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ASSESSMENT OF MORPHO-PHYSIOLOGICAL TRAITS IN GUAVA GENOTYPES UNDER SALINITY STRESS

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Abstract

Climate change is leading to soil salinization, which is producing significant reductions in crop yields worldwide. Salinity stress negatively affects the plant growth through various mechanisms. The presence of salinity is a significant challenge to crop cultivation. Hence, it is essential to introduce salt-tolerant genotypes to alleviate the drastic impacts of salinity stress. The present study evaluated the tolerance potential of different guava genotypes to different levels of salt concentrations (0, 8, 12, 16 dS m^{-1}) by examining various traits related to growth, biomass, and physiology. One and half year-old guava plants of twelve different genotypes were grown in plastic pots using soil medium in a screenhouse. The experiment was conducted using a completely randomized design, with three replications. Salinity stress hinderd the growth of guava genotypes, and the degree of inhibition increased with higher salt concentrations. Additionally, the physiological parameters like photosynthetic rate, stomatal conductance, and transpiration rate decreased as the salt concentration increased. The guava genotype “Sadabahar Sufaid Gola” and “Apple Guava” presented good results in terms of growth and physiological parameters under the highest salinity level 16 dS m^{-1} while the genotypes “Surahi” and “Sufaida” depicted highest reduction in these parameters. These results highlighted the physiological basis and could be promising for the commercial development of salt-tolerant guava genotypes.

Keywords: Climate Change, Guava Genotypes, Salinization, Tolerance Potential, Physiology.

1. INTRODUCTION

Soil salinization is a significant global environmental challenge that has a detrimental impact on agricultural productivity and food security. The process of salinization is steadily intensifying because of both climate change and human activities. This widespread phenomenon has already impacted 400 million hectares of agricultural land, and an equal land is at risk due to this problem (Pour-Aboughadareh et al. 2021; Boussora et al. 2024). The sustainability of agricultural land is at risk by the growing human population and decreasing availability of arable land (Hryvusevich et al. 2021). Soil salinity in agricultural soils is the condition where there is a high concentration of soluble salts in the soil moisture inside the root zone (Paz et al. 2023). The high osmotic pressures resulting from the concentrations of soluble salts hinder plant growth by limiting water absorption

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through the roots (Abbas et al. 2024). It has a negative impact on nutrient availability that affects plant growth, resulting in decreased crop yields (Sahbeni et al. 2023). Salinity has emerged as a significant environmental challenge for horticultural crops in recent decades. The detrimental impacts of salinity on horticultural crops are apparent through the observed decline in growth patterns resulting from the suppression of physiological processes (Shahid et al. 2020). Soil salinity has a negative impact on photosynthetic activity in plants and promotes the generation of reactive oxygen species (ROS), leading to a decrease in plant development (Khan and Bano 2018). Guava cultivation in the semiarid irrigated areas is subjected to periodic water shortages, little rainfall throughout the year, and high salt concentrations in the irrigation water.

Guava (*Psidium guajava* L.) is a plant that belongs to the Psidium genus and Myrtaceae family. It is widely cultivated in tropical and subtropical regions since it can thrive in different agro-climatic conditions (Ratna and Bahadur, 2019; Singh et al., 2020). The Myrtaceae family contains approximately 130 genera and 3,000 species (Akram et al., 2017). Guava is commonly referred to as the apple of tropics because of its abundant nutritional content (including vitamin A, B, and C), strong fragrance, and delicious taste (Singh et al., 2020). (Almadhor et al., 2021) while India, Pakistan, Thailand, Brazil, and Mexico are the primary countries renowned for producing guava. Guava is native to South America (Almadhor et al., 2021) while India, Pakistan, Thailand, Brazil, and Mexico are the primary countries renowned for producing guava (Rajan and Hudedamani, 2019). Globally guava production amounts to approximately 6.8 million tonnes annually, with India and Pakistan contributing 50 percent of the entire production (Yousaf et al., 2020). Guava is a significant fruit in Pakistan, contributing to the country's economy. It is produced annually at a volume of 547,546 tonnes, covering an area of 56,141 hectares. Punjab is the most productive province in terms of guava production, contributing to around 80% of the total production (GOP, 2019). Fruit crops such as citrus, grapevines, stone fruits, and avocado are highly susceptible to salt damage (Singh and Sharma, 2018). Additionally, Cavalcante et al. (2007) found that guava is particularly susceptible to salinity at the seedling stage.

Multiple approaches are employed to alleviate the adverse effects of salt stress on plant growth and productivity (Sabagh et al., 2020). The most commonly employed methods for soil reclamation include scraping, flushing, and leaching; yet these procedures are somewhat costly. One of the most effective methods for assuring long-term agricultural output is the development of salt-tolerant cultivars (Bhattarai et al., 2020). It is essential to select and identify genotypes that can tolerate salt in order to minimise the harmful effects of salt stress on plant growth and productivity (Noreen et al., 2018). Hence, the main objective of this research work was to assess the salt stress tolerance of different guava genotypes by examining their morpho-physiological characteristics.

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2. MATERIALS AND METHODS

This research study was performed to evaluate different guava genotypes against salinity stress and carried out at the screenhouse, Institute of Horticultural Sciences (IHS), University of Agriculture Faisalabad (UAF). The study utilized twelve different genotypes of guava. These guava genotypes were chosen based on either their widespread cultivation across the country or their popularity among consumers. The study involved exposing one and half year-old guava plants of twelve different genotypes (Karela, Lal Surahi, Surahi, Sufaida, Gola, China Gola, Lal Gola, Sadabahar Sufaid Gola, Sadabahar Sufaid Surahi, Golden Gola, Moti Sufaid Surahi, Apple Guava) to four different salinity levels (0, 8 dS m^{-1}, 12 dS m^{-1} and 16 dS m^{-1}). Prior to the application of salt, a planting media analysis was conducted at the Ayub Agricultural Research Institute Faisalabad. This analysis aimed to assess the nutritional composition of the growth media. The growth media consisted of sand, silt, and clay in proportions of 62.5%, 25.0%, and 12.5% respectively. The substrate had an electrical conductivity (EC) of 2.5 dS m^{-1}, a pH of 8.1, an organic matter content of 0.70%, and a saturation level of 32%.

