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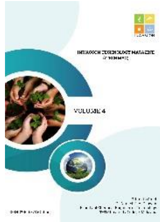

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RESEARCH REVIEW

EVALUATION OF THE EFFECTS OF SEVERAL PRIMING CHEMICALS ON OKRA SEED GERMINATION AND GROWTH CHARACTERISTICS

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ABSTRACT

Lady's finger, or okra (Abelmoschus esculentus), is a warm-season vegetable that is grown extensively in tropical and subtropical areas due to its economic and nutritional value. Despite its importance, challenges such as uneven germination and poor seedling establishment often limit okra production. An experiment was carried out in May 2024 at the Girija Prasad Koirala College of Agriculture and Research Centre in Morang, Nepal, to investigate the effects of several seed priming treatments on the germination and development of two okra cultivars, Mahima (NOH-100) and Swastik-2, to solve these problems. The study utilized a two-factorial Completely Randomized Design (CRD) to evaluate the effects of seven priming treatments on okra seed germination and seedling performance. The experiment was conducted with three replications and involved two different okra cultivars. Growth indicators were examined 10, 20, and 30 days after sowing (DAS), and germination was tracked for seven days. The Mahima (NOH-100) variety fared better than Swastik-2 with respect to the sprouting and development according to the data. The best priming method, which produced the highest germination parameters, was the 5% PEG solution. Conversely, the treatments with the worst germination and growth results were 2% NaOH and 2% $CuSO_4 \cdot 5H_2O$. This study indicates that seed priming is a good method for increasing okra output since it may greatly improve the germination and development of okra seedlings, especially when done using a 5% PEG solution.

KEYWORDS

Okra, Chemical Priming, Germination, Polyethylene glycol (PEG)

1. INTRODUCTION

Okra is a widely cultivated vegetable belonging to the Malvaceae family, thriving in tropical, subtropical, and mildly temperate regions. It is valued for its tender green pods, which are rich in essential nutrients, making it a healthy addition to human diets (Chen et al., 2021). The vegetable is particularly known for its high fiber content, vitamins, minerals, and antioxidants, contributing to its numerous health benefits, such as improved digestion, cholesterol regulation, and potential blood sugar control (Barupal et al., 2022). Okra is widely consumed in various cuisines, where it is eaten raw, boiled, roasted, or fried, making it a popular ingredient in many cultural dishes. Beyond its culinary importance, okra is also recognized for its medicinal properties, with different plant parts used in traditional remedies for treating inflammation, digestive issues, and even certain metabolic disorders (Khanal et al., 2022; Kharat and Pottathil, 2021). Despite its agricultural and dietary significance, successful okra cultivation is often hindered by poor and inconsistent seed germination, which directly affects crop yield and profitability. The germination of okra seeds is a complex physiological process that involves several key stages, including water absorption, metabolic activation, enzymatic breakdown of stored nutrients, genetic material repair, and embryo elongation, ultimately leading to seed coat rupture and seedling emergence (Naqve et al., 2018).

However, the hard seed coat of okra presents a major obstacle to germination, acting as a physical and physiological barrier that restricts water absorption and delays seedling development (Dhakal et al., 2023; Bereded Sheferie, 2023). This dormancy mechanism, while beneficial for natural seed preservation, creates challenges for farmers who require uniform and rapid germination for optimal crop establishment. Poor seed germination leads to uneven plant growth, reduced crop density, and financial losses, necessitating the adoption of effective strategies to enhance seedling emergence and vigor (Bhandari et al., 2023; Balchhaudi, 2023). To overcome these challenges, researchers and farmers have explored various seed enhancement techniques, with seed priming emerging as one of the most promising solutions for improving germination rates and overall plant performance. Seed priming is a pre-sowing treatment that partially hydrates seeds, triggering the initial stages of germination without allowing radicle emergence. This process improves metabolic activation, breaks dormancy, synchronizes germination, and enhances seedling vigor, leading to more robust plant establishment (Tahir et al., 2019). Several priming techniques have been developed, each offering unique benefits. Hydro-priming involves soaking seeds in deionized water and re-drying them before sowing, while osmo-priming utilizes osmotic solutions to regulate water uptake and enhance stress tolerance (Kaur et al., 2015; Thakur et al., 2023).

