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RESEARCH

Evaluating the Impact of Various Seed Priming Agents (SPAs) on Germination and Development Parameters of Okra (*Abelmoschus esculentus* L. Moench)

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Abstract

The present study has been conducted to study the effect of various primer treatments i.e., PEG (5%), PEG (10%), NaCl (2%), KCl (2%), $CuSO_4{\cdot}5H_2O$ (2%), NaOH (2%) and control on germination and growth of two okra (*Abelmoschus esculentus*) varieties (var. Arka Anamika and Clemson). Growth parameters were measured at 10, 20, and 30 DAS, while germination parameters were recorded over a period of seven days. Compared to Arka Anamika, Clemson showed better germination and growth metrics, which also showed significant differences in seed priming treatments. The use of different concentrations of PEG solution for seed priming proved to be particularly effective as evidenced by the highest germination percentage (79%), speed (95.95%), energy (76%), and Vigor index (2037.94 cm). Growth parameters also showed significant differences with these treatments. Similarly, seed priming with 2% NaOH and 2% $CuSO_4{\cdot}5H_2O$ had the lowest results for growth and germination metrics. The results highlight how priming can significantly improve the germination and growth of okra seedlings; the Clemson and PEG solution treatments stand out as particularly successful techniques. This highlights the potential for improved okra production through the use of these priming methods.

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Statement of Sustainability: By investigating different seed primers for okra germination, this research makes a significant contribution to Sustainable Development Goal 2 (Zero Hunger) by improving crop yield efficiency. Optimizing seed treatments promotes sustainable agricultural practices that ensure food security and promote resilient ecosystems. These efforts align with global initiatives to achieve a hunger-free and sustainable future.

1. Introduction

Okra (*Abelmoschus esculentus* L. Moench) is a popular summer vegetable crop that grows in tropical, subtropical, and temperate climates worldwide. It belongs to the family Malvaceae (Bereded Sheferie, 2023; Ziaf et al., 2022; Yadav et al., 2023a). The fibrous fruit of the okra plant provides 5.4% of its calories from carbohydrates, 4% from protein, and 0.5% from total fat, making it a highly nutritious fruit. The vegetable is a good source of protein and iodine and is high in vitamins A, B, and C (Ziaf et al., 2022; Mehata et al., 2023). It is mainly grown for its delicate pods, which can be eaten raw, roasted, boiled, or fried, and is a popular summer vegetable in Nepal (Su-Yi et al., 2018). Seed germination is the process by which a dormant seed becomes a healthy seedling (Chen et al., 2021). The process of radicle formation involves several steps, including water absorption, molecular breakdown, genetic material repair, endosperm and embryo elongation, and seed coat disintegration (Rima, 2021; Rhaman et al., 2020). Successful germination is crucial for both the final product and the early-stage development of seedlings (Khanal et al., 2022; Kharat and Pottathil, 2021).

Okra growers often face the challenge of poor and inconsistent seed germination, which can lead to reduced yields and significant economic losses (Vibhuti et al., 2015; Bhandari et al., 2023). This issue is primarily caused by the hard seed coat of okra, which acts as a physiological barrier, hindering water absorption and affecting the consistency of stand establishment and overall plant health (Bereded Sheferie, 2023). Priming is a technique used in okra farming to enhance seed germination (Wahocho et al., 2023). Seed priming is an easy, affordable, and effective method for timing germination and encouraging early seedling growth (Lamichhane et al., 2021). This method achieves its objectives by enhancing seed vigor, breaking dormancy, accelerating germination, and promoting better overall plant establishment (Finch-Savage and Leubner-Metzger, 2006). As a result, it helps produce high-quality harvests in both stressful and non-stressful environments (Adhikari and Shrestha, 2020). Several techniques have been shown to increase seed germination and Vigor, including seed priming (Khanal et al., 2022). One such technique is hydropriming, which involves soaking seeds in deionized water and then re-drying them to their original moisture content before sowing (Khan et al., 2023). Osmo-priming involves soaking seeds in an osmoticum solution, while hormonal priming requires submerging seeds in plant growth regulators, including GA3 and NAA (Khanal et al., 2022). Bio-priming combines seed imbibition with biological inoculation, such as bacteria and fungus, while halo-priming uses salt solutions for seed soaking (Adhikari and Shrestha, 2020; Shah et al., 2018). To promote regulated water absorption, solid matrix priming involves soaking seeds in a solid medium. This method initiates the metabolic processes required for germination without causing germination itself, which ultimately enhances the seed's overall performance (Bareke, 2018). Studies have shown that these techniques have a beneficial effect on seed germination and Vigor, leading to a more durable and effective crop establishment. Therefore, the use of these techniques is supported (Su-Yi et al., 2018).

