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RESEARCH ARTICLE

Aeroponic cultivation of chrysanthemum (*Chrysanthemum morifolium*): Influence of electrical conductivity on morphological, physiological and yield traits

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Abstract

The present study investigates the influence of different electrical conductivity (EC) levels (0.5 EC and 1 EC) on the morphdogical, physiological and yield parameters of chrysanthemum grown under an aeroponic system. Significant differences were observed in plant height (V_2 - 37.34 cm), stem diameter (V_1 - 1.92 cm), number of leaves, internodal length, root length (V_2 - 44.31 cm), root fresh and dry weight (V_5 - 10.15 g), fresh and dry weight of the plant (V_2 - 140.61 g), leaf area, transpiration rate, photosynthetic rate, stomatal conductance, total chlorophyll content and biochemical parameters such as soluble protein content (V_5 - 67.29 mg g^{-1}), catalase activity (V_5 - 38.81 µg H_2O g^{-1} min^{-1}) and peroxidase activity. Flowering characteristics, including number of flowers per plant (V_4 - 56.94 number), flower diameter (V_3 - 6.62 cm), vase life and weight of cut stem (V_3 - 5.53 g), were also significantly affected. The results indicate that the aeroponic system with optimized EC levels enhances growth and flowering performance in chrysanthemum.

Keywords: aeroponic system; chrysanthemum; electrical conductivity; flowering characteristics; morphological parameters; physiological parameters

Introduction

Chrysanthemum (*Chrysanthemum morifolium*) is an economically important ornamental plant widely cultivated for its aesthetic and commercial value. Optimizing growth conditions, particularly nutrient management through electrical conductivity (EC) regulation, is crucial for enhancing plant performance. Aeroponic cultivation offers precise control over nutrient delivery, enabling better growth and flowering. However, limited research exists on the impact of different EC levels on chrysanthemum under aeroponic conditions.

The EC and pH are both good indicators. The EC should not be more than 2.0 mS/cm. Crop output responds positively in increasing concentrations until it reaches an optimal level, further increase in concentration often result in yield decrease (luxury use) (1). Yield may be reduced if concentrations are excessively high toxicity. The total nutrient solution ion concentration determines the plant's growth, development and productivity. Osmotic pressure is determined by the total quantity of ion in the nutritional solution (2). The quantity of nutrient concentration in nitrate fertilisers, such as calcium nitrate and potassium nitrate, increases the mean total number of mini tubers collected decreased, but treatments that utilised lesser nitrate fertilisers produced higher yield (3). This study aims to assess the morphological and physiological responses of chrysanthemum to varying EC levels under aeroponic condition, providing insights into optimal growth conditions for improved productivity.

Materials and Methods

Experimental design

The study was conducted in a controlled aeroponic growing system with two EC levels (0.5 - E1 and 1 - E2) and was predicted using preliminary studies conducted. Five chrysanthemum varieties [V_1 - Larenzo (green colour), V_2 - Prius Pink (peach colour), V_3 - Furore (white colour), V_4 - Merel Gold (white colour) and V_5 - Lotte Orange (red colour)] were collected from local nursery, conoor, Tamil Nadu used in a factorial randomized block design with three replications.

Details of polyhouse

The naturally ventilated polyhouse (NVP) was oriented in East-West direction with the central height of 5.7 m. The frame was constructed with the galvanized iron pipe. A rollable 150 g/m^2 (GSM) white colour polyethylene sheet, flap was provided on all the sides of the polyhouse to control the ventilation area and to cover the side vents during rainy season and to avoid the entry of rainwater. The temperature (25-30 °C) and relative humidity (70-85 %) inside the polyhouse was maintained by watering and overhead heating. 0.5 horsepower motor was used for pumping the water which was conveyed to the

mainline/laterals after filtering through screen filter. In the solution tank water and fertilizers are mixed, water was taken for spraying through laterals/mainline of low-density polyethylene (LDPE) material. Along the laterals, emitters/sprinklers with discharge rate of 7 L/hr at 4 bar pressure was assembled. Whereas misting interval was 2 min spray and 1 min off conditions given throughout the study.

Preparation of nutrient solution

The nutrients used were calcium nitrate, potassium nitrate, mono-potassium phosphate, magnesium sulphate, manganese sulphate, zinc sulphate, copper sulphate, chelates of iron and boron (IAC Krishitech Private Limited).

Crop growth stage and day length manipulation

Specific day length was imposed for different growth stages, such as vegetative stage occurred during long day conditions and reproductive stage was taken place at short day conditions. Day length was controlled first by determining the length of the prevailing natural day light conditions and then providing artificial light or dark condition for the required time.

In winter (December to March), natural day length of 9 hr was observed. For imposing long day conditions, artificial light was given for 4 hr (i.e., 9 + 4 = 13 h photoperiod), under tropical conditions of Madurai. Likewise for imposing short day, dark screening with UV stabilized black polythene sheet of 400 gauge was done and it was ensured that the light level was below 20 Watts.

Growth parameters measured

Plant height, stem diameter, number of leaves, internodal length, root length, root fresh weight and root dry weight were recorded at 30, 60 and 90 days after transplanting (DAT) based on crop growth stages.

Physiological and biochemical analysis

Leaf area, leaf area index, transpiration rate, photosynthetic rate (measured using LI-6400XT, LI-COR Inc., Nebraska, USA), stomatal conductance, total chlorophyll content and chlorophyll a and b were analyzed (4, 5). Soluble protein content and catalase and peroxidase activity were analyzed using standard protocols (6, 7).

Flowering parameters

Number of flowers per plant, flower diameter, vase life and weight of cut stem were measured to evaluate the impact of EC levels on flowering performance.

Statistical analysis

Data were subjected to analysis of variance (ANOVA) and significant differences were analysed statistically by Agricultural Research Statistics (AGRES) software to interpret the results.

Results and Discussions

Plant height

Among the varieties, V_2 recorded the highest plant height (37.34 cm), while V_1 recorded the minimum plant height of 22.80 cm at the 0.5 EC level (Fig. 1). At the 1 EC level, V_2 recorded the utmost plant height (36.76 cm), while the lowest plant height was recorded in V_1 (21.60 cm). Among the interactions (V × E × D), V_2E_1 recorded the maximum plant height at 90 DAT (46.09 cm), followed by V_5E_1 (43.93 cm), while V_1E_2 recorded the minimum plant height (30.72 cm). Similar findings were reported in potato (8). The findings of this study are consistent with those found on tomato plants, where plant height, leaf number and stomatal density were reduced as electrical conductivity increased (9). Reduced osmotic pressure of EC of the greenhouse tomato cultivars was the most important factor for growth and development (10). The electrical conductivity (EC) of the nutrient solution determines the success of aeroponics.