Hormonal priming employs growth regulators like gibberellic acid to stimulate germination, whereas bio-priming combines seed hydration with beneficial microbial inoculation to improve plant health and resistance to pathogens (Adhikari and Shrestha, 2020; Shah et al., 2018). Other methods, such as halo-priming (using salt solutions) and solid matrix priming (embedding seeds in a controlled medium), have also shown significant improvements in germination rates, stress resistance, and early seedling growth (Bareke, 2018; Chen et al., 2021). These techniques play a crucial role in mitigating the challenges associated with okra seed dormancy and enhancing the success of crop establishment. Research has consistently demonstrated the effectiveness of seed priming in improving okra germination and seedling vigor, leading to better crop resilience and higher yield potential (Su-Yi et al., 2018). Primed seeds germinate faster, exhibit uniform growth, and develop stronger root systems, allowing for improved nutrient absorption and resistance to adverse environmental conditions such as drought and salinity. This study aims to assess the effects of seven priming treatments on the germination and growth of two okra cultivars, Swastik-2 and Mahima (NOH-100), by evaluating germination traits, seedling vigor, and growth parameters to enhance okra cultivation in challenging environments.

2. Materials and Methodology

2.1 Description of experimental site

The study was conducted in May 2024 in the laboratory of the G. P. Koirala College of Agriculture and Research Centre in Sundarharaicha, Morang, Nepal. The physical coordinates of the lab are 27.5° N latitude and 86.22° E longitude. Two okra varieties Swastik-2 and Mahima (NOH-100) were used for this investigation. The Agrovet provided the seeds for these types.

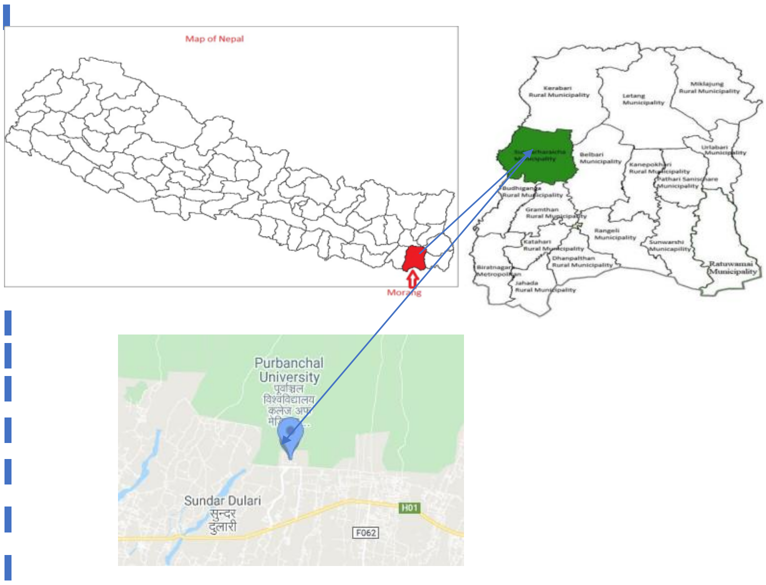

Figure 1: Location map of study area

2.2 Experimental design and treatments

The study utilized a Completely Randomized Design (CRD) to evaluate the effects of six distinct seed priming agents compared to a control group that underwent hydro-priming. Before being planted, seeds were hydro-primed by soaking them in water to return to their original moisture content. Priming solutions were made by dissolving the designated amounts of each agent in 500 millilitres of water for each treatment, which was repeated three times to ensure dependability. To encourage germination and seedling vigour, seeds were immersed in these solutions for a full day. After that, they were allowed to air dry for at least two hours to return to their initial moisture levels. 50 seeds from each type and treatment were chosen at random and put on germination paper that had been soaked with distilled water in order to test for germination. These seeds were rolled and stored in a controlled germination room maintained at 90% relative humidity and 25 °C. After seven days of recording seedling emergence, 25 seedlings per treatment were moved into trays with a 3:1 soil-to-vermicompost combination on the eighth day. This configuration guaranteed consistent circumstances for evaluating the development of seedlings.

Table 1: Details of Variety and different treatments used in study

Factor A		Factor B			
Symbol	**Varieties**	**Symbol**	**Priming agents**	**Doses**	**Chemical formula**
V1	Swastik-2	T1	Polyethylene glycol	5%	$(C_2H_4O)\ nH_2O$
V2	Mahima (NOH-100)	T2	Polyethylene glycol	10%	$(C_2H_4O)\ nH_2O$
		T3	Sodium chloride	2%	Nacl
		T4	Potassium chloride	2%	KCL
		T5	Copper sulphate pentahydrate	2%	$CuSO_4.5H_2O$
		T6	Sodium hydroxide	2%	NaOH
		T7	Control (water)	N/A	H_2O

2.3 Data collecting and observation

Throughout the trial, germination and growth indices were closely monitored by counting germinated seeds daily for seven days to assess germination characteristics. For growth analysis, 25 seedlings per replication were transplanted into trays, and every 10 days, five randomly selected seedlings underwent detailed destructive analysis to evaluate growth dynamics over time.

