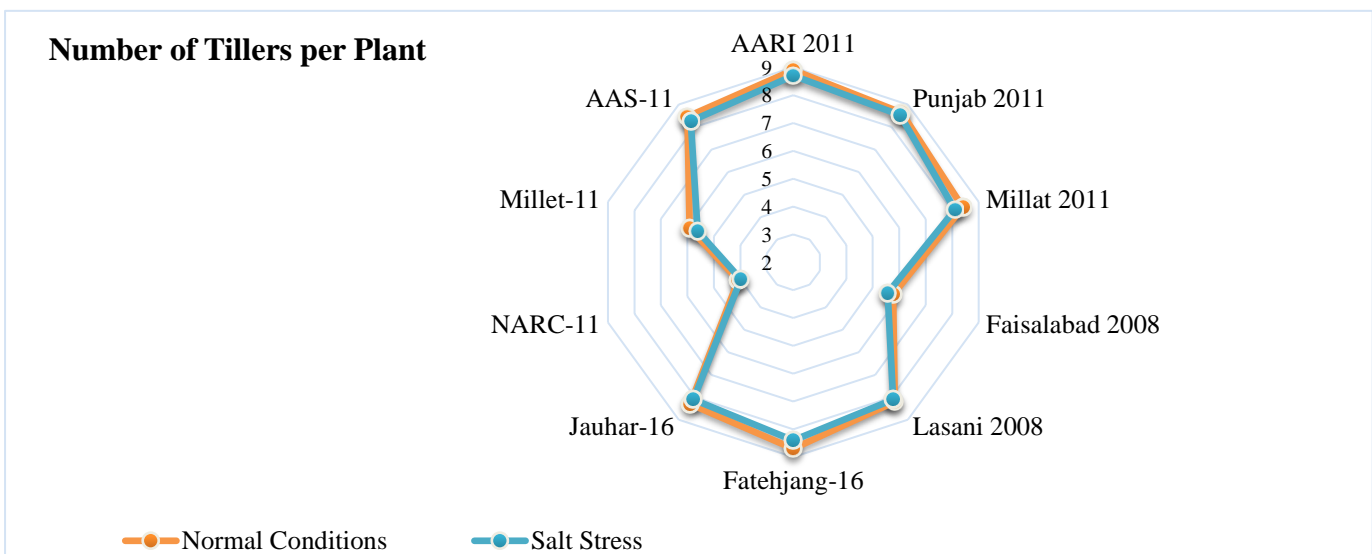


Figure 5. Impact of salinity on the performance of wheat genotypes for number of tillers per plant.