This study assesses the impact of various priming agents on the germination and growth traits of two okra cultivars, Arka Anamika and Clemson. The study provides new insights for improving okra production in challenging environmental conditions by analyzing variables such as germination energy, speed, percentage, seedling Vigor, and growth metrics. This aligns with the broader goals of promoting financial stability and food security.

2. Materials and Methods

2.1. Experimental Site

The research was conducted in June 2023 at the G. P. Koirala College of Agriculture and Research Centre laboratory in Sundarharaicha, Morang, Nepal. The laboratory is located at 87.21° E longitude and 26.4° N latitude. Two okra varieties, Arka Anamika and Clemson, were selected for the study using seeds obtained from Agrovet. Figure 1 displays the meteorological data recorded during the study.

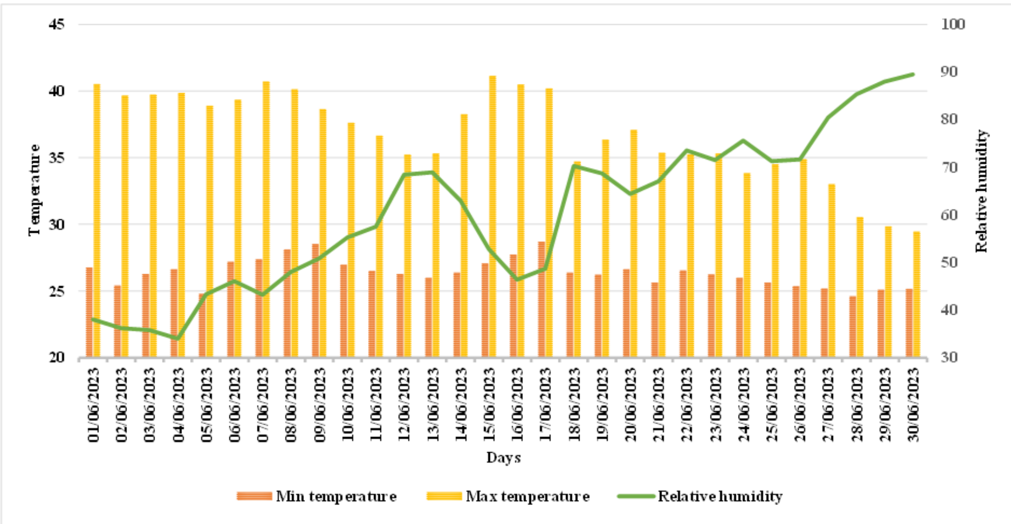

Figure 1. Meteorological data throughout the research period.

2.2. Experimental Setup and Priming Treatments

The study used a Completely Randomized Design (CRD) and included six different priming agents, as well as a control group that received hydro-priming, which involves soaking seeds in water and then allowing them to return to their natural moisture content before planting. Each treatment was repeated three times to ensure consistency. Figure 2 illustrates the experimental design, including the list of several priming agents and their dosages. The priming solutions were prepared by mixing the recommended amount for each treatment with 500 mL of water. A 24-h priming period was used to promote germination and seedling development in okra. Germination testing was conducted on seeds from two varieties per treatment using the rolled towel method. After being immersed in various priming treatments, the seeds were allowed to air dry for a minimum of two h to return to their initial moisture content. Fifty seeds were randomly selected from each variety and treatment and evenly distributed on germination paper soaked in distilled water. The rolled towels containing the seeds were placed in a seed germination room maintained at 25±1 °C and 95% relative humidity. The germination paper was kept in a temperature-controlled environment with an optimal temperature of 25 °C. The emergent seedlings were recorded daily for seven days. To track and evaluate the growth performance of each treatment, 25 seedlings were transplanted into seedling trays filled with a 4:1 combination of soil and vermicompost on the eighth day.

