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All authors' names and
affiliations are given below,
after the references.

***In vitro* screening of snake gourd (*Trichosanthes anguina* L.) genotypes for sodicity tolerance using the roll towel method under sodium bicarbonate-induced stress**

J Marimuthu, KR Vijayalatha, V Jegadeeswari, S.Nithila, A Sabir Ahamed, R Rajeswari, N Malini, S Kumar, T Uma Maheswari and R Gangai Selvi

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Abstract

Sodicity is a major abiotic stress affecting seed germination, seedling establishment and crop productivity in many vegetable-growing regions. The present study was conducted to identify sodicity-tolerant snake gourd (*Trichosanthes anguina* L.) genotypes through laboratory screening under sodium bicarbonate-induced stress. Thirty snake gourd genotypes collected from different geographical regions were evaluated during October–November 2024 at the Seed Technology Laboratory, Department of Vegetable Science, Horticultural College and Research Institute for Women, Tiruchirappalli, Tamil Nadu. The experiment was laid out in a Factorial Completely Randomized Design with thirty genotypes and three sodium bicarbonate concentrations, viz., 0 mM (control), 50 mM and 75 mM NaHCO₃, with two replications. The roll towel method was employed to assess germination percentage, root length, shoot length and vigour index. Significant differences were observed among genotypes and treatment levels for all the studied traits. Increasing sodium bicarbonate concentration adversely affected germination and seedling growth, indicating the detrimental effects of sodicity stress on early plant establishment. Under control conditions, genotypes S06 and S21 recorded 100 per cent germination, while S19 exhibited the lowest germination percentage. Genotype S06 consistently maintained superior performance across all stress levels with higher germination (81.00%), root length (8.50 cm), shoot length (10.50 cm) and vigour index (1356.90) at 75 mM NaHCO₃. Genotype S21 also exhibited comparable performance under stress conditions. The overall results demonstrated substantial genetic variability among the tested genotypes for sodicity tolerance. Based on germination percentage, root length, shoot length and vigour index, genotypes S06, S21 and S18 were identified as promising sources of sodicity tolerance. These genotypes may serve as valuable parental materials in breeding programmes aimed at developing sodicity-tolerant snake gourd cultivars for salt-affected environments.

Keywords: Snake gourd, *trichosanthes anguina*, sodicity tolerance, sodium bicarbonate, germination, seedling vigour, root length, shoot length, abiotic stress

Introduction

Snake gourd (*Trichosanthes anguina* L.) is an important cucurbitaceous vegetable crop widely cultivated in tropical and subtropical regions of Asia. It is valued for its tender fruits, nutritional richness and medicinal properties. The fruits are rich sources of vitamins, minerals, dietary fibre and bioactive compounds that contribute to human nutrition and health (Robinson and Decker-Walters, 1997)^[1]. In India, snake gourd is extensively cultivated and serves as an important source of income for small and marginal farmers owing to its adaptability and market demand (Rai *et al.*, 2008)^[2].

Soil degradation due to salinity and sodicity is a major challenge to sustainable agricultural production worldwide. Sodic soils are characterized by high levels of exchangeable sodium and alkaline pH, which adversely affect soil structure, water infiltration, nutrient availability and crop productivity (Qadir and Schubert, 2002)^[3]. According to the Food and Agriculture Organization, millions of hectares of agricultural land are affected by salt-related problems, posing a serious threat to food security (FAO, 2021)^[4]. In India, sodic soils are particularly prevalent in arid and semi-arid regions, limiting the cultivation of sensitive vegetable crops. Sodicity stress adversely affects plants by causing osmotic stress, ion toxicity and nutrient imbalance.

Corresponding Author:
KR Vijayalatha
Department of Vegetable
Science, Horticultural College
and Research Institute for
Women, Tamil Nadu
Agricultural University
(TNAU), Tiruchirappalli,
Tamil Nadu, India

Excess sodium ions disrupt cellular ion homeostasis, reduce water uptake and interfere with metabolic processes, resulting in poor seed germination, stunted seedling growth and reduced yield (Parida and Das, 2005; Munns and Tester, 2008) [5, 6]. Germination and early seedling growth are among the most critical stages in the plant life cycle and are highly sensitive to sodicity stress. Therefore, evaluation of genotypes at these stages provides a rapid and reliable approach for identifying tolerant genotypes suitable for cultivation under sodic conditions (Ashraf and Foolad, 2005) [7].

Screening at the germination stage has been widely employed in several crops because it allows the identification of stress-tolerant genotypes within a short period of time. Traits such as germination percentage, root length, shoot length and vigour index have been recognized as reliable indicators of salinity and sodicity tolerance in vegetable crops (Abdul-Baki and Anderson, 1973; Ghoulam and Fares, 2001) [8, 9]. Genotypes capable of maintaining higher germination and seedling growth under stress conditions are generally considered more tolerant and possess greater adaptive potential.

