



RESEARCH ARTICLE

Comparative study of seed germination and seedling development of tomato genotypes under different salinity levels

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Abstract

Salinity is one of the important constraints that militate against crop production in salt affected areas worldwide. Tomato being one of the important vegetable crops, has been studied under salinity stress at seedling stage in search of salt tolerant genotypes. In this study, seedlings of twelve tomato genotypes were treated with four levels of sodium chloride (NaCl) (0, 50, 100 and 150 mM) and characterised for germination percentage, seedling length and lengths of shoot and root. The data revealed that as the salt concentrations increased, the percentage of germination and seedling length along with shoot and root length decreased, while mean germination time increased. Remarkable variation existed among the genotypes in their response to salt stress. Under high salt stress, Pusa Ruby and Giant Ferry manifested the highest increase in germination percentage, seedling growth and vigour index. These two genotypes had the highest stress tolerance indices which revealed higher stress tolerance potential. The results suggested the existence of genetic variation for salinity tolerance among studied tomato genotypes. Some genotypes like Pusa Ruby and Giant Ferry may be identified and utilised in breeding programmes for developing salt tolerant tomato cultivars. The study described genotypic variations at seedling stage and their responses to saline conditions, which are critical for seedling establishment and plant growth under saline environments.

Keywords: genotypes; germination; salinity; sodium chloride; stress tolerance; tomato

Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most widely cultivated and nutritionally important vegetable crops worldwide. It is grown throughout the India due to its ability to grow in a variety of soil types (1). Tomato ranks among the most extensively cultivated vegetable crops worldwide (2). Not only is it a source of income for smallholder farmers, but it also provides job opportunity for those in the manufacturing of tomato products (3). Tomatoes can be eaten in their fresh form or can be incorporated into a variety of processed tomato products, including tomato soups, sauces, pastes, jellies, pickles, ketchup, jams and tomato juice. Tomatoes are also well known for their high levels of antioxidants, earning the fruit the nickname of love apple. The tomato is a vegetable that is recognised for its significance, popularity and nutritional value to humans; it has become one of the most popular vegetables in the world (4). Tomato is a rich source of minerals, organic acids, antioxidants, phenolic compounds, vitamins and trace elements, while being low in fat and cholesterol-free. Regular consumption of tomato and tomato products helps reduce the risk of cardiovascular diseases and certain cancers (5-7).

Salinity is another a major abiotic stress affecting agricultural productivity. High levels of salinity significantly reduce the productivity of numerous crops, especially vegetables. Knowledge of the salt tolerance of vegetable plants is essential to increasing the

productivity and profitability of these crops in coastal regions with saline soils. The tomato plant displays varying levels of tolerance to salinity, depending on the cultivar and growth stage of the plant (8-10). The response of tomato cultivars to varying salinity levels showed significant differences (11). Several key processes are affected by stress, including growth, chlorophyll content and germination (12). The stages of initiation of the crop include germination, emergence and early seedling growth, all of which are notably affected by salinity (13, 14). The overbearing absorption of ions leads to toxicity in the plant, resulting in decreased water imbibition between the seeds and their external environment, which in turn hinders the emergence of the primary root (15). The seed germination stage is paramount for establishing seedlings and ensuring a successful crop establishment (16). Salinity reduces both the dry and fresh weights of shoots and roots in tomato seedlings (17).

The inclusion of salt in the nutriment solution had a negative impact on tomato root and shoot development, plant height, potassium concentration and the potassium to sodium ratio (18). Salinity tolerance plays a crucial role throughout the lifespan of any species. Tomato genotypes exhibit a significant array of genetic variations regarding their tolerance to varying salt levels. Many commercial tomato varieties show resilience to moderate salinity levels (up to 2.5 dSm⁻¹) without experiencing substantial yield loss. The interaction between seedbed environment and varieties

significantly affects crop establishment during the early seedling stages, which is crucial for successful crop production in saline conditions. Addressing saline conditions in both greenhouse and field settings can incur significant costs and yield only temporary relief. In contrast, selecting and breeding for salt tolerance presents a strategic approach to mitigate the impacts of salinity and enhance production efficiency. Therefore, it is essential to develop cultivars of tomato that can tolerate saline conditions through breeding efforts. Identifying the sensitivity and tolerance levels of tomato genotypes is essential for breeding salt-tolerant cultivars (19). The genotypes that exhibit the least impact could serve as a valuable resource for enhancing salinity tolerance in tomato breeding (20, 21). The crops exhibit tolerance during the seedling stage and demonstrate enhanced salinity resistance as adults (22). Therefore, the present study was undertaken to evaluate the response of 12 tomato genotypes to increasing salinity levels during germination and seedling stages and to identify salt-tolerant genotypes for future breeding programs.

Materials and Methods

Experiment design and treatment

Tomato genotype seeds were obtained from the Indian Agricultural Research Institute (IARI) located in New Delhi, as well as from the Horticultural Research Station in Periyakulam, Tamil Nadu, India. Furthermore, germplasm was sourced from various regions of Tamil Nadu, India, with a focus on selecting only healthy and uniform seeds. Laboratory-grade sodium chloride (NaCl) was utilised to establish salinity conditions during seed germination and seedling growth, with the salt concentration quantified in millimoles (mM). Salinity stress was induced by the addition of NaCl at four varying concentrations: 0, 50, 100 and 150 mM. A factorial based completely randomised design (CRD) with 2 replication was used for the two-factor experiment, including 25 seeds for each replication. Due to the limited availability of seed material for certain genotypes and the large number of treatment combinations, the experiment was carried out with two replications. A total of 12 tomato genotypes (Madhana Palli, Kasi, Country Periyakulam, Polur, Pink Shade, Red Grape, Giant Ferry, Red Berry, Yellow Egg, Black Vernissage, Pusa Ruby, PKM1) were evaluated across four different NaCl concentration levels (0, 50, 100 and 150 mM).

