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Influence of priming agents on Okra seed germination and growth under salinity stress

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Abstract

Salinity is a major abiotic factor which severely limits okra seed germination and early seedling growth. Therefore, this study examines the impact of different priming agents such as carrot root extract, neem leaf extract, garlic clove extract, and $MgSO_4$ on modulating okra (MI-5 Variety) seed germination and plant growth under salinity stress conditions. Firstly, a laboratory experiment was designed to identify a suitable concentration from each of the selected four priming agents based on their reported ability to enhance germination of the okra seeds. Fifteen treatments were arranged in a Complete Randomized Design (CRD), including a control priming with water (T0), 25% (T1), 50% (T2), 75% (T3), 100% (T4) carrot root extract, 25%(T5), 50% (T6) , 75% (T7), 100% (T8) neem leaf extract, 25% (T9), 50% (T10), 75% (T11), 100% (T12) garlic clove extract, and 3% (T13), 5% Magnesium Sulfate ($MgSO_4$) (T14), each with 3 replicates were prepared to prime the okra seeds. Among the tested treatments, 50% carrot root extract, 100% neem leaf extract, 25% garlic clove extract and 3% $MgSO_4$, were identified as an appropriate concentration in enhancing germination of okra seeds in terms of germination percentage and increased radicle length ($p < 0.05$). Further, the selected five treatments (control primed with water (T0*), 50% carrot root extract (T2*), 100% neem leaf extract (T8*), 25% garlic clove extract (T9*) and 3% $MgSO_4$ (T13*)) each with five replicates were prepared and okra seeds were primed. A pot experiment was designed in a CRD and the primed seeds (24 hours) were sown under salinity stress condition (Sodium Chloride 100mM - 5.84 g Sodium Chloride in 1 l of irrigation water). Growth parameters of okra were recorded. All the data were statistically analyzed using Minitab 17.0 and differences between treatment means were compared using Tukey's test. In the pot experiment, okra seeds primed with 3% $MgSO_4$ (T13*) showed a significant enhancement ($p < 0.05$) of plant height, stem girth, leaf number, branch number and relative water content. The findings of this study suggest that compared to carrot, neem and garlic clove extract, 3% $MgSO_4$ acts as an effective priming agent in enhancing the growth performance of okra under salt stress.

Keywords: Okra, plant growth, priming agent, salt stress, seed germination

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Introduction

One of the most significant abiotic factors influencing agricultural production worldwide is salinity [1]. Salinity is caused by natural or man-made processes that accumulate dissolved salts in soil water, limiting plant growth. Extensive salinization of agricultural land leads to significant global economic losses [2]. High Na^+ concentrations disrupt osmotic equilibrium, inhibiting plant water uptake [3]. Salt stress influences multiple physiological processes in plant development, including the inhibition of cell division and cell elongation, leading to a reduction in shoot growth. Early flowering may reduce production in plants under salt stress since it reduces dry matter and increases the root-shoot ratio and leaf size [4].

Okra (*Abelmoschus esculentus*), an annual vegetable and herb, is widely cultivated in tropical and subtropical regions worldwide [5]. Salt-induced stress alters the concentrations of key bioactive compounds in okra, including antioxidants, vitamins, and essential minerals, potentially impacting both agricultural productivity and human nutrition [6]. Consequently, several effective strategies have been developed to enhance seed germination and improve tolerance to salt stress. Among these, seed priming is widely recognized. Seed priming is a pre-sowing treatment that involves partial hydration of seeds for a defined duration under controlled conditions, followed by re-drying to the original moisture content. This treatment triggers a range of biological, cellular, physiological, and molecular processes, which collectively enhance plant growth and resilience under abiotic stress conditions. Use of multiple agents to prime seeds has emerged as a viable strategy to increase plant resistance to stress. Plant extracts, hormones, organic compounds, ions, and chemicals such as potassium nitrate, hydrogen peroxide, ascorbic acid can all be used to prime seeds [7].