After quantifying the amount of salt, it was dissolved in distilled water and then applied to the plants. To mitigate osmotic stress in plants, the salt stress was incrementally increased every 3 days, starting at a concentration of 2.0 (dS m^{-1}) and reaching the desired values. A single application of salt treatments was administered, and the trial was concluded 30 days after the salt levels were completed. This research study utilized a total of 432 pots, with each genotype being represented by 36 pots. The study had four treatments, with each treatment comprising three replications and each replication comprising three pots. Following parameters were studied:

2.1. Measurement of plant growth parameters

The plants were taken out from the pots, and the soil was rinsed out. Subsequently, the shoots and roots were carefully separated. The plants were then assessed for shoot length, measured from the base to the shoot apex and root portion of the plant was then measured for its length using a measuring tape, and recorded in cm. Then the shoot and root samples were wrapped in tissue paper to dry the water droplets. Afterwards, the fresh weight of the root and shoot were measured using a digital scale and the samples were placed in brown paper bags and kept in an oven at 70°C for a duration of three days and then dry weight was measured both for root and shoot (Sarwar et al., 2017).

2.2. Physiological attributes characterization:

The completely developed mature guava leaves were utilized to evaluate gas exchange characteristics, including stomatal conductance, photosynthetic activity, and transpiration rate. The guava leaves were analyzed using a portable InfraRed Gas Analyzer (ADC BioScientific LCi-Sd System). The measurements of the physiological characteristics were taken from 10:00 am to 12:00 pm. The chlorophyll contents were quantified using a portable SPAD meter (SPAD-502, Konica Minolta, Japan) (Khan et al., 2003). Whereas

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water use ion efficiency was determined by the ratio of photosynthetic rate to water transpiration.

$$Water\ use\ efficiency\ (WUE) = \frac{photosynthesis\ rate}{transpiration\ rate}$$

2.3 Statistical analysis

The study was conducted using a completely randomized design (CRD) with factorial arrangements and three replications. An analysis of variance (ANOVA) was performed, followed by multiple comparisons using the least significant difference (LSD) test at a significance level of P≤0.05. The software used for this analysis was Statistix 8.1 (Steel et al., 1997).

3. RESULTS

3.1. Growth traits:

The results indicated a significant reduction (P≤0.05) in growth characteristics such as root and shoot length, as well as their biomass, under salt stress. The results indicated that the genotypes "Karela" and "SSG" exhibited the least decrease in root length, measuring 12.78 cm and 12.68 cm respectively, compared to the other genotypes. On the other hand, the genotype "China Gola" showed a significant reduction in root length, measuring 10.35 cm. The treatment with a salt level of 16.0 dS m^{-1} resulted in a significant decrease in root length (9.15 cm) compared to the control treatment (13.92 cm). Similarly, the genotype × salinity interaction was shown to be significant. In terms of percentage reduction, the guava genotype "Karela" exhibited a minimal growth reduction of 42%, while the genotype "Sufaida" showed a significant growth reduction of 59%. The results showed that among the treatments, a shoot length reduction of 25.49 cm was observed with a salinity level of 16 dS m^{-1}, compared to the control group with a mean shoot length of 33.35 cm, across different genotypes. When comparing genotypes, the "SSG" genotype had the highest shoot length at 34.28 cm, followed by "Karela" at 32.75 cm. Nevertheless, the shortest shoot length was recorded in the genotype "Sufaida" at 23.03 cm, while "Lal Surahi" had a slightly longer shoot length of 26.27 cm. A significant interaction between genotype and salinity was observed for shoot length. The genotype "Apple Guava" exhibited the least reduction (29%), while the genotype "Surahi" showed the highest reduction (60%). The salinity stress had an impact on the fresh and dry weight of both the above and below portions. The results indicated that the "Apple Guava" genotype exhibited the highest root fresh weight, with a mean of 8.28 g. This was followed by the "SSG" genotype, which had a mean of 7.79 g. The lowest results were observed in the "Surahi" genotype, with a mean weight of 5.74 g. The root fresh weight decreased the most at a salt treatment level of 16.0 dS m^{-1}, with an average of 5.14 g, compared to the control treatment with an average of 8.95 g. The results also indicated a significant interaction between genotype and salinity. The guava genotype "SSG" showed a minimal 63% reduction in root fresh weight, while the genotype "Suafaida" exhibited the highest 84% reduction. The results indicated that the "Apple Guava" genotype exhibited the least

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decrease in shoot fresh weight (34.43 g), followed by "SSG" (34.16 g). On the other hand, the "Sufaida" genotype showed a significant reduction (25.31 g), followed by "Surahi" (25.72 g). A significant reduction in shoot fresh weight was observed at 16.0 dS m^{-1}, with an average weight of 25.20 g, compared to the control treatment which had an average weight of 33.72 g. A significant interaction between genotype and salinity was noted for shoot fresh weight. The genotype "SSG" exhibited the least reduction (29%), while the "Apple Guava" genotype showed the highest reduction (41%). For root dry weight, the results indicated that the treatment with a salinity level of 16 dS m^{-1} resulted in a significant reduction, with a decrease of 1.39 g compared to the control group, which had a root dry weight of 3.43 g. The genotype "SSG" had the maximum root dry weight of 3.22 g, whereas "Apple Guava" had a slightly lower weight of 2.90 g. Nevertheless, the lowest recorded value was observed in the "Surahi" genotype, measuring 2.91 g, whereas the "MSS" genotype had a slightly higher value of 2.00 g. A strong interaction was observed between genotype and salinity, with the genotype "SSG" showing the least reduction (72%) and the genotype "Surahi" showing the highest reduction (210%). The highest reduction in shoot dry weight was recorded at a salt level of 16.0 dS m^{-1}. The results indicated that the "Apple Guava" genotype exhibited the least reduction in shoot dry weight, measuring 9.71 g, followed by the "SSG" genotype with 9.67 g. On the other hand, the "Surahi" genotype depicted highest reduction with 7.24 g. The treatment with a salt level of 16.0 dS m^{-1} showed a reduced shoot dry weight of 6.96 g compared to the control treatment (9.87 g). A significant interaction between genotype and salinity was observed for shoot dry weight. The genotype "Gola" exhibited the least reduction (30%), followed by genotype "SSG" (32%).