		Factor B							
Factor A	Replication	1	2	3	4	5	6	7	Total A
1	1	T_{111}	T_{121}	T_{131}	T_{141}	T_{151}	T_{161}	T_{171}	T_1
	2	T_{112}	T_{122}	T_{132}	T_{142}	T_{152}	T_{162}	T_{172}	
	3	T_{113}	T_{123}	T_{133}	T_{143}	T_{153}	T_{163}	T_{173}	
	Total AB	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	
2	1	T_{211}	T_{221}	T_{231}	T_{241}	T_{251}	T_{261}	T_{271}	T_2
	2	T_{212}	T_{222}	T_{232}	T_{242}	T_{252}	T_{262}	T_{272}	
	3	T_{213}	T_{223}	T_{233}	T_{243}	T_{253}	T_{263}	T_{273}	
	Total AB	T_{21}	T_{22}	T_{23}	T_{24}	T_{25}	T_{26}	T_{27}	
Total B		T_1	T_2	T_3	T_4	T_5	T_6	T_7	T

Factor A		Factor B			
S.N.	Varieties	S.N.	Priming agents	Doses	Chemical formula
1	Arka Anamika	1	Polyethylene glycol	5%	$(C_2H_4O)\ nH_2O$
2	Clemson	2	Polyethylene glycol	10%	$(C_2H_4O)\ nH_2O$
		3	Sodium chloride	2%	$NaCl$
		4	Potassium chloride	2%	KCl
		5	Copper sulphate pentahydrate	2%	$CuSO_4.5H_2O$
		6	Sodium hydroxide	2%	$NaOH$
		7	Control (Water)	N/A	H_2O

Figure 2. Experimental design with a list of the several priming agents and their dosages.

2.3. Observation and Data Collection

During the trial, we closely monitored several germination and growth indices. To examine the germination process and gather important information about germination characteristics, researchers counted the number of seeds that germinated continuously for seven days following sowing. Furthermore, for each replication, 25 seedlings were randomly selected and placed into trays. Every ten days, we removed five randomly selected seedlings from each replication and conducted a thorough investigation to examine their growth metrics. This method allowed us to carefully analyze and understand the dynamics of the seedlings' development over time.

2.3.1. Germination Variables

The study aimed to evaluate various germination traits, including the proportion of seeds that germinate, and their speed, energy, and Vigor index. Germination percentage reflects the proportion of viable seeds that thrive and develop into plants under optimal growing conditions. Germination energy assesses the percentage of seeds sprouting within a specific time frame in a given sample, while germination speed indicates how quickly seeds successfully germinate within a set timeframe. The Vigor index represents all of the characteristics of a seed that affect its ability to function and be active during germination and emergence. To determine these germination parameters, we used the formulas provided by Tania et al. (2020) and Yadav et al. (2023b). This methodical technique enabled a comprehensive evaluation of the germination properties and provided a structured framework for interpreting the experimental results.

$$\text{Germination Percentage (G\%)} = \frac{\text{Number of seed germinated}}{\text{Total number of seed sown}} \times 100$$

$$\text{Germination Speed (GS)} = \frac{\text{Number of seeds germinated in 72 h}}{\text{Number of seeds germinated in 168 h}} \times 100$$

$$\text{Germination Energy (GE)} = \text{Percentage of seed germinated in 72 h}$$

$$\text{Seed Vigor Index (VI)} = \text{Germination percentage (\%)} \times \text{Seedling length (cm)}$$

2.3.2. Growth Indicators

The growth parameters of okra seedlings were evaluated by measuring the length of their roots and shoots using a scale. At 10, 20, and 30 days after sowing (DAS), five seedlings were randomly selected and uprooted, and their root and shoot lengths were measured. Additionally, electronic weighing equipment was used to determine the fresh weight of five seedlings. Another set of five seedlings underwent the air-drying procedure to determine their dry weight. This study offers a comprehensive analysis of the growth of okra seedlings, including their physical dimensions and weight characteristics at various stages of development.

2.4. Statistical Analysis

The raw data was entered chronologically for both replication and treatment blocks using MS Excel 2021 (Microsoft Corporation, Washington, USA). Subsequently, ANOVA was performed using statistical software (R Studio, Version 4.2.2, Boston Massachusetts, USA). To compare mean values among various treatments at a significance level of 5%, Duncan's Multiple Range Test (DMRT) was used. A test of the interaction effects between treatments and varieties was also conducted.

3. Results

3.1. Effect of Priming Agents on Germination Parameters

Table 1 shows the differences in germination characteristics after the application of priming chemicals to different varieties of okra. The Clemson okra variety exhibited superior results across various parameters, including germination energy (66.09%), germination speed (82.70%), germination percentage (78.66%), and Vigor index (1850.72 cm), in that order. All germination parameters, except germination speed, were found to be significant at the 0.1% level among these varieties. The priming treatment with PEG (5%) resulted in optimal germination outcomes, including a maximum germination percentage of 79.0%, germination speed percentage of 95.95%, germination energy percentage of 76.0%, and seed Vigor index of 2037.94 cm. The study found that seeds primed with $CuSO_4{\cdot}5H_2O$ (2%) had the lowest germination energy (17%) and germination speed (25.30%). Similarly, NaOH (2%) priming resulted in the lowest germination percentage (46.33%) and seed Vigor index (798.06 cm).