Despite the economic importance of snake gourd, information on sodicity tolerance among available genotypes is limited. Identification of tolerant genotypes is essential for developing cultivars suitable for cultivation in sodic soils and for utilizing

these genotypes in crop improvement programmes. Therefore, the present investigation was undertaken to evaluate thirty snake gourd genotypes under different levels of sodium bicarbonate-induced sodicity stress and to identify promising genotypes based on germination and seedling growth parameters.

Materials and methods

The present investigation was carried out during October–November 2024 at the Seed Technology Laboratory, Department of Vegetable Science, Horticultural College and Research Institute for Women, Tiruchirappalli, Tamil Nadu. The experimental material comprised thirty snake gourd (*Trichosanthes anguina* L.) genotypes collected from diverse geographical locations of Tamil Nadu and Karnataka. The genotypes were assembled from farmers' fields and traditional cultivation areas representing different agro-climatic regions in order to capture a wide range of genetic variability for germination, seedling growth, vigour and sodicity tolerance. The collected seed samples were cleaned, properly labelled and stored under suitable conditions until their use in the experiment. The details of the genotypes along with their source of collection are presented in Table 1.

Table 1: Details of genotype and their source

S. No.	Genotypes	Genotype details	Source of collection
01	S01	Mallamoopampatti (White)	Salem
02	S02	Mallamoopampatti (Green)	Salem
03	S03	Musiri	Trichy
04	S04	Veeramangudi	Tanjore
05	S05	Thathanur	Ariyalur
06	S06	Oddanchatrum	Dindigul
07	S07	Kovil Patti	Thoothukudi
08	S08	Nallipalayam	Namakkal
09	S09	Periyapatti	Namakkal
10	S10	Purangani	Cuddalore
11	S11	Puliyur	Cuddalore
12	S12	Bandipalya	Mysore
13	S13	Veerapura	Bangalore
14	S14	Kaniyambadi	Vellore
15	S15	Maduramangalam	Kanchipuram
16	S16	Pampatti	Virudhunagar
17	S17	Odaipatti	Virudhunagar
18	S18	Kandamangalam	Villupuram
19	S19	Thingalur	Erode
20	S20	Villarasampatti	Erode
21	S21	Naganam Patty	Dindigul
22	S22	Kalpadi	Perambalur
23	S23	Vettariyarpalyam	Karur
24	S24	Kulathurpatti	Karur
25	S25	Sembarai	Trichy
26	S26	Vadipatti	Madurai
27	S27	Naranpuram	Sivakasi
28	S28	Kattur	Thiruvarur
29	S29	Kallipalayam	Coimbatore
30	S30	Kallupatty	Madurai

The laboratory screening experiment was undertaken to identify superior snake gourd genotypes exhibiting tolerance to sodicity stress during germination and early seedling growth stages. A total of thirty genotypes were evaluated using the roll towel method under varying levels of sodium bicarbonate (NaHCO_3)-induced sodicity stress. Three treatment concentrations were employed, namely T_1 (0 mM NaHCO_3 , control), T_2 (50 mM

NaHCO_3) and T_3 (75 mM NaHCO_3). The required sodium bicarbonate solutions were prepared by dissolving 4.20 g and 6.30 g of NaHCO_3 in distilled water and making the volume up to one litre to obtain 50 mM and 75 mM concentrations, respectively, while distilled water served as the control treatment. The experiment was laid out in a Factorial Completely Randomized Design (FCRD) with two factors,

namely genotype and treatment concentration, and was replicated twice. The details of the experimental setup adopted for the study are presented in Table 2.

The roll towel technique was adopted for screening the genotypes, as it is widely used for assessing seed germination and seedling responses under abiotic stress conditions. Germination tests were conducted according to the procedures prescribed by [ISTA \(2015\)](#) ^[10]. For each treatment and replication, twenty-five seeds were uniformly placed on germination papers moistened with the respective sodium bicarbonate solutions.

The papers were carefully rolled and placed vertically in a germination chamber maintained at 25 ± 2 °C temperature and 95 ± 3 per cent relative humidity under continuous fluorescent illumination. Adequate moisture was maintained throughout the germination period by applying the respective treatment solutions whenever necessary. At the completion of the germination test, observations on germination percentage, root length, shoot length and vigour index were recorded to assess the effect of sodicity stress on seed germination and seedling growth of the snake gourd genotypes. This laboratory screening facilitated the identification of promising genotypes possessing greater tolerance to sodicity stress during the early stages of crop growth.