Stem diameter

Among the varieties, V_1 recorded the highest stem diameter (1.92 cm), while V_4 recorded the lowest stem diameter (1.64 cm) at 0.5 EC level (Table 1). Maximum stem diameter was recorded in V_1 (1.79 cm) and the minimum stem diameter was observed V_4 (1.54 cm) at 1 EC level. Among the interactions (V ×

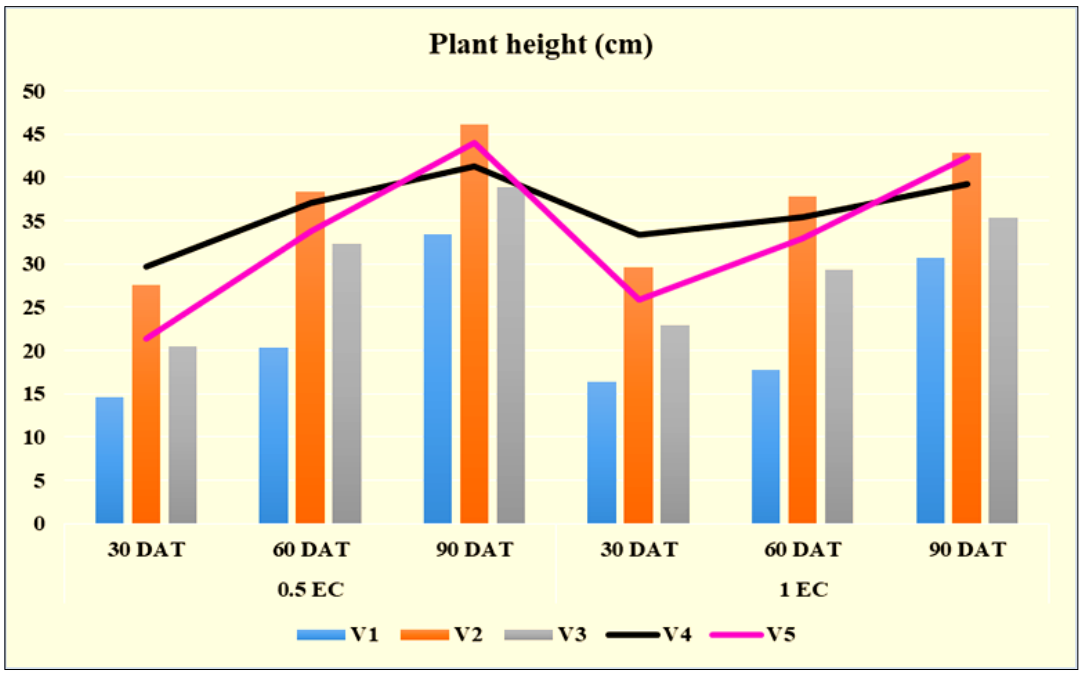

Fig. 1. Effect of electrical conductivity on plant height grown under aeroponic method of cultivation.

Table 1. Effect of electrical conductivity on stem diameter grown under aeroponic method of cultivation.

	Stem diameter (cm)							
	E_1 (0.5 EC)				E_2 (1 EC)			
	30 DAT	60 DAT	90 DAT	Mean	30 DAT	60 DAT	90 DAT	Mean
V_1	1.65	1.93	2.19	1.92	1.15	1.83	1.97	1.79
V_2	1.37	1.68	2.03	1.69	0.86	1.56	2.02	1.62
V_3	1.42	1.70	1.87	1.66	1.36	1.62	1.85	1.61
V_4	1.29	1.79	1.85	1.64	1.18	1.32	1.59	1.54
V_5	1.35	1.88	1.93	1.72	1.32	1.77	1.84	1.64
Mean	1.42	1.80	1.97	1.73	1.35	1.69	1.89	1.64
Factors	**Variety (V)**	**Electrical conductivity (E)**	**V × E**	**Days interval (D)**	**V × D**	**E × D**	**V × E × D**	
Critical Difference	0.054	0.034	0.077	0.042	0.094	0.060	0.133	
Standard Deviation	0.027	0.017	0.038	0.021	0.047	0.030	0.067	

V_1:Larenzo (Green colour - Pompon type), **V_2**:Prius Pink (Peach colour - Spray type), **V_3**:Furore (White colour - Spray type), **V_4**:Merel Gold (Yellow colour - Spray type), **V_5**:Lotte Orange (Red colour - Spray type), **E_1**:0.5 EC, **E_2**:1 EC.

E × D), V_1E_1 recorded the maximum stem diameter (2.19 cm), followed by V_2E_1 (2.03 cm), while V_4E_2 observed the minimum stem diameter (1.59 cm) at 90 DAT. These findings suggest that V_1 is more tolerant or responsive to varying EC levels, maintaining higher stem thickness which is typically associated with better nutrient and water transport, potentially contributing to improved overall plant vigor.

Number of leaves

Among the varieties, V_4 recorded a greater number of leaves (73.89), followed by V_2 (62.88) and V_1 recorded the minimum (34.58) at the 0.5 EC level (Table 2). At the 1 EC level, V_4 (54.21) recorded the highest number of leaves, V_1 recorded the lowest number of leaves (27.99). Among the interactions (V × E × D), V_4E_1 recorded a greater number of leaves (105.28) recorded the least number of leaves at 90 DAT. Highest number of leaves, stem weight, flower diameter and stem diameter at lower EC concentration in rose (11). The result was different to the report in which root length; plant height was higher in higher concentration of nutrients in potato (3). It can be caused by osmotic stress condition in the root zone, resulting in decreased leaf turgor and decreased expansion of leaves (12).

Root length

At the 0.5 EC level, the treatment V_2 had the longest root length (44.31 cm), followed by the treatment V_4, which had the longest root length (35.94 cm) and the treatment V_1 which recorded shortest root length (31.03 cm). At the 1 EC level, the treatment V_2 recorded the highest root length of 44.11 cm and the treatment V_1 recorded the minimum root length of 30.17 cm. Among the interactions, the treatment V_2E_1 recorded supreme root length of 68.48 cm and V_1E_2 recorded minimum root length of 35.19 cm at 90 DAT respectively (Fig. 2). Root length was higher under lowest EC and lower in the highest EC. The size of the root system was necessary to achieve maximum nitrogen uptake which is lowered at high nitrogen concentrations. This reduction in root size indicates a functional balance between root and shoot growth (13).