2.4 Factors influencing germination

Germination energy quantifies the percentage of seeds that sprout within a given time period, whereas germination percentage shows the percentage of viable seeds that grow under ideal circumstances. The vigour index includes all seed characteristics that affect activity during germination and emergence, whereas germination speed indicates the rate of successful germination. The computations, which were based on formulae, provide an organized method for evaluating and interpreting the experimental findings (Akpor et al., 2024).

$$Germination\ Percentage\ (G\%) = \frac{Number\ of\ seed\ germinated}{Total\ number\ of\ seed\ sown} \times 100 \quad (1)$$

$$Germination\ Speed\ (GS) = \frac{Number\ of\ seed\ germinated\ in\ 72\ hours}{Number\ of\ seed\ germinated\ in\ 168\ hours} \times 100 \quad (2)$$

$$Germination\ Energy\ (GE) = percentage\ of\ seed\ germinated\ in\ 72\ hours \quad (3)$$

$$Seed\ Vigor\ Index\ (VI) = Germination\ percentage\ (\%) \times Seedling\ length\ (cm) \quad (4)$$

2.5 Markers of growth

Using a scale to measure the lengths of the roots and shoots, the growth of the okra seedlings was assessed. Five randomly chosen seedlings were removed at 10, 20, and 30 days after sowing (DAS) to determine the length of their roots and shoots. Additionally, electronic weighing scales were used to assess the fresh weight of five seedlings. To determine their dry weight, five more seedlings were allowed to air dry. By documenting the seedlings' weight features and physical measures at various developmental phases, this approach provided a thorough insight of the growth dynamics of the plants.

2.6 Statistical analysis

MS Excel, 2021 was used to enter the raw data for the replication and treatment blocks in chronological sequence. Statistical software (R Studio, Version 4.2.2) was then used to execute an ANOVA. Duncan's Multiple Range Test (DMRT) was used to compare mean results across different treatments at a 5% significance level. An investigation on the interaction effects between treatments and varieties was conducted in R-Studio.

3. Results

3.1 Priming agents' impact on germination parameters:

Significant variations in germination properties between different okra types treated with different priming agents are shown in Table 1. The Mahima (NOH-100) variety demonstrates exceptional performance across several germination parameters. Specifically, Mahima (NOH-100) okra achieves a germination energy of 70.09%, a germination speed of 82.31%, a germination percentage of 83.04%, and a vigor index of 1914.73 cm. These figures indicate that Mahima (NOH-100) okra seeds respond particularly well to the priming treatments applied, significantly outperforming other varieties. Interestingly, among the studied types, all of these germination characteristics are statistically significant at the 0.1% level, highlighting the validity of these results. Among the different priming treatments, a 5% PEG (polyethylene glycol) solution stands out as the most effective, yielding optimal germination results.

Seeds treated with 5% PEG exhibit the highest germination percentage (85%), the fastest germination speed (92.59%), the highest germination energy (79.0%), and the highest seed vigor index (2198.64 cm). These results highlight the efficacy of PEG in enhancing okra seed germination characteristics, making it a recommended treatment for improving seed performance. In contrast, certain priming treatments result in significantly poorer outcomes. The lowest germination energy (20%) and speed (29.66%) are displayed by seeds primed with 2% CuSO4.5H2O, for example, suggesting that this chemical is harmful to seed performance. Priming with 2% NaOH also has the lowest seed vigour index (911.52 cm) and germination percentage (52.33%), underscoring the detrimental effects of this treatment. The study also looks at how different priming chemicals and okra cultivars interact to affect germination characteristics.

The vigour index, speed, and germination percentage do not show any significant interaction effects, although the germination energy does show statistical significance at the 5% level. Interestingly, the Mahima (NOH-100) variety treated with a 10% PEG solution produces exceptional results, such as the greatest vigour index (2253.17 cm), germination energy (90%), and germination percentage (95.33%). Additionally, a high germination rate of 92.0% is observed with the Mahima (NOH-100) variety treated with a 5% PEG solution, reinforcing the superior performance of PEG-treated Mahima (NOH-100) seeds. Conversely, the combination of the Swastik-2 variety and the lowest seed vigour index (852.93 cm) and germination percentage (48.66%) are obtained with 2% NaOH. The poorest germination energy (10.66%) and speed (19.0%) are observed with Swastik-2 treated with 2% CuSO4.5H2O, illustrating the adverse effects of these treatments on this variety.