Preparation of Sodium Bicarbonate Solutions

Sodium bicarbonate solutions were prepared using analytical-grade NaHCO_3 (molecular weight: 84.01 g mol^{-1}). The required quantity of NaHCO_3 was calculated using the molarity equation:

$$\text{Weight (g)} = \text{Molarity (M)} \times \text{Molecular weight (g mol}^{-1}\text{)} \times \text{Volume (L)}$$

For the preparation of 50 mM NaHCO_3 solution, 4.20 g of sodium bicarbonate was dissolved in distilled water and the final volume was made up to one litre. Similarly, 6.30 g of sodium bicarbonate was dissolved in distilled water and the volume was adjusted to one litre to obtain a 75 mM solution. Distilled water without sodium bicarbonate served as the control (0 mM). Fresh solutions were prepared and used for moistening the germination papers during the screening experiment.

Observations recorded

Germination (%)

At the end of the test period, the number of normal seedlings was recorded and the mean germination percentage was computed. Seed germination was estimated for each treatment combination as per following formula. The mean was computed and expressed in percentage.

$$\text{Germination}(\%) = \frac{\text{Number of seeds germinated}}{\text{Total number of seeds}} \times 100$$

Root length (cm)

Root length was recorded from ten healthy and uniformly germinated seedlings randomly selected from each replication. Measurements were taken from the point of seed attachment to the tip of the primary root using a standard measuring scale. The average root length was computed and expressed in centimeter (cm).

Shoot length (cm)

The same seedlings selected for root length measurement were utilized for assessing shoot length. The shoot length was measured from the seed attachment point to the tip of the first true leaf using a measuring scale. The mean shoot length was calculated and expressed in centimeter (cm)

Vigour index

Seedling vigour was estimated using the formula proposed by [Abdul Baki and Anderson \(1973\)](#) ^[8]. The vigour index was derived by multiplying the germination percentage with the sum of the mean root length and shoot length and the values were expressed accordingly.

$$\text{Vigour index} = \text{Germination}(\%) \times (\text{Root Length} + \text{Shoot Length})$$

Statistical analysis

The recorded mean data were subjected to statistical analysis to assess the variability among genotypes for the traits under evaluation. The analysis was performed using AGRI ANALYZER software, which enabled efficient computation of the analysis of variance (ANOVA) and other statistical parameters. The significance of differences among genotypic means was tested at the 5% level of probability using the method described by [Panse and Sukhatme \(1954\)](#) ^[11].

Result

The present investigation was carried out to evaluate the response of thirty snake gourd genotypes to sodium bicarbonate-induced sodicity stress under laboratory conditions. All the genotypes exhibited successful germination under the roll towel method and were subsequently screened for their tolerance to different levels of sodicity stress. Significant differences were observed among the genotypes, treatment concentrations and their interactions for germination percentage, root length, shoot length and vigour index. The results revealed that increasing sodium bicarbonate concentration adversely affected seed germination and seedling growth, indicating the detrimental effects of sodicity stress during the early stages of crop growth. Nevertheless, considerable variation among the genotypes was observed, indicating the presence of differential tolerance mechanisms and the possibility of identifying promising genotypes for cultivation under sodic environments.

Germination percentage was significantly influenced by both genotype and sodicity treatment. The mean germination percentage of the thirty genotypes ranged from 57.66 to 90.00 per cent. Under control conditions, the genotypes S06 and S21 recorded the highest germination of 100 per cent, whereas S19 exhibited the lowest germination of 54.00 per cent. Among the genotypes, S06 maintained superior germination across all sodicity levels, recording 89.00 per cent germination at 50 mM and 81.00 per cent at 75 mM sodium bicarbonate concentration (Table 3).

The overall treatment means indicated that the control treatment recorded the highest germination percentage (94.03%), followed by 50 mM sodium bicarbonate (74.80%), while the highest concentration of 75 mM resulted in the lowest germination percentage (59.86%). The reduction in germination under increasing sodicity stress may be attributed to osmotic stress and ion toxicity, which restrict water uptake and interfere with physiological processes necessary for seed germination.

