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Effects of Chemical Seed Priming on Seed Germination, Yield and Post-Harvest Quality of Okra (*Abelmoschus esculentus* L. Moench)

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Abstract

The growth of okra (*Abelmoschus esculentus* L. Moench) is often limited by slow and non-uniform germination due to hard seed coats leading to poor stand establishment and yield. Seed priming is a simple and cost-effective technique that can improve the seed germination and the crop yield. This study evaluated five chemical priming treatments viz. hydropriming (dH_2O), salicylic acid (SA, 100 ppm), potassium dihydrogen phosphate (KH_2PO_4, 3%), diammonium phosphate (DAP, 0.5%) and copper sulfate ($CuSO_4 \cdot 5H_2O$, 100 ppm) against an unprimed control on germination, growth, yield and post-harvest quality of okra. Significant differences were observed among primed treatments compared with the unprimed control. Regarding germination, DAP (0.5%) produced the earliest seedling emergence (4.33 days) and highest germination percentage (89.95%), while KH_2PO_4 (3%) recorded the greatest seedling vigor index (939.47) and survival percentage (88.57%). For vegetative growth and yield, DAP (0.5%) promoted the shortest flowering period (36 days) and tallest plant height (106.65 cm), whereas KH_2PO_4 (3%) achieved the longest fruit length (16.65 cm), highest seeds per pod (57.89), and maximum total yield per plant (693.71 g). In terms of post-harvest quality, SA (100 ppm) most effectively minimized weight loss (15.94%) and color deterioration, while KH_2PO_4 (3%) recorded the lowest pod rotting (10.33%) under polyethylene storage over 12 days. Pearson correlation revealed strong positive associations between germination

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percentage and total yield (r = 0.88), while post-harvest deterioration traits were negatively correlated with yield performance. Among the tested treatments, KH_2PO_4 (3%) showed the most consistent overall performance in improving seedling vigor, yield, and post-harvest quality of okra. Therefore, it may be considered the most suitable seed priming treatment under the conditions of this study. However, Profitability analysis should be done before advising widespread adoption by farmers.

Keywords: Diammonium phosphate, Okra, Potassium dihydrogen phosphate, Salicylic acid, Seed priming

Introduction

Okra (*Abelmoschus esculentus* L. Moench), ladyfinger, or bhendi, is a commercially important vegetable crop grown extensively in tropical and subtropical countries, including Bangladesh. (Biswas *et al*., 2016). It belongs to the family Malvaceae and is widely appreciated due to its tender green pods, high nutritional content and economic value. Okra pods contain a lot of dietary fiber, vitamin C, potassium, calcium and antioxidants and also contain essential amino acids like tryptophan and lysine. Okra contains massive quantities of glycans that are responsible for the viscosity of the aqueous suspension (Elkhalifa *et al*., 2021). Okra is a highly perishable vegetable due to its high moisture content (approximately 85%) and rapid respiration rate. These characteristics make the crop susceptible to postharvest deterioration-like quality and yield losses. These attributes render okra very prone to postharvest loses, both quantitative and qualitative. Postharvest losses of fruits and vegetables in Bangladesh have been reported to range from 25–50%, while global losses are estimated at 30–50% (Kaysar *et al*., 2016; Kitinoja and Kader, 2015). So, proper post-harvest management practices are critical in minimizing losses and sustainable production of okra. On the other hand, poor and uneven seed germination of okra can adversely affect seedling establishment and subsequent crop performance. The hard seed coat of okra restricts water absorption, resulting in delayed, uneven and erratic germination. (Barupal *et al*., 2022). Hence, it is important to enhance germination and early seedling vigor to maximize productivity. Seed priming is an effective pre-sowing technique for enhancing seed germination and improving seedling establishment. Seed priming is a controlled hydration process in which seeds are partially soaked to activate the metabolic processes required for germination without allowing radicle emergence. After this treatment, the seeds are re-dried before sowing to ensure proper handling and improved germination performance (Farooq *et al*., 2019). This method increases the rate and uniformity of germination, improves stress tolerance and promotes better seedling emergence under field conditions.