Table 1: Effect of priming agents on germination parameters

Variety	G (%)	GS (%)	GE (%)	Vigor index
Swastik-2 (A)	70.47b	77.11b	55.80b	1597.30b
Mahima (NOH-100) (B)	83.04a	82.31a	70.09a	1914.73a
Grand mean	76.76	79.71	62.95	1756.01
F-test	***	*	***	***
Treatments				
PEG (5%)	85a	92.59a	79a	2198.64a
PEG (10%)	85a	91.80a	78.33a	1979.47ab
NaCl (2%)	85a	89.83a	76.33a	2060.98ab
KCL (2%)	83a	88.73a	73.66a	1789.95b
CuSO4.5H2O (2%)	65b	29.66c	20c	1304.54c
NaOH (2%)	52.33c	73.81b	38.33b	911.52c
Control	82a	91.54a	75a	2046.99ab
F-test	***	***	***	***
Interaction (varieties × treatments)				
Swastik-2 × PEG (5%)	78.0cd	88.10ab	68.66c	2141.64ab
Swastik-2 × PEG (10%)	74.66d	89.18ab	66.66c	1705.78c
Swastik-2 × NaCl (2%)	82.66bcd	87.16ab	72.0bc	1868.82abc
Swastik-2 × KCL (2%)	74.66d	87.29ab	68.0c	1692.62c
Swastik-2 × CuSO4.5H2O (2%)	58.0e	19.0e	10.66e	1097.03d
Swastik-2 × NaOH (2%)	48.66e	77.90bc	38.0d	852.93d
Swastik-2 × Control	73.33d	91.15a	66.66c	1822.26bc
Mahima (NOH-100) × PEG (5%)	92.0ab	97.09a	89.33a	2255.64a
Mahima (NOH-100) × PEG (10%)	95.33a	94.41a	90.00a	2253.17a
Mahima (NOH-100) × NaCl (2%)	87.33abc	92.50a	80.66ab	2253.14a
Mahima (NOH-100) × KCL (2%)	88.0abc	90.17ab	79.33ab	1887.27abc
Mahima (NOH-100) × CuSO4.5H2O (2%)	72.0d	40.33d	29.33d	1512.04c
Mahima (NOH-100) × NaOH (2%)	56.0e	69.73c	38.66d	970.11d
Mahima (NOH-100) × Control	90.66ab	91.93a	83.33a	2271.72a
CV %	7.59	8.14	8.85	11.69
SEM (±)	2.352	3.904	3.682	78.835
F-test	NS	*	*	NS

*Significant at 5 % level of significance, GP; Germination percentage, GS: Germination speed, GE: Germination energy, VI: Vigor index

3.2 Effect of priming agents on growth parameters

3.2.1 Effect of priming agents on shoot length and root length

Table 2 provides detailed insights into the growth characteristics of okra when seeds are primed with various chemical agents. The results indicate significant variations in shoot and root lengths among different treatments and okra varieties, with the Mahima (NOH-100) variety exhibiting particularly notable growth. 10 days after sowing (DAS), the mean plant height for the Mahima (NOH-100) variety was 9.64 cm, which increased to a peak of 19.03 cm at 30 DAS. This growth trajectory highlights Mahima (NOH-100)'s superior performance in terms of shoot length. Similarly, root growth followed a consistent upward trend, with the mean root length starting at 2.20 cm at 10 DAS and reaching a maximum of 3.69 cm at 30 DAS. These results underscore Mahima (NOH-100)'s overall robust growth compared to the Swastik-2 variety.

At the 0.1% level, the efficacy of the various priming treatments was noteworthy, especially for shoot and root lengths. At all time periods (10, 20, and 30 DAS), the seeds treated with 5% PEG, 10% PEG, and 2% NaCl showed the longest shoots and roots. For example, 5% PEG-primed seeds showed exceptional shoot and root development, reinforcing the value of PEG as a potent priming agent. Additionally, seeds treated with 2% KCl exhibited similar growth patterns to those primed with PEG and NaCl, suggesting that KCl is also an effective priming agent for enhancing okra growth. On the other hand, seeds primed with 2% NaOH had the shortest shoot and root lengths throughout the course of the development period, suggesting that NaOH is not as useful for priming okra seeds. This persistent underperformance demonstrates how negatively NaOH affects okra development. While shoot length was not considerably changed at 20 and 30 DAS, the interaction between okra cultivars and priming treatments showed that root length greatly varied throughout the growth period.