Table 3: Germination of snake gourd genotypes on screening under roll towel method

Genotypes (G)	Germination (%)			
	T ₁ (0mM)	T ₂ (50mM)	T ₃ (75mM)	Mean
S01	96.00	79.00	65.00	80.00
S02	95.00	75.00	59.00	76.33
S03	97.00	81.00	67.00	81.66
S04	96.00	79.00	65.00	80.00
S05	85.00	58.00	37.00	60.00
S06	100.00	89.00	81.00	90.00
S07	95.00	74.00	59.00	76.00
S08	92.00	71.00	51.00	71.33
S09	98.00	85.00	71.00	84.66
S10	90.00	67.00	47.00	68.00
S11	97.00	81.00	65.00	81.00
S12	98.00	81.00	71.00	83.33
S13	94.00	73.00	59.00	75.33
S14	96.00	77.00	61.00	78.00
S15	90.00	66.00	45.00	67.00
S16	97.00	81.00	67.00	81.66
S17	95.00	75.00	61.00	77.00
S18	99.00	87.00	79.00	88.33
S19	84.00	54.00	35.00	57.66
S20	92.00	71.00	57.00	73.33
S21	100.00	89.00	79.00	89.33
S22	94.00	73.00	57.00	74.66
S23	92.00	71.00	51.00	71.33
S24	90.00	67.00	49.00	68.66
S25	86.00	61.00	45.00	64.00
S26	97.00	81.00	69.00	82.33
S27	99.00	87.00	77.00	87.66
S28	86.00	59.00	41.00	62.00
S29	95.00	75.00	61.00	77.00
S30	96.00	77.00	65.00	79.33
Mean	94.03	74.80	59.86	76.23
	G	T	GxT	
SE(d)	1.08	0.34	1.87	
CD (0.05)	2.15	0.68	3.73	

Root length also showed significant variation among the genotypes and treatment concentrations. The overall mean root length ranged from 7.30 cm to 10.86 cm. The genotype S06 recorded the highest root length across all treatments, measuring 13.20 cm under control conditions, 10.90 cm at 50 mM and 8.50 cm at 75 mM sodium bicarbonate concentration. A similar trend was observed in genotype S21, which recorded root lengths of 13.00 cm, 10.80 cm and 8.50 cm under T₁, T₂

and T₃, respectively. In contrast, S19 recorded the lowest mean root length of 7.30 cm. Among the treatment means, the control treatment exhibited the highest root length (11.60 cm), followed by the 50 mM treatment (9.38 cm), whereas the 75 mM treatment recorded the lowest root length (6.87 cm) (Table 4). The decline in root growth under sodicity stress may be due to the inhibitory effects of excess sodium ions on cell division, cell elongation and water absorption.

Table 4: Root length of snake gourd genotypes on screening under roll towel method

Genotypes (G)	Root length (cm)			
	T ₁ (0mM)	T ₂ (50mM)	T ₃ (75mM)	Mean
S01	12.00	10.00	7.40	9.80
S02	11.70	9.50	6.80	9.33
S03	12.10	10.00	7.50	9.86
S04	12.00	9.80	7.30	9.70
S05	9.70	7.50	5.00	7.40
S06	13.20	10.90	8.50	10.86
S07	11.70	9.40	6.70	9.26
S08	10.90	8.60	6.10	8.53
S09	12.40	10.40	7.90	10.23
S10	10.80	8.50	6.00	8.43
S11	12.10	10.00	7.40	9.83
S12	12.30	10.20	7.70	10.06
S13	11.60	9.20	6.60	9.13
S14	11.90	9.70	7.20	9.60
S15	10.60	8.30	6.00	8.30
S16	12.10	10.10	7.60	9.93

S17	11.90	9.60	7.10	9.53
S18	12.70	10.60	8.30	10.53
S19	9.60	7.40	4.90	7.30
S20	11.10	8.70	6.30	8.70
S21	13.00	10.80	8.50	10.76
S22	11.50	9.20	6.60	9.10
S23	11.00	8.80	6.20	8.66
S24	10.90	8.50	6.00	8.46
S25	10.50	8.00	5.40	7.96
S26	12.20	10.10	7.70	10.00
S27	12.50	10.50	8.00	10.33
S28	10.20	7.90	5.30	7.80
S29	11.80	9.60	7.00	9.46
S30	12.00	9.80	7.30	9.70
Mean	11.60	9.38	6.87	9.28
	G	T	GxT	
SE(d)	0.08	0.02	0.14	
CD (0.05)	0.16	0.05	0.28	

Significant differences were also observed for shoot length among the genotypes and treatment levels. The overall mean shoot length ranged from 9.63 cm to 13.33 cm. The genotype S06 recorded the highest shoot length under all treatment conditions, with values of 16.20 cm, 13.30 cm and 10.50 cm under 0, 50 and 75 mM sodium bicarbonate concentrations, respectively. This was followed by genotype S21, which recorded shoot lengths of 16.00 cm, 13.20 cm and 10.30 cm under the respective treatment levels. The lowest mean shoot

length was observed in S19 (9.63 cm). The treatment means revealed that the control treatment recorded the highest shoot length (14.69 cm), followed by the 50 mM treatment (11.73 cm), while the 75 mM treatment resulted in the lowest shoot length (8.83 cm) (Table 5). The observed reduction in shoot growth under increasing sodicity stress may be attributed to reduced nutrient uptake, impaired photosynthetic activity and restricted translocation of assimilates within the plant.