The study also evaluated the interaction effects between various priming agents and okra types on germination parameters. The results show that germination energy is statistically significant at the 5% level, while germination percentage, speed, and Vigor index are not. The Clemson variety exhibited the highest germination percentage (89.33%), germination energy (86%), and Vigor index (2178.01 cm) when exposed to a 10% PEG solution. Furthermore, the Clemson variety achieved a remarkable 99.22% maximum germination rate in a 5% PEG solution. The interaction between Arka Anamika and NaOH (2%) resulted in the lowest germination percentage (42.66%) and seed Vigor index (714.49 cm). Additionally, the interaction between Arka Anamika and $CuSO_4{\cdot}5H_2O$ (2%) resulted in the least favorable germination energy (8.66%) and speed (17.42%).

3.2. Effect of Priming Agents on Shoot and Root Lengths

The use of various priming agents has a significant impact on the growth characteristics of seeds. Table 2 shows the outcomes of using different priming agents on different cultivars of okra. The results indicate that shoot length for both varieties of okra is consistently significant throughout the growing period, while root length shows no significant difference. A comparison between the Clemson and Arka Anamika varieties shows that Clemson exhibits superior growth characteristics. At 10 DAS, the mean plant height was 9.60 cm, which increased to a maximum of 18.62 cm at 30 DAS. Similarly, the mean root length showed a similar pattern of growth, measuring 1.94 cm at 10 DAS and reaching a maximum of 3.68 cm at 30 DAS. The results of the experiment showed that the shoot length and root length of seeds treated with various chemical priming methods were significantly different at the 0.1% significance level. Specifically, seeds primed with 5% PEG, 10% PEG, and 2% NaCl had the highest shoot and root lengths at 10, 20, and 30 DAS, respectively. Additionally, the growth trends of seeds primed with KCl (2%) were similar to those of seeds primed with PEG and NaCl solutions. The results indicate that seeds treated with a NaOH (2%) solution had the lowest shoot and root lengths during the growth period. Throughout the growth period, root length was significant for the interaction between the okra varieties and priming treatments, while shoot length was not significant at 20 and 30 days after sowing. Our study reveals a positive interaction between priming agents and okra varieties. In the study of the interaction between Clemson and Peg solution, as well as Clemson and NaCl, the highest shoot length was recorded. Additionally, variety Arka Anamika showed positive interaction with PEG 5% and fresh water, recording the maximum root length at 10, 20, and 30 days after sowing.

Table 1. Effect of priming agents on germination parameter.

Variety	G (%)	GS (%)	GE (%)	Vigor index
Arka Anamika	64.47[b]	81.14[a]	53.80[b]	1413.37[b]
Clemson	78.66[a]	82.70[a]	66.09[a]	1850.72[a]
Grand mean	71.57	81.92	59.95	1632.04
F-test	***	NS	***	***
Treatments				
PEG (5%)	79.00[a]	95.95[a]	76.00[a]	2037.94[a]
PEG (10%)	79.00[a]	95.18[a]	75.33[a]	1846.66[ab]
NaCl (2%)	79.00[a]	92.92[a]	73.33[a]	1899.16[ab]
KCL (2%)	77.00[a]	91.85[a]	70.66[a]	1645.01[b]
$CuSO_4{\cdot}5H_2O$ (2%)	64.66[b]	25.30[c]	17.00[c]	1292.01[c]
NaOH (2%)	46.33[c]	77.18[b]	35.33[b]	798.06[d]
Control	76.00[a]	95.05[a]	72.00[a]	1905.46[ab]
F-test	***	***	***	***
Interaction among varieties and treatments				
Arka Anamika × PEG (5%)	72.00[bcd]	92.68[ab]	66.66[def]	1920.68[ab]
Arka Anamika × PEG (10%)	68.66[cd]	94.09[ab]	64.66[f]	1515.32[b]
Arka Anamika × NaCl (2%)	76.66[abcd]	91.41[ab]	70.00[cdef]	1673.46[b]
Arka Anamika × KCl (2%)	72.00[bcd]	91.81[ab]	66.00[ef]	1506.34[b]
Arka Anamika × $CuSO_4{\cdot}5H_2O$ (2%)	52.00[e]	17.42[e]	8.66[i]	942.61[c]
Arka Anamika × NaOH (2%)	42.66[e]	84.16[b]	36.00[g]	714.49[c]
Arka Anamika × Control	67.33[d]	96.39[ab]	64.66[f]	1620.68[b]
Clemson × PEG (5%)	86.00[ab]	99.22[a]	85.33[ab]	2155.20[a]
Clemson × PEG (10%)	89.33[a]	96.27[ab]	86.00[a]	2178.01[a]
Clemson × NaCl (2%)	81.33[abcd]	94.42[ab]	76.66[abcd]	2124.86[a]
Clemson × KCl (2%)	82.00[abc]	91.89[ab]	75.33[bcde]	1783.68[ab]
Clemson × $CuSO_4{\cdot}5H_2O$ (2%)	77.33[abcd]	33.18[d]	25.33[h]	1641.42[b]
Clemson × NaOH (2%)	50.00[e]	70.19[c]	34.66[gh]	881.63[c]
Clemson × Control	84.66[ab]	93.72[ab]	79.33[abc]	2190.23[a]
CV %	10.49	9.17	9.30	13.44
SEM (±)	2.352	3.904	3.682	78.835
F-test	NS	NS	*	NS