This finding suggests that while priming treatments universally benefit root growth, their effects on shoot length may vary over time. Positive interactions between specific priming agents and okra varieties were also noted. For instance, the Mahima (NOH-100) variety treated with PEG solution or NaCl showed the highest shoot lengths, emphasizing the synergy between Mahima (NOH-100)'s genetic traits and these priming agents. Similarly, the Swastik-2 variety exhibited maximum root length when primed with 5% PEG and fresh water at 10, 20, and 30 DAS, indicating that these treatments are particularly effective for enhancing root development in Swastik-2. In conclusion, the study demonstrates that chemical priming significantly influences the growth characteristics of okra. The Mahima (NOH-100) variety, especially when treated with PEG, shows superior growth, both in shoot and root lengths. These findings suggest that selecting appropriate priming agents, such as PEG and NaCl, can substantially improve okra cultivation outcomes.

Table 2: Priming agents' effects on root and shoot length

Variety	Shoot length (cm)			Root length (cm)		
	10 DAS	20 DAS	30 DAS	10 DAS	20 DAS	30 DAS
Swastik-2	8.62^{b}	12.60^{b}	18.51^{b}	2.47^{a}	3.54^{a}	3.76^{a}
Mahima (NOH-100)	10.66^{a}	14.58^{a}	19.56^{a}	1.93^{b}	3.07^{b}	3.62^{a}
Grand mean	9.64	13.59	19.03	2.20	3.30	3.69
F-test	*	**	*	*	**	NS
Treatments						
PEG (5%)	10.62ab	15.21^{a}	21.05^{a}	3.21^{a}	4.72^{a}	5.45^{a}
PEG (10%)	10.45ab	14.54^{ab}	19.83^{ab}	2.94^{a}	4.43^{a}	5.25^{a}
NaCl (2%)	10.79a	15.09^{a}	20.66^{ab}	2.20^{b}	3.49^{b}	3.70^{b}
KCL (2%)	9.41bc	13.05^{bc}	19.00^{bc}	1.68^{c}	2.68^{cd}	2.72^{c}
$CuSO_4.5H_2O$ (2%)	8.58^{c}	12.05^{cd}	17.57^{c}	1.57^{c}	2.44^{d}	2.56^{c}
NaOH (2%)	7.37^{d}	10.56^{d}	15.21^{d}	1.52^{c}	2.25^{d}	2.37^{c}
Control	10.26^{ab}	14.62^{ab}	19.93^{ab}	2.29^{b}	3.14^{bc}	3.79^{b}
F-test	*	*	**	**	*	**
Interaction (varieties × treatments)						
Swastik-2 × PEG (5%)	9.40^{cd}	15.09^{abc}	21.04^{ab}	3.86^{a}	5.40^{a}	6.42^{a}
Swastik-2 × PEG (10%)	8.80^{cde}	13.44^{bcde}	19.07^{bc}	2.41^{bc}	3.25^{cde}	3.74^{cd}
Swastik-2 × NaCl (2%)	8.62^{cde}	12.79^{cdef}	18.84^{bc}	2.43^{bc}	3.71^{bc}	3.74^{cd}
Swastik-2 × KCL (2%)	8.93^{cde}	11.88^{defg}	19.06^{bc}	1.82^{cd}	2.90^{cdef}	2.62^{e}
Swastik-2 × $CuSO_4.5H_2O$ (2%)	7.91^{de}	11.30^{efg}	16.62^{cd}	1.65^{d}	2.50^{def}	2.35^{e}
Swastik-2 × NaOH (2%)	7.58^{de}	10.21^{g}	15.52^{d}	1.58^{d}	2.15^{f}	2.00^{e}
Swastik-2 × Control	9.13^{cd}	13.49^{bcde}	19.40^{b}	3.58^{a}	4.86^{a}	5.43^{b}
Mahima (NOH-100) × PEG (5%)	11.85^{a}	17.40^{a}	22.48^{a}	2.03^{cd}	3.46^{cd}	4.08^{c}
Mahima (NOH-100) × PEG (10%)	12.09^{a}	15.75^{ab}	21.06^{ab}	2.17^{bcd}	3.02^{cdef}	3.84^{c}
Mahima (NOH-100) × NaCl (2%)	12.97^{a}	15.34^{ab}	21.04^{ab}	1.97^{cd}	3.27^{cde}	3.67^{cd}
Mahima (NOH-100) × KCL (2%)	9.90^{bc}	14.22^{bcd}	18.94^{bc}	1.54^{d}	2.45^{def}	2.83^{de}
Mahima (NOH-100) × $CuSO_4.5H_2O$ (2%)	9.25^{cd}	12.80^{cdef}	18.52^{bc}	1.49^{d}	2.38^{ef}	2.76^{de}
Mahima (NOH-100) × NaOH (2%)	7.17^{e}	10.92^{fg}	14.90^{d}	1.46^{d}	2.36^{ef}	2.73^{de}
Mahima (NOH-100) × Control	11.39^{ab}	15.63^{ab}	20.59^{ab}	2.84^{b}	4.58^{ab}	5.47^{b}
CV %	9.59	8.99	6.77	17.33	15.93	13.96
SEM (±)	0.294	0.367	0.378	0.116	0.164	0.206
F-test	*	NS	NS	*	*	**