Table 5: Shoot length of snake gourd genotypes on screening under roll towel method

Genotypes (G)	Shoot length (cm)			
	T ₁ (0mM)	T ₂ (50mM)	T ₃ (75mM)	Mean
S01	15.20	12.30	9.40	12.30
S02	14.80	11.70	8.80	11.76
S03	15.30	12.40	9.50	12.40
S04	15.10	12.20	9.30	12.20
S05	12.90	9.80	6.80	9.83
S06	16.20	13.30	10.50	13.33
S07	14.70	11.70	8.70	11.70
S08	13.90	10.90	8.10	10.96
S09	15.60	12.70	9.80	12.70
S10	13.70	10.70	7.90	10.76
S11	15.20	12.30	9.50	12.33
S12	15.50	12.70	9.80	12.66
S13	14.60	11.60	8.70	11.63
S14	15.00	12.10	9.20	12.10
S15	13.60	10.60	7.80	10.66
S16	15.30	12.40	9.60	12.43
S17	14.90	12.00	9.00	11.96
S18	16.00	13.10	10.20	13.10
S19	12.70	9.60	6.60	9.63
S20	14.20	11.10	8.30	11.20
S21	16.00	13.20	10.30	13.16
S22	14.60	11.40	8.50	11.50
S23	14.00	11.00	8.20	11.06
S24	13.80	10.80	8.00	10.86
S25	13.50	10.50	7.50	10.50
S26	15.40	12.50	9.60	12.50
S27	15.80	13.00	10.00	12.93
S28	13.20	10.20	7.30	10.23
S29	14.90	12.00	9.00	11.96
S30	15.10	12.20	9.20	12.16
Mean	14.69	11.73	8.83	11.75
	G	T	GxT	
SE(d)	0.08	0.02	0.14	
CD (0.05)	0.16	0.05	0.28	

The vigour index exhibited significant differences among the genotypes and sodicity treatments, reflecting the combined influence of germination percentage and seedling growth under stress conditions. The mean vigour index among the genotypes ranged from 990.40 to 2035.10. The highest vigour index was recorded by genotype S06 (2035.10), followed by S21 (2012.30), indicating their superior ability to withstand sodicity stress and maintain seedling growth. Conversely, S19 recorded the lowest vigour index (990.40), indicating greater sensitivity to sodicity stress. Among the treatment means, the control treatment recorded the highest vigour index (2438.96), whereas

the highest sodium bicarbonate concentration (75 mM) recorded the lowest vigour index (994.75) (Table 6). The progressive decline in vigour index with increasing sodicity levels clearly demonstrated the adverse effects of sodium bicarbonate stress on seedling establishment. Based on the overall performance for germination percentage, root length, shoot length and vigour index, the genotypes S06 and S21 were identified as the most promising and sodicity-tolerant genotypes, while S19 was found to be highly susceptible under laboratory screening conditions.

Table 2: Experimental Details

Particulars	Details
Location	Seed Technology Laboratory, Department of Vegetable Science, Horticultural College and Research Institute for Women, Tiruchirappalli
Period	October–November 2024
Crop	Snake gourd (<i>Trichosanthes anguina</i> L.)
Number of genotypes	30
Design	Factorial Completely Randomized Design (FCRD)
Factors	Genotype and sodicity treatment
Replications	2
Treatment levels	T1: 0 mM NaHCO ₃ , T2: 50 mM NaHCO ₃ , T3: 75 mM NaHCO ₃
Number of treatment combinations	90
Seeds per replication	25
Screening technique	Roll towel method
Germination standard	ISTA (2015)
Temperature	25 ± 2°C
Relative humidity	95 ± 3%
Light condition	Continuous fluorescent illumination

Table 6: Vigour index of snake gourd genotypes on screening under roll towel method