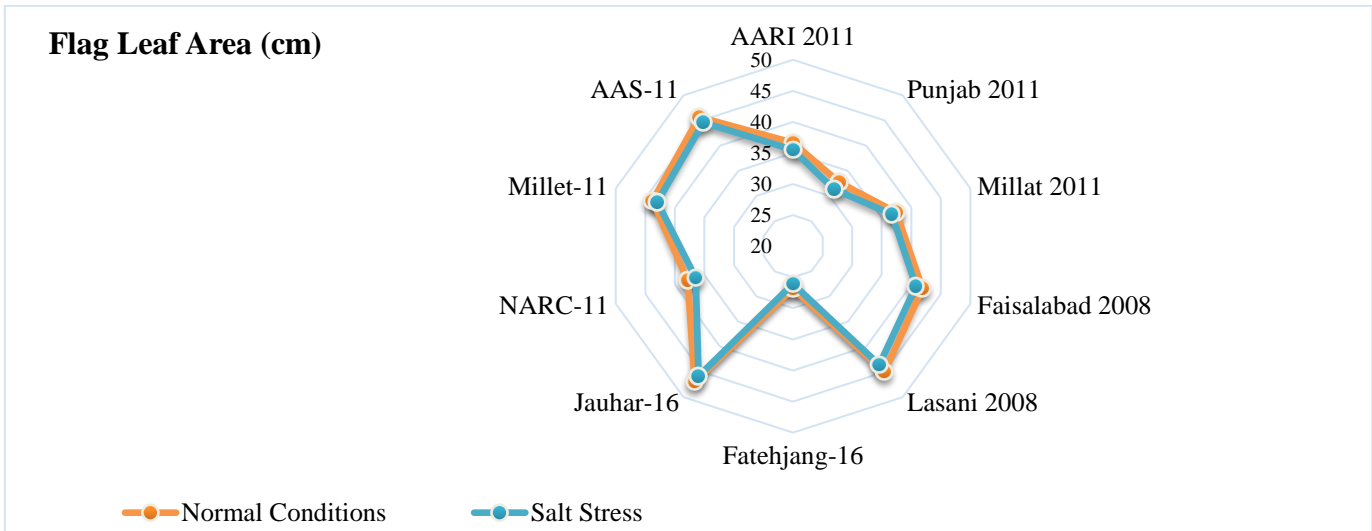


Figure 6. Impact of salinity on the performance of wheat genotypes for flag leaf area.

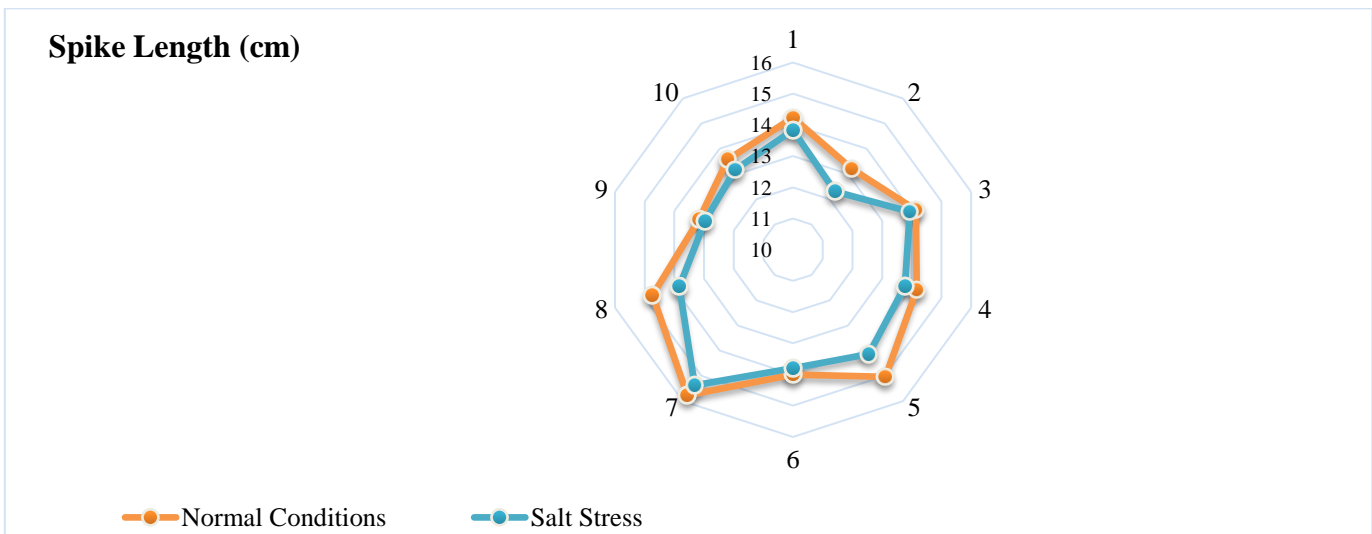


Figure 7. Impact of salinity on the performance of wheat genotypes for spike length.

