



RESEARCH ARTICLE

Physiological response of selected ornamental shrubs under salinity stress

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Received: 29 April 2026; Accepted: 11 June 2026; Available online: Version 1.0: 13 July 2026

Cite this article: Logeshwaran K, Shakila S, Ganesh S, Nagajothi R. Physiological response of selected ornamental shrubs under salinity stress. Plant Science Today. 2026;13(sp2):01–09. <https://doi.org/10.14719/pst.15325>

Abstract

Salinity stress significantly affects plant growth, development and ornamental value, especially in coastal and peri-urban landscaping. This study evaluated the physiological and biochemical responses of four ornamental shrubs, *Eranthemum pulchellum* Andrews, *Leucophyllum frutescens* (Berland.) I.M.Johnst., *Acalypha wilkesiana* Müll.Arg. and *Tabernaemontana divaricata* (L.) R.Br. ex-Roem. & Schult. under varying levels of salinity (0, 20, 40 and 60 dS m⁻¹) using sodium chloride (NaCl) and calcium chloride (CaCl₂) in a 7 : 3 ratio under open-field conditions. Salinity significantly affected physiological and biochemical traits except leaf pH. Increasing salinity caused progressive reductions in chlorophyll a (Chl-a), chlorophyll b (Chl-b), total chlorophyll content, chlorophyll stability index (CSI), membrane stability index (MSI) and relative water content (RWC), while leaf electrical conductivity (EC) and total phenolic content (TPC) increased. Among the evaluated shrubs, *L. frutescens* exhibited superior salinity tolerance, maintaining total chlorophyll (0.16 mg g⁻¹ FW), CSI (43.58 %), MSI (9.10 %) and RWC (58.64 %) at 60 dS m⁻¹. In contrast, *T. divaricata* was highly susceptible, recording 96 % reduction in total chlorophyll and MSI and a 57 % reduction in RWC at 60 dS m⁻¹. *Eranthemum pulchellum* and *A. wilkesiana* showed moderate physiological stability up to 20 dS m⁻¹, indicating mild salinity tolerance, but exhibited substantial declines at higher salinity levels. Total phenolic content increased with salinity, reaching 1.89 mg GAE g⁻¹ FW in *P₂* at 60 dS m⁻¹, indicating enhanced antioxidant defence. Principal component analysis (PCA) revealed that the first three components explained 92.73 % of the total variation, with chlorophyll content, membrane stability and water status contributing most strongly to salinity tolerance. The study identifies *L. frutescens* as a highly salt-tolerant ornamental shrub suitable for coastal landscaping.

Keywords: coastal landscaping; ornamental species; physiological response; salinity

Introduction

Soil salinity is one of the major abiotic stresses that affects plant growth and development. Plants capable of withstanding high salinity in soil or water are termed salt/saline tolerant. Globally, 160 million hectares (ha) of cultivable land are affected by salinity (1). In India, 9.9 million ha of land are affected by salinity (2). Under high salinity, plant physiology is altered by a reduction in turgor potential, impaired photosynthesis and excess salt accumulation in the leaves. This ultimately leads to reduced carbohydrates synthesis, hormonal imbalance and overall growth inhibition. Early symptoms include leaf tip burn, necrosis and chlorosis (3). Salinity reduces photosynthetic rates, synthesis of growth-promoting metabolites and enhances ion toxicity (4). Different plant species have different levels of salinity tolerance, which are governed by morphological, physiological and biochemical mechanisms. Several ornamental plants have demonstrated modest salt tolerance, indicating the possibility of developing and selecting salt-tolerant varieties. For example, *Fuchsia hybrida* Voss, *Solenostemon scutellarioides* (L.) Codd (*Coleus*) and *Begonia hiemalis* Fotsch can withstand salt levels up to 9.8 dS m⁻¹ (5). While,

Lilium × elegans Thunb can tolerate salinity stress up to 3 dS m⁻¹ (5). Visual indicators of salt injury are complemented by physiological and biochemical parameters such as chlorophyll content, relative water content (RWC), chlorophyll stability index (CSI), membrane stability index (MSI), total phenolic content (TPC), leaf electrical conductivity (EC) and leaf pH. In semi-arid and arid regions, salinity is exacerbated due to competition for high-quality water among agriculture, landscaping and industry. Identifying and recommending suitable saline-tolerant shrubs will promote the use of alternative water sources (i.e., seawater or brackish water) for irrigation (6).

Ornamental plants are an integral part of urban and peri-urban landscaping, contributing significantly to environmental quality and aesthetic appeal. However, increasing soil and water salinity poses a major challenge to the growth and performance of ornamental plants. Despite their importance, the responses of ornamental plants to salinity stress have received considerably less attention than those of major flower crops (7). Previous studies have investigated the salinity tolerance of individual shrub species such as *Acalypha wilkesiana* Müll.Arg., *Clerodendron inerme* currently

Volkameria inermis (L.) Benth. & Hook.f. ex B.D.Jacks. and *Leucophyllum frutescens* (Berland.) I.M. Johnst. (8). However, these studies were conducted independently and under varying experimental conditions, limiting direct comparisons among species.