***Significant at 0.1 % level of significance, **Significant at 1% level of significance, *Significant at 5 % level of significance, G (%): Germination percentage, GS (%): Germination speed, GE (%): Germination energy.

3.3. Effect of Priming Agents on Fresh and Dry Weight

Table 3 shows the effects of several seed priming agents on growth metrics, including the fresh and dry weight of seedlings. The results indicate that the fresh weight and dry weight of seedlings of two okra varieties, namely Arka Anamika and Clemson, were not significantly different at 10, 20, and 30 days after sowing. Seed treated with 5% and 10% PEG, as well as a 2% NaCl solution, exhibited superior results for both fresh and dry seedling weights. In contrast, treatments with NaOH (2%) and $CuSO_4{\cdot}5H_2O$ (2%) solutions showed the lowest weight. The findings also reveal that seeds treated with fresh water exhibited similar trends to the results recorded by PEG and NaCl solutions. The priming treatments used in the study showed significant differences among each other for both fresh and dry weight.

The interaction effect between varieties of okra and priming treatments was not significant for the fresh and dry weight of okra seedlings, as presented in Table 3. Both varieties showed an increasing trend in fresh and dry weight of seedlings when treated with these priming chemicals. Specifically, in Arka Anamika, the fresh weight and dry weight increase was notable with PEG solution up to 30 days after sowing, while NaCl priming exhibited a gradual rise. The Clemson variety exhibited maximum fresh and dry weight when treated with PEG (5%). A similar trend was observed in the control group treated with fresh water up to 30 days after sowing. In contrast, both Arka Anamika and Clemson varieties treated with 2% NaOH priming agent recorded the lowest weight of seedlings in terms of both fresh and dry.

Table 2. Effect of priming agents on growth parameters.