In vitro sterilisation and germination of seeds

The Petri plate technique was utilised to carry out germination studies. Petri dishes measuring 15 cm diameter were employed to conduct germination studies. The items were meticulously cleaned, first with water, then with alcohol, dried in an oven and finally autoclaved. A consistent, even layer of absorbent cotton was placed on the underside of the germination paper prior to its arrangement in the Petri dishes. Seeds of uniform size were selected and surface sterilised to prevent any potential contamination. The seeds were washed with tap water, treated with 0.5 % mercuric chloride (HgCl₂) and rinsed using sterile distilled water. The 25 seeds were placed in each Petri dish. Solutions (10 mL) of four different concentrations were poured onto the surface of the medium. Concentrations of NaCl were set up in the Petri dishes. Petri dishes were placed in the laboratory at a room temperature of around 25.0 ± 2 °C. A control was maintained for each set by using distilled water.

Germination (%)

The ratio of germinated seeds to the total seeds designated for germination was recorded and the number of germinated seeds was subsequently converted to a percentage to determine the germination rate (23).

Germination (%) =

$$\frac{\text{Number of seeds germinated}}{\text{Total number of seeds placed in Petri dish}} \times 100 \quad \text{Eq. (1)}$$

Root length (cm)

The root length of all germinated seedlings from the respective treatments was measured using a scale, from the base of the shoot to the tip of the root and recorded in centimeters (cm).

Shoot length (cm)

The length of the shoot was assessed for all germinated seedlings across the respective treatments, utilising a measuring scale from the base of the shoot to the tip and the measurements were documented in cm.

Total seedling length (cm)

The total length is calculated by adding the length of the shoot to the length of the root, both measured in cm.

$$\text{Seedling length (cm)} = \text{Total length of shoot (cm)} + \text{Total length of root (cm)} \quad \text{Eq. (2)}$$

Seedling vigour index

The seedling vigour index (SVI I) has been calculated by using the method and expressed numerically by following the formula (24):

$$\text{Seedling vigour index (SVI I)} = \text{Germination (\%)} \times \text{Seedling length (cm)} \quad \text{Eq. (3)}$$

The germination percentage was multiplied by the dry weight of the seedlings to calculate the SVI II, which was then expressed as a whole number.

$$\text{Seedling vigour index (SVI II)} = \text{Germination (\%)} \times \text{Seedling dry weight (mg)} \quad \text{Eq. (4)}$$

Fresh weight (g)

The fresh weight of all germinated seedlings was recorded using a precision balance after gently wiping the salt solution or sterile distilled water with tissue paper and the average seedling weight in grams was calculated.

Dry weight (mg)

A precision balance was used to measure the total dry weight in milligrams after the identical set of seedlings that were used to record the fresh weight were stored in a hot air oven at 80 °C for 48 hr.

Root to shoot ratio

The measurement compares the length of the root and shoot. The calculation was performed utilising the established formula:

$$\text{Root to shoot ratio} = \frac{\text{Length of root (cm)}}{\text{Length of shoot (cm)}} \quad \text{Eq. (5)}$$

Root length stress tolerance index (%)

The measurement compares the root length of plants grown under stress conditions with that of plants grown under control conditions. The root length stress tolerance index (RLSTI) was calculated using the formula described below (25):

$$\text{Root length stress tolerance index} = \frac{\text{Root length of stressed plants (cm)}}{\text{Root length of control plants (cm)}} \times 100 \quad \text{Eq. (6)}$$

Plant height stress tolerance index (%)

The measurement compares the height of plants grown under stress conditions with that of plants grown under control conditions. The plant height stress tolerance index (PHSTI) was calculated using the formula described below (26):

$$\text{Plant height stress tolerance index} = \frac{\text{Plant height of stressed plants (cm)}}{\text{Plant height of control plants (cm)}} \times 100 \quad \text{Eq. (7)}$$

Statistical analysis

Data were analysed using a two-factor factorial CRD. An analysis of variance was conducted to assess the impacts of genotype, treatment and their interaction. The significance was assessed through an *F*-test at $p \leq 0.05$ and the critical difference (CD) values were computed for the purpose of mean comparison. Standard error of difference (SE(d)), standard error of mean (SEm) and coefficient of variation (CV %) were calculated as well.

Results and Discussion

Germination percentage (%)

Germination of different genotypes was significantly affected by varying levels of salinity (Table 1 and 2; Fig. 1). An increase in NaCl concentration resulted in decrease in germination percentage of all the genotypes tested. Among the studied genotypes, highest germination (%) was recorded in Pusa Ruby (80 %) and Giant Ferry (78 %) at salinity concentration of 50 mM. At increased salinity levels of 100 mM and 150 mM, Pusa Ruby (76 %) and Giant Ferry (74 %) were found to perform best, followed by Pusa Ruby (70 %) and Giant Ferry (64 %). Yellow Egg exhibited minimum germination at 13 % followed by Pink Shade at 14 % and Black Vernissage at 18 %. At low salinity levels, certain genotypes continued to germinate, but at greater concentrations, germination was significantly reduced. This pattern indicates that seeds may be able to tolerate low salinity levels, but not high enough to disturb the physiological processes needed for germination due to the absence of osmotic or ionic stress. The decline in germination at increased salt concentrations is due to limited water absorption, ion toxicity and disruptions in the enzymatic and hormonal processes essential for reserve mobilisation and seedling establishment (27). The exceptional performance of specific genotypes suggests the potential engagement of adaptive mechanisms, including osmotic adjustment, effective ion management and improved antioxidant defence, which may aid in sustaining cellular function in saline environments. The observed genotypic variance indicates heterogeneity across tomato genotypes in their capacity to withstand salt-induced stress, despite the processes not being explicitly assessed in this study. Prior research has indicated a decrease in germination percentage and a postponement in germination associated with elevated salt levels in tomatoes (28, 29). This work expands on