In the coastal regions of India, several ornamental shrubs are grown. Among them, *A. wilkesiana*, *L. frutescens*, *Tabernaemontana divaricata* (L.) R.Br. ex Roem. & Schult and *Eranthemum pulchellum* Andrews are widely used in landscaping. Previous studies have screened flower crops such as marigold (9) and chrysanthemum (10), as well as trees, herbs and grasses (11–14). Despite the functional and aesthetic importance of coastal landscaping, there is limited information on the comparative physiological and biochemical responses of these ornamental shrubs under saline stress (8). Specifically, comparative evaluations of key physiological parameters, including chlorophyll a (Chl-a), chlorophyll b (Chl-b), total chlorophyll content, CSI, leaf EC and leaf pH, together with biochemical traits such as TPC, are lacking for these ornamental shrub species under saline conditions prevalent in Indian coastal conditions. Hence, the present study was conducted to comparatively assess the physiological and biochemical responses and salinity tolerance of four commonly used ornamental shrubs and to identify suitable plant species for coastal landscaping.

Materials and Methods

Plant material

One month old healthy and uniform plants of four ornamental shrubs, namely *E. pulchellum* (P₁), *L. frutescens* (P₂), *A. wilkesiana* (P₃) and *T. divaricata* (P₄) were used in the study. The planting materials were sourced from the SRM College of Agricultural Sciences (SRMCAS) nursery and were selected based on uniform height, growth and free from pests and disease symptoms. The plant species were identified and authenticated by the Head of the Department, Department of Floriculture and Landscaping, SRM College of Agricultural Sciences. All plants were propagated through stem cuttings and maintained under uniform nursery conditions prior to the experiment. These species were chosen due to their ornamental importance and potential suitability for coastal landscaping. *Eranthemum pulchellum* and *A. wilkesiana* are widely grown for their attractive green, lush foliage and yellow-coloured markings on the leaves. *Leucophyllum frutescens* is also known as Texas sage, popularly known for its attractive ash-coloured foliage, purple flowers and salinity tolerance. *Tabernaemontana divaricata* is an evergreen shrub commonly used as hedges and edges in landscaping.

Experimental site and condition

The experiment was conducted under open-field conditions at the Department of Floriculture and Landscape Architecture, SRM College of Agricultural Sciences, Chengalpattu. One month old saplings were transplanted into grow bags (24 x 24 x 40 cm) containing 5 kg of a soil mixture composed of red soil, farmyard manure (FYM) and cocopeat in a 2:1:1 (v/v) ratio. Plants were allowed to establish for 60 days under uniform environmental conditions and irrigated using potable water (EC = 0 dS m⁻¹; pH 6.8).

Salinity treatment

Salinity stress was imposed by irrigating with saline water containing sodium chloride (NaCl) and calcium chloride (CaCl₂) at a 7:3 ratio (15). The treatments were maintained at four electrical

conductivity (EC) levels of 0 dS m⁻¹(control), 20 dS m⁻¹, 40 dS m⁻¹ and 60 dS m⁻¹ by adding 0, 7, 12 and 20 g L⁻¹ of the salt mixture, respectively, dissolved in water. The salinity treatments were imposed for 30 days. The plants were irrigated with respective saline solutions whenever the growing media showed signs of moisture depletion.

Experimental design

The experiment was laid out in a factorial completely randomised design (FCRD) comprising two factors: four plant species and four salinity levels, with 16 treatment combinations (Table 1). Each treatment was replicated thrice with five plants per replicate.

Table 1. Treatment combinations of the experiment, indicating plant species (P) under salinity treatments (S)

Plant species (P)	Salinity levels (S)
P ₁ - <i>Eranthemum pulchellum</i>	S ₁ -0 dS m ⁻¹
P ₂ - <i>Leucophyllum frutescens</i>	S ₂ -20 dS m ⁻¹
P ₃ - <i>Acalypha wilkesiana</i>	S ₃ -40 dS m ⁻¹
P ₄ - <i>Tabernaemontana divaricata</i>	S ₄ -60 dS m ⁻¹

Physiological and biochemical characterisation of ornamental shrubs

Parameters were assessed 30 days after salinity imposition.

Chlorophyll content

Fresh leaf tissue (0.5 g) was homogenised in 80 % acetone, centrifuged at 5000 rpm for 10 min. The supernatant was collected and the final volume was made up to 25 mL using 80 % acetone. The absorbance was recorded at 645 nm, 652 nm and 663 nm (16). Chlorophyll a (Chl-a), Chl-b and total chlorophyll content were calculated using the following equations:

$$\text{Chlorophyll a (mg g}^{-1} \text{ FW)} = \frac{(12.7 \times A_{663} - 2.69 \times A_{645}) \times V}{1000 \times W} \quad (\text{Eqn. 1})$$

$$\text{Chlorophyll b (mg g}^{-1} \text{ FW)} = \frac{(22.9 \times A_{645} - 4.68 \times A_{663}) \times V}{1000 \times W} \quad (\text{Eqn. 2})$$

$$\text{Total chlorophyll (mg g}^{-1} \text{ FW)} = \frac{(20.2 \times A_{645} + 8.02 \times A_{663}) \times V}{1000 \times W} \quad (\text{Eqn. 3})$$

where: A₆₆₃ = absorbance at 663 nm; A₆₄₅ = absorbance at 645 nm; V = final volume of extract (mL); W = fresh weight of tissue (g).