Among the available seed priming techniques, hydropriming is the most widely adopted due to its simplicity, low cost and ease of application. Several studies have reported that hydropriming can improve germination percentage, seedling growth, flowering time, fruit traits and overall yield of okra as well as other vegetable crops (Tania *et al*., 2020). Salicylic acid (SA), a hormone-based priming agent, has also shown promising effects. As a phenolic plant growth regulator, SA is involved in regulating seed germination, photosynthetic efficiency and plant responses to abiotic stress. Previous studies have demonstrated that SA priming can enhance vegetative growth, biochemical attributes and yield performance of okra (Rhaman *et al*., 2021). However, its role in mitigating postharvest losses still require further investigation.

In addition to these approaches, nutrient-based priming using phosphorus-containing compounds such as KH_2PO_4 and diammonium phosphate (DAP) has been reported to significantly improve early seedling establishment and growth (Thakur et al., 2023). Phosphorus plays a central role in plant metabolism, particularly in energy transfer (ATP synthesis), nucleic acid formation and root development (Shah *et al*., 2011). Priming with phosphorus solutions enhances early nutrient availability and promotes better crop establishment even in soils that have sufficient phosphorus (Shafi, 2015). Similarly, micronutrient priming has gained attention, particularly the use of copper sulfate ($CuSO_4$). Copper is an essential micronutrient involved in enzyme activation and oxidative stress regulation (Saboor *et al*., 2019). Low concentrations of copper have been shown to stimulate plant growth, whereas higher concentrations may inhibit root development and induce chlorosis (Bouazizi *et al*., 2010).

While some studies have reported on the effect of each seed-priming agent on germination, growth, yield, and post-harvest quality of okra in the same field environment, there is limited comparative information about the effects of different chemical priming treatments under these conditions. Some priming agents, including salicylic acid and nutrient-based priming compounds, have also been reported to improve postharvest quality by limiting moisture loss, senescence, and microbial deterioration during storage (Siddiqui *et al*., 2014; Kuppusamy & Ranganathan, 2014). Therefore, the present study was conducted to compare the effectiveness of hydropriming, salicylic acid, KH_2PO_4, DAP, and $CuSO_4$ on seed germination, vegetative growth, yield attributes, and post-harvest quality of okra under uniform field conditions.

Materials and Methods

Experimental Site

The experiment was conducted at the Agricultural Research Field of Noakhali Science and Technology University (NSTU), Noakhali, Bangladesh, from March to July 2024. The experimental site is located at approximately 22.79° N latitude and 91.10° E longitude. The study lies within the Young Meghna Estuarine Floodplain (AEZ-18), which is formed from recent alluvial deposits in the Meghna Estuary region (Abdi *et al*., 2024). The topography of the area is predominantly flat, with minor variations in elevation characterized by low swells and shallow depressions. The predominant soils of the area are deep calcareous silt loam and silty clay loam, typically grey to olive-grey in colour. These soils are moderately fertile, with low organic matter content and a moderately high pH.

The climate was tropical monsoon and has a lot of rain. Meteorological data obtained from the Bangladesh Meteorological Department (BMD), Maijdee Court station, indicated a mean temperature of 28.3°C, average relative humidity of 61.1%, and annual rainfall of approximately 3,302 mm during the study period (BMD, 2024).

Soil Sampling and Analysis

Before land preparation, soil samples were collected randomly from different locations across the experimental field at a depth of 0–30 cm. Collected samples were well mixed to obtain a composite sample. The composite soil sample was air-dried, ground, and passed through a 2-mm sieve before analysis. The physico-chemical properties of the soil were determined at the Soil Resource Development Institute (SRDI), Noakhali, Bangladesh. Soil pH and electrical conductivity (EC) were measured by the methods described by Jackson (1973). Organic matter content was estimated using the Walkley and Black method (Walkley & Black, 1934). Total nitrogen (N) was measured using the Kjeldahl method (Bremner & Mulvaney, 1982). Available phosphorus (P) was determined by the Olsen extraction method (Olsen et al., 1954). Exchangeable potassium (K) was extracted using ammonium acetate and quantified with a flame photometer (Black, 1965). Available S and B were analyzed by the turbidimetric and hot water extraction methods, respectively (Page *et al.*, 1982; Gupta, 1967). Table 1 shows the results of soil analysis.