Table 1: Effect of salt stress on root length (cm) of guava genotypes

Genotypes	NaCl treatments (dS m^{-1})				Mean
	0	8	12	16	
Apple Guava	14.62 ± 0.81 B	12.85 ± 0.70 L	11.23 ± 0.94 O	9.78 ± 0.82 G	**12.12 B**
China Gola	12.93 ± 0.63 G	10.83 ± 0.76 M	9.15 ± 0.55 P	8.48 ± 0.59 QR	**10.35 H**
Gola	13.93 ± 0.99 C	11.85 ± 0.91 IJ	10.42 ± 0.67 N	9.82 ± 0.83 O	**11.50 C**
Golden Gola	13.52 ± 1.01 EF	11.62 ± 0.63 JK	9.16 ± 0.88 P	8.53 ± 0.61 QR	**10.70 G**
Karela	14.52 ± 0.79 B	13.91 ± 0.76 C	12.45 ± 0.52 H	10.26 ± 0.56 N	**12.78 A**
Lal Gola	13.76 ± 0.73 C-E	11.71 ± 0.79 IJ	10.27 ± 0.81 N	9.31 ± 0.65 P	**12.26 D**
Lal Surahi	13.94 ± 0.78 C	11.69 ± 0.68 IJ	10.43 ± 0.53 N	8.71 ± 0.66 Q	**11.19 D**
MSS	13.86 ± 0.90 CD	11.39 ± 0.82 KL	10.28 ± 0.75 N	8.52 ± 0.61 QR	**11.01 E**
SSG	15.25 ± 1.04 A	13.62 ± 0.92 D-F	11.66 ± 0.82 J	10.21 ± 0.65 N	**12.68 A**
SSS	13.81 ± 0.77 CD	11.36 ± 0.69 L	9.84 ± 0.84 O	8.32 ± 0.59 R	**10.83 F**
Sufaida	13.49 ± 0.85 F	11.35 ± 0.61 L	10.27 ± 0.79 N	8.46 ± 0.84 QR	**10.89 EF**
Surahi	13.42 ± 0.81 F	11.91 ± 0.69 I	10.27 ± 0.64 N	9.37 ± 0.63 P	**11.24 D**
Mean	**13.92 A**	**12.01 B**	**10.45 C**	**9.15 D**	
P values		**Treatment** **Genotypes** **Treatment*Genotypes**		**0.0001**** **0.0004**** **0.0000****	

MSS: Moti Sufaid Surahi, SSG: Sadabahar Sufaid Gola, SSS: Sadabahar Sufaid Surahi; The dataset denotes the averages derived from three distinct replicates. Means with letters represent statistical differences by LSD test (P ≤ 0.05).

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Table 2: Effect of salt stress on shoot length (cm) of guava genotypes

Genotypes	NaCl treatments (dS m^{-1})				Mean
	0	8	12	16	
Apple Guava	35.63 ± 1.61 C	32.62 ± 1.44 G	30.41 ± 1.32 L	27.67 ± 1.22 RS	**31.58 C**
China Gola	31.72 ± 1.32 HI	27.50 ±1.21 ST	25.88 ± 1.12 X	23.62 ± 1.26 B	**27.18 I**
Gola	32.62 ± 1.54 G	27.19 ± 1.32 T	26.29 ± 1.16 VW	24.93 ± 1.34 Z	**27.76 H**
Golden Gola	33.42 ± 1.46 F	31.30 ± 1.27 J	29.11 ± 1.34 O	26.54 ± 1.28 UV	**30.09 E**
Karela	38.95 ± 1.69 A	33.31 ± 1.34 F	30.82 ± 1.37 K	27.93 ± 1.38 QR	**32.75 B**
Lal Gola	32.62 ± 1.23 G	27.23 ± 1.45 T	26.19 ± 1.28 WX	24.93 ± 1.40 Z	**27.74 H**
Lal Surahi	32.62 ± 1.41 G	26.18 ± 1.45 WX	25.23 ± 1.21 YZ	23.42 ± 1.18 B	**26.27 J**
MSS	32.40 ± 1.20 G	29.52 ± 1.34 N	27.38 ± 1.42 ST	24.37 ± 1.22 A	**28.42 G**
SSG	36.98 ± 1.48 B	34.32 ± 1.36 D	33.94 ± 1.38 E	31.89 ± 1.42 H	**34.28 A**
SSS	34.50 ± 1.30 D	31.53 ± 1.36 IJ	29.48 ± 1.28 N	26.61 ± 1.28 U	**30.53 D**
Sufaida	28.61 ± 1.22 P	25.32 ± 1.29 Y	20.38 ± 1.22 C	17.83 ± 1.14 D	**23.03 K**
Surahi	32.52 ± 1.38 G	29.91 ± 1.23 M	28.14 ± 1.32 Q	26.14 ± 1.33 WX	**29.18F**
Mean	**33.35 A**	**29.66 B**	**27.77 C**	**25.49 D**	
P values		**Treatment Genotypes Treatment* Genotypes**		**0.0006** 0.0004** 0.0000****	