Chlorophyll stability index (CSI)

Leaf discs from each species were heated at 65 °C for 30 min, chlorophyll was extracted using 80 % acetone and absorbance was recorded at 660 nm. Chlorophyll stability index was calculated using the following formula and expressed in percent (17).

$$\text{CSI (\%)} = \frac{\text{Total chlorophyll (heated)}}{\text{Total chlorophyll (control)}} \times 100 \quad (\text{Eqn. 4})$$

Membrane stability index (MSI)

Membrane stability index was determined by measuring the EC of a 0.1 g leaf sample in 10 mL distilled water at 40 °C for 30 min (C₁) followed by boiling at 100 °C for 10 min (C₂). Membrane stability index (MSI) was calculated using the formula and expressed in percent (17).

$$MSI (\%) = 1 - \frac{C_1}{C_2} \times 100 \quad (\text{Eqn. 5})$$

Relative water content (RWC)

Leaf samples were weighed for fresh weight (FW), floated in distilled water for 4 hr to obtain turgid weight (TW) and oven dried at 75 °C to constant weight (DW), calculated and expressed (18) as:

$$RWC = \frac{FW - DW}{TW - DW} \times 100 \quad (\text{Eqn. 6})$$

Leaf pH and electrical conductivity

Fresh leaf sap pH was measured with a digital pH meter (Systronics. Model no: 335). Leaf EC was recorded using a digital conductivity meter (Systronics. Model no: 307) from crushed leaf samples soaked in distilled water.

Total phenolic content

Phenols were extracted from 0.5 g of leaves in 80 % methanol (50 °C, 10 min.), centrifuged (5000 rpm, 10 min). An aliquot of the extract was reacted with Folin-Ciocalteu reagent and absorbance was measured at 760 nm. Total phenolic content was quantified using a gallic acid (GA) standard curve and expressed as (mg GAE g⁻¹ FW) (19).

Salinity damage score

Foliar symptoms (scorching, necrosis, chlorosis) were visually scored on a 1–5 scale; 1 = no visible salinity damage to leaves; 2 = slight salinity damage to leaves (25 % marginal scorching of leaves); 3 = moderate salinity damage to leaves (50 % scorching and yellowing of leaves); 4 = high salinity damage to leaves (75 % scorching, yellowing and drying of leaves); 5 = severe salinity damage to leaves, almost all leaves dry (100 % drying of leaves) (20).

Statistical analysis

Data were analysed using analysis of variance (ANOVA) suitable for FCRD and means were compared using Duncan's multiple range test (DMRT) ($p \leq 0.05$). Mean data were used for principal component analysis (PCA) to evaluate the overall variation and relationship among physiological and biochemical traits under salinity stress. Principal component analysis was carried out using R (version 2026). Eigen values, percentage of variance and cumulative variance were computed to determine the contribution of each principal component.

Results and Discussion

Changes in the photosynthetic pigments of ornamental plant species under salt stress

Chlorophyll a, b and total chlorophyll content declined progressively with increasing salinity levels, with > 80 % reduction at 60 dS m⁻¹ (S₄) across the species. Highly significant differences were

observed among the species, salinity levels and their interactions.

Chlorophyll a

P₂ maintained relatively higher Chl-a content under salinity stress (0.54 mg g⁻¹ FW) and a steady decline to 0.28 mg g⁻¹ (48 % loss) at S₂, 0.27 mg g⁻¹ (50 % loss) at S₃ and 0.19 mg g⁻¹ (65 % loss) at S₄ (Table 2). A relatively smaller reduction was observed up to S₃ and at higher salinity levels, the Chl-a content declined drastically, indicating the plant may exhibit salinity tolerance up to 40 dS m⁻¹. P₄ recorded the highest Chl-a content at S₁ 0.76 mg g⁻¹ FW compared to the other species, but a sharp decline was recorded at S₄ 0.02 mg g⁻¹ FW (97 % loss). This drastic decline indicates ionic imbalance under salt stress (21). P₂ exhibited relatively higher tolerance, suggesting osmotic adjustments and protective mechanisms due to the presence of trichomes on the adaxial and abaxial leaf surfaces (22). This reduction is primarily due to salt-induced oxidative stress that damages chloroplast structure and accelerates pigment degradation (21). Increased accumulation of Na⁺ and Cl⁻ ions disrupts the uptake of essential nutrients, which in turn inhibits the chlorophyll biosynthesis, enhancing the degradation process (23). Similar chlorophyll reduction under salinity stress has been reported in *gladiolus* (24), *Acalypha* and *Leucophyllum* (8). Chlorophyll a levels decreased with increasing external salinity, particularly at high (400–800 mM NaCl) salt concentrations and similar results were reported in *Nerium* (25).

Chlorophyll b

Chlorophyll b exhibited a pattern similar to that of Chl-a. P₂ recorded 0.26 mg g⁻¹ FW at S₁ (control), followed by a decline to 0.17 mg g⁻¹ FW (34.62 % loss) at S₂, 0.18 mg g⁻¹ FW (30.77 % loss) at S₃, 0.13 mg g⁻¹ FW (50 % loss) at S₄. P₄ was found to be highly sensitive to salinity with 0.44 mg g⁻¹ FW at S₁ and a sharp decline to 0.27 mg g⁻¹ FW (38.64 %) at S₂, 0.03 mg g⁻¹ FW (93.18 % loss) at S₃ and 0.02 mg g⁻¹ FW (95.45 %) at S₄ (Table 2). This reduction in Chl-b at increasing salinity levels may be due to damage in the photosystem, inhibition of chlorophyll synthesis by disruption of thylakoid membranes (26). Similar reduction in chl-b under salinity stress has been reported in ornamentals like *Petunia* (27) and *Alstroemeria* (28).