Table 1. Effect of salinity on germination % and root length in tomato genotypes

Genotype	Germination (%)					Root length (cm)				
	0 (mM)	50 (mM)	100 (mM)	150 (mM)	Mean	0 (mM)	50 (mM)	100 (mM)	150 (mM)	Mean
Madhana Palli	86	62	46	26	55.00	21.85	21.43	19.85	4.80	16.98
Kasi	98	66	50	42	64.00	19.24	21.23	20.70	11.85	18.25
Country Periyakulam	62	34	26	24	36.50	27.46	13.70	10.10	9.80	15.26
Polur	74	62	56	26	54.50	19.10	14.13	8.70	10.50	13.10
Pink Shade	70	30	20	14	33.50	20.50	14.20	14.00	13.90	15.65
Red Grape	70	34	26	18	37.00	20.35	12.40	16.00	15.30	16.01
Giant Ferry	98	78	74	64	78.50	27.94	24.86	13.73	8.43	18.74
Red Berry	58	34	26	22	35.00	19.26	20.90	20.10	11.70	17.99
Yellow Egg	62	30	18	13	30.75	20.45	15.10	14.60	13.50	15.91
Black Vernissage	54	42	22	18	34.00	20.35	12.46	16.00	15.30	16.02
Pusa Ruby	98	80	76	70	81.00	27.94	22.36	20.36	14.73	21.34
PKM1	90	68	50	34	60.50	21.10	17.00	16.50	8.50	15.77
Mean	76.66	51.66	39.16	32.58		22.12	17.48	15.88	11.52	
	SEm±				CD (5 %)	SEm±				CD (5 %)
EC	0.69				1.98	0.16				0.45
Genotypes	1.21				3.44	0.27				0.79
Interaction (E × G)	2.42				6.88	0.55				1.58

EC: electrical conductivity; CD: critical difference at 5 % level of significance; SEm±: standard error of mean; E × G: genotype × electrical conductivity interaction.

Table 2. Promising tomato genotypes for the quantitative traits' summary table of salinity tolerance

Genotypes	Germination (%)	Root length (cm)	Shoot length (cm)	Seedling length (cm)	Seedling vigour index I	Seedling vigour index II
Madhana Palli	55.00	16.98	5.07	22.05	360.29	2855.70
Kasi	64.00	18.25	6.24	24.49	1616.78	5048.79
Country Periyakulam	36.50	15.26	4.09	19.35	829.97	492.23
Polur	54.50	13.10	3.94	17.05	991.37	2706.49
Pink Shade	33.50	15.65	4.30	19.95	734.30	1555.94
Red Grape	37.00	16.01	4.00	20.01	791.79	2144.89
Giant Ferry	78.50	18.74	5.42	24.16	1995.60	4806.95
Red Berry	35.00	17.99	4.32	22.31	804.78	1622.92
Yellow Egg	30.75	15.91	5.25	21.16	701.98	1901.18
Black Vernissage	34.00	16.02	5.57	21.58	761.72	1917.65
Pusa Ruby	81.00	21.34	5.32	26.67	9710.36	4445.93
PKM1	60.50	15.77	4.67	20.45	1342.38	2094.10



Fig. 1. Effect of salinity stress on germination in tolerant and susceptible tomato genotypes.

previous findings by showing that tolerance responses are dependent on genotype and by identifying genotypes that exhibit comparatively increased germination and seedling vigour index under salty circumstances. The observation that germination remained mostly unaffected at lower salt levels but decreased markedly at elevated concentrations further suggests the presence of threshold-dependent salinity responses in the initial phases of tomato growth.

The highest germination percentage, was observed under control conditions, followed by a decline in salinity stress. All genotypes showed varied degrees of salinity tolerance. Pusa Ruby and Giant Ferry were found most tolerant followed by other genotypes.

Root, shoot and seedlings length (cm)

The findings regarding the average length of the root, shoot and seedlings (Table 1, 2 and 3; Fig. 2) indicated that all twelve genotypes demonstrated inhibition as NaCl concentration increased, especially at elevated salinity levels (100 and 150 mM).

The highest root length (21.34 cm) was recorded in Pusa Ruby followed by Giant Ferry (18.74 cm) and Kasi (18.25 cm) under salinity stress. At the other end of spectrum, the three