Table 3: Effect of salt stress on root fresh weight (g) of guava genotypes

Genotypes	NaCl treatments (dS m^{-1})				Mean
	0	8	12	16	
Apple Guava	10.77 ± 0.89 A	8.58 ± 0.67 E	7.48 ± 0.71 HI	6.32 ± 0.47 N-P	**8.28 A**
China Gola	8.83 ± 72 D	6.70 ± 0.54 K-M	5.56 ± 0.45 QR	5.06 ± 0.39 TU	**6.54 D**
Gola	9.05 ± 0.56 D	8.43 ± 0.61 EF	6.53 ± 0.42 MN	5.18 ± 0.53 ST	**7.30 C**
Golden Gola	8.52 ± 0.44 E	6.88 ± 0.35 K	5.66 ± 0.62 QR	4.95 ± 0.48 UV	**6.50 D**
Karela	10.56 ± 0.88 A	7.93 ± 0.74 G	6.61 ± 0.45 LM	5.75 ± 0.32 QR	**7.71 B**
Lal Gola	9.61 ± 0.61 C	7.67 ± 0.65 H	6.30 ± 0.54 OP	5.29 ± 0.58 S	**7.22 C**
Lal Surahi	7.93 ± 0.49 G	6.77 ± 0.55 KL	5.70 ± 0.67 QR	4.58 ± 0.33 W	**6.24 E**
MSS	8.27 ± 0.55 F	7.46 ± 0.68 HI	5.55 ± 0.73 R	4.73 ± 0.31VW	**6.50 D**
SSG	9.97 ± 0.85 B	7.91 ± 0.68 G	7.15 ± 0.56 J	6.12 ± 0.49 P	**7.79 B**
SSS	7.99 ± 0.72 G	6.37 ± 0.59 NO	5.57 ± 0.47 QR	4.88 ± 0.45 UV	**6.20 E**
Sufaida	8.55 ± 0.43 E	7.17 ± 0.63 J	5.79 ± 0.56 Q	4.65 ± 0.61 W	**6.54 D**
Surahi	7.41 ± 0.84 I	6.10 ± 0.63 P	5.27 ± 0.67 ST	4.17 ± 0.54 X	**5.74F**
Mean	**8.95 A**	**7.33 B**	**6.10 C**	**5.14 D**	
P values		**Treatment Genotypes Treatment* Genotypes**		**0.0000** 0.0000** 0.0000****	

MSS: Moti Sufaid Surahi, SSG: Sadabahar Sufaid Gola, SSS: Sadabahar Sufaid Surahi; The dataset denotes the averages derived from three distinct replicates. Means with letters represent statistical differences by LSD test ($P \leq 0.05$).

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Table 4: Effect of salt stress on shoot fresh weight (g) of guava genotypes

Genotypes	NaCl treatments (dS m^{-1})				Mean
	0	8	12	16	
Apple Guava	40.17 ± 1.87 A	36.25 ± 1.65 D	32.76 ± 1.75 HI	28.55 ± 1.43 P	**34.43 A**
China Gola	34.71 ± 1.54 F	31.67 ± 1.49 K	28.70 ± 1.55 P	25.47 ± 1.27 V	**30.14 D**
Gola	32.64 ± 1.32 IJ	29.41 ± 1.22 NO	27.33 ± 1.41 RS	25.61 ± 1.25 UV	**28.75 F**
Golden Gola	32.39 ± 1.41 J	29.58 ± 1.38 MN	27.11 ± 1.29 S	24.94 ± 1.43 W	**28.50 G**
Karela	36.63 ± 1.25 C	32.43 ± 1.46 J	29.58 ± 1.49 MN	27.37 ± 1.31 RS	**31.50 C**
Lal Gola	33.45 ± 1.12 G	30.42 ± 1.44 L	27.10 ± 1.35 S	24.23 ± 1.24 X	**28.80 F**
Lal Surahi	31.54 ± 1.37 K	27.58 ± 1.44 R	25.80 ± 1.35 U	23.71 ± 1.42 Y	**27.16 I**
MSS	33.04 ± 1.62 H	29.25 ± 1.34 O	26.39 ± 1.35T	23.31 ± 1.32 Z	**28.00 H**
SSG	38.32 ± 1.76 B	35.64 ± 1.54 E	32.94 ± 1.43 HI	29.73 ± 1.53 M	**34.16 B**
SSS	33.57 ± 1.67 G	30.60 ± 1.68 L	27.93 ± 1.44 Q	25.49 ± 1.33 V	**29.40 E**
Sufaida	28.75 ± 1.49 P	26.59 ± 1.44 T	24.52 ± 1.25 X	21.40 ± 1.21 B	**25.31 K**
Surahi	29.49 ± 1.48 M-O	26.30 ± 1.39 T	24.46 ± 1.28 X	22.64 ±1.33 A	**25.72 J**
Mean	**33.72 A**	**30.48 B**	**27.88 C**	**25.20 D**	
P values		Treatment Genotypes Treatment* Genotypes		0.0000** 0.0000** 0.0000**	

Table 5: Effect of salt stress on root dry weight (g) of guava genotypes

Genotypes	NaCl treatments (dS m^{-1})				Mean
	0	8	12	16	
Apple Guava	4.54 ± 0.32 A	2.91 ± 0.24 JK	2.29 ± 0.21 NO	1.87 ± 0.18 S	**2.90 B**
China Gola	3.23 ± 0.12 H	2.45 ± 0.14 M	1.96 ± 0.15 R	1.44 ± 0.23 V	**2.27 E**
Gola	3.54 ± 0.37 F	3.14 ± 0.32 I	2.35 ± 0.28 N	1.37 ± 0.14 W	**2.60 D**
Golden Gola	3.85 ± 0.24 D	2.85 ± 0.35 K	2.14 ± 0.16 P	1.46 ± 0.22 V	**2.57 D**
Karela	3.91 ± 0.29 C	2.94 ± 0.13 J	2.03 ± 0.11 Q	1.67 ± 0.19 U	**2.64 C**
Lal Gola	3.54 ± 0.33 F	3.15 ± 0.28 I	2.17 ± 0.24 P	1.45 ± 0.12 V	**2.57 D**
Lal Surahi	3.23 ± 0.35 H	2.34 ± 0.23 N	1.62 ± 0.16 U	1.04 ± 0.11 Z	**2.05 G**
MSS	2.74 ± 0.12 L	2.25 ± 0.22 O	1.85 ± 0.18 S	1.16 ± 0.13 Y	**2.00 H**
SSG	4.05 ± 0.39 B	3.75 ± 0.24 E	2.75 ± 0.28 L	2.35 ± 0.19 N	**3.22 A**
SSS	2.85 ± 0.25 K	2.24 ± 0.16 O	1.86 ±0.13 S	1.26 ± 0.22 X	**2.05 G**
Sufaida	3.45 ± 0.35 G	2.33 ± 0.18 N	1.75 ± 0.10 T	1.04 ± 0.07 Z	**2.14 F**
Surahi	2.24 ± 0.18 O	1.44 ± 0.13 V	0.84± 0.04 A	0.64 ± 0.05 B	**1.29 I**
Mean	**3.43 A**	**2.65 B**	**1.96 C**	**1.39 D**	
P values		**Treatment** **Genotypes** **Treatment* Genotypes**		**0.0000**** **0.0000**** **0.0000****	