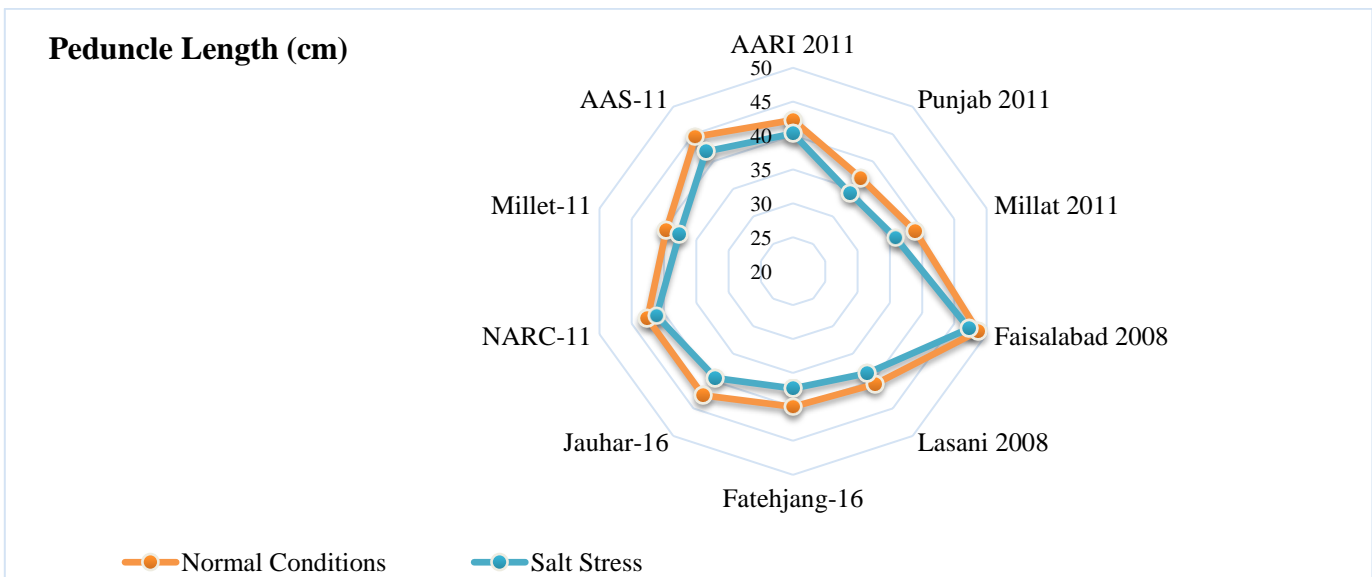


Figure 8. Impact of salinity on the performance of wheat genotypes for peduncle length.

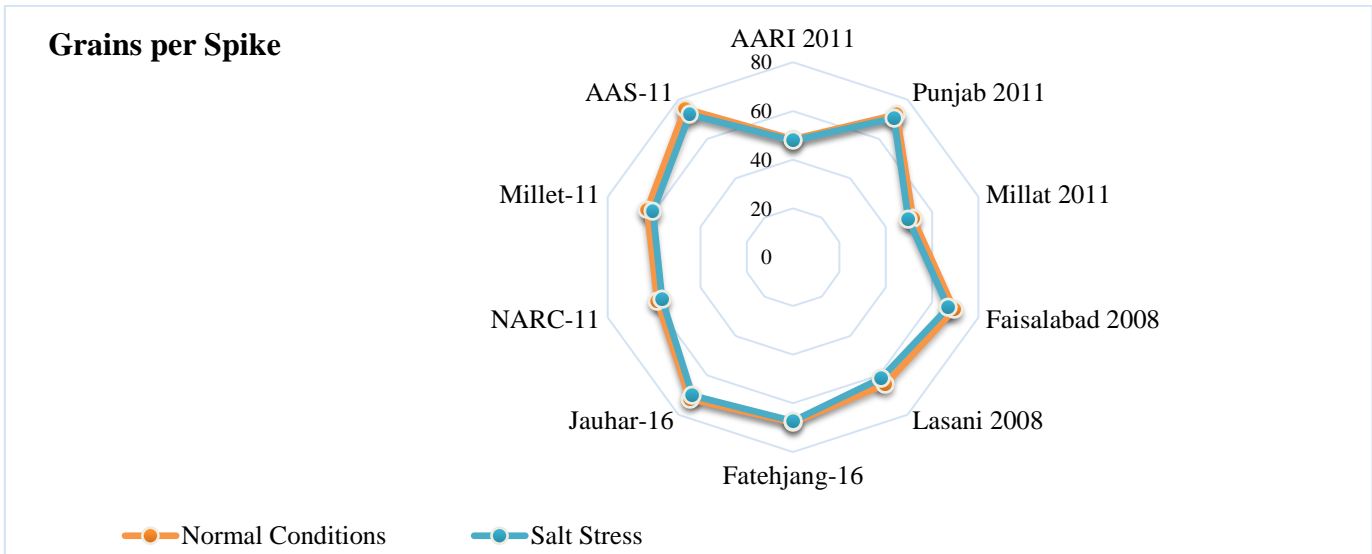


Figure 9. Impact of salinity on the performance of wheat genotypes for grains per spike.