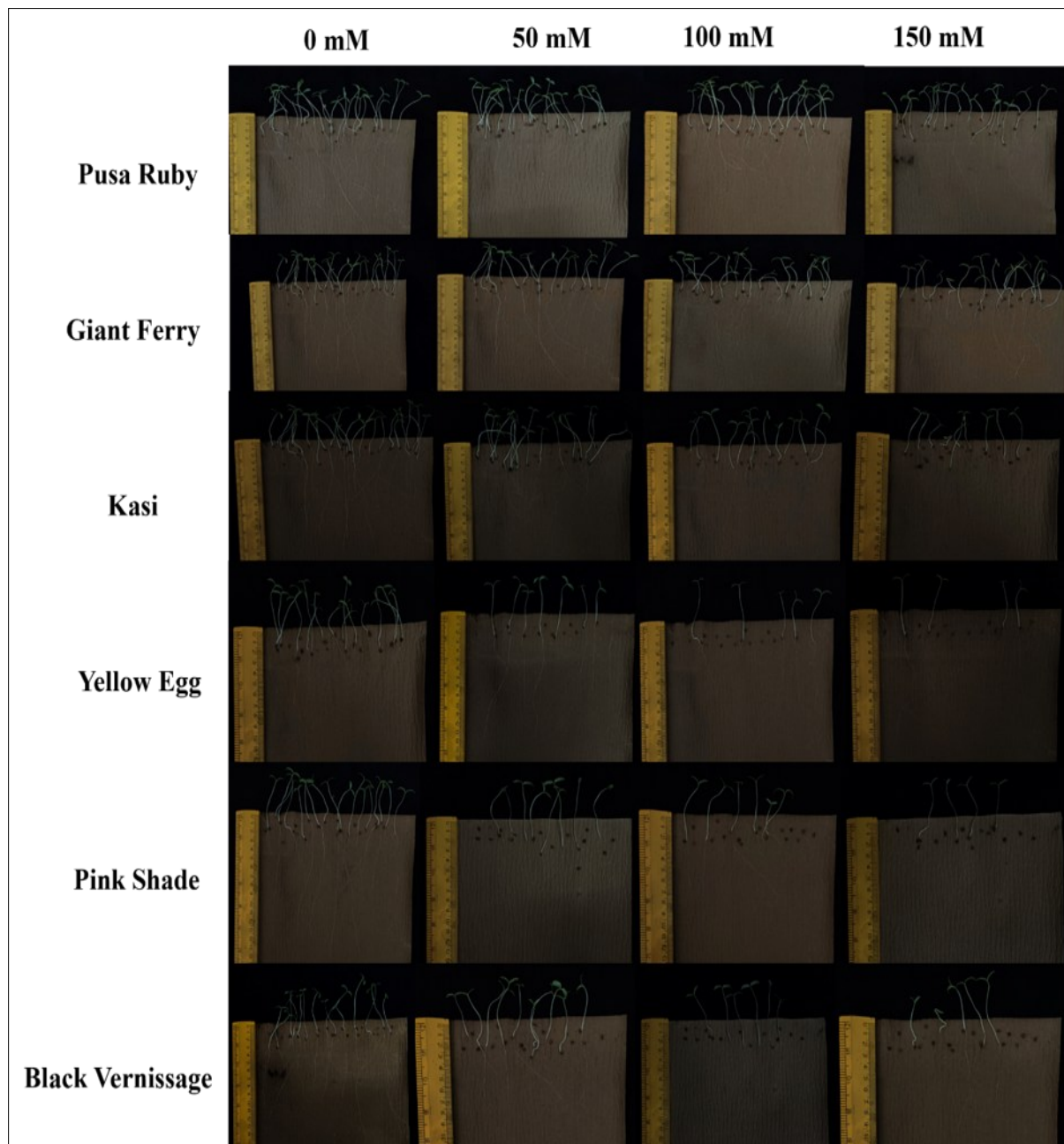
varieties, namely Country Periyakulam (15.26 cm), Pink Shade (15.65 cm) and PKM1 (15.77 cm) showed marked reduction in root length under salt stress. A study observed that salt stress can instantly inhibit root growth. High salinity may inhibit root and shoot elongation due to slowing down the water uptake by the plant (30). Similarly, the length of the shoots decreased with increasing salinity levels. The three genotypes i.e., Kasi (6.24 cm), Black Vernissage (5.57 cm) and Giant Ferry (5.42 cm), had higher shoot length under salinity stress. In contrast, significantly reduced shoot lengths were recorded in Polur (3.94 cm), Red Grape (4.00 cm) and Country Periyakulam (4.09 cm) under salinity stress. However, the decrease in root length was more pronounced than the decrease in shoot length, suggesting that roots are more sensitive than shoots to osmotic and ionic stress and that ion regulation and osmotic adjustment may allow for sustained growth in some genotypes. Similar findings have been described for tomatoes under salt stress (31). Salt stress affected growth of tomato roots more severely than shoot growth (31). Growth of roots and shoots of different plant species were affected differently by salt stress as previously (32, 33). Roots were found to be more sensitive than shoot of seedlings.

In general, Pusa Ruby had the highest seedling length (26.67 cm) followed by Kasi (24.49 cm) and Giant Ferry (24.16 cm).

Table 3. Effect of salinity on shoot length and total seedling length in tomato genotypes

Genotypes	Shoot length (cm)					Total seedling length (cm)				
	0 (mM)	50 (mM)	100 (mM)	150 (mM)	Mean	0 (mM)	50 (mM)	100 (mM)	150 (mM)	Mean
Madhana Palli	6.57	4.46	5.95	3.30	5.07	28.42	25.89	25.80	8.10	22.05
Kasi	7.50	5.46	6.25	5.75	6.24	26.74	26.69	26.95	17.60	24.49
Country Periyakulam	5.76	3.50	2.50	4.60	4.09	33.22	17.20	12.60	14.40	19.35
Polur	5.20	3.83	4.06	2.70	3.94	24.30	17.96	12.76	13.20	17.05
Pink Shade	4.80	4.20	4.30	3.90	4.30	25.30	18.40	18.30	17.80	19.95
Red Grape	4.50	5.50	2.60	3.40	4.00	24.85	17.90	18.60	18.70	20.01
Giant Ferry	6.50	6.60	4.30	4.30	5.42	34.44	31.46	18.03	12.73	24.16
Red Berry	4.90	3.00	5.40	4.00	4.32	24.16	23.90	25.50	15.70	22.31
Yellow Egg	4.80	6.50	5.40	4.30	5.25	25.25	21.60	20.00	17.80	21.16
Black Vernissage	6.50	5.90	5.20	4.70	5.57	26.85	18.30	21.20	20.00	21.58
Pusa Ruby	6.00	5.50	5.10	4.70	5.32	33.94	27.86	25.46	19.43	26.67
PKM1	5.90	4.90	4.50	3.40	4.67	27.00	21.90	21.01	11.90	20.45
Mean	5.74	4.94	4.63	4.08		27.87	22.42	20.51	15.61	
	SEm±		CD (5%)			SEm±		CD (5%)		
EC	0.04		0.12			0.20		0.57		
Genotypes	0.07		0.22			0.34		0.99		
Interaction (E × G)	0.15		0.44			0.69		1.98		

EC: electrical conductivity; CD: critical difference at 5 % level of significance; SEm±: standard error of mean; E × G: genotype × electrical conductivity interaction.