Genotypes (G)	Vigour index			
	T ₁ (0mM)	T ₂ (50mM)	T ₃ (75mM)	Mean
S01	2609.70	1669.50	1134.15	1804.45
S02	2518.20	1537.50	1015.20	1690.30
S03	2650.20	1692.75	1157.10	1833.35
S04	2589.30	1668.30	1108.50	1788.70
S05	1725.00	937.50	454.50	1039.00
S06	2880.60	1867.80	1356.90	2035.10
S07	2492.70	1522.80	987.90	1667.80
S08	2224.10	1326.90	897.30	1482.76
S09	2718.30	1799.40	1262.55	1926.75
S10	2148.60	1290.30	715.80	1384.90
S11	2646.60	1692.20	1138.35	1825.71
S12	2692.20	1775.70	1216.50	1894.80
S13	2468.05	1486.50	976.50	1643.68
S14	2577.00	1632.30	1078.95	1762.75
S15	2089.50	1144.50	708.45	1314.15
S16	2661.90	1699.80	1165.20	1842.30
S17	2572.20	1620.00	1036.50	1742.90
S18	2799.30	1852.95	1277.40	1976.55
S19	1646.40	907.50	417.30	990.40
S20	2323.20	1385.10	924.00	1544.10
S21	2827.50	1857.60	1351.80	2012.30
S22	2405.70	1459.80	927.75	1597.75
S23	2271.15	1376.40	902.25	1516.60
S24	2158.20	1319.85	774.45	1417.50
S25	2037.80	1117.20	638.10	1264.36
S26	2672.70	1747.80	1194.30	1871.60
S27	2732.25	1832.40	1272.30	1945.65
S28	1872.60	1064.40	613.05	1183.35
S29	2572.10	1597.50	1033.20	1734.26
S30	2586.00	1650.90	1106.40	1781.10
Mean	2438.96	1517.77	994.75	1650.49
	G	T	G×T	
SE(d)	32.48	10.27	56.26	
CD (0.05)	64.53	20.40	111.77	

Discussion

Sodicity is one of the major abiotic constraints affecting crop establishment and productivity, particularly during seed germination and early seedling growth. Excess accumulation of sodium ions in the germination medium alters osmotic balance, restricts water uptake, disrupts nutrient acquisition and causes ionic toxicity, ultimately leading to poor germination and seedling establishment. In addition, sodicity-induced oxidative stress adversely affects cellular metabolism, membrane integrity and enzyme activities, thereby impairing normal plant growth and development. The present study was undertaken to evaluate the response of thirty snake gourd (*Trichosanthes anguina* L.) genotypes to sodium bicarbonate-induced sodicity stress and to identify promising genotypes capable of withstanding adverse sodic conditions during the early stages of growth. The results revealed significant differences among genotypes for germination percentage, root length, shoot length and vigour index under varying levels of sodium bicarbonate stress, indicating the existence of substantial genetic variability for sodicity tolerance.

Seed germination is considered one of the most sensitive stages in the life cycle of a plant and is often used as a reliable indicator

for screening stress tolerance. In the present investigation, germination percentage decreased progressively with increasing sodium bicarbonate concentration, indicating the inhibitory effect of sodicity stress on seed germination. However, certain genotypes such as S06, S21 and S18 maintained comparatively higher germination percentages even under 75 mM NaHCO₃ stress, demonstrating their ability to tolerate adverse osmotic and ionic conditions. The superior germination performance of these genotypes may be attributed to their ability to maintain cellular hydration, membrane stability and metabolic activity under stress conditions. Similar reductions in germination under salinity and sodicity stress have been reported in several vegetable crops and cucurbits by Ghoulam *et al.* (2002) [12], Ashraf and Foolad (2005) [7], and Munns and Tester (2008) [6], who observed that tolerant genotypes were capable of sustaining higher germination rates through efficient osmotic adjustment and maintenance of enzymatic activities. The ability of S06, S21 and S18 to maintain high germination percentages under stress suggests the presence of inherent genetic mechanisms that confer tolerance during the critical germination phase (Figure 1).

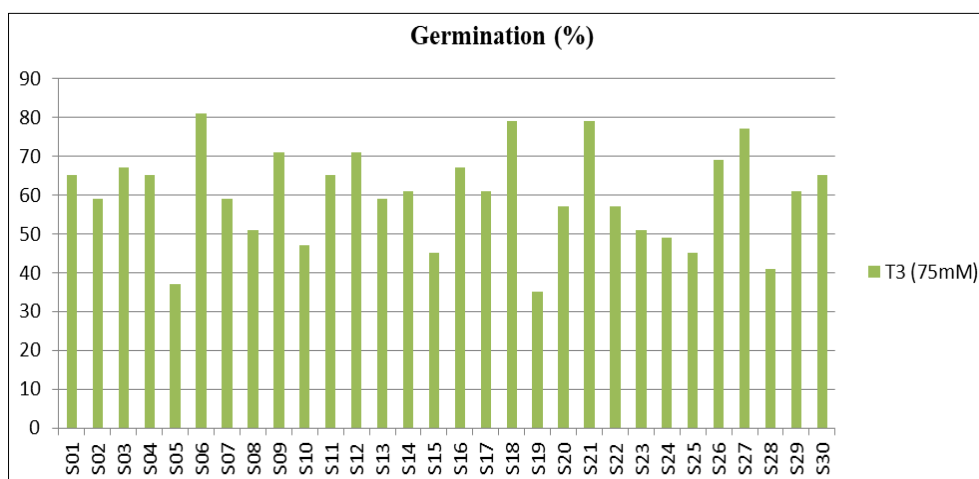


Fig 1: Germination (%) on screening under laboratory conditions at 75 mM of sodium bicarbonate