Carrot root extract induces salinity tolerance as it is rich in vitamins which are antioxidants and regarded as bio-regulators, thus using carrot root extract as a pre-soaking method efficiently overcomes salt stress in several plants such as cowpea. Therefore, this is a promising seed priming agent [8]. Garlic (*Allium sativum*) is a nutrient-rich extract with over 200 biological constituents, including enzymes, vitamins, and antioxidants [9]. Aqueous garlic extract (AGE) can activate plant defense responses [10]. AGE preparation is convenient and cost-effective, with minimal or no risks to consumers. Accordingly, it has been identified as an effective seed-priming agent capable of improving seed germination and facilitating early seedling development [11]. Neem (*Azadirachta indica*) leaf extract has been recognized as a highly promising agent for seed priming, enhancing both stress tolerance and uniformity in seed germination [12, 13]. Priming seeds with $MgSO_4$ has been shown to mitigate the detrimental effects of salt stress in plants such as cotton. Mg^{2+} influences seed germination and early seedling development by modulating specific growth-promoting metabolites and enzymatic activities under saline conditions [14]. However, the effect of organic priming agents such as carrot root extract, garlic clove extract, neem leaf extract, and 3% and 5% $MgSO_4$ on enhancing the growth of okra MI5 variety under salt stress condition is not studied so far. Therefore, the present study aimed to evaluate the efficacy of seed priming using carrot root extract, garlic clove extract, neem leaf extract, and $MgSO_4$ and to find the suitable concentration of these priming agents in enhancing the germination and growth of okra under salt stress conditions.

Materials and Methods

Area of Study

A laboratory study was conducted at the Department of Biosystems Technology, Faculty of Technology, Eastern University of Sri Lanka from November 2024 to April 2025, to identify the optimal concentration of priming agents for okra (*Abelmoschus esculentus* L.) seed germination. Using the selected concentration, a subsequent pot experiment was performed in a home garden in Hatton, Nuwara Eliya District, Central Province, Sri Lanka (6°53′ N, 80°35′ E) to assess the impact of seed priming on germination and growth of okra under saline conditions.

Experimental Design

All the experiments were arranged in a completely randomized design (CRD).

Treatments

The laboratory experiment was carried out with fifteen treatments, each with 3 replicates.

Table 1: Treatment description for lab experiment

Treatments	Descriptions
T0	Control (water)
T1	25% extract from carrot roots
T2	50% extract from carrot roots
T3	75% extract from carrot roots
T4	100% extract from carrot roots
T5	25% neem leaf extract
T6	50% neem leaf extract
T7	75% neem leaf extract
T8	100% neem leaf extract
T9	25% garlic clove extract
T10	50% garlic clove extract
T11	75% garlic clove extract
T12	100% garlic clove extract
T13	3% $MgSO_4$
T14	5% $MgSO_4$

The pot experiment was carried out with the five selected treatments from the lab experiment with five replicates.

Table 2: Treatment description for pot experiment

Treatments	Descriptions
T0*	Seeds primed with water and pot irrigated with 100 mM NaCl (Control)
T2*	Seeds primed with 50% carrot root extract and pot irrigated with 100 mM NaCl.
T8*	Seeds primed with 100% neem leaf extract and pot irrigated with 100 mM NaCl.
T9*	Seeds primed with 25% garlic clove extract and pot irrigated with 100 mM NaCl.
T13*	Seeds primed with 3% $MgSO_4$ and pot irrigated with 100 mM NaCl.

Laboratory Experiment

This experiment aimed to identify the suitable concentration of priming agents (garlic clove extract, carrot root extract, neem leaf extract, and $MgSO_4$) for okra seed germination. The experiment was conducted in sterilized Petri dishes.

Preparation of Extracts

Carrot Root Extract (100%)

Fresh carrot roots were washed thoroughly with tap water. A total of 200 g of cleaned roots were cut into small pieces and homogenized with 640 mL of distilled water using an electric blender. The resulting mixture was filtered through muslin cloth, and the filtrate was adjusted to a final volume of 1 L with distilled water [15].

Garlic Clove Extract (100%)

Garlic cloves were cleaned, and the outer peels were removed. A total of 250 g of clove was combined with 250 mL of distilled water and subjected to three consecutive freeze-thaw cycles as freezing helps to maintain integrity of bioactive compounds while thawing allows for easier extraction. The cloves were then homogenized using an electric blender and filtered through muslin cloth. The filtrate was adjusted to a final volume of 1 L with distilled water [15].

Neem Leaf Extract (100%)

Neem leaves were collected from the vicinity of EUSL and rinsed thoroughly with distilled water. Excess surface moisture was removed by blotting the leaves on filter paper. A total of 25 g of fresh leaves was ground with 25 mL of distilled water to obtain the extract. The final volume was adjusted to 100ml with distilled water [16].