Root fresh weight and root dry weight

The greatest root fresh weight was observed in V_5 (10.15 g), followed by V_4 (8.40 g), while the lowest root fresh weight was reported in V_1 (6.72 g). Among the interactions, the treatment V_5E_2 had the highest root fresh weight of 10.36 g, followed by V_5E_1 with a root fresh weight of 9.94 g and treatment V_1E_1 recorded the lowest root fresh weight of 6.68 g. In respect to root dry weight, the maximum root dry weight was observed in V_1 (1.84 g), followed by V_2 (1.41 g) and the minimum root dry weight was reported in V_4 (1.21 g). Among the interactions, maximum root dry weight was recorded in V_1E_2 (1.94 g), followed by V_1E_1 (1.73 g) and V_3E_2 (1.05 g) recorded minimum root dry weight (Table 3).

Table 2. Effect of electrical conductivity on number of leaves grown under aeroponic method of cultivation.

	Number of leaves (number)							
	E_1 (0.5 EC)				E_2 (1 EC)			
	30 DAT	60 DAT	90 DAT	Mean	30 DAT	60 DAT	90 DAT	Mean
V_1	14.63	35.56	53.55	34.58	10.38	26.91	46.68	27.99
V_2	27.68	68.34	92.63	62.88	26.64	53.17	65.31	48.37
V_3	18.54	42.89	63.16	41.53	17.39	30.58	41.56	29.84
V_4	26.23	90.17	105.28	73.89	23.45	65.34	73.84	54.21
V_5	16.89	38.36	60.37	38.54	15.69	29.87	53.57	33.04
Mean	20.79	55.06	75.00	50.29	18.71	41.17	56.19	38.69
Factors	**Variety (V)**	**Electrical conductivity (E)**	**V × E**	**Days interval (D)**	**V × D**	**E × D**	**V × E × D**	
Critical Difference	0.881	0.557	1.246	0.682	1.526	0.965	2.158	
Standard Deviation	0.440	0.278	0.623	0.341	0.763	0.482	1.078	

V_1:Larenzo (Green colour - Pompon type), **V_2**:Prius Pink (Peach colour - Spray type), **V_3**:Furore (White colour - Spray type), **V_4**:Merel Gold (Yellow colour - Spray type), **V_5**: Lotte Orange (Red colour - Spray type), **E_1**:0.5 EC, **E_2**:1 EC.

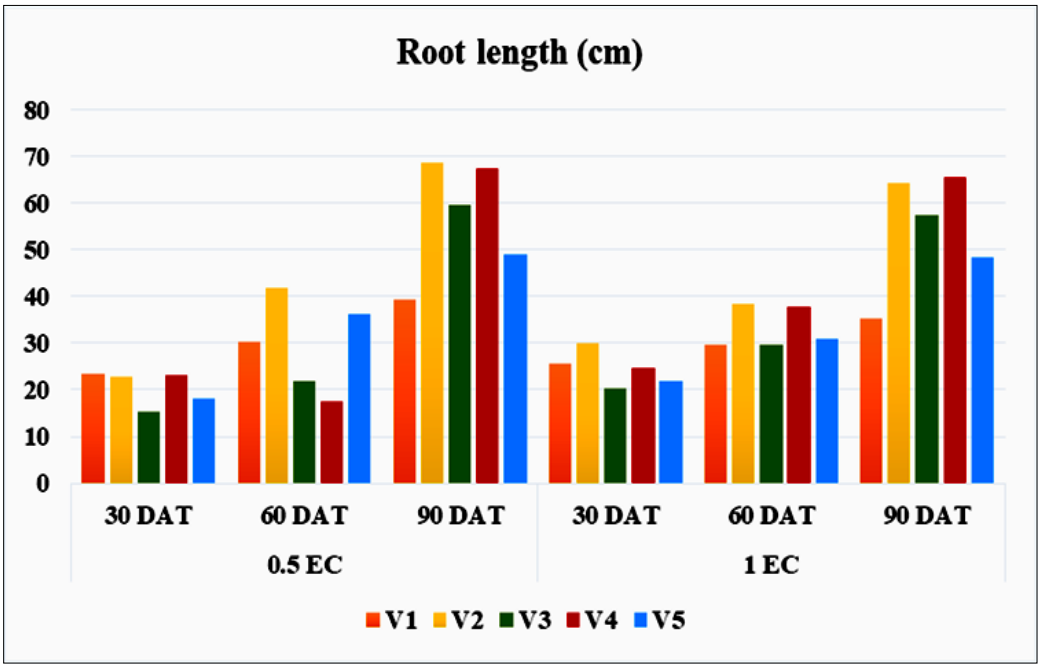

Fig. 2. Effect of electrical conductivity on root length grown under aeroponic method of cultivation.

Table 3. Effect of electrical conductivity on root fresh weight and root dry weight grown under aeroponic method of cultivation.

	Root fresh weight (g)			Root dry weight (g)		
	E_1 (0.5 EC)	**E_2 (1 EC)**	**Mean**	**E_1 (0.5 EC)**	**E_2 (1 EC)**	**Mean**
V_1	6.68	6.75	6.72	1.73	1.94	1.84
V_2	7.93	8.07	8.00	1.30	1.51	1.41
V_3	7.28	7.39	7.34	1.39	1.05	1.22
V_4	8.17	8.62	8.40	1.19	1.23	1.21
V_5	9.94	10.36	10.15	1.23	1.37	1.30
Mean	8.00	8.24	8.12	1.37	1.42	1.39

Factors	**Root fresh weight**		**Root dry weight**	
	Critical Difference	**Standard Deviation**	**Critical Difference**	**Standard Deviation**
Variety (V)	0.099	0.047	0.061	0.029
Electrical conductivity (E)	0.067	0.030	0.039	0.018
V × E	0.140	0.067	0.086	0.041

V_1:Larenzo (Green colour - Pompon type), **V_2**:Prius Pink (Peach colour - Spray type), **V_3**:Furore (White colour - Spray type), **V_4**:Merel Gold (Yellow colour - Spray type), **V_5**:Lotte Orange (Red colour - Spray type), **E_1**:0.5 EC, **E_2**:1 EC.

The observed variations in root fresh and dry weights among different treatments indicate significant genotypic and environmental influences on root development. The highest root fresh weight recorded in V_5 suggests that this variety possesses a robust root system, likely contributing to improved nutrient and water uptake, which are crucial for plant growth and productivity (14, 15). The relatively lower fresh weight in V_1 may point to a less developed root system or slower initial growth, potentially reducing the plant's ability to adapt to abiotic stress.