**Fig. 2.** Effect of salinity stress on seedling growth in tolerant and susceptible tomato genotypes.

The three varieties of tomato, namely Polur (17.05 cm), Country Periyakulam (19.35 cm) and a Pink Shade (19.95 cm), were found to be shorter in terms of seedling length under salinity stress. Similar results were reported in other study (30). This reduction in growth may be due to detrimental effect of salt ions to plant growth, besides, alteration in nutrient uptake by seedlings. Salt stress could, therefore, prevent plants from completing their life cycle. Root development is vital for plant growth from soil for regulating ion entry to shoot and for survival under saline environment (34).

In comparison to the control, only some of the genotypes showed non-significant increases in growth at reduced NaCl concentrations. However, all genotypes showed a reduction in growth at higher NaCl concentrations, root growth being more affected than shoot growth.

Seedling vigour index I and II

The SVI I and II showed significant differences amongst the genotypes, electrical conductivity (EC) levels and their interactions (Table 2 and 4). The SVI declined gradually as salinity increased. When the salinity levels were compared, the control treatment (0 mM) had the highest SVI I followed by 50 mM and the lowest SVI was found in 100 mM and 150 mM. This higher seedling vigour index at low salinity levels may be due to the low osmotic stress imposed on germinating seeds, which allows efficient water uptake and normal metabolic activity, whereas increasing salinity reduced seedling vigour index by limiting water absorption and impairing seedling growth through ionic and osmotic stress (21, 35).

Table 3 revealed highly significant genotypic differences for SVI I and II, EC level and their interaction. Seedling vigour index I was highest in Pusa Ruby (9710.36) followed by Giant Ferry (1995.60) and Kasi (1616.78) under control as well as saline conditions. By contrast, Yellow Egg (701.98), Pink Shade (734.30) and Black Vernissage (761.72) exhibited a marked decrease in SVI I values with an increase in salinity suggesting a greater sensitivity to salt stress. The highest SVI II values were recorded for Kasi (5048.79) followed by Giant Ferry (4806.95) and Pusa Ruby (4445.93) possessing better salinity tolerance. The lowest SVI II was observed in Country Periyakulam (492.23) followed by Pink Shade (1555.94) and Red Berry (1622.92) showing greater susceptibility to salinity. The results show that a

decline in seedling vigour index may be attributed to reduced germination, diminished plumule and radicle development, as well as decreased mobilisation efficiency of seed stores under stressful conditions. Salinity induces both osmotic and ionic stress, disrupting metabolic processes and hindering embryonic development, which ultimately leads to reduced seedling vigour index (36).

Seedling vigour index I and II showed decline with increase in NaCl concentration. However, at low salinity levels some of the genotypes performed non-significantly compared to control. Salinity reduced seedling vigour of all genotypes; but tolerant genotypes showed higher SVI I values under stress.

Fresh weight (g) and dry weight (mg)

The effects of varying salinity levels on the seedlings' fresh weight and dry weight are depicted in Fig. 3 and 4. The highest fresh weight and dry weight of seedlings was recorded in 0 mM. The second highest was 50 mM, while the lowest was recorded at 100 and 150 mM.

The interaction between variety and salinity significantly affected the fresh weight and dry weight of the seedlings. The highest fresh weight was recorded for the Black Vernissage accession at 0.63 g, followed by Madhana Palli at 0.59 g and Red Berry at 0.57 g. Conversely, the lowest fresh weight was noted in PKM1 at 0.34 g, with Pink Shade at 0.36 g and Polur at 0.41 g trailing behind. The lower fresh weight in salinity stress may be due to the osmotic stress that reduces the water uptake and cellular hydration, which will limit the cell expansion and biomass accumulation. Similar observations have been reported for tomato under saline conditions (37, 38). While the highest dry weight of seedlings (mg) was observed in Kasi (76.61), followed by Giant Ferry (59.07) and Yellow Egg (58.62). In contrast, the lowest dry weight was noted in Country Periyakulam (15.62), with PKM1 (30.22) and Polur (43.02) following closely behind. Under salinity stress, the decreased dry weight was correlated with reduced shoot and root growth, indicating the inhibitory effect of salt on biomass accumulation; lower dry matter production may be attributed to reduced cell division, limited nutrient uptake and lowered photosynthetic efficiency in saline conditions. These findings are like those previously reported (39, 40).

Table 4. Effect of salinity on seedling vigour index I and seedling vigour index II in tomato genotypes

Genotypes	Seedling vigour index I					Seedling vigour index II				
	0 (mM)	50 (mM)	100 (mM)	150 (mM)	Mean	0 (mM)	50 (mM)	100 (mM)	150 (mM)	Mean
Madhana Palli	2442.40	1603.10	1185.24	210.44	360.29	5958.70	4211.92	474.00	778.20	2855.70
Kasi	2622.62	1760.48	1345.34	738.70	1616.78	8512.72	4833.40	4427.02	2422.04	5048.79
Country Periyakulam	2062.18	586.18	328.48	343.04	829.97	45.86	1345.54	571.56	5.96	492.23
Polur	1796.74	1112.22	712.88	343.64	991.37	5979.42	2199.18	2230.40	416.96	2706.49
Pink Shade	1769.84	550.70	368.20	248.48	734.30	1891.08	2979.18	1002.00	351.50	1555.94
Red Grape	1737.96	609.82	484.76	334.62	791.79	5484.14	1448.20	974.38	672.84	2144.89
Giant Ferry	3377.68	2456.38	1333.14	815.20	1995.60	7307.82	5862.30	3775.02	2282.68	4806.95
Red Berry	1399.82	813.56	660.96	344.78	804.78	2559.56	2299.22	897.82	735.10	1622.92
Yellow Egg	1567.42	649.72	358.80	231.99	701.98	4151.32	1578.30	1351.50	523.60	1901.18
Black Vernissage	1451.78	769.58	464.80	360.72	761.72	3777.20	2376.6	1002.02	514.80	1917.65
Pusa Ruby	3324.76	2225.24	1932.20	1359.24	9710.36	7013.94	4393.40	3878.04	2498.34	4445.93
PKM1	2429.31	1486.56	1049.60	404.06	1342.38	4531.28	2416.52	758.30	670.32	2094.10
Mean	4665.21	1218.62	852.03	477.90		4767.75	2995.31	1778.50	989.36	
	SEm±				CD (5 %)	SEm±				CD (5 %)
EC	71.06				202.06	38.08				108.29
Genotypes	123.08				349.97	65.96				187.57
Interaction (E × G)	246.16				699.95	131.93				375.15

EC: electrical conductivity; CD: critical difference at 5 % level of significance; SEm±: standard error of mean; E × G: genotype × electrical conductivity interaction.