3.2.2 *Priming agents' effects on dry and fresh weight*

The effects of several seed priming agents on the fresh and dry weight growth parameters of okra seedlings are shown in Table 3. Mahima (NOH-100) and Swastik-2 were the two okra cultivars used in the study. The results showed that these cultivars' fresh and dry weights at 10, 20, and 30 days after sowing (DAS) did not differ considerably. The efficacy of the treatment options themselves, however, varied noticeably. The seeds that produced the highest fresh and dry seedling weights were those treated with 5% and 10% PEG and 2% NaCl solutions. These treatments' ability to increase seedling biomass was demonstrated by the consistently better growth results they provided. Conversely, seeds treated with 2% NaOH and 2% $CuSO_4.5H_2O$ solutions produced the lowest fresh and dry weights, suggesting that these agents are either ineffective or perhaps harmful to the development of seedlings. Curiously, seeds primed with PEG and NaCl solutions showed growth patterns that were identical to those of seeds treated with fresh water, indicating that even basic water priming can be advantageous. The significance of choosing the right priming agents is shown by the study's finding of notable variations in fresh and dry weights between the different priming regimens. However, for both fresh and dry weights, the interaction impact between the priming treatments and the okra types was not significant. This indicates that although the priming treatments themselves were significant, there were no statistically significant variations in the particular okra variety and priming agent combination. After being treated with these priming compounds, the fresh and dried seedling weights of both okra kinds exhibited an increasing tendency. With PEG treatment up to 30 DAS, Swastik-2's fresh and dry weight increased noticeably, with a steady increase observed with NaCl priming. The 5% PEG treatment produced the highest fresh and dry weights in the Mahima (NOH-100) variety; same pattern was also seen in the control group, which received freshwater treatment up to 30 DAS. On the other hand, the Mahima (NOH-100) and Swastik-2 cultivars treated with 2% NaOH had the lowest seedling weights according to both fresh and dry measures. The conclusion that NaOH is an inappropriate priming agent for okra seedlings is supported by this persistent underperformance