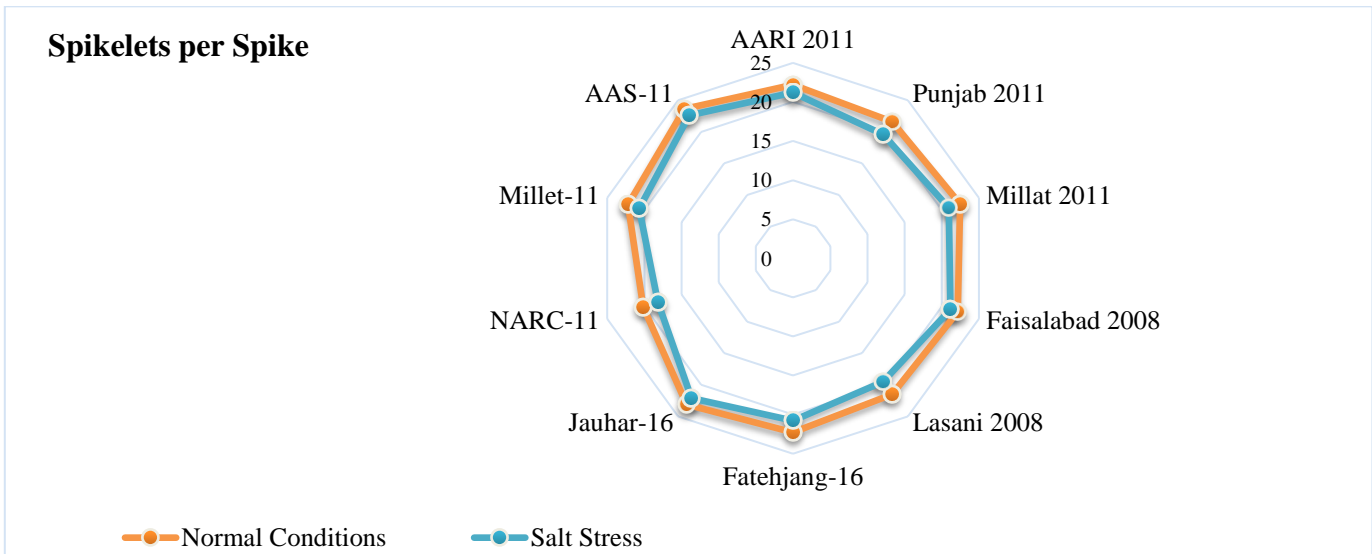


Figure 10. Impact of salinity on the performance of wheat genotypes for spikelets per spike.