$MgSO_4$ (1M)

1 M $MgSO_4$ solution was prepared by dissolving 12.04 g of $MgSO_4$ in distilled water and made up to 100 ml, following the method described by [17]. Working solutions of 3% and 5% were prepared by diluting the stock solution to the required volume with distilled water.

Priming

Okra seeds of the 'MI5' variety were selected for the experiment. For seed priming, 2g of seeds were soaked in 10 ml (w/v: 1:5) [18] of fifteen treatments in 3 replicates for 24 hours. After that, the soaked seeds were washed 3-4 times in distilled water, and then the seeds were air-dried for 3 hours [19]. Upon completion of drying, the seeds were placed on filter paper within Petri dishes, which served as experimental replicates. Each replicate consisted of 29 seeds (After weighing the seeds to ensure consistency, it was determined that 29 seeds (a specific average weight) were the correct amount to ensure accuracy) positioned on the filter paper in a single Petri dish. A completely randomized design was used to place the petri dishes (CRD) inside the incubator at 25°C for 7 days. The moisture level was kept at the same level by adding two drops of water to each petri dish throughout the experiment. Germination percentage was evaluated after 24 hours and subsequently recorded until the end of the second day. Radicle (Length of the emerging root) and plumule length (Length of the emerging shoot) were measured using a ruler (cm) at two-day intervals, from the third to the seventh day.

Pot Experiment

Agronomic Practices

Okra variety MI5 was used in this experiment. For the experiment, black polybags (35.56 cm height and 35.56 cm diameter) were used. Every polybag contained a mixture of potting soil (Topsoil: loam at a ratio of 1:1), leaving a 5 cm gap at the top. Holes were made at the bottom of the polybags for drainage purposes. All the polybags were kept at a 60 cm × 60 cm interval. Based on the laboratory experimental result, among the tested treatments, 50% carrot root extract, 100% neem leaf extract, 25% garlic clove extract and 3% $MgSO_4$, were identified as appropriate concentration in enhancing germination of okra seeds in terms of germination percentage and increased radicle length. Thereafter, seeds were primed with those identified appropriate concentrations of solutions and sown directly into the filled poly bags (Three seeds per polybag) at a depth of around 1-2 cm.

In accordance with the recommendations of the Department of Agriculture, Sri Lanka, basal fertilization was applied two days before sowing, comprising 0.496 g of urea [$CO(NH_2)_2$], 0.937 g of triple superphosphate (TSP), and 0.248 g of muriate of potash (MOP) per experimental unit. After 2 weeks, 0.496g of urea and 0.248g MOP were added as top dressing. Pots were irrigated from seeding to germination stage, twice a day, in the early morning and late evening, and then it was reduced to once daily till the development of pods [20]. Salt stress (100 mM) was applied to the pots by dissolving 5.84 g sodium chloride in 1 L of irrigation water [21].

Data was collected at two-week intervals, beginning from the second week post-planting. Plant height (cm) was measured from the soil surface to the apical growing point using a ruler. Stem girth (cm) was determined by measuring the circumference at three different points along the stem using a thread, and the length of the thread was then measured using a ruler, and the mean value was calculated. The number of leaves and branches per plant were recorded. Relative water content was assessed following the method described by [21] using the below equation.

$$RWC\ (\%) = FW - \frac{DW}{TW - DW} \times 100$$

Data Analysis

The Minitab software application (version 17) was used to analyze all the data at a significance level of 5%. All the mean differences were analyzed using the Tukey range test.

Results and Discussion

Germination Percentage (%)

As shown in Table 3, the concentrations of priming agents tested did not exert a significant effect ($p > 0.05$) on okra seed germination within the first 24 hours. By contrast, the priming agents carrot root extract (T2), garlic clove extract (T9, T10, T11, T12) and neem leaf extract (T6, T8) significantly influenced ($p<0.05$) the germination percentage in the next 24 hours compared to the control.