The treatment interaction results further support this, with V_5E_2 showing the highest root fresh weight (10.36 g), suggesting that V_5 not only has strong genetic potential but also responds favorably to the environmental conditions of E_2. In contrast, the minimum value in V_1E_1 (6.68 g) reflects the compounded impact of genotype and environment on below-ground biomass accumulation (16).

Interestingly, the trend in root dry weight differed from fresh weight, with V_1 showing the highest dry weight (1.84 g) despite having the lowest fresh weight. This indicates a higher root tissue density or lower water content, which may be an adaptive trait for water conservation under stress conditions (17). The high dry weight values observed in V_1E_2 and V_1E_1 emphasize this variety's ability to maintain biomass investment in root systems under varying environmental conditions.

On the other hand, the lower dry weights observed in V_4 and V_3E_2 may reflect a reduced allocation of resources to root development or a response to environmental constraints that limit root biomass accumulation (18). These differences are significant, as root dry weight has a direct correlation with plant anchorage, storage capacity and sustained nutrient absorption (19).

Overall, the results suggest that V_5 may be more suitable for conditions favoring rapid early growth and water-rich environments, while V_1's denser root system may confer a competitive advantage under drought or nutrient-limited conditions. Such information is essential for breeding and selecting varieties for specific agroecological zones or stress-prone areas (20, 21).

Fresh weight and dry weight of the plant

The fresh weight of the plant was recorded higher in V_2 (140.61 g), while the least fresh weight of the plant was recorded in V_4 (101.06 g) given in Table 4. Among the interactions, the fresh weight of the plant was recorded the greatest in V_2E_1 (142.98 g) and the minimum was recorded in V_4E_2 (98.27 g). In respect to dry weight of the plant, the highest dry weight of the plant was recorded in V_2 (18.61 g) and the lowest was recorded in V_5 (13.41 g). Among the interactions, maximum dry weight was recorded in V_2E_1 (21.29 g), followed by the V_1E_1 (19.53 g) and the minimum was recorded in V_5E_2 (10.24 g).

The total ions in the nutritional solution are represented by electrical conductivity. The EC concentration has an impact on nutrient absorption, tuber productivity and tuber quality at different stages of plant growth in potato (22). EC is incompatible with plant growth, can be hazardous to plants (23). Because of the reduced osmotic potential of the nutrient solution, the availability of ions in the nutrient solution increases. Higher in nutrient solution, EC leads to water deficit in crop (24).

Leaf area and leaf area index per plant

For leaf area of the plant, the maximum leaf area of the plant was recorded in V_3 (284.11 cm^2) and the minimum was recorded in V_4 (225.01 cm^2). Among the interactions, highest leaf area was recorded in V_3E_1 (401.74 cm^2) and the lowest was recorded in V_3E_2 (166.47 cm^2), respectively (Table 5).

In respect to leaf area index per plant, the higher leaf area index per plant was recorded in V_3 (0.355) and the lower was recorded in V_4 (0.281). Among the interactions, maximum leaf area index per plant was recorded in V_3E_1 (0.502) followed by V_2E_1 (0.405) and minimum was recorded in V_3E_2 (0.208). These findings are in line with earlier studies that reported genotypic differences in leaf area expansion and LAI due to inherent genetic potential and their interaction with the environment (25). The superior performance of V_3 under E_1 could be attributed to better adaptation or physiological responses such as higher stomatal conductance and efficient nutrient utilization, which are known to support enhanced leaf development. On the other hand, the poor performance under E_2 suggests that either abiotic stresses like drought or

Table 4. Effect of electrical conductivity on fresh weight of plant and dry weight of plant grown under aeroponic method of cultivation.

	Fresh weight of plant (g)			Dry weight of plant (g)		
	E_1 (0.5 EC)	**E_2 (1 EC)**	**Mean**	**E_1 (0.5 EC)**	**E_2 (1 EC)**	**Mean**
V_1	123.56	118.89	121.23	19.53	13.30	16.42
V_2	142.98	138.23	140.61	21.29	15.92	18.61
V_3	129.26	123.49	126.38	17.38	12.20	14.79
V_4	103.84	98.27	101.06	16.76	10.52	13.64
V_5	121.43	106.43	113.93	16.58	10.24	13.41
Mean	124.21	117.06	120.64	18.31	12.44	15.37

Factors	**Fresh weight of plant**		**Dry weight of plant**	
	Critical Difference	**Standard Deviation**	**Critical Difference**	**Standard Deviation**
Variety (V)	3.562	1.696	0.464	0.221
Electrical conductivity (E)	2.253	1.073	0.294	0.140
V × E	5.038	2.398	0.657	0.313

V_1:Larenzo (Green colour - Pompon type), **V_2**:Prius Pink (Peach colour - Spray type), **V_3**:Furore (White colour - Spray type), **V_4**:Merel Gold (Yellow colour - Spray type), **V_5**:Lotte Orange (Red colour - Spray type), **E_1**:0.5 EC, **E_2**:1 EC.

Table 5. Effect of electrical conductivity on leaf area of plant and leaf area index per plant grown under aeroponic method of cultivation.

	Leaf area of plant (cm^2)			Leaf area index per plant		
	E_1 (0.5 EC)	**E_2 (1 EC)**	**Mean**	**E_1 (0.5 EC)**	**E_2 (1 EC)**	**Mean**
V_1	304.31	182.40	243.36	0.380	0.228	0.304
V_2	323.93	205.67	264.80	0.405	0.257	0.331
V_3	401.74	166.47	284.11	0.502	0.208	0.355
V_4	282.70	167.32	225.01	0.353	0.209	0.281
V_5	274.67	189.73	232.20	0.343	0.237	0.29
Mean	317.47	182.32	249.89	0.40	0.23	0.31

Factors	**Leaf area of plant**		**Leaf area index per plant**	
	Critical Difference	**Standard Deviation**	**Critical Difference**	**Standard Deviation**
Variety (V)	6.630	3.156	0.011	0.005
Electrical conductivity (E)	4.193	1.996	0.007	0.003
V × E	9.377	4.464	0.015	0.007

V_1:Larenzo (Green colour - Pompon type), **V_2**:Prius Pink (Peach colour - Spray type), **V_3**:Furore (White colour - Spray type), **V_4**:Merel Gold (Yellow colour - Spray type), **V_5**:Lotte Orange (Red colour - Spray type), **E_1**:0.5 EC, **E_2**:1 EC.

suboptimal nutrient availability might have adversely impacted the leaf development process (26).