Root growth is an important adaptive trait under sodicity stress because roots are the first organs to encounter adverse soil conditions. In the present study, root length decreased significantly with increasing sodium bicarbonate concentration, indicating the negative influence of sodicity on root development. Nevertheless, genotypes S06, S21 and S18 consistently recorded greater root length across all treatment levels compared with the remaining genotypes. Maintenance of root growth under stress conditions is considered an important tolerance mechanism because it enables continued water and nutrient uptake and supports subsequent seedling development. The superior root growth observed in these genotypes may be attributed to their enhanced capacity for osmotic adjustment, maintenance of cell turgor and efficient ion regulation. Similar findings have been reported by Khan *et al.* (2010) [13], Mahmood *et al.* (2012) [14] and Choudhary *et al.* (2022) [15], who identified root length as a reliable criterion for screening salinity and sodicity tolerance in cucurbitaceous crops. The ability of tolerant genotypes to sustain root elongation under stress conditions is often associated with improved adaptability and greater survival potential in adverse environments.

Shoot growth was also markedly influenced by sodicity stress, with a gradual decline in shoot length observed as sodium

bicarbonate concentration increased. The reduction in shoot growth may be attributed to osmotic stress-induced reduction in water availability, impaired nutrient uptake, ion toxicity and decreased photosynthetic efficiency. However, genotypes S06, S21, S18 and S27 maintained comparatively higher shoot lengths under sodicity stress, indicating their ability to sustain growth despite adverse conditions. The maintenance of shoot growth under stress conditions reflects efficient physiological and biochemical adjustments that enable continued cell division and elongation. Similar observations have been reported by Ashraf and Foolad (2005) [7], Sharma and Bali (2018) [16] and Singh *et al.* (2020) [17], who noted that tolerant genotypes exhibited greater shoot growth due to better ion homeostasis, osmotic regulation and stress adaptation mechanisms. The ability of these genotypes to maintain higher shoot length under increasing sodium bicarbonate concentrations suggests their potential usefulness in breeding programmes aimed at improving sodicity tolerance.

The vigour index integrates germination percentage and seedling growth parameters and is widely regarded as a comprehensive indicator of seedling performance under stress conditions. In the present study, vigour index declined substantially with increasing sodicity stress, reflecting the

cumulative adverse effects of sodium bicarbonate on germination and seedling growth. Nevertheless, genotypes S06, S21, S18, S27 and S12 consistently recorded higher vigour index values across all treatment levels, indicating superior adaptability and stress tolerance (Figure 2). The maintenance of high vigour index under sodicity stress suggests efficient mobilization of seed reserves, enhanced seedling growth and better physiological resilience. Similar findings were reported

by Ashraf and Foolad (2005)^[7], Kumar *et al.* (2019)^[18] and Choudhary *et al.* (2022)^[15], who emphasized the importance of seedling vigour as an effective selection criterion for identifying salt-tolerant genotypes in vegetable crops. The superior vigour exhibited by these genotypes highlights their ability to withstand sodicity stress during the critical establishment phase and suggests their suitability for cultivation under sodic soil conditions.

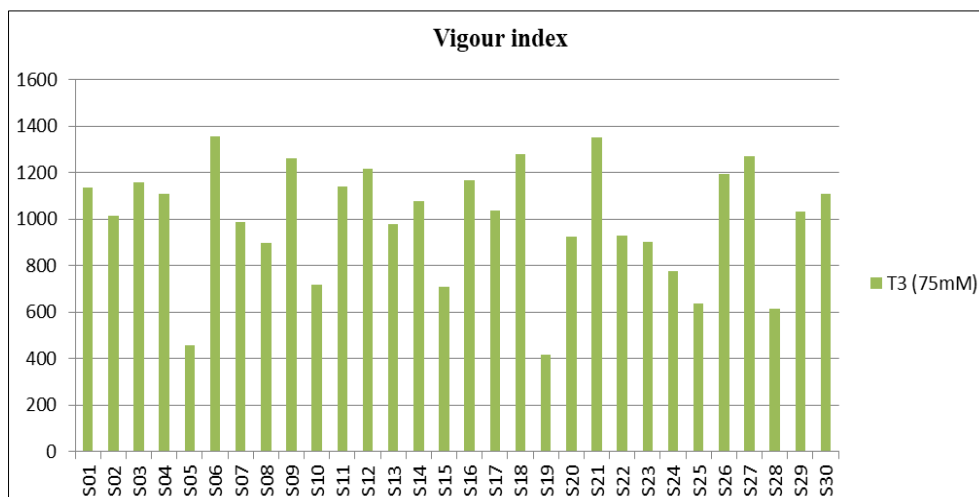


Fig 2: Vigour index on screening under laboratory condition at 75 mM of sodium bicarbonate