Table 3: Germination percentage of okra seeds treated with different concentrations of priming agents measured at successive time intervals

Extracts	Treatments	After 24 hours (%)	After 48 hours (%)
Water (Control)	T0	56.30 ± 1.25^{a}	59.77 ± 1.15^{b}
	T1	44.82 ± 6.90^{a}	64.37 ± 7.54^{ab}
Carrot root	T2	40.23 ± 5.75^{a}	83.94 ± 6.11^{a}
Extract	T3	35.60 ± 11.70^{a}	74.53 ± 3.01^{ab}
	T4	60.90 ± 14.90^{a}	80.46 ± 4.60^{ab}
	***P* Value**	**0.334**	**0.029**
Water (Control)	T0	56.32 ± 1.15^{a}	59.77 ± 1.15^{b}
	T5	51.70 ± 10.50^{a}	82.76 ± 7.96^{ab}
Neem leaf	T6	43.70 ± 18.90^{a}	88.51 ± 3.04^{a}
Extract	T7	34.48 ± 7.18^{a}	82.76 ± 5.27^{ab}
	T8	47.12 ± 6.04^{a}	91.95 ± 4.60^{a}
	***P* Value**	**0.662**	**0.008**
Water (Control)	T0	56.32 ± 1.15^{a}	59.77 ± 1.15^{b}
	T9	60.92 ± 8.05^{a}	89.80 ± 1.86^{a}
Garlic clove	T10	59.77 ± 4.60^{a}	82.76 ± 3.98^{a}
Extract	T11	77.00 ± 5.75^{a}	87.36 ± 3.04^{a}
	T12	49.40 ± 19.60^{a}	89.65 ± 3.45^{a}
	***P* Value**	**0.442**	**0.000**
Water (Control)	T0	56.32 ± 1.15^{a}	59.77 ± 1.15^{a}
	T13	45.97 ± 9.41^{a}	81.61 ± 6.08^{a}
$MgSO_4$	T14	32.18 ± 3.04^{a}	71.30 ± 15.10^{a}
	***P* Value**	***0.066***	***0.328***

*Values represent the mean ± standard error of three replicates. Mean values in a row having dissimilar letters indicate significant differences at a 5% level of significance according to Tukey's HSD Test.

After 48 hours of incubation, among the different concentrations of carrot root extract tested, the 50% concentration (T2) showed a significantly higher germination percentage (83.94%) compared to the control (59.77%). For neem leaf extract, the 100% concentration (T8) recorded the highest germination percentage (91.95%), which was significantly higher than the control but not significantly different from the other neem extract concentrations tested. Similarly, treatment with 25% garlic clove extract (T9) resulted in a higher germination percentage (89.80%) compared to the control. However, no significant difference was observed among the various garlic extract treatments, indicating that all concentrations enhanced germination to a similar extent. In contrast, the $MgSO_4$ treatments (T13 and T14) did not show any significant difference in germination percentage compared to the control, suggesting that $MgSO_4$ had a limited effect on okra seed germination under the conditions tested.

Radicle and Plumule length (cm)

Radicle length

Radicle length was measured on the 3rd, 5th, and 7th days after sowing to evaluate the effects of different concentrations of carrot root, neem leaf, garlic clove extracts, and $MgSO_4$ on okra seed germination (Table 4).

Table 4: Effect of different concentration of priming agents on radicle length (cm) measured at various time intervals