Higher leaf area and LAI are associated with greater light interception and carbon assimilation, which are critical for plant growth and yield. Therefore, the superior leaf development observed in V_3, especially under E_1, could potentially translate into higher productivity. These results underscore the importance of selecting appropriate genotypes in conjunction with optimal environmental or management conditions to maximize growth and yield potential.

Transpiration rate and photosynthetic rate

The transpiration rate was recorded higher in V_4 (7.63 m mol H_2O m^{-2} s^{-1}) followed by V_2 (4.88 m mol H_2O m^{-2} s^{-1}) and the lower transpiration rate was observed in V_3 (2.08 m mol H_2O m^{-2} s^{-1}). Among the interactions, maximum transpiration rate was recorded in V_4E_1 (8.72 m mol H_2O m^{-2} s^{-1}) and the minimum was observed in V_3E_2 (1.29 m mol H_2O m^{-2} s^{-1}), according to the interactions (Table 6). High transpiration in V_4 could be indicative of greater stomatal conductance and higher water loss, potentially due to a less conservative water-use strategy, especially under favorable conditions like E_1.

In contrast, V_3's lower transpiration rate, particularly under E_2, suggests a possible drought-avoidance or water-saving strategy, often seen in genotypes adapted to stress-prone environments. Such genotypes maintain tighter stomatal control to limit water loss and emphasize that reduced transpiration is a key adaptive trait under water-limited conditions (27).

In respect to photosynthetic rate, V_2 (1.38 µ mol CO_2 m^{-2} s^{-1}) had the maximum photosynthetic rate and V_1 (0.13 µ mol CO_2 m^{-2} s^{-1}) had the minimum. Among the interactions, the maximum photosynthetic rate was observed in V_2E_1 (1.53 µ mol CO_2 m^{-2} s^{-1}) and the minimum was observed in V_1E_2 (0.09 µ mol CO_2 m^{-2} s^{-1}). These differences in photosynthetic efficiency may be linked to variations in leaf morphology, chlorophyll content and stomatal behavior among the varieties (28). The decoupling between photosynthesis and transpiration, especially in varieties like V_2 and V_3, highlights the complex regulation of water use and carbon gain. Notably, high transpiration does not always equate to high photosynthesis, which supports the idea that water use efficiency (WUE) should also be assessed when evaluating plant performance under variable environments (29).

Stomatal conductance and total chlorophyll content

V_3 (519.50 m mol H_2O m^{-2} s^{-1}) had the highest stomatal conductance, followed by V_4 (426 m mol H_2O m^{-2} s^{-1}) and V_5 (251.5 m mol H_2O m^{-2} s^{-1}) with minimum stomatal conductance. Among the interactions, maximum stomatal conductance was observed in V_3E_1 (521 m mol H_2O m^{-2} s^{-1}) and minimum was reported in V_5E_2 (227 m mol H_2O m^{-2} s^{-1}) (Table 7).

In respect to total chlorophyll content of the plant, V_3 (3.80 mg g^{-1}) recorded maximum total chlorophyll and V_5 (2.43 mg g^{-1}) observed the minimum total chlorophyll. Among the interactions, highest total chlorophyll recorded in V_3E_1 (3.86 mg g^{-1}), followed by V_2E_1 (3.82 mg g^{-1}) and minimum total chlorophyll was observed in V_5 E_2 (2.26 mg g^{-1}). These results were similar in *Brassica campestris* (30). Stomatal closure or a decrease in total chlorophyll concentration in the leaves are due to high electrical conductivity (31).

Soluble protein content and catalase activity

The highest soluble protein content of the plant was recorded in V_5 (67.29 mg g^{-1}), followed by V_2 (66.83 mg g^{-1}) and lowest was reported in V_3 (61.71 mg g^{-1}). Among the interactions, maximum soluble protein content was recorded in V_5E_2 (67.84 mg g^{-1}), followed by the treatment V_2E_2 (67.38 mg g^{-1}), whereas minimum was observed in V_3E_1 (61.15 mg g^{-1}) (Table 8). Soluble protein accumulation is often used as a biochemical marker of metabolic activity and stress response. The higher protein content in V_5 and V_2 under E_2 suggests that these varieties have a robust capacity for maintaining protein synthesis under varied conditions, possibly due to enhanced enzymatic activity and stable cellular functions (32).

For catalase activity of the plant, the maximum was recorded in V_5 (38.81 µg H_2O g^{-1} min^{-1}), followed by V_3 (27.12 µg H_2O g^{-1} min^{-1}) and minimum was recorded in V_1 (19.68 µg H_2O g^{-1} min^{-1}). Among the interactions, the highest catalase activity was recorded in V_5E_1 (39.09 µg H_2O g^{-1} min^{-1}), followed by the treatment V_5E_2 (38.53 µg H_2O g^{-1} min^{-1}) and lowest was recorded in V_1E_1 (19.01 µg H_2O g^{-1} min^{-1}) (Table 8). Higher catalase activity

Table 6. Effect of electrical conductivity on transpiration rate and photosynthetic rate grown under aeroponic method of cultivation.

	Transpiration rate (m mol H_2O m^{-2} s^{-1})			Photosynthetic rate (µ mol CO_2 m^{-2} s^{-1})		
	E_1 (0.5 EC)	E_2 (1 EC)	Mean	E_1 (0.5 EC)	E_2 (1 EC)	Mean
V_1	3.53	2.03	2.78	0.17	0.09	0.13
V_2	5.79	3.96	4.88	1.53	1.23	1.38
V_3	2.87	1.29	2.08	1.24	1.17	1.21
V_4	8.72	6.53	7.63	0.78	0.65	0.72
V_5	4.89	2.87	3.88	1.09	0.98	1.04
Mean	5.16	3.34	4.25	0.96	0.82	0.89

Factors	Transpiration rate		Photosynthetic rate	
	Critical Difference	Standard Deviation	Critical Difference	Standard Deviation
Variety (V)	0.134	0.064	0.029	0.014
Electrical conductivity (E)	0.085	0.040	0.018	0.009
V × E	0.190	0.090	0.041	0.020

V_1:Larenzo (Green colour - Pompon type), **V_2**:Prius Pink (Peach colour - Spray type), **V_3**:Furore (White colour - Spray type), **V_4**:Merel Gold (Yellow colour - Spray type), **V_5**:Lotte Orange (Red colour - Spray type), **E_1**:0.5 EC, **E_2**:1 EC.

Table 7. Effect of electrical conductivity on stomatal conductance and total chlorophyll grown under aeroponic method of cultivation.