MSS: Moti Sufaid Surahi, SSG: Sadabahar Sufaid Gola, SSS: Sadabahar Sufaid Surahi

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Table 6: Effect of salt stress on shoot dry weight (g) of guava genotypes

Genotypes	NaCl treatments (dS m^{-1})				Mean
	0	8	12	16	
Apple Guava	11.52 ± 0.95 A	9.94 ± 0.89 E	8.84 ± 0.88 M	8.54 ±0.76 O	**9.71 A**
China Gola	9.36 ± 0.75 I	8.58 ± 0.66 O	7.78 ± 0.69 S	7.16 ± 0.77 X	**8.22 F**
Gola	9.93 ± 0.65 E	8.75 ± 0.78 N	8.34 ± 0.74 P	7.64 ± 0.67 T	**8.66 D**
Golden Gola	10.03 ± 0.81 D	8.93 ± 0.76 L	7.85 ± 0.69 R	7.26 ± 0.55 W	**8.52 E**
Karela	10.84 ± 0.89 C	9.92 ± 0.88 E	9.26 ± 0.72 J	7.65 ± 0.87 T	**9.41 C**
Lal Gola	9.43 ± 0.78 H	8.24 ± 0.67 Q	7.81 ± 0. 65 RS	7.23 ± 0.63 W	**8.18 G**
Lal Surahi	9.26 ± 0.54 J	8.74 ± 0.57 N	6.95 ± 0.51 Y	5.94± 0.49 C	**7.72 H**
MSS	9.64 ± 0.66 G	7.61 ± 0.78 T	6.74 ± 0.58 Z	5.94 ± 0.43 C	**7.48 J**
SSG	11.04 ± 0.95 B	9.84 ± 0.83 F	9.44 ± 0.74 H	8.34 ± 0.55 P	**9.67 B**
SSS	9.36 ± 0.65 I	8.54 ± 0.53 O	6.75 ± 0.64 Z	5.69 ± 0.48 E	**7.58 I**
Sufaida	8.94 ± 0.78 L	7.35 ± 0.64 V	6.94 ± 0.45 Y	6.26 ± 0.44 B	**7.37 K**
Surahi	9.13 ± 0.77 K	7.46 ± 0.54 U	6.55 ± 0.45 A	5.84 ± 0.42 D	**7.24 L**
Mean	**9.87 A**	**8.66 B**	**7.77 C**	**6.96 D**	
P values		**Treatment** **Genotypes** **Treatment*Genotypes**		**0.0000**** **0.0000**** **0.0000****	

MSS: Moti Sufaid Surahi, SSG: Sadabahar Sufaid Gola, SSS: Sadabahar Sufaid Surahi

The dataset denotes the averages derived from three distinct replicates. Means with letters represent statistical differences by LSD test (P ≤ 0.05).

3.2. Physiological traits

The results showed that salinity stress affected the physiological characteristics (chlorophyll contents, stomatal conductance, photosynthetic rate, transpiration rate, and water use efficiency) of all the guava genotypes.

The results indicated that the "SSG" genotype exhibited the least reduction in chlorophyll content (27.45 mg/cm^2). On the other hand, the "MSS" genotype showed the highest decline (13.87 mg/cm^2), followed by the "Surahi" genotype (14.65 mg/cm^2). The most significant decrease in chlorophyll content was observed at a salinity level of 16.0 dS m^{-1} (13.0 mg/cm^2), compared to the control treatment (26.19 mg/cm^2). Furthermore, the interaction between genotype and salinity was also shown to be significant. The genotype "SSG" exhibited the least reduction of 51%, whereas the "Surahi" genotype displayed the highest reduction (162%). There was a significant reduction in stomatal conductance at a salinity level of 16.0 dS m^{-1}. The results indicated that the genotype "Apple Guava" exhibited the highest stomatal conductance (0.12 µmol $m^{-2}s^{-1}$), followed by "SSG" (0.11 µmol $m^{-2}s^{-1}$), which was statistically similar to "Lal Gola". Within the different treatments, the minimal stomatal conductance of 0.04 µmol $m^{-2}s^{-1}$ was seen under a salinity level of 16.0 dS m^{-1}, which was much lower compared to the control treatment (0.13 µmol $m^{-2}s^{-1}$). The results also indicated that the interaction between genotype and salinity was significant. The results indicated that the "Apple Guava" genotype exhibited the highest transpiration rate (1.60 µmol H_2O $m^{-2}s^{-1}$) which was statistically similar to the "SSG"

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genotype. On the other hand, the "Surahi" genotype had the lowest transpiration rate (0.88 µmol H_2O $m^{-2}s^{-1}$), which was comparable to the "MSS" genotype (1.03 µmol H_2O $m^{-2}s^{-1}$). The treatment with a salinity level of 16.0 dS m^{-1} resulted in the lowest transpiration rate (0.84 µmol H_2O $m^{-2}s^{-1}$), compared to the control group which had a transpiration rate (1.84 µmol H_2O $m^{-2}s^{-1}$). Furthermore, the data indicated that the interaction between genotype and salinity was also statistically significant. Similarly, the photosynthetic rate was significantly reduced at a salinity level of 16.0 dS m^{-1}. The results indicated that the "Apple Guava" genotype had the lowest reduction in photosynthetic rate (9.60 µmol CO_2 $m^{-2}s^{-1}$), followed by "Golden Gola" (8.31 µmol CO_2 $m^{-2}s^{-1}$). A significant reduction was observed in the "Sufaida" genotype (4.18 µmol CO_2 $m^{-2}s^{-1}$), followed by the "Lal Surahi" genotype (4.46 µmol CO_2 $m^{-2}s^{-1}$). Among the different treatments, the one with a salinity level of 16.0 dS m^{-1} showed the lowest photosynthetic rate, measuring 25.20 µmol CO_2 $m^{-2}s^{-1}$, compared to the control treatment which had a rate of 33.72 µmol CO_2 $m^{-2}s^{-1}$. Furthermore, the data also indicated that the interaction between genotype and salinity was statistically significant.