Extracts	Treatments	3rd Day	5th Day	7th day
Water (Control)	T0	1.20 ± 0.20^{a}	1.50 ± 0.11^{b}	2.33 ± 0.23^{b}
	T1	1.56 ± 0.44^{a}	2.47 ± 0.41^{ab}	3.30 ± 0.18^{ab}
Carrot root	T2	3.14 ± 0.41^{b}	3.39 ± 0.45^{ab}	4.04 ± 0.54^{a}
Extract	T3	2.92 ± 0.57^{a}	3.69 ± 0.66^{a}	3.51 ± 0.31^{ab}
	T4	2.96 ± 0.42^{a}	3.56 ± 0.19^{a}	3.86 ± 0.23^{ab}
	***P* Value**	**0.026**	**0.019**	**0.032**
Water (Control)	T0	1.20 ± 0.20^{b}	1.50 ± 0.11^{c}	2.33 ± 0.23^{c}
	T5	2.02 ± 0.44^{ab}	2.55 ± 0.26^{b}	3.43 ± 0.22^{ab}
Neem leaf	T6	1.81 ± 0.26^{b}	2.56 ± 0.14^{b}	2.90 ± 0.15^{bc}
Extract	T7	2.23 ± 0.09^{ab}	2.47 ± 0.05^{b}	3.50 ± 0.16^{ab}
	T8	3.16 ± 0.24^{a}	3.76 ± 0.08^{a}	3.96 ± 0.06^{a}
	***P* Value**	**0.007**	**0.000**	**0.001**
Water (Control)	T0	1.20 ± 0.20^{a}	1.50 ± 0.11^{b}	2.33 ± 0.23^{b}
	T9	3.48 ± 0.32^{a}	3.72 ± 0.20^{a}	4.10 ± 0.23^{a}
Garlic clove	T10	2.56 ± 1.12^{a}	3.55 ± 0.72^{a}	3.99 ± 0.50^{a}
Extract	T11	3.08 ± 0.32^{a}	3.62 ± 0.19^{a}	3.78 ± 0.17^{a}
	T12	2.84 ± 0.33^{a}	3.44 ± 0.17^{a}	3.77 ± 0.12^{a}
	***P* Value**	**0.125**	**0.007**	**0.008**
Water (Control)	T0	1.20 ± 0.20^{a}	1.50 ± 0.11^{b}	2.33 ± 0.23^{b}
	T13	3.21 ± 0.33^{b}	3.42 ± 0.32^{a}	3.84 ± 0.36^{a}
$MgSO_4$	T14	2.24 ± 0.36^{a}	2.96 ± 0.28^{ab}	3.82 ± 0.16^{a}
	***P* Value**	**0.030**	**0.001**	**0.007**

*Values represent the mean ± standard error of three replicates. Mean values in a row having dissimilar letters indicate significant differences at a 5% level of significance according to Tukey's HSD Test.

After 3 days, all the priming treatments showed a positive influence on radicle length compared to the control. Among the carrot root extract treatments, the 50% concentration (T2) recorded the highest mean radicle length (3.14 cm), which was significantly higher ($p = 0.026$) than the control (1.20 cm). Similarly, for neem leaf extract, the 100% concentration (T8) produced the highest radicle length (3.16 cm), which was significantly higher than T6 and the control. Garlic clove extract treatments also increased radicle length, although the differences were not statistically significant at this stage ($p = 0.125$). $MgSO_4$ treatments showed significant improvement in radicle length ($p = 0.030$), with T13 (3.21 cm) producing a notable increase over the control.

By the 5th day, the growth differences became more distinct. The highest radicle lengths were observed in treatments with carrot root extract (T3 = 3.69 cm), neem leaf extract (T8 = 3.76 cm), and garlic clove extract (T9 = 3.72 cm), all significantly higher than the control ($p < 0.05$). Among the $MgSO_4$ treatments, T13 (3.42 cm) showed a marked increase compared to the control (1.50 cm), indicating that Mg^{2+} ions may contribute to early seedling vigor.

After 7 days, a consistent trend was observed, where all treated seeds produced longer radicle than the control (2.33 cm). The 50% carrot root extract (T2 = 4.04 cm), 100% neem leaf extract (T8 = 3.96 cm), and 25% garlic clove extract (T9 = 4.10 cm) exhibited the greatest seedling lengths, with statistically significant differences ($p < 0.05$) compared to the control. $MgSO_4$ treatments (T13 = 3.84 cm; T14 = 3.82 cm) also showed significantly improved growth ($p = 0.007$). Overall, the results indicate that seed priming with natural extracts, particularly carrot root (50%), neem leaf (100%), and garlic clove (25%), markedly enhanced okra radicle growth during early stages. This improvement could be attributed to the presence of growth-promoting compounds such as vitamins, phenolics, and antioxidants in these extracts, which may enhance metabolic activity, enzyme function, and nutrient uptake during germination and early growth [22,23,24]. $MgSO_4$ also promoted radicle elongation, possibly by improving cellular metabolism and photosynthetic activity through magnesium's role in chlorophyll synthesis [25].

Plumule length

The effects of different concentrations of priming agents on okra plumule length are presented in Table 5. On the 3rd, 5th, and 7th days after sowing, the priming treatments exhibited no significant influence on plumule length ($p > 0.05$).

The result indicated that varying concentrations of different priming agents had no significant effect on plumule length. This may suggest that plumule elongation is not sensitive to these specific priming agents. However, plumule length increased with time in each treatment group.