Table 3: Priming agents' effects on both dry and fresh weight

Variety	Fresh weight (gm)			Dry weight (gm)		
	10 DAS	20 DAS	30 DAS	10 DAS	20 DAS	30 DAS
Swastik-2	0.29^{a}	0.60^{a}	0.98^{a}	0.07^{a}	0.09^{a}	0.11^{a}
Mahima (NOH-100)	0.25^{a}	0.58^{a}	1.01^{a}	0.02^{b}	0.08^{b}	0.10^{a}
Grand mean	0.27	0.59	1.00	0.04	0.08	0.11
F-test	NS	NS	NS	*	*	NS
Treatments						
PEG (5%)	0.37^{a}	0.69^{a}	1.05^{a}	0.053^{a}	0.092^{a}	0.122^{ab}
PEG (10%)	0.33^{ab}	0.68^{a}	1.08^{a}	0.051^{a}	0.091^{a}	0.124^{a}
NaCl (2%)	0.32^{ab}	0.63^{ab}	1.04^{ab}	0.050^{ab}	0.089^{ab}	0.122^{ab}
KCL (2%)	0.25^{bc}	0.61^{ab}	1.00^{ab}	0.047^{bc}	0.088^{ab}	0.119^{ab}
$CuSO_4.5H_2O$ (2%)	0.19^{cd}	0.51^{bc}	0.93^{bc}	0.043^{cd}	0.082^{bc}	0.114^{bc}
NaOH (2%)	0.15^{d}	0.48^{c}	0.87^{c}	0.041^{d}	0.080^{c}	0.110^{c}
Control	0.28^{abc}	0.56^{abc}	1.02^{ab}	0.048^{abc}	0.085^{abc}	0.120^{ab}
F-test	*	*	**	*	**	**
Interaction (varieties × treatments)						
Swastik-2 × PEG (5%)	0.38^{ab}	0.61^{abcd}	1.04^{ab}	0.075^{ab}	0.093^{ab}	0.123^{ab}
Swastik-2 × PEG (10%)	0.35^{ab}	0.62^{abcd}	1.07^{a}	0.074^{ab}	0.093^{ab}	0.125^{a}
Swastik-2 × NaCl (2%)	0.40^{a}	0.68^{abc}	1.04^{ab}	0.077^{a}	0.097^{a}	0.123^{ab}
Swastik-2 × KCL (2%)	0.25^{bcd}	0.56^{bcd}	0.96^{abc}	0.068^{bc}	0.090^{abc}	0.117^{abc}
Swastik-2 × $CuSO_4.5H_2O$ (2%)	0.18^{cd}	0.53^{cd}	0.91^{abc}	0.064^{c}	0.089^{abcd}	0.114^{abc}
Swastik-2 × NaOH (2%)	0.13^{d}	0.53^{cd}	0.88^{bc}	0.061^{c}	0.088^{abcd}	0.112^{bc}
Swastik-2 × Control	0.35^{ab}	0.58^{abcd}	0.98^{abc}	0.074^{ab}	0.092^{abc}	0.118^{abc}
Mahima (NOH-100) × PEG (5%)	0.37^{ab}	0.77^{a}	1.05^{ab}	0.031^{d}	0.091^{abc}	0.122^{ab}
Mahima (NOH-100) × PEG (10%)	0.31^{abc}	0.75^{ab}	1.08^{a}	0.028^{de}	0.090^{abc}	0.123^{ab}
Mahima (NOH-100) × NaCl (2%)	0.25^{bcd}	0.58^{abcd}	1.05^{ab}	0.024^{de}	0.081^{cdef}	0.121^{ab}
Mahima (NOH-100) × KCL (2%)	0.26^{abcd}	0.67^{abc}	1.04^{ab}	0.025^{de}	0.085^{bcde}	0.120^{abc}
Mahima (NOH-100) × $CuSO_4.5H_2O$ (2%)	0.19^{cd}	0.49^{cd}	0.95^{abc}	0.022^{e}	0.075^{ef}	0.115^{abc}
Mahima (NOH-100) × NaOH (2%)	0.17^{cd}	0.43^{d}	0.86^{c}	0.020^{e}	0.072^{f}	0.109^{c}
Mahima (NOH-100) × Control	0.20^{cd}	0.54^{cd}	1.06^{ab}	0.022^{e}	0.079^{def}	0.122^{ab}
CV %	26.23	16.91	9.00	8.59	6.29	5.01
SEM (±)	0.016	0.019	0.016	0.0009	0.001	0.001
F-test	NS	NS	NS	NS	NS	NS

4. Discussion

The physiology and botany of freshly formed seedlings are influenced by various environmental conditions at each stage of development and germination. Understanding and optimizing the process of seed germination is crucial since it is directly related to plant development and total production. Priming chemical pre-sowing treatments have been thoroughly investigated to improve okra germination, seedling growth, and vigour with the goal of creating robust seedlings that can withstand environmental stress (Khaing et al., 2020). In line with the findings of Sibeko our results demonstrate that seeds treated with PEG solution had the highest percentage of germination parameters (Nomkhosi B et al., 2021). These results were achieved using PEG solutions at concentrations of 5% and 10%, which aligns with our study's outcomes. This agreement suggests that PEG is highly effective in improving germination metrics across different okra varieties. Priming chemicals have also been shown to have positive impacts on several germination metrics, including okra seedling vigour and germination % (Tania et al., 2020).