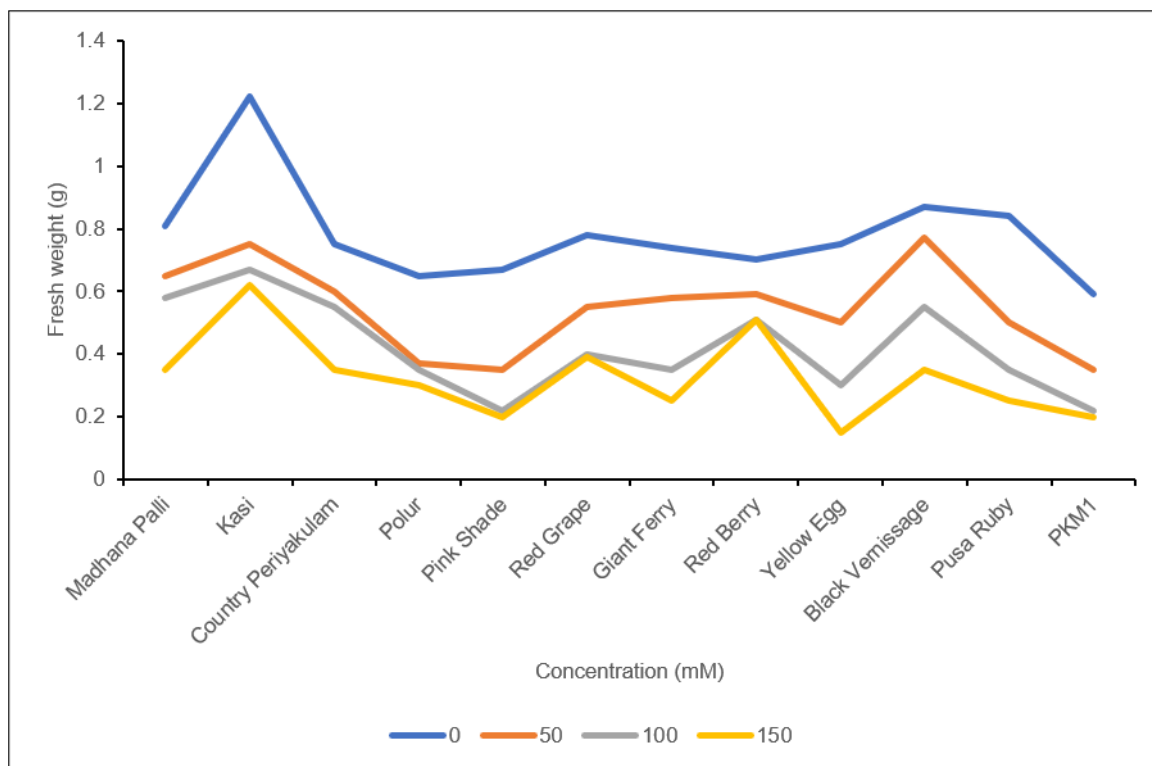


Fig. 3. Effect of salinity stress on fresh weight (g) in tomato genotypes.

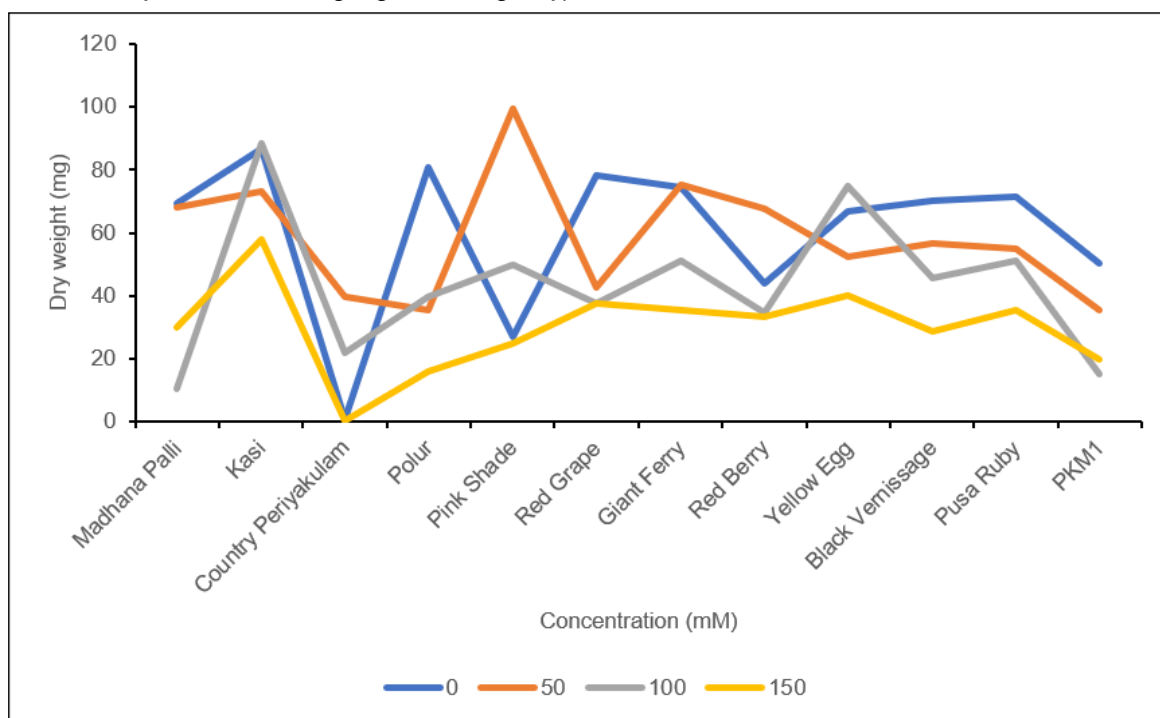


Fig. 4. Effect of salinity stress on dry weight (mg) in tomato genotypes.