The overall superior performance of genotypes S06, S21 and S18 across all evaluated traits indicates that these genotypes possess effective physiological and biochemical mechanisms for coping with sodicity stress. Their ability to maintain higher germination percentage, root length, shoot length and vigour index under increasing sodium bicarbonate concentrations may be associated with efficient sodium exclusion, maintenance of favourable Na⁺/K⁺ balance, + accumulation of compatible solutes and enhanced antioxidant defence systems. Similar mechanisms have been reported in salt-tolerant vegetable crops by Zhu (2001)^[19], Mahmood *et al.* (2012)^[14] and Huang *et al.* (2016)^[20]. The observed variation among the genotypes clearly demonstrates the existence of exploitable genetic diversity for sodicity tolerance in snake gourd. Therefore, genotypes S06, S21 and S18 may be considered promising donor parents for future breeding programmes aimed at developing sodicity-tolerant snake gourd varieties suitable for cultivation in salt-affected and sodic soils. The findings of the present study corroborate earlier reports on stress tolerance in vegetable crops and provide valuable information for the selection and improvement of snake gourd genotypes under sodicity stress conditions.

Conclusion

The present study demonstrated significant variability among thirty snake gourd genotypes in their response to sodium bicarbonate-induced sodicity stress during germination and early seedling growth stages. Increasing levels of sodicity stress significantly reduced germination percentage, root length, shoot length and vigour index, confirming the adverse effects of excess sodium on seedling establishment. However, considerable differences among genotypes indicated the presence of exploitable genetic variation for sodicity tolerance. Among the evaluated genotypes, S06, S21 and S18 consistently exhibited superior performance under both moderate and severe sodicity stress conditions. These genotypes maintained higher germination percentage, greater root and shoot growth and

superior vigour index compared with other genotypes, indicating their ability to withstand sodium-induced stress during the critical seedling stage. In contrast, genotype S19 was found to be highly susceptible to sodicity stress.

The findings suggest that germination percentage, root length, shoot length and vigour index are reliable screening parameters for identifying sodicity-tolerant snake gourd genotypes at the seedling stage. Based on their overall performance, genotypes S06, S21 and S18 may be considered promising sources of sodicity tolerance and can be utilized as potential donor parents in breeding programmes aimed at developing high-yielding and sodicity-tolerant snake gourd cultivars for cultivation in salt-affected soils. Further physiological, biochemical and molecular investigations under field conditions are required to validate and exploit their tolerance mechanisms for crop improvement.

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Consent for publication

All authors consent the publication of the current article.

Competing interests

The authors declare no competing interests.

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All authors' names and affiliations**J Marimuthu**

Department of Vegetable Science, Horticultural College and Research Institute for Women, Tamil Nadu Agricultural University (TNAU), Tiruchirappalli, Tamil Nadu, India

KR Vijayalatha

Department of Vegetable Science, Horticultural College and Research Institute for Women, Tamil Nadu Agricultural University (TNAU), Tiruchirappalli, Tamil Nadu, India

V Jegadeeswari

Grapes Research Station, Tamil Nadu Agricultural University (TNAU), Theni, Tamil Nadu, India

S Nithila

Department of Basic Science, Horticultural College and Research Institute for Women, Tamil Nadu Agricultural University (TNAU), Tiruchirappalli, Tamil Nadu, India

A Sabir Ahamed

Department of Vegetable Science, Horticultural College and Research Institute for Women, Tamil Nadu Agricultural University (TNAU), Tiruchirappalli, Tamil Nadu, India

R Rajeswari

Department of Vegetable Science, Horticultural College and Research Institute for Women, Tamil Nadu Agricultural University (TNAU), Tiruchirappalli, Tamil Nadu, India

N Malini

Department of Basic Science, Horticultural College and Research Institute for Women, Tamil Nadu Agricultural University (TNAU), Tiruchirappalli, Tamil Nadu, India

S Kumar

Department of Fruit Science, Horticultural College and Research Institute for Women, Tamil Nadu Agricultural University (TNAU), Tiruchirappalli, Tamil Nadu, India

T Uma Maheswari

Department of Fruit Science, Horticultural College and Research Institute for Women, Tamil Nadu Agricultural University (TNAU), Tiruchirappalli, Tamil Nadu, India

R Gangai Selvi

Department of Physical Sciences and Information Technology, Agricultural Engineering College and Research Institute, TNAU, Coimbatore, Tamil Nadu, India