The genetic variety and differences in the level of priming solutions utilised are probably the causes of these favorable results. Similarly found that different priming techniques, including those applied to Swastik-2 and Mahima (NOH-100) cultivars, resulted in significant improvements in germination metrics (Bereded Sheferie et al., 2023). The Mahima (NOH-100) cultivar performed better than Swastik-2 in our investigation with regard to seed vigour, speed, energy, and germination %. This superior performance can be attributed to Mahima (NOH-100)'s innate genetic features, which may promote quicker and more robust seed growth. Several factors may contribute to these outcomes, including hormonal balances, genetic susceptibility to environmental factors, and seed coat permeability. Mahima (NOH-100)'s adaptability to experimental conditions could also play a crucial role in achieving better germination results. On the other hand, priming with 2% NaOH and 2% CuSO4.5H2O dramatically reduced seed germination, likely due to their harsh chemical compositions.

These treatments possibly exceeded optimal concentrations for priming, hindering seed viability and metabolic functions. Research by supports our findings, demonstrating how priming chemicals may greatly increase the dry and fresh masses of seedlings, plant height, and root length in okra cultivars (Eshkab and Harris et al., 2020). Reduced imbibition time, greater pre-germinative enzyme activation, and improved metabolite synthesis are the reasons for these benefits. Our findings show that Mahima (NOH-100) has better growth potential and is naturally adaptable. During seedling growth, Mahima (NOH-100) consistently outperformed Swastik-2 in shoot length, most likely because of genetic features that support robust shoot development. Additionally, discovered that plant height was dramatically impacted by okra seeds treated with varying amounts of single super phosphate (Shah et al., 2018). In a similar vein, we found that different priming agents had a substantial effect on plant height. Growth metrics were improved in seeds treated with varying doses of PEG solution, mirroring the results observed (Sibeko Nomkhosi et al., 2021).

The adverse effects of CuSO4.5H2O (2%) and NaOH (2%) on shoot and root lengths were consistently observed in our study. These chemicals likely disrupt cellular processes, inhibiting overall seedling growth due to their harsh properties. Our results are consistent with those of who noted that excessive chemical concentrations could hinder seedling development (Shah et al., 2018). Furthermore, some researchers reported significant results in seedling lengths and dry weights for both Swastik-2 and Mahima (NOH-100) varieties (Bereded Sheferie et al., 2023). The highest seedling length in their study was around 11 cm, which is comparable to our results for shoot length at 10 DAS. However, they observed lower seedling dry weights compared to our results, possibly due to differences in priming agents used.

In our study, different concentrations of PEG resulted in the highest fresh and dry weights, highlighting PEG's effectiveness in promoting water absorption and enhancing overall seed germination. Recent studies continue to support our findings. Some researchers for instance, showed that PEG priming greatly increased okra seedling vigour and stress tolerance (Ali et al., 2022). Their study focused on how PEG might improve the physiological and biochemical processes that occur during seed germination. Similarly, by maximizing water intake and metabolic activity, PEG priming had a good impact on the germination and early development of a variety of vegetable seeds, including okra, according to study (Nascimento et al., 2021).

In summary, our research confirms that PEG works well as a priming agent for okra seeds, especially those of the Mahima (NOH-100) type. PEG priming continuously improves seedling vigour, speed, energy, and germination percentage. The overall results highlight the significance of choosing the right priming agents to maximize okra seedling development, even if NaOH and CuSO4.5H2O priming agents were less successful. These insights are valuable for agricultural practices aiming to improve okra cultivation through effective seed priming strategies.

5. Conclusion

Seed priming is a proven technique to enhance germination and early growth in okra, offering a sustainable solution to improve crop productivity. This study demonstrated that priming treatments significantly influence germination and seedling vigor, with the Mahima (NOH-100) variety showing superior performance over Swastik-2. Among the treatments, 5% polyethylene glycol (PEG) proved most effective, achieving the highest germination percentage, speed, energy, and vigor index for Mahima (NOH-100). Sodium chloride (2% NaCl) also showed promise, highlighting the versatility of priming agents. In contrast, 2% sodium hydroxide (NaOH) and 2% copper sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$) were less effective, making them unsuitable for okra priming. The findings emphasize seed priming as an eco-friendly and cost-efficient approach to improving okra crop establishment and growth. Incorporating seed priming into modern agricultural practices can enhance yield potential while promoting resource efficiency. Future research should optimize treatment protocols, including exploring diverse agents, concentrations, and durations. Evaluating mature plant traits, such as yield, pest resistance, and drought tolerance, will provide a deeper understanding of the long-term benefits. Overall, this study highlights seed priming as a valuable and sustainable tool for advancing okra production and supporting environmentally conscious farming.

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