Table 5: Effect of different concentration of priming agents on plumule length (cm) measured at various time intervals

Extracts	Treatments	3rd Day	5th Day	7th day
Water (Control)	T0	0.87 ± 0.13^a	1.43 ± 0.08^a	1.67 ± 0.08^a
	T1	0.90 ± 0.05^a	1.33 ± 0.14^a	1.64 ± 0.06^a
Carrot root	T2	1.00 ± 0.02^a	1.60 ± 0.10^a	1.73 ± 0.08^a
Extract	T3	0.92 ± 0.08^a	1.40 ± 0.19^a	1.70 ± 0.02^a
	T4	0.96 ± 0.08^a	1.48 ± 0.18^a	1.65 ± 0.11^a
	***P* Value**	**0.824**	**0.775**	**0.938**
Water (Control)	T0	0.87 ± 0.13^a	1.43 ± 0.08^a	1.67 ± 0.08^a
	T5	0.89 ± 0.02^a	1.16 ± 0.12^a	1.38 ± 0.13^a
Neem leaf	T6	1.04 ± 0.06^a	1.57 ± 0.09^a	1.66 ± 0.07^a
Extract	T7	1.07 ± 0.03^a	1.58 ± 0.10^a	1.71 ± 0.03^a
	T8	1.01 ± 0.02^a	1.43 ± 0.09^a	1.63 ± 0.16^a
	***P* Value**	**0.247**	**0.078**	**0.280**

Water (Control)	T0	0.87 ± 0.13^{a}	1.43 ± 0.08^{a}	1.67 ± 0.08^{a}
	T9	1.11 ± 0.01^{a}	1.54 ± 0.07^{a}	1.77 ± 0.10^{a}
Garlic clove	T10	0.88 ± 0.09^{a}	1.35 ± 0.12^{a}	1.62 ± 0.08^{a}
Extract	T11	0.91 ± 0.07^{a}	1.45 ± 0.17^{a}	1.65 ± 0.07^{a}
	T12	1.00 ± 0.07^{a}	1.43 ± 0.11^{a}	1.49 ± 0.11^{a}
	***P* Value**	**0.343**	**0.844**	**0.380**
Water (Control)	T0	0.87 ± 0.13^{a}	1.43 ± 0.08^{a}	1.67 ± 0.08^{a}
	T13	1.03 ± 0.01^{a}	1.34 ± 0.07^{a}	1.57 ± 0.02^{a}
$MgSO_4$	T14	0.99 ± 0.05^{a}	1.25 ± 0.03^{a}	1.46 ± 0.04^{a}
	***P* Value**	**0.450**	**0.272**	**0.097**

*Values represent the mean ± standard error of three replicates. Mean values in a row having dissimilar letters indicate significant differences at a 5% level of significance according to Tukey's HSD Test.

Pot Experiment Results

Plant height (cm)

The effects of different concentrations of priming agents on okra plant height are presented in Table 6.

Table 6: Variation in plant height (cm) of okra in response to different concentrations of priming agents at weekly growth intervals

Extracts	Treatments	2^{nd} Week(cm)	4^{th} Week(cm)	6^{th} Week(cm)	8^{th} Week(cm)
Water (Control)	T0*	11.20 ± 0.93^{b}	12.88 ± 1.13^{b}	21.86 ± 2.11^{b}	28.14 ± 2.18^{b}
50% Carrot root Extract	T2*	12.60 ± 0.80^{ab}	17.30 ± 2.45^{ab}	27.40 ± 0.79^{ab}	35.02 ± 1.54^{ab}
100% Neem leaf Extract	T8*	12.38 ± 1.17^{ab}	13.54 ± 1.54^{b}	24.96 ± 2.21^{ab}	31.92 ± 2.35^{ab}
25% Garlic clove Extract	T9*	12.16 ± 0.97^{ab}	16.06 ± 0.88^{ab}	24.56 ± 2.44^{ab}	30.58 ± 1.53^{ab}
3% $MgSO_4$	T13*	16.00 ± 0.82^{a}	20.26 ± 1.47^{a}	31.32 ± 2.01^{a}	38.00 ± 2.67^{a}
	***p* value**	**0.021**	**0.024**	**0.036**	**0.029**

*Values represent the mean ± standard error of five replicates. Mean values in a row having dissimilar letters indicate significant differences at a 5% level of significance according to Tukey's HSD Test.