Total chlorophyll content

Total chlorophyll represents the combined concentration of Chl-a and Chl-b. P₂ recorded 0.72 mg g⁻¹ FW at S₁ with a steady decline to 0.52 mg g⁻¹ FW (28 % loss) at S₂, 0.31 mg g⁻¹ FW (57 % loss) at S₃ and 0.16 mg g⁻¹ FW (78 % loss) at S₄. In contrast, P₄ showed a higher total chlorophyll content at S₁ (0.83 mg g⁻¹ FW) and a drastic decline of 96 % loss at S₄ (0.03 mg g⁻¹) (Table 2). The decline in total chlorophyll under salt stress is due to chlorophyll pigment degradation, inhibition of chlorophyll biosynthesis and structural damage in the chloroplast (29). Stress enhances the production of reactive oxygen species (ROS), which damage the photosynthetic membranes; however, plants may partially mitigate stress through antioxidant upregulation (30). Similar reduction in total chlorophyll has been

Table 2. Variations in chlorophyll a, chlorophyll b and total chlorophyll content (mg g⁻¹ FW) of plant species (P) under salinity treatments (S)

	Chlorophyll a (mg g ⁻¹ FW)				Chlorophyll b (mg g ⁻¹ FW)				Total chlorophyll (mg g ⁻¹ FW)			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
P ₁	0.18	0.09	0.08	0.04	0.07	0.04	0.02	0.02	0.20	0.10	0.09	0.04
P ₂	0.54	0.28	0.27	0.19	0.26	0.17	0.18	0.13	0.72	0.52	0.31	0.16
P ₃	0.57	0.32	0.08	0.04	0.29	0.12	0.03	0.03	0.82	0.33	0.29	0.05
P ₄	0.76	0.28	0.04	0.02	0.44	0.27	0.03	0.02	0.83	0.23	0.19	0.03
Mean	0.51	0.24	0.12	0.07	0.27	0.15	0.07	0.05	0.64	0.30	0.22	0.07
	P	S	PxS		P	S	PxS		P	S	PxS	
SE(d)	0.005	0.005	0.009		0.003	0.003	0.005		0.006	0.006	0.012	
CD	0.009	0.009	0.019		0.006	0.006	0.011		0.012	0.012	0.025	

Values are means of three replicates; CD ($p \leq 0.05$). P: plant species; S: salinity levels; PXs: Interaction between plant species and salinity.

reported in *Alstroemeria* (21, 28).

Chlorophyll stability index

Chlorophyll stability index (CSI) is the ability of a plant to withstand chlorophyll degradation under stress. Chlorophyll stability index declined significantly with increasing salt concentrations. Under control conditions (S₁), the CSI ranged from 83.26 % in P₁ to 89.22 % in P₄, indicating stable chlorophyll content. Significant differences were observed across the salinity treatment among the plant species. P₄ decreased from 89.22 % at S₂ to 29.47 % at S₄ (Table 3), suggesting a major loss in chlorophyll stability due to salt stress. This might be due to oxidative stress damaging the chloroplast and accelerating pigment breakdown. This directly influences the total chlorophyll content, visual quality and plant vigour (31). P₂ recorded the highest CSI with a gradual decline across salinity treatments, which may be due to low stress injury and enhanced physiological stability and maintained the photosynthetic efficiency (29).

Membrane and water status of ornamental plant species under salinity

Membrane stability index

Membrane stability index (MSI) is a reliable indicator of salinity tolerance and is strongly associated with total chlorophyll content and CSI. Significant differences were observed across the salinity levels and their interactions with plant species. Although P₃ and P₄ exhibited higher MSI values under control conditions (79.47 % and 75 %, respectively) than P₂ (50 %), a higher baseline MSI does not necessarily indicate greater salinity tolerance. Baseline MSI values may vary among species due to inherent differences in membrane composition, electrolyte concentration and cellular organisation under non-stress conditions (29). Therefore, salinity tolerance is more accurately reflected by the ability of a species to maintain membrane stability under increasing salt stress rather than by its initial MSI value alone. Among the tested species, P₂ exhibited greater capacity to retain membrane stability under saline conditions. Its MSI declined from 50 % at S₁, to 28.60 % at S₂ (43 % loss), 16.70 % at S₃ (67 % loss) and 9.10 % at S₄ (81.80 % loss) (Table 3). This higher retention of MSI in P₂ indicates better membrane integrity, reduced electrolyte leakage and effective antioxidant protection against peroxidation, consistent with saline-tolerant shrubs under high EC (8). In contrast, variation in MSI response was observed among the species. P₄ exhibited a drastic decrease in MSI at S₂ (88 % loss), S₃ (94 % loss) and S₄ (96 % loss). This may be attributed to rapid ionic disruption and membrane damage even at 20 dS m⁻¹ (32). High salinity leads to excess accumulation of Na⁺ and Cl⁻ ions, which induces oxidative stress, resulting in lipid peroxidation, membrane destabilisation and increased permeability and similar findings were reported (33–35).