For the water use efficiency, the results indicated that the "Karela" genotype had the lowest reduction in water use efficiency (6.20 Pn/E), followed by "SSG" (5.88 Pn/E), which was statistically similar to "Golden Gola". The highest decline in water use efficiency was observed in the "Sufaida" genotype (3.80 Pn/E), which was statistically similar to the "Lal Surahi" genotype (3.63 Pn/E). The treatment with a salinity level of 16.0 dS m^{-1} had the lowest water use efficiency, measured at 4.35 Pn/E, compared to the control treatment which had a water use efficiency of 5.43 Pn/E. Similarly, the data indicated that the interaction between genotype and salinity was also statistically significant.

Table 7: Effect of salt stress on chlorophyll contents (SPAD values) (mg/cm^2) of guava genotypes

Genotypes	**NaCl treatments (dS m^{-1})**				**Mean**
	0	**8**	**12**	**16**	
Apple Guava	30.52 ± 1.34 BC	25.89 ± 1.22 G	21.68 ± 1.15 L	14.46 ± 1.18 R	**23.14 C**
China Gola	24.73 ± 1.20 H	20.39 ± 1.22 M	14.21 ± 1.24 R	12.42 ± 1.01 T	**17.94 G**
Gola	24.70 ± 1.20 H	21.50 ± 1.32 L	16.50 ±1.27 P	11.93 ± 1.12 U	**18.66 F**
Golden Gola	30.12 ± 1.23 C	26.26 ± 1.28 FG	22.38 ± 1.25 K	16.55 ± 1.18 P	**23.83 B**
Karela	30.66 ± 1.54 B	23.17 ± 1.36 IJ	19.44 ± 1.34 N	15.63 ± 1.27 Q	**22.22 D**
Lal Gola	27.64 ± 1.13 E	22.34 ± 1.22 K	19.58 ± 1.36 N	14.61 ± 1.12 R	**21.04 E**
Lal Surahi	26.63 ± 1.12 F	19.58 ± 1.14 N	15.48 ± 1.22 Q	10.57 ± 1.27 V	**18.06 G**
MSS	19.80 ± 1.25 N	15.27 ± 1.22 Q	11.65 ± 1.10 U	8.76 ± 0.91 W	**13.87 K**
SSG	32.48 ± 1.34 A	29.27 ± 1.33 D	26.54 ± 1.25 F	21.54 ± 1.28 L	**27.45 A**
SSS	23.57 ± 1.16 I	18.59 ± 1.22 O	15.34± 1.15 Q	10.49 ± 1.11 V	**17.00 H**
Sufaida	22.79 ± 1.24 J	15.54 ± 1.19 Q	11.56 ± 1.10 U	8.71 ± 0.84 W	**14.65 J**
Surahi	20.65 ± 1.34 M	16.50 ± 1.14 P	13.62 ± 1.10 S	10.37 ± 1.10 V	**15.29 I**
Mean	**26.19 A**	**21.19 B**	**17.33 C**	**13.00 D**	
P values		**Treatment** **Genotypes** **Treatment* Genotypes**		**0.0006**** **0.0008**** **0.0000****	

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Table 8: Effect of salt stress on stomatal conductance (μmol $m^{-2}s^{-1}$) of guava genotypes

Genotypes	NaCl treatments (dS m^{-1})				Mean
	0	8	12	16	
Apple Guava	0.18 ± 0.03 A	0.14 ± 0.02 C	0.11 ± 0.02 E	0.06 ± 0.01 HI	**0.12 A**
China Gola	0.16 ± 0.04 B	0.11 ± 0.03 E	0.07 ± 0.01 GH	0.04 ± 0.01 JK	**0.09 C**
Gola	0.14 ± 0.03 C	0.09 ± 0.02 F	0.05 ± 0.01 IJ	0.03 ± 0.00 L-N	**0.08 D**
Golden Gola	0.14 ± 0.04 C	0.11 ± 0.03 E	0.07 ± 0.02 GH	0.04 ± 0.01 JK	**0.09 C**
Karela	0.15± 0.03 C	0.08 ± 0.02 F	0.06 ± 0.01 HI	0.03 ± 0.00 K-M	**0.08 D**
Lal Gola	0.15 ± 0.04 BC	0.12 ± 0.03 DE	0.08 ± 0.02 FG	0.06 ± 0.01 HI	**0.10 B**
Lal Surahi	0.11 ± 0.02 E	0.08 ± 0.02 FG	0.05 ± 0.01 IJ	0.03 ± 0.00 L-N	**0.07 E**
MSS	0.12 ± 0.03 DE	0.08 ± 0.01 FG	0.04 ± 0.01 KL	0.02 ± 0.00 NO	**0.06 E**
SSG	0.16 ± 0.04 B	0.12 ± 0.03 DE	0.08 ± 0.02 F	0.06 ± 0.01 HI	**0.11 B**
SSS	0.12 ± 0.03 D	0.08 ± 0.01 F	0.06 ± 0.01 HI	0.04 ± 0.00 KL	**0.08 D**
Sufaida	0.11 ± 0.02 E	0.08 ± 0.01 FG	0.05 ± 0.01 IJ	0.02 ± 0.00 MN	**0.07 E**
Surahi	0.08 ± 0.01 F	0.06 ± 0.01 HI	0.03 ± 0.01 K-M	0.01± 0.00 O	**0.05F**
Mean	**0.13 A**	**0.09 B**	**0.06 C**	**0.04D**	
P values		**Treatment** **Genotypes** **Treatment* Genotypes**		**0.0003**** **0.0000**** **0.0000****	

Table 9: Effect of salt stress on transpiration rate (μmol H_2O $m^{-2}s^{-1}$) of guava genotypes