Table 1. Physico-chemical properties of experimental soil prior to sowing

Parameter	Value
pH	8.0
EC (dS m^{-1})	0.34
Organic matter (%)	1.15
Total N (%)	0.06
K (meq 100 g^{-1})	0.22
P (µg g^{-1})	1.40
S (µg g^{-1})	40.9
B (µg g^{-1})	0.47

Planting Materials

The seeds used were okra (cv. Super Shomy), obtained from AR Malik Seeds (Pvt.)

Ltd., with a purity of 98% and a minimum germination rate of 80%. The priming of seeds followed the treatment requirements and occurred over 24 hours before sowing, which took place on 4 March 2024 with a 30 cm plant and 60 cm row spacing.

Experimental Design and Treatments

The design of the experiment was a Randomized Complete Block Design (RCBD) and had three replications. Every replication was divided into six plots of treatment, making a total of 18 plots. Plots were 3 m² (2 m × 1.5 m), and the spacing between plots was 0.5 m.

Six treatments were evaluated:

T1: Control (no priming)

T2: Hydropriming (dH_2O)

T3: Salicylic acid (100 ppm)

T4: KH_2PO_4 (3%)

T5: Diammonium phosphate (0.5%)

T6: $CuSO_4 \cdot 5H_2O$ (100 ppm)

Seeds were primed by immersing them in the solutions for 24 h at room temperature (25 ± 2°C). The priming solutions were made by dissolving salicylic acid (100 mg L^{-1}), KH_2PO_4 (30 g L^{-1}), DAP (5 g L^{-1}), and $CuSO_4 \bullet 5H_2O$ (100 mg L^{-1}) in distilled water. Seeds soaked in distilled water served as the hydropriming treatment. The seeds were taken out of the solutions after priming and shade-dried at room temperature for 24 h to restore their moisture content and allow sowing. The selected concentrations were based on previous studies reporting positive effects on seed germination, seedling vigor, and crop performance in okra and other vegetable crops (Shah *et al*., 2011; Shafi, 2015; Hussein, 2015; Rhaman *et al*., 2021; Thakur *et al*., 2023).

Crop Husbandry

The land was prepared by repeated plowing and harrowing to obtain a fine tilth. The soil clods were broken by hand, and weeds and crop residues were pulled from the field. The experimental area was divided into three blocks as per the experimental design, and drainage channels were made so as to avoid waterlogging. Cow dung, urea, triple super phosphate (TSP), and muriate of potash (MP) were applied based on the recommendations provided in the Fertilizer Recommendation Guide-2018 of the Bangladesh Agricultural Research Council (BARC, 2018) (Table 2). During final land preparation, cow dung, TSP, and half of the required urea and MP were incorporated into the soil. The remaining urea and MP were given in 3 equal doses at 30, 50, and 80 days after sowing (DAS). Soil-borne nematode control was achieved using 20 kg/ha of furadan. Irrigation was made as soon as seed was sown and then applied at 45-day intervals when needed. Gap filling was done with healthy seedlings to ensure a uniform plant population. The field was hand weeded on a regular basis to avoid weeds. Leaf miner infestation was controlled by applying Forwatap 50 SP at 800 g ha^{-1}. Red cotton bug infestation was managed using Nitro 505 EC at 1 mL/L of water, with applications reduced during the flowering stage.

Table 2. Fertilizer doses applied during the experiment

Fertilizer	Land preparation	30 DAS	50 DAS	80 DAS	Total (kg ha^{-1})
Cow dung	10000	–	–	–	10000
Urea	75	25	25	25	150
TSP	100	–	–	–	100
MP	75	25	25	25	150

Data Collection

Three plants were randomly chosen from each of the plots and tagged to record growth and yield data throughout the experimental period. Germination, growth, yield, and post-harvest quality parameters were measured according to standard procedures.