Relative water content

The data on RWC showed a progressive decline with increasing salinity levels. Among the four species, P₄ showed the greatest reduction, falling from 89.36 % at S₁ to 52.31 % at S₂, 40.85 % at S₃ and 38.36 % at S₄. Reduction in RWC under salinity stress is primarily due to osmotic imbalance that limits water uptake and leads to cellular dehydration (32, 35, 36). Further, the results suggest that higher stress levels at S₃ and S₄ lead to severe metabolic disruption in the species and reduced physiological activity (37). P₂ exhibited a comparatively lower reduction at S₂ (7.38 % loss), followed by S₃ (24.71 % loss) and S₄ (30.51 % loss) (Table 3). This suggests that P₂ is more tolerant compared to the other plant species, which may be due to the improved osmotic adjustment and stress-protective mechanism (38), such as succulent leaves and the presence of trichomes on the leaf surface (22).

Leaf electrical conductivity

An increase in leaf EC suggests that, at high salt concentrations, disruption of lipid bilayer and membrane-bound proteins causes loss in membrane integrity. Under control conditions, all plant species exhibited low EC values ranging from 0.6–0.9 dS m⁻¹. In P₃, EC increased to 2.3-fold at S₂. At a higher salinity level (S₄), EC recorded a substantial increase in P₄ (7.8), followed by P₃ (6.6), P₁ (6.5) and P₂ (4.1) (Fig. 1). This might be due to severe cellular damage and reduced membrane stability (35). Elevated EC values indicate increased electrolyte leakage due to membrane disintegration as a direct effect of Na⁺ and Cl⁻ ion accumulation. Hence, the results revealed that a relatively lower increase in P₂ indicates a better adaptive response mechanism due to ion regulation, osmotic adjustment and better membrane stability (32). The relationship between MSI and leaf EC confirms that the increased membrane damage leads to higher electrolyte leakage under salinity stress.

Biochemical response of ornamental plant species under salinity

Total phenolic content

Total phenolic content (TPC) is an important biochemical indicator for stress tolerance because phenolic compounds scavenge reactive oxygen species and increase the antioxidant capacity (39). The present results suggest that the plant accumulates more phenol to protect the plant from salt stress. Among the plant species, P₁ showed increasing phenol content from 1.42 mg g⁻¹ at S₁ to 1.76 mg g⁻¹ at S₄, P₂ from 1.43 mg g⁻¹ to 1.89 mg g⁻¹, P₃ from 0.97 mg g⁻¹ to 1.53 mg g⁻¹ and P₄ from 0.49 mg g⁻¹ to 1.72 mg g⁻¹ (Fig. 2). Phenol content was recorded the highest in P₂, indicating strong phenol accumulation under stress. This may be attributed to increased antioxidant capacity with an increase in phenol synthesis to mitigate oxidative stress and protect the cellular structure (40). P₃ recorded lower phenol accumulation than the other treatment,

Table 3. Chlorophyll stability index, membrane stability index and relative water content (%) of plant species under salinity treatments

	Chlorophyll stability index (%)				Membrane stability index (%)				Relative water content (%)			
	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
P ₁	83.27	75.36	61.27	44.19	41.70	16.30	11.10	2.50	88.37	79.25	57.69	43.86
P ₂	83.79	76.09	64.77	58.88	50.00	28.60	16.70	9.10	84.31	76.79	72.03	62.50
P ₃	88.55	72.89	57.89	32.39	79.47	26.62	6.70	4.00	71.15	52.31	44.16	40.00
P ₄	89.22	72.43	49.56	29.47	75.00	9.10	4.80	3.30	89.36	57.81	48.72	37.18
Mean	86.21	74.19	58.37	41.23	61.54	20.16	9.83	4.73	83.30	66.54	55.65	45.89
	P	S	PxS		P	S	PxS		P	S	PxS	
SE(d)	1.000	1.000	1.999		0.477	0.477	0.953		0.970	0.970	1.939	
CD	2.036	2.036	4.073		0.971	0.971	1.942		1.975	1.975	3.95	

Values are means of three replicates; CD ($p \leq 0.05$). P: plant species; S: salinity levels; PXS: Interaction between plant species and salinity.

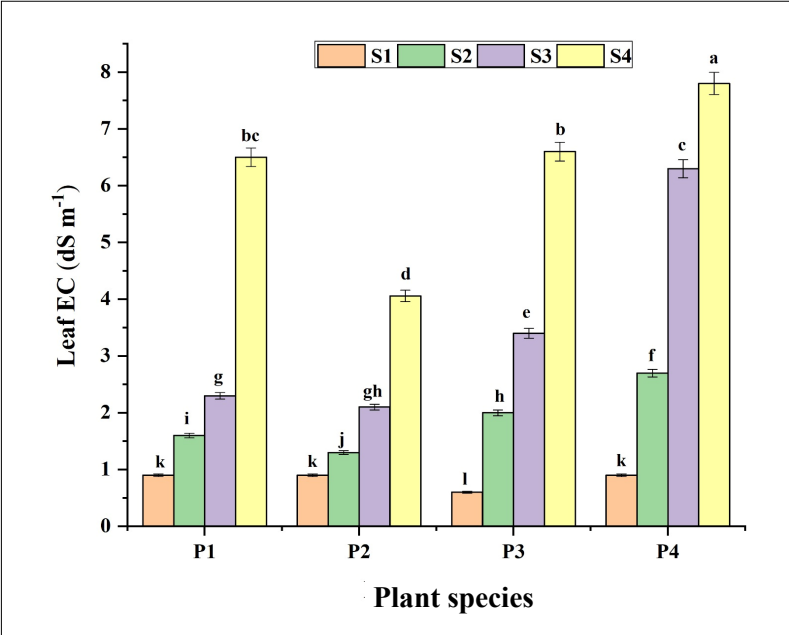


Fig. 1. Leaf electrical conductivity (dS m^{-1}) in four ornamental plant species. P₁: *Eranthemum pulchellum*; P₂: *Leucophyllum frutescens*; P₃: *Acalypha wilkesiana*; P₄: *Tabernaemontana divaricata* under varying salinity levels: S₁: 0 dS m^{-1} ; S₂: 20 dS m^{-1} ; S₃: 40 dS m^{-1} ; S₄: 60 dS m^{-1} . Bars represent mean $\pm$ SE. Letters above bars indicate significant differences among the treatments at $p \leq 0.05$.