Genotypes	NaCl treatments (dS m^{-1})				Mean
	0	8	12	16	
Apple Guava	2.04 ± 0.11 B	1.74 ± 0.08 F	1.44 ± 0.09 L	1.16 ± 0.07 I	**1.60 A**
China Gola	1.88 ± 0.10 DE	1.54 ± 0.09 H	1.12 ± 0.07 L	0.84 ± 0.04 O	**1.34 C**
Gola	1.87 ± 0.09 DE	1.44 ± 0.06 I	1.15 ± 0.07 L	0.92 ± 0.06 N	**1.34 C**
Golden Gola	1.95 ± 0.10 C	1.52 ± 0.07 H	1.26 ± 0.05 K	0.94 ± 0.03 N	**1.41 B**
Karela	1.93 ± 0.08 CD	1.54 ± 0.07 H	1.14 ± 0.05 L	1.05 ± 0.04 M	**1.41 B**
Lal Gola	1.92 ± 0.09 CD	1.43 ± 0.06 I	1.15 ± 0.05 L	0.91 ± 0.03 N	**1.35 C**
Lal Surahi	1.65 ± 0.08 G	1.27 ± 0.07 K	1.03 ± 0.04 M	0.77 ± 0.03 PQ	**1.18 E**
MSS	1.74 ± 0.06 F	1.02 ± 0.04 M	0.83 ± 0.03 OP	0.54 ± 0.03 R	**1.03 G**
SSG	2.15 ± 0.11 A	1.64 ± 0.07 G	1.36 ± 0.06 J	1.14 ±0.06 L	**1.57 A**
SSS	1.85 ± 0.08 E	1.14 ± 0.05 L	1.05 ± 0.04 M	0.84 ± 0.03 O	**1.22 D**
Sufaida	1.75 ± 0.09 F	1.35 ± 0.06 J	0.93 ± 0.04 N	0.54 ± 0.02 R	**1.14 F**
Surahi	1.40 ± 0.08 IJ	0.95 ± 0.07 N	0.74 ± 0.04 Q	0.42 ± 0.02 S	**0.88 H**
Mean	**1.84 A**	**1.38 B**	**1.10 C**	**0.84 D**	
P values		**Treatment** **Genotypes** **Treatment* Genotypes**		**0.0000**** **0.0000**** **0.0000****	

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Table 10: Effect of salt stress on photosynthetic rate (μmol CO_2 $m^{-2}s^{-1}$) of guava genotypes

Genotypes	NaCl treatments (dS m^{-1})				Mean
	0	8	12	16	
Apple Guava	13.67 ± 1.09 A	10.68 ± 0.91 D	7.64 ± 0.87 G	4.24 ± 0.32 JK	**9.06 A**
China Gola	9.39 ± 0.94 E	7.54 ± 0.73 G	4.61 ± 0.33 J	2.88 ± 0.21 MN	**6.10 E**
Gola	11.54 ± 1.11 C	8.40 ± 0.88 F	6.43 ± 0.52 H	3.39 ±0.22 L	**7.44 D**
Golden Gola	11.57 ± 0.99 C	9.44 ± 0.87 E	7.64 ± 0.54 G	4.61 ± 0.31 J	**8.31 B**
Karela	12.66 ± 1.21 B	9.59 ± 1.03 E	7.72 ± 0.91 G	5.57± 0.62 I	**8.88 A**
Lal Gola	11.57 ± 0.98 C	8.68 ± 0.74 F	5.62 ± 0.34 I	4.39 ± 0.33 JK	**7.56 D**
Lal Surahi	7.64 ± 0.61 G	4.28 ± 0.57 JK	3.36 ± 0.44 L	2.55 ± 0.31 NO	**4.46 I**
MSS	7.66 ± 0.74 G	5.71 ± 0.65 I	3.42 ± 0.33 L	2.41 ± 0.25 O	**4.80 H**
SSG	11.79 ± 1.13 C	9.44 ± 0.88 E	6.64 ± 0.54 H	4.45 ± 0.39 JK	**8.08 C**
SSS	8.63 ± 0.64 F	6.49± 0.44 H	4.56 ± 0.28 JK	3.40 ± 0.28 L	**5.77 F**
Sufaida	6.59 ± 0.75 H	4.28 ± 0.37 JK	3.21 ± 0.44 LM	2.63 ± 0.36 NO	**4.18 J**
Surahi	8.42 ± 0.77 F	5.70 ± 0.69 I	4.19 ± 0.41 K	2.50 ± 0.29 NO	**5.20 G**
Mean	**10.09 A**	**7.52 B**	**5.42 C**	**3.58 D**	
P values		**Treatment** **Genotypes** **Treatment* Genotypes**		**0.0000**** **0.0000**** **0.0000****	

MSS: Moti Sufaid Surahi, SSG: Sadabahar Sufaid Gola, SSS: Sadabahar Sufaid Surahi. The dataset denotes the averages derived from three distinct replicates. Means with letters represent statistical differences by LSD test ($P \leq 0.05$).

Table 11: Effect of salt stress on water use efficiency (WUE) (Pn/E) of guava genotypes