Variety	Shoot Length (cm)			Root Length (cm)		
	10 DAS	20 DAS	30 DAS	10 DAS	20 DAS	30 DAS
Arka Anamika	8.57^{b}	12.04^{b}	17.73^{b}	1.97^{a}	3.14^{a}	3.76^{a}
Clemson	10.63^{a}	14.50^{a}	19.51^{a}	1.91^{a}	2.82^{a}	3.59^{a}
Grand mean	9.60	13.27	18.62	1.94	2.98	3.68
F-test	***	***	***	NS	NS	NS
Treatments						
PEG (5%)	10.58^{a}	14.89^{a}	20.63^{a}	2.68^{a}	4.10^{a}	5.24^{a}
PEG (10%)	10.41^{ab}	14.22^{a}	19.41^{ab}	2.03^{b}	2.81^{bc}	3.78^{b}
NaCl (2%)	10.75^{a}	14.77^{a}	20.25^{a}	1.94^{b}	3.16^{b}	3.69^{b}
KCl (2%)	9.37^{bc}	12.73^{b}	18.59^{bc}	1.42^{c}	2.35^{cd}	2.71^{c}
$CuSO_4{\cdot}5H_2O$ (2%)	8.54^{c}	11.73^{b}	17.15^{c}	1.31^{c}	2.11^{d}	2.54^{c}
NaOH (2%)	7.33^{d}	10.24^{c}	14.79^{d}	1.26^{c}	1.93^{d}	2.35^{c}
Control	10.22^{ab}	14.30^{a}	19.52^{ab}	2.94^{a}	4.39^{a}	5.44^{a}
F-test	***	***	***	***	***	***
Interaction among varieties and treatments						
Arka Anamika × PEG (5%)	9.35^{cd}	14.53^{bc}	20.26^{abc}	3.36^{a}	5.00^{a}	6.42^{a}
Arka Anamika × PEG (10%)	8.75^{cdef}	12.88^{cd}	18.29^{c}	1.91^{bc}	2.85^{bc}	3.74^{c}
Arka Anamika × NaCl (2%)	8.57^{cdef}	12.23^{cd}	18.06^{c}	1.93^{bc}	3.31^{b}	3.74^{c}
Arka Anamika × KCl (2%)	8.88^{cdef}	11.32^{de}	18.28^{c}	1.32^{cd}	2.50^{bcd}	2.62^{e}
Arka Anamika × $CuSO_4{\cdot}5H_2O$ (2%)	7.86^{def}	10.74^{de}	15.84^{d}	1.15^{d}	2.10^{cd}	2.35^{e}
Arka Anamika × NaOH (2%)	7.53^{ef}	9.65^{e}	14.74^{d}	1.08^{d}	1.75^{d}	2.00^{e}
Arka Anamika × Control	9.08^{cde}	12.93^{cd}	18.62^{bc}	3.07^{a}	4.46^{a}	5.43^{b}
Clemson × PEG (5%)	11.82^{a}	15.26^{ab}	21.01^{ab}	2.01^{bc}	3.21^{b}	4.05^{c}
Clemson × PEG (10%)	12.06^{a}	15.55^{ab}	20.54^{abc}	2.15^{b}	2.77^{bc}	3.81^{c}
Clemson × NaCl (2%)	12.94^{a}	17.32^{a}	22.43^{a}	1.95^{bc}	3.02^{bc}	3.64^{cd}
Clemson × KCl (2%)	9.87^{bc}	14.14^{bc}	18.89^{bc}	1.52^{bcd}	2.20^{cd}	2.80^{de}
Clemson × $CuSO_4{\cdot}5H_2O$ (2%)	9.22^{cde}	12.72^{cd}	18.47^{c}	1.47^{bcd}	2.13^{cd}	2.73^{de}
Clemson × NaOH (2%)	7.14^{f}	10.84^{de}	14.85^{d}	1.44^{bcd}	2.11^{cd}	2.70^{de}
Clemson × Control	11.36^{ab}	15.67^{ab}	20.42^{abc}	2.82^{a}	4.33^{a}	5.44^{b}
CV %	9.63	9.21	6.92	19.64	17.66	14.02
SEM (±)	0.294	0.367	0.378	0.116	0.164	0.206
F-test	**	NS	NS	**	*	***

***Significant at 0.1 % level of significance, **Significant at 1% level of significance, *Significant at 5 % level of significance.

4. Discussions

Seed germination is closely correlated with plant growth and total production, as it is influenced by various environmental conditions throughout the development and germination stages. To promote healthy seedlings that are resistant to environmental stress, multiple pre-sowing treatments with priming chemicals are often used in okra to enhance germination, seedling development, and Vigor (Khaing et al., 2020). Research conducted by Mabuza and Tana (2021) found that seeds primed with different concentrations of PEG solution exhibited significant changes in germination characteristics. The study showed that higher concentrations of PEG solution resulted in better germination outcomes, including germination percentage, germination rate, and seed Vigor, compared to other concentrations tested. Our investigation using a 5% PEG solution yielded similar results in all relevant germination parameters. In line with their findings, Bhandari et al. (2023) demonstrated that seed priming lentils with a PEG solution leads to improved outcomes, with the best germination metrics. This is because germination can be facilitated by reducing osmotic stress and enhancing metabolic activities, which is achieved by improving water absorption through the use of polyethylene glycol solution. In our investigation, the control group treated with fresh water and the seeds treated with 2% NaCl showed similar results to those treated with PEG solutions, indicating improved germination metrics. This finding is consistent with the conclusions of Adhikari and Shrestha (2020).

Bereded Sheferie (2023) presented data showing that the interaction between varieties and priming solutions significantly impacted several germination metrics, including seed Vigor, germination percentage, germination speed, and energy. Our results are similar, based on the interaction between two okra varieties and various priming procedures. Mabuza and Tana (2021) reported that seeds primed with water for 24 h yielded 86.0% germination. Our findings indicate that the outcome was greater than the 76% result of the control group. This may be due to the longer period of increased hydration. Our findings show that seeds treated with NaOH and $CuSO_4{\cdot}5H_2O$ had the lowest germination percentages, Vigor, energy, and speed. The use of these priming chemicals resulted in the lowest germination metrics for all okra cultivars. This may be due to the strong chemical impacts, which could impair the germination and metabolism of seeds, thereby affecting their overall Vigor and performance. In a study on lentil landraces, Bhandari et al. (2023) discovered that different solutions of polyethylene glycol (PEG) resulted in better germination characteristics, including germination percentage, energy, speed, and seed Vigor. This finding is similar to our PEG solution priming results. Polyethylene glycol may improve water absorption, reduce osmotic stress, and encourage ideal hydration conditions for seeds, potentially leading to better overall performance.