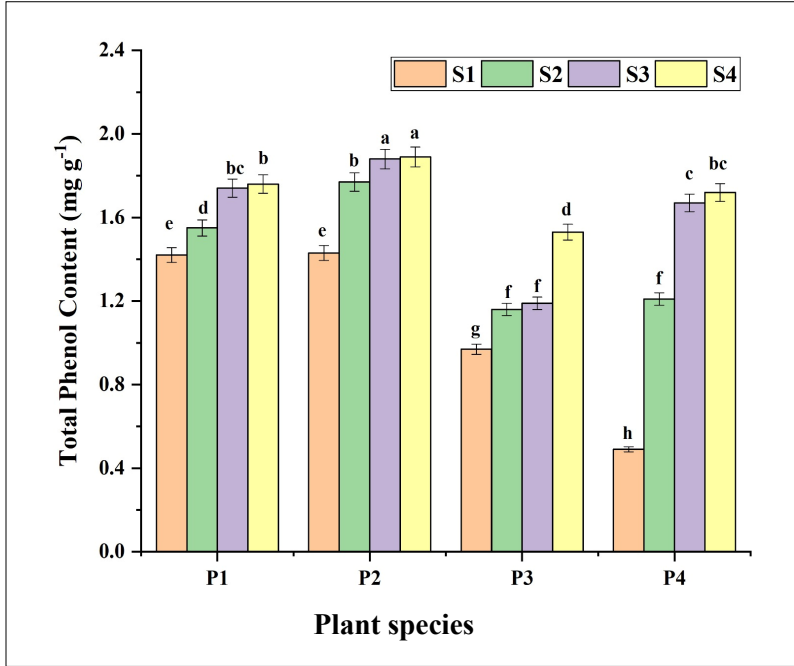


Fig. 2. Total phenolic content (mg g^{-1}) in four ornamental plant species. P₁: *Eranthemum pulchellum*; P₂: *Leucophyllum frutescens*; P₃: *Acalypha wilkesiana*; P₄: *Tabernaemontana divaricata* under varying salinity levels: S₁: 0 dS m^{-1} ; S₂: 20 dS m^{-1} ; S₃: 40 dS m^{-1} ; S₄: 60 dS m^{-1} . Bars represent mean $\pm$ SE. Letters above bars indicate significant differences among the treatments at $p \leq 0.05$.

indicating the reduced activity of the phenylpropanoid pathway, which in turn lowers the stress response (35).

Leaf pH

Leaf pH increased with increasing salinity in all plant species, while the effects of plant species and salinity were not statistically significant. In P₁ leaf pH ranged from 7.1 at S₁ to 7.3 at S₂, 7.4 at S₃ and 7.7 at S₄. P₂ increased from 5.1–5.2, 5.3 and 5.7 at S₁, S₂, S₃ and S₄, respectively. P₃ recorded an increase from 4.8–5.1, 5.4 and 5.7, while P₄ increased from 5.1–5.2, 5.5 and 6.1 at S₁, S₂, S₃ and S₄, respectively (Table 4). This gradual increase in pH was observed with increasing salinity; the differences were not significant and therefore should be considered as a trend rather than definitive treatment responses. Similar trends have been reported under salinity and stress, where

Table 4. Leaf pH of plant species under salinity stress

	Leaf pH			
	S ₁	S ₂	S ₃	S ₄
P ₁	7.10	7.30	7.40	7.70
P ₂	5.10	5.20	5.30	5.70
P ₃	4.80	5.10	5.40	5.70
P ₄	5.10	5.20	5.50	6.10
Mean	5.53	5.70	5.90	6.30
	P	S	PxS	
CD	NS	NS	NS	

Values are means of three replicates; CD ($p \leq 0.05$). P: plant species; S: salinity levels; PXS: Interaction between plant species and salinity.

alteration in ion balance may influence cellular metabolism and physiological processes. However, in the present study, salinity did not exert a statistically significant effect on leaf pH (32, 35, 41).

Salinity damage scoring of ornamental plant species

Visual symptoms in all plant species were scored on a scale of 1 (no damage) to 5 (severe damage) (20). The results of the present study demonstrate the deleterious effects of salt stress. At S_1 (control), all plant species recorded a score of 1, indicating no damage or normal growth. However, at S_2 , all plants showed symptoms such as leaf tip burn and chlorosis, while P_4 exhibited a pronounced injury symptom (Fig. 3). These symptoms indicate reduced water uptake and impaired osmotic adjustment (35). At higher salinity levels, S_3 and S_4 exhibited severe injury symptoms such as complete leaf drying and plant death. This may be due to membrane disintegration, ion toxicity and decreased enzyme production (42). The visual damage scoring shows a strong positive correlation with the physiological response of plant species under salt stress.