Root to shoot ratio

The genotypes, salinity levels and their interaction had a significant impact on the root-to-shoot ratio (Fig. 5). The highest root to shoot ratio was observed at the control level (0 mM), followed by the 50 and 100 mM treatments, while the lowest ratio was recorded at the 150 mM level.

The root-to-shoot ratio showed a gradual decline as salinity levels increased, suggesting that root growth experienced greater negative impacts compared to shoot growth in stressful conditions. Among the genotypes, Red Berry (4.38) exhibited the highest root to shoot ratio, followed closely by Red Grape (4.35) and Pusa Ruby (3.96). In contrast, Black Vernissage (2.88) showed the lowest value,

trailed by Kasi (2.92) and Yellow Egg (3.10). Data analysis showed a significant effect of salt stress on root to shoot ratio. Root and shoot growth were both inhibited by increased salinity due to osmotic stress and ionic imbalance, limiting water uptake and cell expansion. However, some genotypes maintained a higher root-to-shoot ratio under stress, which could be an adaptive mechanism that enhances water acquisition and improves tolerance to saline conditions (41).

Root stress tolerance index and plant height stress tolerance index (%)

Salinity influenced root stress tolerance index and PHSTI which depicted highest value at 0 mM salinity followed by 50 mM and the lowest at 100 mM and 150 mM.

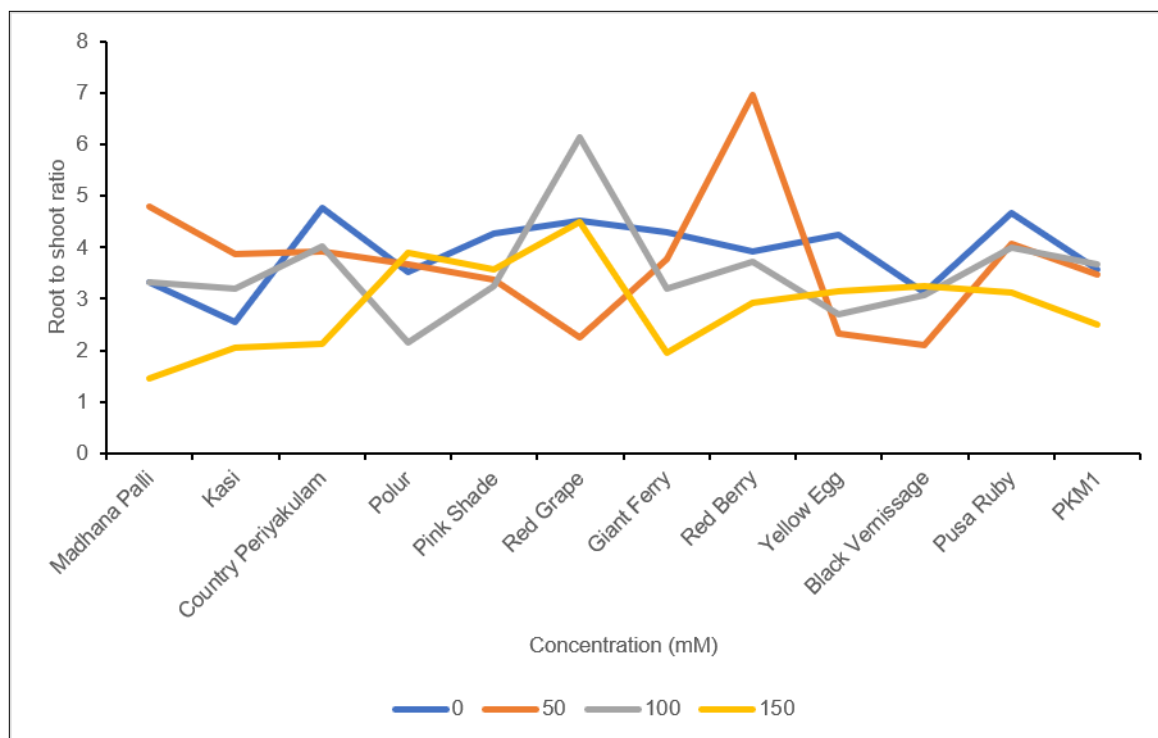


Fig. 5. Effect of salinity stress on root to shoot ratio in tomato genotypes.

Significant genotype $\times$ salinity interaction was observed for RLSTI and PHSTI (Fig. 6 and 7). The highest RLSTI was obtained for Kasi (94.98 %), followed by Red Berry (93.50 %) and Red Grape (78.77 %). The least RLSTI was recorded in Country Periyakulam (55.64 %) followed by Polur (68.69 %) and Giant Ferry (67.14%) and the highest PHSTI values were obtained for Red Berry (92.46 %) followed by Kasi (91.69 %) and Yellow Egg (83.94 %). The least PHSTI was obtained for Country Periyakulam (58.32 %) followed by Giant Ferry (70.23 %) and Polur (70.25 %). Stress tolerance indices decreased with increasing salinity levels, suggesting that salt stress negatively affected plant growth and development; the index values also showed that sensitive genotypes were unable to maintain growth under saline conditions, whereas tolerant genotypes exhibited comparatively higher values, suggesting a greater ability to withstand osmotic and ionic stress. This variation in the responses of

genotypes to salinity points to variation in their ability to adapt to salinity, particularly in maintaining growth under stress conditions. Other similar findings have been reported in earlier studies (42, 43).