Genotypes	NaCl treatments (dS m^{-1})				Mean
	0	8	12	16	
Apple Guava	6.69 ± 0.32 A	6.11 ± 0.30 B-E	5.28 ± 0.25 J-L	3.65 ± 0.16 T-W	**5.43 C**
China Gola	4.99 ± 0.28 K-M	4.90 ± 0.31 K-N	4.10 ± 0.27 Q-S	3.42 ± 0.21 V-X	**4.35 F**
Gola	6.15 ± 0.41 B-D	5.83 ± 0.33 C-I	5.58 ± 0.35 G-J	3.66 ± 0.19 S-W	**5.30 C**
Golden Gola	5.93 ± 0.33 C-H	6.21 ± 0.48 BC	6.07 ± 0.42 C-F	4.91 ± 0.27 K-N	**5.78 B**
Karela	6.53 ± 0.47 AB	6.21 ± 0.49 BC	6.78 ± 0.49 A	5.29 ± 0.32 JK	**6.20 A**
Lal Gola	6.01 ± 0.42 C-G	6.04 ± 0.42 C-F	4.89 ± 0.22 K-N	4.80 ± 0.21 M-O	**5.43 C**
Lal Surahi	4.61 ± 0.31 OP	3.37 ± 0.22 V-X	3.24 ± 0.15 WX	3.32 ± 0.11 V-X	**3.63 G**
MSS	4.39 ± 0.28 O-Q	5.56 ± 0.25 H-J	4.14 ± 0.17 QR	4.48 ± 0.18 O-Q	**4.64 E**
SSG	5.98 ± 0. 35 C-H	6.00 ± 0.38 C-G	5.65 ± 0.13 F-J	5.91 ± 0.43 C-I	**5.88 B**
SSS	4.66 ± 0.28 M-P	5.67 ± 0.38 E-J	4.34 ± 0.22 PQ	4.05 ± 0.29 Q-T	**4.68 E**
Sufaida	3.75 ± 0.18 R-V	3.17 ± 0.16 X	3.45 ± 0.16 U-X	4.84 ± 0.25 L-N	**3.80 G**
Surahi	5.47 ± 0.34 IJ	5.76 ± 0.23 D-I	4.88 ± 0.24 K-N	3.88 ± 0.20 R-U	**4.99 D**
Mean	**5.43 A**	**5.40 A**	**4.86 B**	**4.35 C**	
P values		**Treatment** **Genotypes** **Treatment* Genotypes**		**0.0005**** **0.0003**** **0.0002****	

MSS: Moti Sufaid Surahi, SSG: Sadabahar Sufaid Gola, SSS: Sadabahar Sufaid Surahi

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The dataset denotes the averages derived from three distinct replicates. Means with letters represent statistical differences by LSD test ($P \leq 0.05$).

4. DISCUSSION

Screening for salt tolerance is more reliable during the initial stage than mature development stage, since it requires less effort and is more cost-effective (Sarwar et al., 2017). This study assessed the performance of 12 guava genotypes under different levels of salinity (0, 8.0, 12.0, and 16.0 dS m^{-1}). The results indicated that increased salt concentration negatively impacts the morphological and physiological traits of the guava plants (Table 1-11). The genotypes "SSG" and "AG" were identified as highly salt tolerant due to their minor decreases in shoot and root length, as well as their fresh and dry weight (Table 1-6). In contrast, the genotypes "Surahi" and "Sufaida" showed a notable decrease in plant biomass and were classified as salt-sensitive genotypes. Sa et al. (2016) also found that higher saline levels have a negative impact on the growth characteristics of guava genotypes. Desai and Singh, (1980) also reported similar findings, indicating that salt treatments inhibited the development features of guava. The production of fresh or dry mass is hindered by factors such as instability in metabolic pathways, imbalances in nutritional intake, the inability to maintain turgor, or the presence of ionic toxicity (Hasanuzzaman et al., 2013; Shahid et al., 2020). The reduction in cell turgor is caused by the water potential in saline soil, leading to a reduction in cell elongation (Sarwar et al., 2021; Soni et al., 2023).

The chlorophyll levels also decreased in response to excessive salt stress. The chlorophyll contents had a significant decrease at a salinity level of 16.0 dS m^{-1}. The findings of our study align with previous research, indicating that exposure to high salt stress led to a reduction in chlorophyll levels in guava plants (Abrar et al., 2022). Prior studies have demonstrated reductions in chlorophyll content in guava that were treated with NaCl (Silva et al., 2017). Similar results were reported in soybean, where a high concentration of salt caused a drop in chlorophyll levels (Patil et., 2016). The decrease in chlorophyll content is likely linked to the breakdown of the grana and stroma lamellae structure within chloroplasts (Zhu et al., 2022). Moreover, the catalytic function of chlorophyllase (enzymes that degrade chlorophyll) is enhanced, resulting in an accelerated degradation of chlorophyll. The occurrence can be ascribed to the significant accumulation of harmful ions, such as Na^{+}, within the leaf tissues (Askari et al., 2021). The higher salt concentration causes a nutritional imbalance and ionic toxicity, leading to a decrease in the efficiency of enzymes involved in photosynthesis. Therefore, a decrease in the process of photosynthesis ultimately leads to a decrease in the overall amount of plant biomass (Saddiq et al., 2021).

The physiological traits including photosynthetic rate, transpiration rate, stomatal conductance and water use efficiency of the guava genotypes exhibited a decline when exposed to high salinity stress (Table 8-11). However, the "Surahi" genotype displayed the highest sensitivity to salt stress and showed a significant decrease in physiological

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markers. Previous investigations have also shown that a higher quantity of salt has a harmful effect on the physiological parameters of "Paluma" guava seedlings (Xavier et al., 2022). The decrease in photosynthetic activity could be caused by changes in stomatal conductance and transpiration rate (Lu et al., 2021). The observed results may be attributed to the fact that salinity causes osmotic stress, whereas extended exposure to high salt concentrations can be associated with ionic toxicity, leading to cellular damage in plants (Kamran et al., 2019) and exerting a substantial impact on the rubisco activity. The detrimental influence on plant growth can be due to both the irregular functioning of stomata and the limited supply of intercellular CO2. These factors further enhance the occurrence of photochemical damage (Sachdev et al., 2023).

When exposed to high saline levels, the guava genotypes exhibited a reduction in water use efficiency (WUE). However, the tolerant genotypes displayed a somewhat higher WUE compared to the sensitive genotypes, as shown in Table 11. The maintenance of efficient stomatal conductance may serve as a primary factor contributing to the higher WUE observed in salt tolerant guava genotypes. The high stomatal conductance of salt-tolerant genotypes enhances the efficiency of photosynthetic activities (Arif et al., 2020). As a result, this improved conversion process leads to a general enhancement in plant water use efficiency (WUE) (Hafez and Farig, 2019).

5. CONCLUSION

The outcomes of this research study presented that salinity stress negatively impacted the guava genotypes thereby reducing the growth and physiological traits. However, the genotype “SSG and “Apple Guava” performed well in terms of growth and physiological parameters under the highest salinity level 16 dS m^{-1} and were classified as tolerant genotypes while the genotypes “Surahi” and “Sufaida” depicted minimum results and were classified as sensitive genotypes.

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