Germination Parameters

Germination observations were recorded daily from sowing until seedling establishment. Days to first emergence were calculated as the days between sowing and the first seedling above the soil surface. Germination percentage was determined following the International Seed Testing Association (ISTA, 2023) rules:

Germination (%) = (Germinated/Total number of seeds sown) x 100

The seedling vigor index (SVI) was determined according to Abdul-Baki and Anderson (1973):

SVI = (Germination percentage x means seedling length) / 100

After establishment, survival percentage was calculated as follows:

(Number of surviving seedlings / Total number of emerged seedlings x 100 = survival rate)

Growth Parameters

Growth parameters measured were days to first flowering, number of nodes at first flowering, plant height, number of branches per plant, and number of leaves per plant. Days to first flowering were recorded as the number of days between sowing and the opening of the first flower. Plant height was measured from the soil surface to the apical growing point at 90 days after sowing (DAS). The number of branches and leaves per plant was counted manually at 90 DAS.

Yield Parameters

During harvest, some yield-related data was taken from the selected plants. The length of the fruit was measured by ruler, and the diameter of the fruit was measured by a digital Vernier caliper. Fruit weight was determined on average using a digital balance. After drying and opening mature fruits, the number of seeds per pod was counted manually. Total yield per plant was defined as the sum of all fruit harvested from a single plant during the harvest period.

Post-Harvest Quality Assessment

Freshly harvested marketable pods were stored under two storage conditions: open storage and polyethylene packaging (30 µm thickness) under ambient laboratory conditions (26.3 ± 1°C and 73 ± 5% relative humidity) for 12 days. Observations were recorded at two-day intervals. The weight loss was measured as the percentage of pod loss from initial weight. The percentage of rot was measured from the equation below:

The percent of rotting = (Number of rotten pods / Total number of pods) × 100

The color change was evaluated in a visual sense on a 1 to 5 scale; 1 = no discoloration; 2 = slight discoloration; 3 = moderate discoloration; 4 = severe discoloration; and 5 = complete loss of marketable green color. These methods have been adopted for post-harvest quality assessment of vegetables and fruits (Siddiqui *et al*., 2014).

Statistical Analysis

All data collected was analyzed using analysis of variance (ANOVA) with a Randomized Complete Block Design (RCBD) on Statistix 10 software (Analytical Software, Tallahassee, FL, USA). Treatment means were compared using Tukey's Honest Significant Difference (HSD) test at the 5% level of significance ($P \leq 0.05$). Mean ± SE is provided. The relationships between germination, growth, yield, and post-harvest quality traits were assessed by Pearson's correlation analysis using treatment mean values.

Results and Discussion

Germination Parameters

Seed priming treatments significantly affected all germination-related traits of okra (Figure 1).