	Stomatal conductance (m mol H_2O m^{-2} s^{-1})			Total chlorophyll (mg g^{-1})		
	E_1 (0.5 EC)	**E_2 (1 EC)**	**Mean**	**E_1 (0.5 EC)**	**E_2 (1 EC)**	**Mean**
V_1	281	263	272	3.18	3.07	3.13
V_2	405	401	403	3.82	3.65	3.74
V_3	521	518	519.50	3.86	3.73	3.80
V_4	443	409	426	3.27	3.18	3.23
V_5	276	227	251.5	2.59	2.26	2.43
Mean	385.2	363.6	374.4	3.34	3.18	3.26

Factors	**Stomatal conductance**		**Total chlorophyll**	
	Critical Difference	**Standard Deviation**	**Critical Difference**	**Standard Deviation**
Variety (V)	11.663	5.552	0.101	0.034
Electrical conductivity (E)	7.025	3.511	0.064	0.021
V × E	16.494	7.852	0.142	0.048

V_1:Larenzo (Green colour - Pompon type), **V_2**:Prius Pink (Peach colour - Spray type), **V_3**:Furore (White colour - Spray type), **V_4**:Merel Gold (Yellow colour - Spray type), **V_5**:Lotte Orange (Red colour - Spray type), **E_1**:0.5 EC, **E_2**:1 EC.

Table 8. Effect of electrical conductivity on soluble protein and catalase grown under aeroponic method of cultivation.

	Soluble protein (mg g^{-1})			Catalase (µg H_2O g^{-1} min^{-1})		
	E_1 (0.5 EC)	**E_2 (1 EC)**	**Mean**	**E_1 (0.5 EC)**	**E_2 (1 EC)**	**Mean**
V_1	62.89	63.97	63.43	19.01	20.35	19.68
V_2	66.28	67.38	66.83	22.63	23.77	23.20
V_3	61.15	62.26	61.71	26.38	27.85	27.12
V_4	61.98	63.09	62.54	23.49	25.68	24.59
V_5	66.73	67.84	67.29	39.09	38.53	38.81
Mean	63.81	64.91	64.36	26.12	27.24	26.68

Factors	**Soluble protein**		**Catalase**	
	Critical Difference	**Standard Deviation**	**Critical Difference**	**Standard Deviation**
Variety (V)	1.894	0.902	0.928	0.442
Electrical conductivity (E)	0.125	0.570	0.491	0.279
V × E	2.679	1.275	1.313	0.625

V_1:Larenzo (Green colour - Pompon type), **V_2**:Prius Pink (Peach colour - Spray type), **V_3**:Furore (White colour - Spray type), **V_4**:Merel Gold (Yellow colour - Spray type), **V_5**:Lotte Orange (Red colour - Spray type), **E_1**:0.5 EC, **E_2**:1 EC.

typically signifies enhanced capacity to mitigate oxidative stress by breaking down reactive oxygen species (ROS), particularly H_2O_2, which accumulates under various abiotic stresses like drought, salinity and high light intensity (33). Therefore, the higher catalase activity in V_5 suggests its superior stress resilience and better oxidative balance, which may contribute to its higher protein content and overall physiological performance.

In contrast, the low catalase activity in V_1E_1 (19.01 µg H_2O g^{-1} min^{-1}) indicates limited oxidative protection, which could lead to oxidative damage and compromised cellular function. These results align with previous studies that have linked catalase activity and protein accumulation to environmental adaptability and stress tolerance (34).

Altogether, V_5 emerges as a metabolically active and stress-tolerant variety with superior protein metabolism and antioxidative defense mechanisms, especially under E_1 and E_2 treatments. These traits make it a promising candidate for cultivation in environments where plants may encounter fluctuating or stressful conditions.

Peroxidase activity and days to first flowering

For peroxidase activity of the plant, highest was recorded in V_2 (0.89 change in OD g^{-1} min^{-1}) and minimum peroxidase activity observed in V_1 (0.40 change in OD g^{-1} min^{-1}) (Table 9). Among the interactions, peroxidase activity was recorded the higher in V_2E_1 (0.97 change in OD g^{-1} min^{-1}) and the minimum was observed in V_1E_1 (0.39 Change in OD g^{-1} min^{-1}). Peroxidase enzymes are known to play a critical role in plant defense responses against biotic and abiotic stresses through the detoxification of ROS and involvement in lignin biosynthesis (35). The elevated peroxidase activity in V_2 suggests a better adaptive or defense mechanism in this variety under the given environmental conditions. Similar findings have been reported stress conditions such as drought and salinity often elevate peroxidase activity in plants as a protective mechanism (36).

In respect to days to first flowering, the minimum days to first flowering were recorded in V_2 (26.40 days), followed by V_1 (26.62 days), which was on par with V_4 and a greater number

of days to first flowering was recorded in V_3 (35.26 days). Among the interactions, minimum days to first flowering were recorded in V_2E_2 (25.82 days), which was on par with V_4E_2 and a greater number of days to first flowering was recorded in V_3E_1 (35.87 days) (Table 9). Early flowering is often associated with early maturity, which can be advantageous under stress-prone environments or in regions with a short growing season. These results are consistent with genotypic variation in flowering time as an important selection criterion in breeding programs (37). Environmental cues such as temperature, light and water availability are known to influence floral induction and timing (38).

Crop growth rate

The treatment V_3 had the maximum crop growth rate of 2.88 g m^{-2} day^{-1} followed by the treatment V_1 with 2.85 and the treatment V_4 with minimum crop growth rate of 2.23 g m^{-2} day^{-1} at 0.5 EC. However, at the 1 EC level, the treatment V_2 had the maximum crop growth rate of 3.31 g m^{-2} day^{-1}, followed by the treatment V_1 with 3.00 g m^{-2} day^{-1} and treatment V_4 with minimum crop growth rate of 1.56 g m^{-2} day^{-1}(Table 10). This shift in performance under varying EC levels suggests genotype -specific adaptability to salinity or ionic stress, where V_2 may activate physiological or metabolic mechanisms to sustain or enhance growth even under higher osmotic stress. These findings align with previous research, which indicates that certain cultivars can maintain growth through improved osmotic adjustment, ion compartmentalization or increased antioxidant activity under salinity (39, 40).