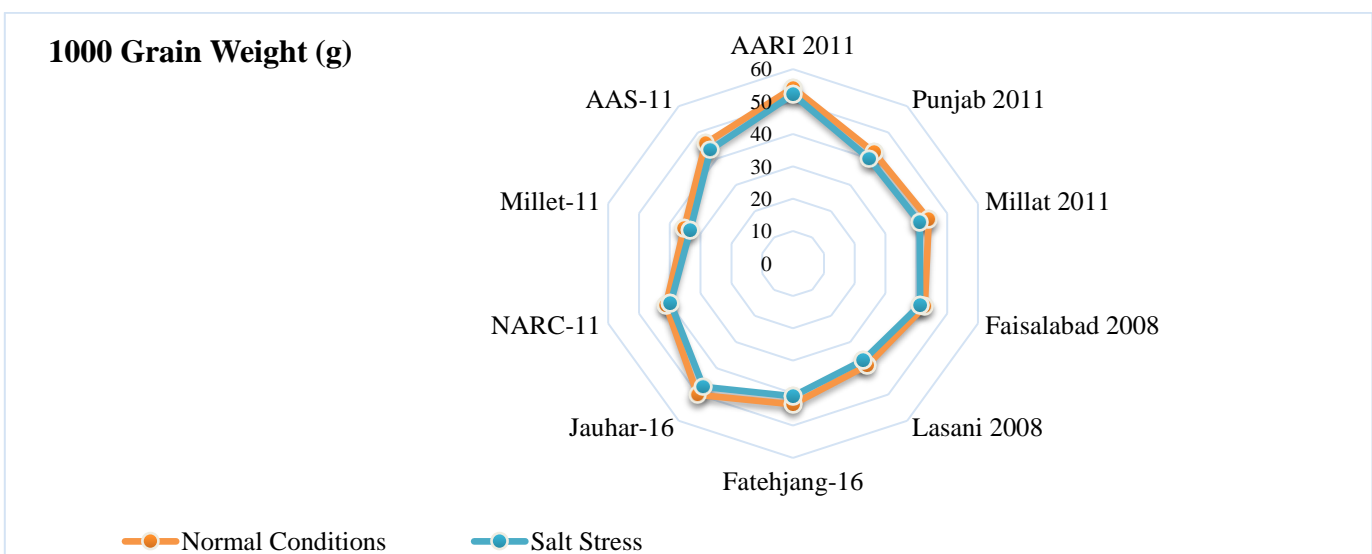


Figure 11. Impact of salinity on the performance of wheat genotypes for 1000 grain weight.

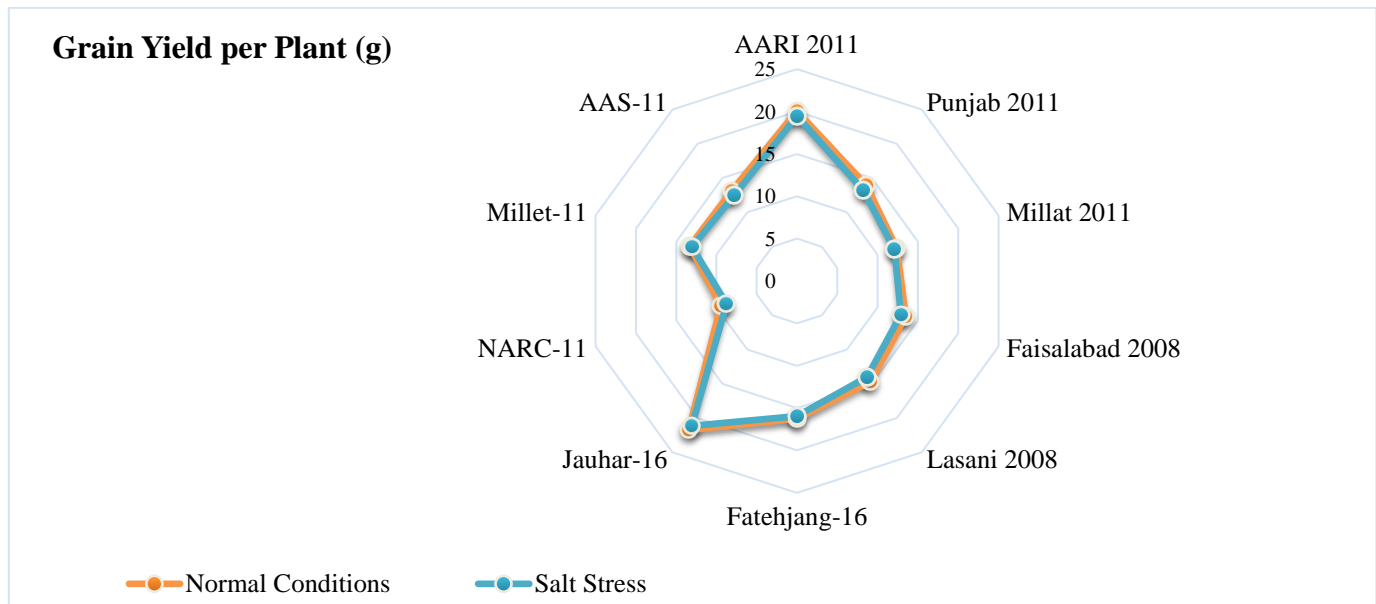


Figure 12. Impact of salinity on the performance of wheat genotypes for grain yield per plant.

Correlation Analysis

Results of correlation analysis are presented in table 2 for normal conditions and in table 3 for stress conditions. Under normal conditions, grain yield per plant was positively and significantly correlated with number of grains per spike, number of tillers per plant, peduncle length, spike length and 1000 grain weight. Grain yield per plant showed negative correlation with days to heading under control conditions. Under salinity stress, grain yield per plant showed highly significant and positive correlation with number of grains per spike and spike length. It also showed significant and positive correlation with number of tillers per plant, peduncle length and 1000 grain weight.

Table 2. Correlation analysis under normal conditions.