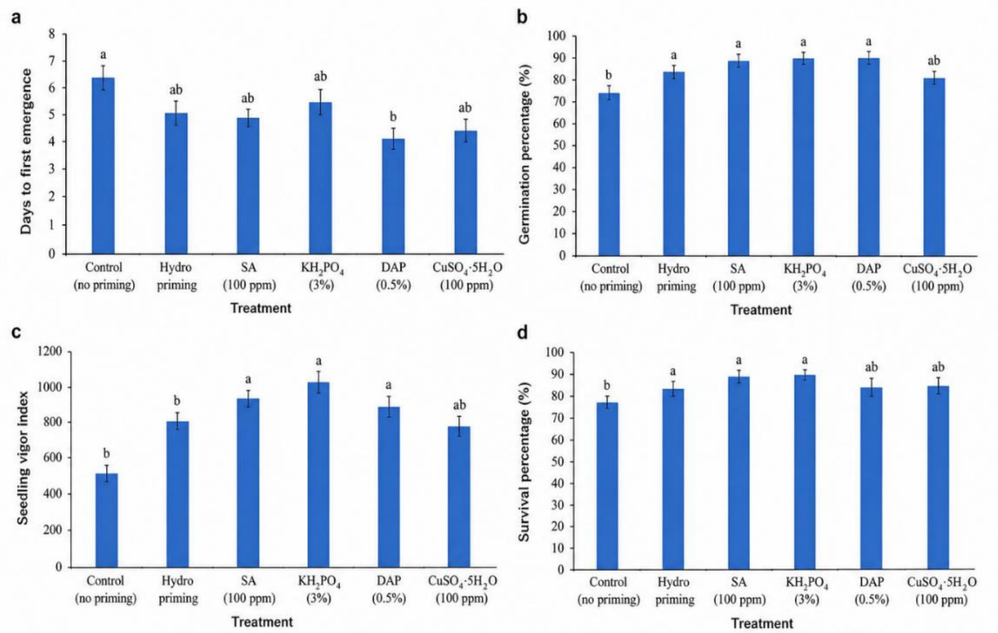

Fig. 1. Effects of different seed priming treatments on germination characteristics of okra: (a) days to first emergence, (b) germination percentage, (c) seedling vigor index, and (d) survival percentage. Values represent treatment means ± standard error (SE) based on three replications. Bars with different letters indicate significant differences among treatments according to Tukey's HSD test at $P \leq 0.05$. Treatments: Control (no priming), Hydropriming, Salicylic acid (SA, 100 ppm), KH_2PO_4 (3%), DAP (0.5%), and $CuSO_4 \cdot 5H_2O$ (100 ppm).

The days to first emergence were significantly different between the treatments ($F = 3.58$, $P = 0.041$). The seeds primed with DAP (0.5%) showed the earliest emergence (4.33 days), while the unprimed seed control showed the longest emergence period (6.67 days). The seeds primed with $CuSO_4 \cdot 5H_2O$ (100 ppm) also emerged quickly (4.67 days), while the emergence of the seeds treated with KH_2PO_4 took 6.00 days (Figure 1a).

The germination percentage was significantly affected by seed priming treatments ($F = 8.14$, $P = 0.003$). The DAP-primed seeds had the highest germination percentage (89.95%), which is 26.12% higher than the control (71.32%). Germination percentages obtained with hydropriming, salicylic acid (100 ppm), and KH_2PO_4 (3%) were statistically comparable to that of DAP, whereas $CuSO_4 \cdot 5H_2O$ (100 ppm) resulted in a moderate germination percentage of 80.02% (Figure 1b).

Seedling vigor index was significantly affected by the priming treatments ($F = 11.25$, $P < 0.001$). The KH_2PO_4 (3%) produced the maximum SVI (939.47), which is 89.9% higher than the control treatment (494.71). Salicylic acid (100 ppm) resulted in the second-highest SVI, indicating a substantial improvement in seedling vigor following seed priming (Figure 1c).

Likewise, the survival percentage varied significantly between treatments (F = 4.80, P = 0.017). The survival rate was highest in the salicylic acid treatment (88.73%) and KH_2PO_4 treatment (88.57%) and lowest in the control (73.97%). Overall, all priming treatments improved seedling survival compared with the untreated control, demonstrating the beneficial effects of seed priming on seedling establishment (Figure 1d).

The improved germination and seedling establishment of the primed seeds is probably related to better metabolic activity, membrane repair, and mobilization of reserves prior to sowing. DAP (0.5%) significantly improved germination, vigor of seedlings, plant height, branching, and early flowering, suggesting that it was more effective in providing nutrients and vegetative growth. The results are similar to those reported earlier on the advantages of nutrient and chemical priming (Shafi, 2015; Hussein, 2015; Khan *et al*., 2023).

Growth Parameters

Seed priming had a significant effect on flowering and vegetative growth parameters of okra plants (Figure 2).