Among the interactions, observations on crop growth rate were recorded during vegetative stage to bud appearance stage and bud appearance stage to flowering stage (V × E × S), the treatment V_1E_2 recorded maximum crop growth rate of 3.87 g m^{-2} day^{-1} at vegetative stage to bud appearance stage and V_2E_2 (2.98 g m^{-2} day^{-1}) at bud appearance stage to flowering stage followed by V_2E_2 which recorded a crop growth rate of 3.64 g m^{-2} day^{-1} at vegetative stage to bud appearance stage

Table 9. Effect of electrical conductivity on peroxidase and days to 1st flowering grown under aeroponic method of cultivation.

	Peroxidase (change in OD g^{-1} min^{-1})			Days to 1st flowering (days)		
	E_1 (0.5 EC)	**E_2 (1 EC)**	**Mean**	**E_1 (0.5 EC)**	**E_2 (1 EC)**	**Mean**
V_1	0.39	0.41	0.40	27.23	26.01	26.62
V_2	0.97	0.81	0.89	26.98	25.82	26.40
V_3	0.68	0.67	0.68	35.87	34.64	35.26
V_4	0.56	0.52	0.54	27.54	26.13	26.84
V_5	0.48	0.44	0.46	33.69	30.95	32.32
Mean	0.62	0.57	0.59	30.26	28.71	29.49

Factors	**Peroxidase**		**Days to 1st flowering**	
	Critical Difference	**Standard Deviation**	**Critical Difference**	**Standard Deviation**
Variety (V)	0.017	0.008	0.900	0.428
Electrical conductivity (E)	0.011	0.005	NS	0.271
V × E	0.025	0.012	1.273	0.606

V_1:Larenzo (Green colour - Pompon type), **V_2**:Prius Pink (Peach colour - Spray type), **V_3**:Furore (White colour - Spray type), **V_4**:Merel Gold (Yellow colour - Spray type), **V_5**:Lotte Orange (Red colour - Spray type), **E_1**:0.5 EC, **E_2**:1 EC.

Table 10. Effect of electrical conductivity on crop growth rate of plant grown under aeroponic method of cultivation (g m^{-2} day^{-1}).

	E_1 (0.5 EC)			**E_2 (1 EC)**		
	Vegetative to bud appearance stage	**Bud appearance stage to flowering**	**Mean**	**Vegetative to bud appearance stage**	**Bud appearance stage to flowering**	**Mean**
V_1	3.14	2.56	2.85	3.87	2.12	3.00
V_2	2.79	2.29	2.54	3.64	2.98	3.31
V_3	2.99	2.76	2.88	2.52	1.59	2.06
V_4	2.35	2.10	2.23	2.02	1.09	1.56
V_5	2.90	2.09	2.50	2.46	1.76	2.11
Mean	2.83	2.36	2.60	2.90	1.91	2.41

Factors	**Critical Difference**	**Standard Deviation**	**Factors**	**Critical Difference**	**Standard Deviation**
Variety (V)	0.059	0.029	V × S	0.083	0.041
Electrical conductivity (E)	0.037	0.018	E × S	0.051	0.026
V × E	0.083	0.041	V × E × S	0.118	0.058
Stage (S)	0.037	0.018			

V_1:Larenzo (Green colour - Pompon type), **V_2**:Prius Pink (Peach colour - Spray type), **V_3**:Furore (White colour - Spray type), **V_4**:Merel Gold (Yellow colour - Spray type), **V_5**:Lotte Orange (Red colour - Spray type), **E_1**:0.5 EC, **E_2**:1 EC.

and V_3E_1 (2.76 g m^{-2} day^{-1}) at bud appearance stage to flowering stage and the treatment V_4E_2 recorded minimum crop growth rate of 2.02 g m^{-2} day^{-1} at vegetative stage to bud appearance stage and V_4E_2 (1.09 g m^{-2} day^{-1}) at bud appearance stage to flowering stage. Growth rate differences between stages further reflect developmental priorities. The vegetative stage to bud appearance typically exhibits the highest CGR (crop growth rate) due to rapid canopy expansion and nutrient uptake (41). The slightly lower CGR during the bud to flowering stage may be attributed to a shift in resource allocation from vegetative growth to reproductive development.

These results underscore the importance of selecting genotypes like V_2 and V_1 for environments with higher salinity or variable EC levels, as they demonstrate both resilience and consistent biomass production. Moreover, the dynamic response of Crop Growth Rate across stages and interactions confirms the role of genotype × environment × growth stage interplay in determining crop productivity (42).

Number of flowers per plant

In respect to number of flowers per plant, a greater number of flowers was recorded in V_4 (56.94), followed by V_2 (51.39) and minimum number of flowers was recorded in V_3 (18.69). Among the interactions, a greater number of flowers was recorded in V_2E_1 (67.58), followed by treatment V_4E_1 (64.72 number) and minimum was recorded in V_1E_2 (14.87 number) (Fig. 3). A high flower count is often an indicator of strong vegetative vigor and effective nutrient partitioning toward reproductive development (43). The superior floral productivity of V_4 and V_2 may be attributed to favorable sink-source dynamics and hormonal balance promoting floral differentiation and retention. Environmental condition E_1 possibly enhanced flowering through better light or nutrient availability, a common driver for florogenesis (44).

Weight of cut stem

The maximum weight of cut stem was recorded in V_3 (5.53 g), followed by V_1 (4.94 g) and lowest was observed in V_4 (4.11 g). Among the interactions, the highest weight of cut stem was recorded in V_3E_1 (5.80 g), followed by treatment V_3E_2 (5.26 g), which was on par with V_2E_2 and minimum weight of cut stem was observed in V_4E_2 (4.09 g) (Fig. 3). Higher stem weight typically reflects greater structural strength and water-conducting capacity, both crucial for postharvest performance and mechanical handling (45). The consistent performance of V_3 under both E_1 and E_2 implies resilience and strong growth dynamics across environments.

Flower diameter and vase life

The highest flower diameter was recorded at V_3 (6.62 cm), followed by V_2 (6.12 cm) and the lowest was observed in V_1 (5.20 cm). Among the interactions, the maximum diameter was recorded in V_3E_2 (6.71 cm), followed by treatment V_3E_1 (6.53 cm) and minimum was recorded in V_1E_2 (5.19 cm) (Table 11). Larger flower diameter is a desirable ornamental trait and often results from optimal cell expansion and petal development influenced by both genetic and environmental factors (46). The consistent superior bloom size of V_3, especially under E_2, suggests its suitability for premium floral markets.