In the 2^{nd} week among the priming treatments, 3% $MgSO_4$ (T13*) recorded the highest mean plant height (16.00 cm), which was significantly higher than the control (11.20 cm) under salt stress. Similarly, by the 4^{th},6^{th} and 8^{th} weeks, T13* exhibited significantly highest ($p < 0.05$) plant height (20.26 cm, 31.32 cm, 38.00 cm respectively) compared to the control under salt stress. These findings support the results of [26], who reported enhanced plant height in okra when seeds were primed with $MgSO_4$. This improvement could be attributed to the function of magnesium sulphate ($MgSO_4$) in boosting plant height by improving nutrient absorption, particularly of nitrogen, which is essential for photosynthesis and protein synthesis.

Effect of priming agents on leaf number

Table 7 presents the effect of different priming agents on the leaf number of okra plants. Seed priming treatments significantly ($p < 0.05$) influenced leaf production under salt stress.

In the 2nd week, among the treatments, 3% $MgSO_4$ (T13*) exhibited the highest mean leaf count, which was significantly higher than ($p = 0.000$) other treatments and the control. By the 4th week T13* (5.2 cm) exhibited the greatest leaf count, with statistically significant differences ($p < 0.05$) compared to the control. After 6th and 8th weeks, T13* consistently showed the highest mean leaf count (7.0, and 9.4, respectively), which was significantly higher than T8*, T9* and the control. These results are consistent with the findings of [27], who reported that okra plants subjected to seed priming with 3% $MgSO_4$ showed a significant increase in leaf production under salt stress condition. Which could be the reason that, Mg^{2+} is an essential component of chlorophyll, which enables photosynthesis and promotes growth and biomass buildup [28].

Table 7: Effects of varying priming treatments on the number of leaves of the okra plant at different week intervals

Extracts	Treatments	2nd Week	4th Week	6th Week	8th Week
Water (Control)	T0*	2.2 ± 0.2^{b}	3.0 ± 0.0^{b}	4.0 ± 0.0^{c}	5.2 ± 0.2^{c}
50% Carrot root Extract	T2*	2.8 ± 0.2^{b}	4.2 ± 0.3^{ab}	6.4 ± 0.2^{ab}	8.0 ± 0.3^{ab}
100% Neem leaf Extract	T8*	2.4 ± 0.2^{b}	4.2 ± 1.5^{ab}	5.2 ± 1.4^{bc}	6.2 ± 0.3^{bc}
25% Garlic clove Extract	T9*	2.6 ± 0.2^{b}	4.4 ± 1.5^{ab}	5.6 ± 0.2^{b}	6.0 ± 0.7^{c}
3% $MgSO_4$	T13*	3.8 ± 0.2^{a}	5.2 ± 0.2^{a}	7.0 ± 0.3^{a}	9.4 ± 0.5^{a}
	***p* value**	**0.000**	**0.016**	**0.000**	**0.000**

*Values represent the mean ± standard error of five replicates. Mean values in a row having dissimilar letters indicate significant differences at a 5% level of significance according to Tukey's HSD Test.

Number of branches per plant

The effect of different priming agents on the number of branches of okra plants is shown in Table 8. A significant influence ($p<0.05$) was observed by the priming agents in the number of branches of okra plants grown under salt stress condition.

Table 8: Effects of varying priming agent concentrations on each plant's number of branches at various week intervals

Extracts	Treatments	4th Week	6th Week	8th Week
Control	T0*	0.4 ± 0.4^{b}	2.0 ± 0.0^{b}	2.2 ± 0.2^{b}
50% Carrot root Extract	T2*	1.2 ± 0.5^{ab}	2.0 ± 0.0^{b}	2.8 ± 0.2^{b}
100% Neem leaf Extract	T8*	0.0 ± 0.0^{b}	2.0 ± 0.0^{b}	2.4 ± 0.3^{ab}
25% Garlic clove Extract	T9*	0.4 ± 0.4^{b}	2.2 ± 0.2^{ab}	2.4 ± 0.3^{ab}
3% $MgSO_4$	T13*	2.0 ± 0.0^{a}	2.6 ± 0.3^{a}	3.2 ± 0.2^{a}
	***p* value**	**0.003**	**0.028**	**0.030**

*Values represent the mean ± standard error of five replicates. Mean values in a row having dissimilar letters indicate significant differences at a 5% level of significance according to Tukey's HSD Test.