Overall, salinity induced a decline in Chl-a, Chl-b, total chlorophyll, CSI, MSI and RWC, indicating impaired photosynthetic efficiency and membrane integrity. In contrast, TPC, leaf EC and pH increased, indicating improved oxidative stress and ionic

physiological and biochemical responses (Fig. 4). The first three principal components, PC1 (73.4 %), PC2 (13.3 %) and PC3 (6.03 %), together explained 92.73 % of total variance, reflecting the plant's response to salinity stress (Table 5).

PC1 was primarily associated with traits like RWC, CSI, MSI, Chl-a, Chl-b and total chlorophyll. All these traits exhibited a positive correlation, suggesting the photosynthetic system is closely linked with membrane integrity and plant water relations under saline conditions. The clustering of chlorophyll fractions with MSI underscores the tight coupling between photosynthetic efficiency and membrane integrity under salinity stress. This coordinated response suggests that maintenance of pigment composition and cellular integrity is central to stress tolerance and consistent with recent reports in soybean and other crops (43, 44).

Treatments P_3S_1 , P_4S_1 and P_2S_1 are positioned on the positive side of PC1, were closely aligned with these traits, indicating superior physiological performance under salinity tolerance. In contrast, P_2S_2 and P_3S_2 were located near the vectors of MSI and RWC, reflecting partial maintenance of water status and membrane stability under moderate salinity (20 dS m⁻¹). These patterns highlight a progressive decline in physiological performance with increasing stress intensity.

In contrast, TPC and EC exhibited a negative correlation along PC1, forming a distinct stress-response axis. This inverse association with chlorophyll and MSI indicates a shift from growth-related processes to defence-oriented mechanisms under salinity stress. Treatments P_4S_4 , P_3S_4 , P_4S_3 and P_3S_3 were strongly associated with these variables, indicating increased membrane damage and oxidative stress. Elevated EC is indicative of membrane destabilisation and ion imbalance, a common symptom of salinity-induced injury (45).

Eranthemum pulchellum under different salinity levels (0, 20, 40 dS m⁻¹) were distributed towards the upper quadrant, showing strong association with TPC and RWC but not with the

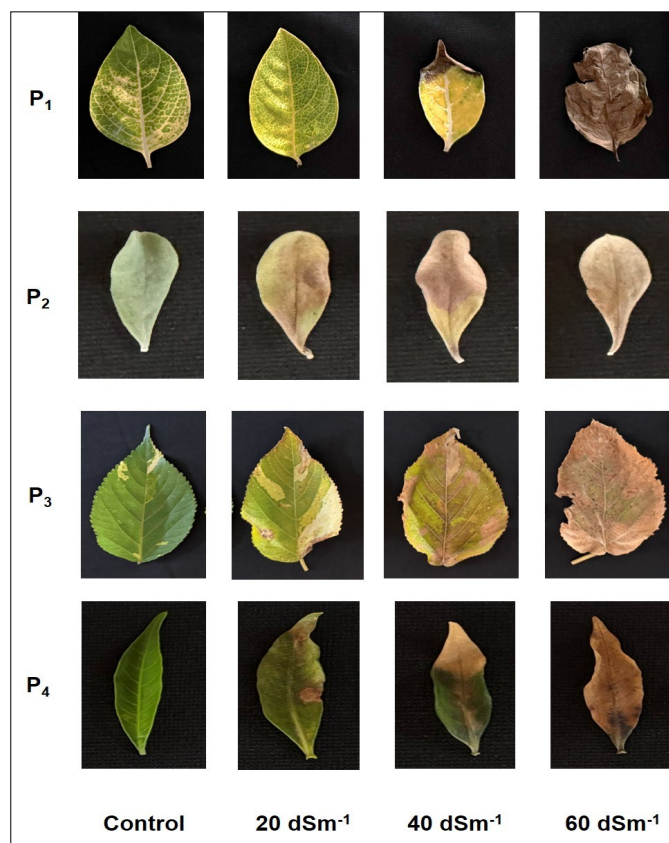


Fig. 3. Visual symptoms such as leaf curling, chlorosis and necrosis on leaves of four ornamental plant species. P_1 : *Eranthemum pulchellum*; P_2 : *Leucophyllum frutescens*; P_3 : *Acalypha wilkesiana*; P_4 : *Tabernaemontana divaricata* under varying salinity levels: S_1 : 0 dS m⁻¹; S_2 : 20 dS m⁻¹; S_3 : 40 dS m⁻¹; S_4 : 60 dS m⁻¹.

imbalance. Species responses varied significantly, confirming different adaptive mechanisms to salinity. Among the plant species, P_2 (*L. frutescens*) showed higher tolerance and P_4 (*T. divaricata*) was highly susceptible to salinity stress.