The maximum vase life was recorded in V_2 (15.72 days), followed by V_5 (11.37 days) and minimum was observed in V_1 (9.30 days) (Table 11). Among the interactions, maximum vase life was recorded in V_2E_1 (16.98 days), followed by V_2E_2 (14.46 days) and minimum vase life was recorded in V_4E_2 (9.25 days). Extended vase life in V_2 may be attributed to reduced ethylene sensitivity, higher antioxidant activity and better water uptake capacity, traits commonly associated with floral longevity (47). The drastic reduction in vase life under E_2 for V_4 further reflects the importance of genotype-environment interaction in postharvest performance.

Cut flower yield was also decreased with increasing EC level and this result was like the reported in cucumber (48). EC value increased, potato seed production decreased, when grown aeroponically in the lowlands with root zone cooling (4). High EC concentrations lowered food and water uptake, salt

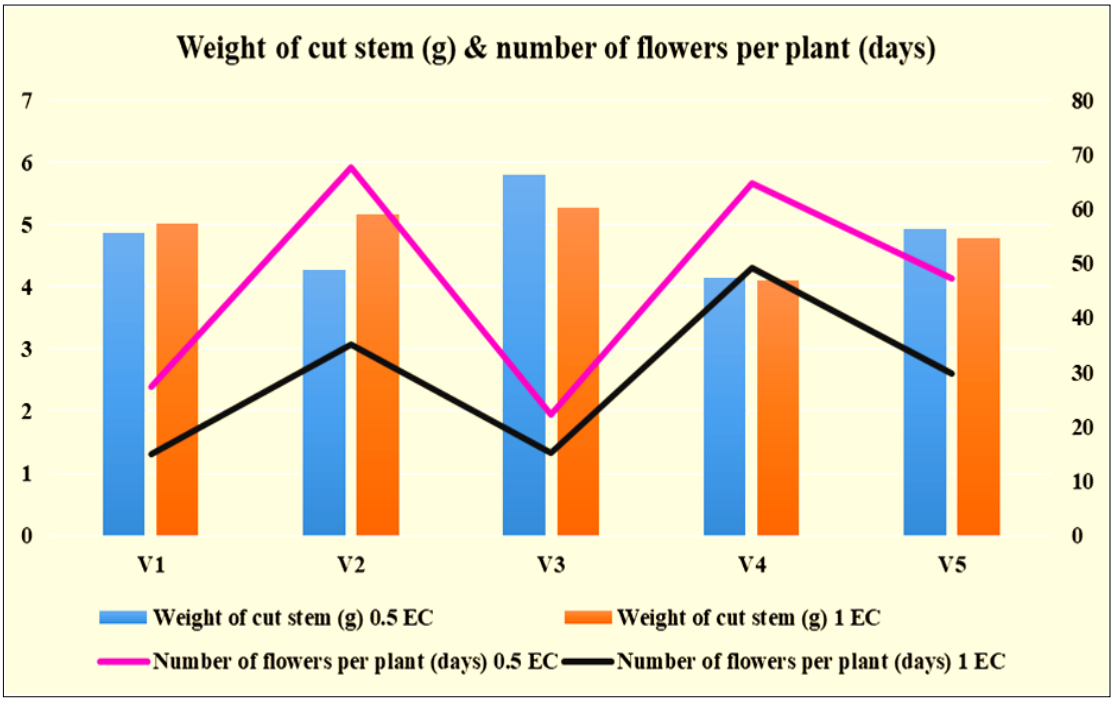

Fig. 3. Effect of electrical conductivity on weight of cut stem and number of flowers per plant grown under aeroponic method of cultivation.

Table 11. Effect of electrical conductivity on flower diameter and vase life of plant grown under aeroponic method of cultivation.

	Flower diameter (cm)			Vase life (days)		
	E_1 (0.5 EC)	**E_2 (1 EC)**	**Mean**	**E_1 (0.5 EC)**	**E_2 (1 EC)**	**Mean**
V_1	5.21	5.19	5.20	9.29	9.31	9.3
V_2	6.08	6.15	6.12	16.98	14.46	15.72
V_3	6.53	6.71	6.62	10.47	9.62	10.045
V_4	5.49	5.48	5.49	9.89	9.25	9.57
V_5	5.23	5.35	5.29	11.93	10.81	11.37
Mean	5.71	5.78	5.74	11.71	10.69	11.20

Factors	**Flower diameter**		**Vase life (days)**	
	Critical Difference	**Standard Deviation**	**Critical Difference**	**Standard Deviation**
Variety (V)	0.189	0.090	0.362	0.172
Electrical conductivity (E)	0.115	0.057	0.229	0.109
V × E	0.268	0.128	0.512	0.244

V_1:Larenzo (Green colour - Pompon type), **V_2**:Prius Pink (Peach colour - Spray type), **V_3**:Furore (White colour - Spray type), **V_4**:Merel Gold (Yellow colour - Spray type), **V_5**:Lotte Orange (Red colour - Spray type), **E_1**:0.5 EC, **E_2**:1 EC.

and chloride toxicity in stem cells and plant photosynthetic ability (49). The result was same as that where the total number of tubers was higher in lower concentration of nutrients in potato (3). Rapid seed multiplication technique, in aeroponics, are currently being used in underdeveloped nations to obtain high-quality mini tubers (3).

This study comprehensively evaluated the impact of varying EC levels on the growth, physiological and biochemical traits of different plant varieties. Results demonstrated significant varietal differences in response to EC levels, with V_2 and V_5 emerging as the most adaptable and vigorous genotypes under varying environmental conditions. V_2 consistently exhibited superior performance across multiple parameters, including plant height, root length, fresh and dry weight, photosynthetic rate and peroxidase activity, especially under the E_1 environment. On the other hand, V_5 showed enhanced root biomass, higher protein content and strong antioxidant enzyme activity, indicating its stress-resilient nature.

In contrast, V_1 generally recorded lower values for many growth and physiological traits, yet showed high root dry weight, suggesting a conservative growth strategy potentially suited for stress conditions. V_3 showed notable performance in leaf area and stomatal conductance, while V_4 displayed higher transpiration but comparatively lower growth efficiency, possibly due to suboptimal water-use strategy.

Conclusion

The findings underscore the importance of genotype × environment × nutrient interaction in determining plant performance under aeroponic growing system. Identifying varieties like V_2 and V_5, which maintain growth and physiological balance under stress, is vital for developing resilient crop systems suited to fluctuating or suboptimal growing conditions. As well as 0.5 EC was best for aeroponic system since it is spraying continuously with less interval. These insights are essential for agronomic management strategies in controlled-environment or stress-prone field conditions.

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Authors' contributions

MR and BR carried out the research work in the field & lab, done statistical analysis and drafted the manuscript. All authors read and approved the final version of the manuscript.

Compliance with ethical standards

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