Table 3. Effect of priming agents on growth parameters.

Variety	Fresh Weight (g)			Dry Weight (g)		
	10 DAS	20 DAS	30 DAS	10 DAS	20 DAS	30 DAS
Arka Anamika	0.28^{a}	0.57^{a}	0.97^{a}	0.015^{a}	0.031^{a}	0.064^{a}
Clemson	0.24^{a}	0.60^{a}	1.00^{a}	0.013^{a}	0.033^{a}	0.066^{a}
Grand mean	0.26	0.59	0.99	0.01	0.03	0.06
F-test	NS	NS	NS	NS	NS	NS
Treatments						
PEG (5%)	0.36^{a}	0.68^{a}	1.04^{a}	0.020^{a}	0.037^{a}	0.068^{a}
PEG (10%)	0.32^{ab}	0.67^{a}	1.07^{a}	0.018^{ab}	0.037^{a}	0.070^{a}
NaCl (2%)	0.31^{ab}	0.62^{ab}	1.03^{ab}	0.017^{ab}	0.034^{ab}	0.068^{ab}
KCl (2%)	0.25^{bc}	0.60^{ab}	0.99^{ab}	0.014^{bc}	0.033^{ab}	0.065^{ab}
$CuSO_4{\cdot}5H_2O$ (2%)	0.18^{cd}	0.50^{bc}	0.92^{bc}	0.010^{cd}	0.027^{bc}	0.060^{bc}
NaOH (2%)	0.14^{d}	0.47^{c}	0.85^{c}	0.008^{d}	0.026^{c}	0.056^{c}
Control	0.27^{b}	0.55^{abc}	1.01^{ab}	0.015^{b}	0.030^{abc}	0.066^{ab}
F-test	***	**	**	***	**	**
Interaction among varieties and treatments						
Arka Anamika × PEG (5%)	0.37^{ab}	0.60^{abc}	1.03^{ab}	0.020^{ab}	0.033^{abc}	0.068^{ab}
Arka Anamika × PEG (10%)	0.34^{ab}	0.60^{abc}	1.07^{a}	0.019^{ab}	0.033^{abc}	0.070^{a}
Arka Anamika × NaCl (2%)	0.39^{a}	0.58^{abc}	1.03^{ab}	0.022^{a}	0.037^{ab}	0.068^{a}
Arka Anamika × KCl (2%)	0.24^{bcd}	0.55^{bc}	0.95^{abc}	0.013^{bcd}	0.030^{bc}	0.062^{abc}
Arka Anamika × $CuSO_4{\cdot}5H_2O$ (2%)	0.17^{cd}	0.52^{bc}	0.90^{abc}	0.009^{cd}	0.029^{bc}	0.059^{abc}
Arka Anamika × NaOH (2%)	0.12^{d}	0.52^{bc}	0.86^{bc}	0.006^{d}	0.028^{bc}	0.056^{bc}
Arka Anamika × Control	0.34^{ab}	0.57^{abc}	0.96^{abc}	0.019^{ab}	0.031^{abc}	0.063^{abc}
Clemson × PEG (5%)	0.36^{ab}	0.76^{a}	1.05^{a}	0.020^{ab}	0.042^{a}	0.069^{a}
Clemson × PEG (10%)	0.30^{abc}	0.74^{a}	1.07^{a}	0.017^{abc}	0.041^{a}	0.070^{a}
Clemson × NaCl (2%)	0.24^{bcd}	0.58^{abc}	1.04^{a}	0.013^{bcd}	0.032^{abc}	0.068^{a}
Clemson × KCl (2%)	0.26^{abcd}	0.67^{ab}	1.03^{ab}	0.014^{abcd}	0.036^{ab}	0.067^{ab}
Clemson × $CuSO_4{\cdot}5H_2O$ (2%)	0.19^{cd}	0.48^{bc}	0.94^{abc}	0.010^{cd}	0.026^{bc}	0.062^{abc}
Clemson × NaOH (2%)	0.16^{d}	0.42^{c}	0.85^{c}	0.009^{d}	0.023^{c}	0.055^{c}
Clemson × Control	0.20^{cd}	0.54^{bc}	1.07^{a}	0.011^{cd}	0.029^{bc}	0.069^{a}
CV %	27.12	17.17	9.10	27.12	17.17	9.10
SEM (±)	0.016	0.019	0.016	0.0009	0.001	0.001
F-test	NS	NS	NS	NS	NS	NS

***Significant at 0.1 % level of significance, **Significant at 1% level of significance, *Significant at 5 % level of significance.