Principal component analysis of stress-responsive traits

Principal component analysis (PCA) revealed significant variation among ornamental shrubs and salinity treatments based on

Table 5. Loading scores (eigenvectors) of physiological and biochemical traits on the principal components (PC1, PC2 and PC3)

Components	PC1	PC2	PC3
Chlorophyll a	0.964	-0.152	-0.019
Chlorophyll b	0.894	-0.268	0.022
Total chlorophyll content	0.941	-0.188	0.074
Chlorophyll stability index	0.894	0.376	0.100
Membrane stability index	0.934	0.071	-0.159
Relative water content	0.893	0.382	0.055
Total phenolic content	-0.736	0.228	0.575
Leaf electrical conductivity (EC)	-0.827	-0.458	-0.203
Leaf pH	-0.548	0.714	-0.356
Eigenvalue	6.610	1.193	0.543
Variance explained (%)	73.44	13.25	6.03
Cumulative variance (%)	73.44	86.70	92.73

Positive and negative values indicate the direction of association between variables and principal components. Higher absolute loading values represent a stronger contribution of the variables to the respective principal component. Eigenvalues, percentage of variance explained and cumulative variance explained for each principal component are also presented.

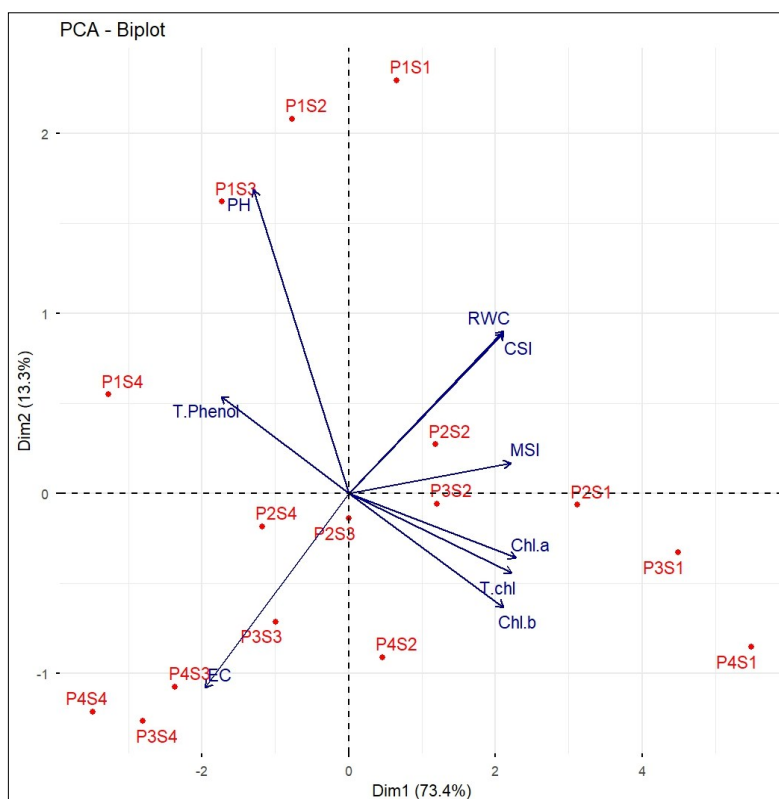


Fig. 4. Principal component analysis biplot showing distribution of treatments and association among physiological and biochemical traits in selected ornamental shrubs. P₁: *Eranthemum pulchellum*; P₂: *Leucophyllum frutescens*; P₃: *Acalypha wilkesiana*; P₄: *Tabernaemontana divaricata* under varying salinity levels- S₁: 0 dS m⁻¹; S₂: 20 dS m⁻¹; S₃: 40 dS m⁻¹; S₄: 60 dS m⁻¹.

chlorophyll traits. This suggests a defensive adaptation strategy, where the plant relies more on antioxidant accumulation rather than maintaining the photosynthetic efficiency. Similar findings were reported in saline-stressed crops, where the antioxidant system partially mitigates cellular damage (46).

PC2 further discriminated treatments based on water relations and pigment stability, with RWC and CSI contributing positively. This indicates that, beyond primary physiological traits, maintenance of tissue hydration and chlorophyll stability provides an additional layer of tolerance.

PC3 represents a secondary biochemical response axis primarily associated with TPC. Although its contribution to the overall variance was comparatively small, PC3 suggests that phenolic metabolism contributed independently to salinity response among the shrubs.

Overall, the PCA biplot differentiated between plant species into tolerant, moderately tolerant and sensitive groups. Salinity tolerance was primarily associated with the maintenance of chlorophyll content, membrane stability and plant water status, whereas increased phenol accumulation and EC reflected stress injury rather than adaptive efficiency. These findings demonstrate that physiological stability outweighs biochemical defence alone in conferring salinity tolerance. This provides a reliable basis for selecting salt-tolerant ornamental shrubs for coastal landscaping.

Conclusion

Salinity is the major abiotic stress that limits the use of irrigation water in the coastal areas of India. The present study highlighted the physiological and biochemical responses of selected ornamental plant species to salinity. Among the evaluated species, *Leucophyllum frutescens* exhibited superior salinity tolerance and outperformed

the other ornamental shrubs under saline conditions. In contrast, *Tabernaemontana divaricata* was found to be sensitive to salinity, while *Eranthemum pulchellum* and *Acalypha wilkesiana* showed mild tolerance. Furthermore, research on the ultrastructural changes under salt stress offers directions for future research.

Acknowledgements

The authors would like to thank the Faculty of Horticulture, SRM College of Agricultural Sciences, for providing an experimental area for carrying out the research.

Authors' contributions

SS conceptualised the study, coordinated, drafted and reviewed the manuscript. LK carried out the research experiment, performed statistical analysis and drafted the manuscript. GS and NR reviewed and edited the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors do not have any conflicts of interest to declare.

Ethical issues: None

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