Conclusion

Salinity stress substantially lowered germination and seedling development in tomato, with the intensity of the effects escalating with salt concentration. Significant genotypic diversity was seen, with Giant Ferry, Pusa Ruby, Kasi and Red Berry consistently demonstrating enhanced performance in germination, seedling development, vigour indices and stress tolerance under saline conditions. The findings suggest that these genotypes exhibit enhanced saline tolerance during early growth stages and may be useful genetic resources for the improvement and production of

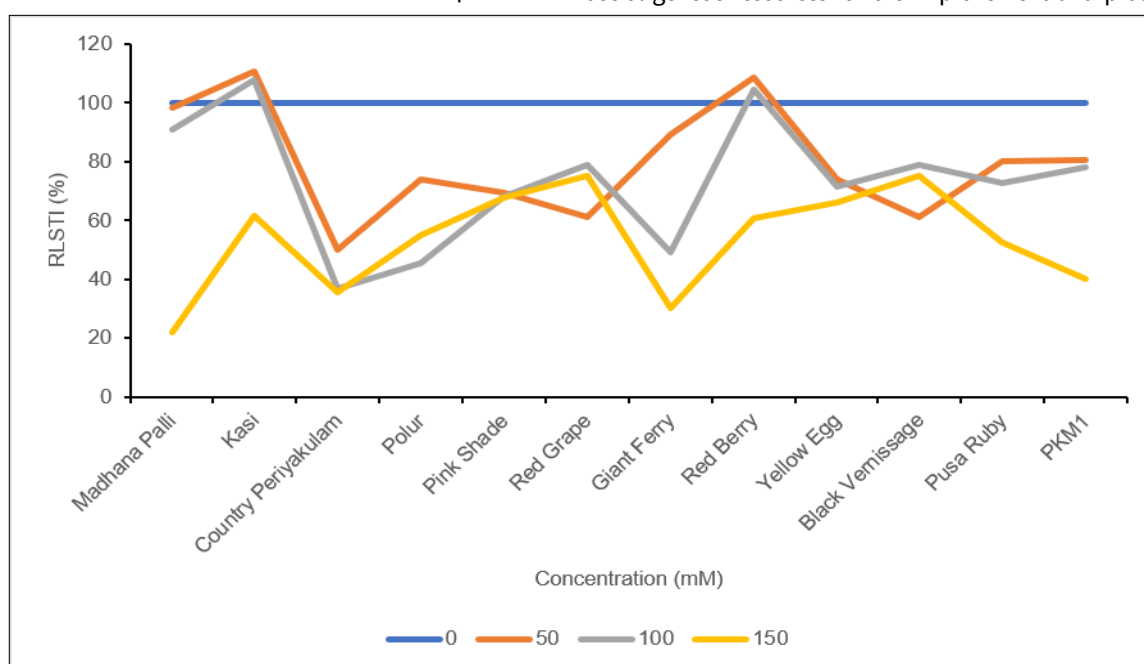


Fig. 6. Effect of salinity stress on root length stress tolerance index (RLSTI) (%) in tomato genotypes.

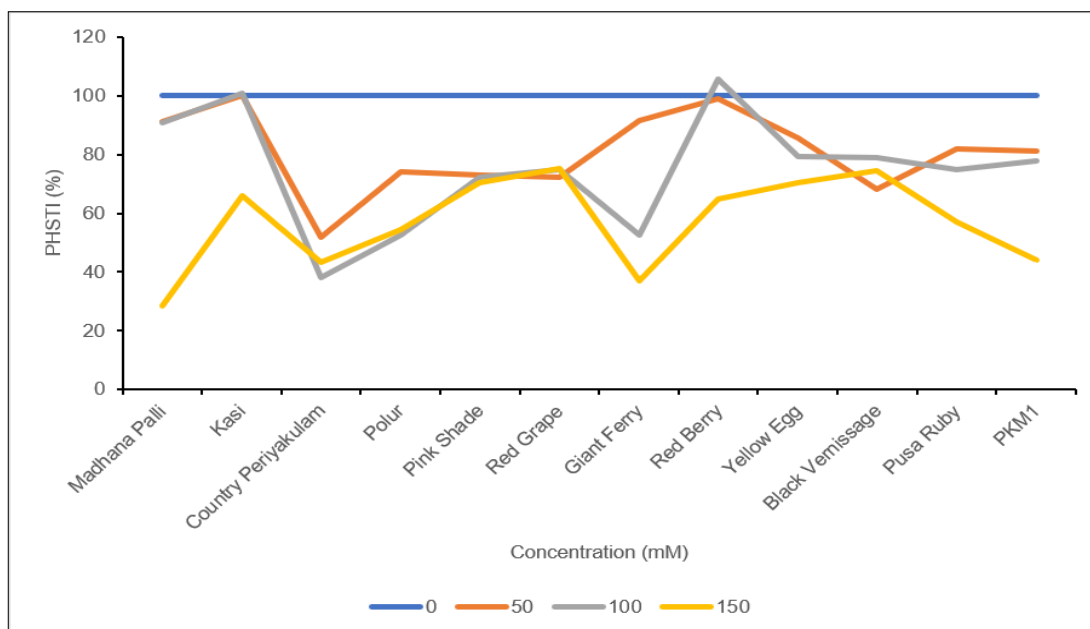


Fig. 7. Effect of salinity stress on plant height stress tolerance index (PHSTI) (%) in tomato genotypes.

tomatoes in salt-affected settings. In the future, research should be conducted to validate their performance under both pot and field conditions, investigate the physiological and biochemical mechanisms that underlying their tolerance and identify genetic factors associated with salinity tolerance in order to support breeding programs for the development of tomato cultivars that are salt-tolerant.

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Authors' contributions

AK carried out the research, data analysis, and manuscript drafting. DK supervised the research and revised the manuscript. MR and RS assisted in proposal preparation, manuscript correction and proofreading. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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