Priming agents can significantly improve the plant height, root length, and fresh and dried weight of okra seedlings (Mabuza and Tana, 2021). Various studies have shown a positive impact of different priming agents on the growth of early seedlings. This is due to a reduction in imbibition time, increased activation of pre-germinative enzymes, and enhanced production of metabolites, as documented in experiments performed by Eshkab and Harris (2020). When these priming treatments were applied to several varieties of okra, growth assessments revealed significant outcomes. These findings are consistent with the study conducted by Abduhu et al. (2017). Clemson variety consistently exceeded Arka Anamika in shoot length during seedling growth, likely due to genetic characteristics that support vigorous shoot development. This suggests that Clemson has exceptional development potential and natural adaptability. During our investigation, we found that using PEG (5% and 10%) and NaCl (2%) as priming agents resulted in the longest shoot and root lengths throughout the study. These results are consistent with those of Adhikari and Shrestha (2020), who found that PEG was the most effective priming agent after being immersed for a full day. The superior performance of these priming treatments can be attributed to their impact on the important biochemical pathway. PEG (polyethylene glycol) solutions enhance water intake by lowering osmotic potential, promoting cell expansion, and facilitating nutrient absorption. This aids in the development of roots and shoots.

Mabuza and Tana (2021) found that PEG (10%) was a better priming agent for overall germination and growth characteristics in okra varieties, which supports similar results. Similarly, seed priming with fresh water leads to substantial increases in the shoot and root length of seedlings, as reported by Tania et al. (2020). Hydro-priming is important for enhancing okra development characteristics, such as shoot and root length. This is supported by the findings of Khanal et al. (2022), who reported that seeds primed with NaCl had the longest shoot length. Although there were no significant differences in fresh weight and dry weight of seedlings among the okra varieties, the use of different priming agents resulted in varying patterns of fresh weight and dry weight for both varieties throughout the days following planting. This highlights the significant impact of priming agents on the absorption, distribution, and utilization of nutrients. These ingredients are necessary for seedling growth and support the hypothesis that priming chemicals can activate physiological mechanisms that enhance nutrient distribution and mobilization in seeds, ultimately leading to increased seedling growth. Our results align with those of Abduhu et al. (2017), who found that osmo-priming with different concentrations of PEG is the most effective priming agent for improving growth metrics, such as fresh and dry weight. Bhandari et al. (2023) recorded similar findings in lentil landraces and concluded that seed priming with a 5% PEG solution was the optimal priming agent for growth metrics. Throughout the study, PEG and NaCl resulted in the highest fresh and dry weight. Yadav et al. (2023b) reported comparable findings in previous research on rice seeds using 2% urea and a 5% PEG solution.

This study shows that the growth characteristics of two okra cultivars, Arka Anamika and Clemson, are significantly influenced by different priming agents. The variations in the ways that different agents stimulate endospermic amylase activity, leading to differences in the amounts of insoluble sugar present, are likely the cause of the reported differences in results (Eshkab and Harris, 2020). Our research shows a significant correlation between priming agents and okra cultivar performance. We concluded that the Clemson variety, when combined with PEG and NaCl priming agents, yields better results in terms of the fresh and dry weight of seedlings at 10, 20, and 30 days after planting. We evaluated the interaction between variety and priming solutions to arrive at this conclusion. This study highlights the significant correlation between growth metrics, chemical treatments, and genetic features of okra cultivars, which is consistent with the findings of Khan et al. (2023). Additionally, the varying germination and growth outcomes observed in different okra cultivars are influenced by the complex relationships among nutritional dynamics, priming factors, pre-germinative metabolism, and endospermic amylase activity.

5. Conclusion

In this study, seed priming appears to be an effective method for enhancing the germination and overall development of okra seedlings. Various priming agents are useful, with the Clemson okra cultivar being particularly sensitive, indicating its potential for high yield. Significant improvements in germination characteristics have been observed with varying doses of PEG and NaCl solutions, highlighting the adaptability of seed priming. The study presents evidence supporting the use of seed priming as an eco-friendly method to increase okra crop yield and recommends its integration into contemporary farming techniques. Further research should investigate various treatment concentrations and durations to optimize seed priming. Additionally, examining characteristics of mature plants, such as pest resistance and yield potential, can provide insight into the long-term impacts of seed priming. Seed priming is a viable method for producing healthier and more abundant okra crops while also being ecologically friendly.

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