	DTH	FLA	NG/S	NS/S	NT/P	PH	PDL	SPL	GW
FLA	-0.189								
NG/S	-0.269	0.220							
NS/S	-0.613	0.334	0.346*						
NT/P	-0.174	-0.191	0.071	0.598					
PH	-0.184	0.335	0.483	0.203	-0.208				
PDL	-0.336	0.434	0.195	0.201	-0.371	0.782			
SPL	-0.218	0.348	-0.074	-0.073	-0.024	-0.038	0.261		
GW	-0.004	-0.060	0.206*	0.405*	0.506	-0.057	0.237*	0.347*	
GY/P	-0.275	0.085	0.022*	0.495	0.602*	0.147	0.018*	0.430**	0.701**

Table 3. Correlation analysis under stress conditions.

	DTH	FLA	NG/S	NS/S	NT/P	PH	PDL	SPL	GW
FLA	-0.147								
NG/S	-0.358	0.148							
NS/S	-0.583	0.370	0.283*						
NT/P	-0.080	-0.180	0.114	0.482					
PH	-0.222	0.340	0.437	0.270	-0.171				
PDL	-0.308	0.407	0.119	0.233	-0.465	0.757			
SPL	-0.424	0.342	-0.116	0.238	0.050	-0.071	0.258		
GW	0.042	-0.058	0.181*	0.464*	0.450	-0.015	0.226*	0.409*	
GY/P	-0.208	0.079	0.060**	0.550	0.603*	0.136	0.067*	0.534**	0.667*

DISCUSSION

Most of the agricultural land is situated in dry or semi-arid regions with a variety of salinities (Hussain *et al.*, 2019). Crop injury is exacerbated by xerothermic variables, such as high temperatures and aridity (Sakadevan and Nguyen, 2010). Salinity has the most detrimental impact on wheat quality and yield (Abbas *et al.*, 2013; Saddiq *et al.*, 2021). ROS are frequently generated because of salt stress, which disrupts redox equilibrium and inflict damage on biomolecules within cells. Geographical factors, climatic effects, edaphic effects, and agronomic practices all contribute to spatial variation in soil salinity. One of the most critical stages in the development of salinity resistance is the integration of agronomical, physiological, and soil management techniques to simultaneously target multiple characteristics (El Sabagh *et al.*, 2021).

The morphological attributes of wheat plants are adversely affected by soil salt. Wheat matured earlier than anticipated under salinity stress, which led to a loss in crop height and leaf area (Mojid *et al.*, 2013). Borlu *et al.* (2018) discovered that wheat stems grew shorter in response to salt stress. The ultimate size of a spike is significantly impacted by salinity, resulting in a decrease in spike length and quantity and decrease in grain size (Grieve *et al.*, 1992). To create new tolerant cultivars that possess superior agro-morphological characteristics, a concerted breeding effort is necessary. Previous research has demonstrated that the reproductive stage of any crop is the most susceptible to abiotic stress, such as salt (Ehtaiwesh and Rashed, 2020). This vulnerability significantly impacts the production of critical commodities, such as wheat. Nevertheless, it is widely recognized that salinity predominantly affects plant development and productivity through osmotic stress and ion toxicity. These physiological and biochemical changes are stage-specific and suggest potential for future production. For instance, salinity decreases grain output by 39.1, 24.3, and 13.4% during distinct phases including anthesis, early booting, and mid-grain filling. Salt stress led to an early terminal spikelet stage characterized by anthesis, fewer spikelet primordia, and increased shoot apex growth. Lastly, the potential wheat yield was reduced by reducing the number of spikes and grains per spike (Maas and Grieve, 1990). The primary factor contributing to the reproductive stage of wheat yield decline has also been identified as insufficient photo assimilates. Gene expression may be affected by salt stress during the pre-anthesis and grain filling stages. (Tareq *et al.*, 2011) found that plant's total grain weight decreased by 16% when subjected to salinity. Reduced partitioning toward economically significant plant sections (grains), decreased assimilate production, and pollen sterility are the primary causes of grain weight losses in saline conditions.

CONCLUSIONS

Salinity stress significantly affects wheat yield, with genotypes responding differently. AAS-11, Jauhar-16, and Faisalabad 2008 showed higher tolerance. Traits like grains per spike, spike length, and tillers per plant correlated positively with yield under stress. Selecting genotypes with favorable traits can improve wheat productivity in saline environments.

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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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