In the 4th week, T13* recorded the highest mean branch count (2.0), which was significantly higher than the control under salt stress. By the 6th week, T13* showed significant improvement in branch count (2.6) compared to T2*, T8* and the control under salt stress. In the 8th week T13* exhibited highest mean branch count (3.2), with statistically significant differences (p = 0.030) compared to the control under salt stress.

Stem girth (cm)

Table 9 illustrates how various priming treatments affect the stem girth of okra plants. The priming treatments have significant impact on weekly stem girth values under salt stress.

Table 9: Effects of varying priming agent concentrations on the stem girth of the okra plant at different week intervals

Treatments	2nd Week (cm)	4th Week (cm)	6th Week (cm)	8th Week (cm)
T0*	0.77 ± 0.06^{b}	1.25 ± 0.05^{b}	1.70 ± 0.11^{b}	2.05 ± 0.14^{b}
T2*	0.84 ± 0.04^{b}	1.42 ± 0.04^{b}	1.84 ± 0.06^{ab}	2.11 ± 0.12^{ab}
T8*	1.00 ± 0.09^{ab}	1.45 ± 0.14^{b}	2.09 ± 0.12^{ab}	2.62 ± 0.11^{ab}
T9*	1.22 ± 0.10^{a}	1.66 ± 0.14^{ab}	2.04 ± 0.13^{ab}	2.65 ± 0.23^{ab}
T13*	1.23 ± 0.09^{a}	1.97 ± 0.09^{a}	2.29 ± 0.11^{a}	2.79 ± 0.14^{a}
***p* value**	**0.001**	**0.001**	**0.015**	**0.010**

The mean ± standard error of five replicates is represented by the values. According to Tukey's HSD Test, mean values in a row with distinct letters indicate significant differences at a 5% level of significance.

According to Table 9, in the 2nd week, T13* showed highest stem girth (1.23 cm), which was significantly higher than T2* and the control T0* (0.77 cm) under salt stress. In the 4th week significantly highest stem girth was recorded in T13* (1.97 cm) compared to T2*, T8* and the control under salt stress. By the 6th and 8th weeks, T13* showed notable increase in stem girth (2.29 cm, and 2.79 cm respectively), which were significantly higher than the control (1.70 cm, and 2.05 cm respectively) under salt stress. These results were on par with the findings of [29] and this could be due to the role of Magnesium in increasing plant biomass [30].

Relative Water Content (%)

According to Table 10, T13* (3% $MgSO_4$) showed a significantly highest RWC with an average of 68.27% compared to the control (59.90%). This demonstrates a marked increase compared to the control, highlighting the effectiveness of 3% $MgSO_4$ in maintaining the highest RWC in leaf tissues under salt stress. The findings of [31] also agreed with these results, which could be the reason that, magnesium and sulphate ions aid in maintaining ion balance and enhancing the general stability of cell membranes which assist the plant to stay hydrated under salt stress condition.

Table 10: Effects of varying priming agent concentrations on the relative water content of okra leaves

Treatments	Relative Water Content (%)
T0*	59.90 ± 1.01^{b}
T2*	64.66 ± 2.03^{ab}
T8*	65.61 ± 1.85^{ab}
T9*	62.03 ± 1.71^{ab}
T13*	68.27 ± 1.66^{a}
***p* value**	**0.021**

The mean ± standard error of five replicates is represented by the values. According to Tukey's HSD Test, mean values in a column with distinct letters indicate significant differences at a 5% level of significance.

Conclusion

As demonstrated by the findings of the laboratory experiment, radicle length was significantly enhanced by seed priming, so as germination percentage at the later stage, though plumule length was not significantly influenced by the priming agents. Results of the pot experiment revealed that the growth of *Abelmoschus esculentus* L. (okra) under salt stress was significantly ($p<0.05$) affected by seed priming with various priming agents, Among the treatments, 3% $MgSO_4$ led to significant improvements in height of the plant, relative water content, stem girth, number of leaves, and number of branches. Based on the results, 3% $MgSO_4$ could be recommended for use to prime okra seeds in order to enhance the growth performance under salt stress.

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Author Contribution

All the authors equally contributed to this study.

Disclosure of Conflicts of Interest

No conflicts of interest are disclosed by the authors.

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