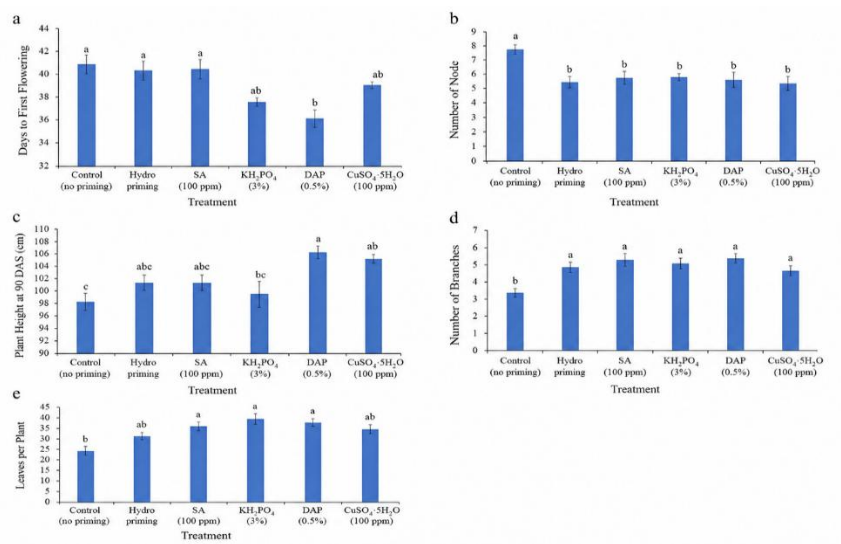

Fig. 2. Effects of different seed priming treatments on growth parameters of okra: (a) days to first flowering, (b) number of nodes at first flowering, (c) plant height at 90 DAS, (d) number of branches per plant at 90 DAS, and (e) number of leaves per plant at 90 DAS. Values represent treatment means ± standard error (SE) based on three replications. Bars with different letters indicate significant differences among treatments according to Tukey's HSD test at $P \leq 0.05$. Treatments: Control (no priming), Hydropriming, Salicylic acid (SA, 100 ppm), KH_2PO_4 (3%), DAP (0.5%), and $CuSO_4 \cdot 5H_2O$ (100 ppm).

Days to first flowering varied significantly among the different treatments (F = 7.75, P = 0.0032). The plants raised from DAP-primed seeds (0.5%) flowered on the earliest, 36 days after sowing, compared to a control treatment that took 41 days. This compared with a 12.2% decrease in time to flowering for the untreated control. The flowering time was also earlier than the control for hydropriming, salicylic acid, KH_2PO_4, and $CuSO_4{\cdot}5H_2O$ treatments (Figure 2a).

The number of nodes at first flowering was significantly affected by seed priming (F=8.62, P=0.0021). The highest number of nodes was observed in the control treatment (7.44), whereas all priming treatments produced significantly fewer nodes at first flowering, ranging from 5.22 to 6.00. Hydropriming (5.22) and $CuSO_4{\cdot}5H_2O$ (5.45) treatments had the lowest values, suggesting that floral initiation occurred at lower nodes (Figure 2b).

Seed priming treatments significantly affected plant height after 90 DAS (F = 6.03; P = 0.0079). The maximum plant height was recorded under the DAP (106.56 cm) treatment, while the minimum plant height was recorded under the control treatment (97.81 cm). The plant height was intermediate for hydropriming and salicylic acid and was not significantly different (Figure 2c).

Seed priming significantly affected the number of branches per plant (F = 14.29, P = 0.0003). DAP produced the maximum number of branches (5.22), which is 62.1% more than the control (3.22). Treatment with salicylic acid, KH_2PO_4, hydropriming, and $CuSO_4{\cdot}5H_2O$ also caused an increase in branch production and was not significantly different from DAP (Figure 2d).

Leaf production was significantly influenced by seed priming at 90 DAS (F = 6.08, P = 0.0077). The KH_2PO_4 treatment had the highest number of leaves per plant with a value of 39.44, followed by DAP (37.78) and salicylic acid (35.56). The control treatment resulted in the lowest leaf count (25.11) (Figure 2e).

In general, DAP (0.5%) was proved to be best for early flowering, plant height, and branch development, while KH_2PO_2 (3%) showed the highest leaf number, suggesting its positive contribution to vegetative growth.

The increased vegetative growth of primed plants could be linked to the uptake of nutrients, improved photosynthetic efficiency, and increased production of assimilate. The earlier flowering and higher plant height of DAP-treated plants indicate higher physiological activity during vegetative growth. Similar improvements in plant growth following seed priming have been reported by Rahman (2016) and Shafi (2015).

Yield Parameters

Seed priming influenced several yield attributes of okra under field conditions (Figure 3).

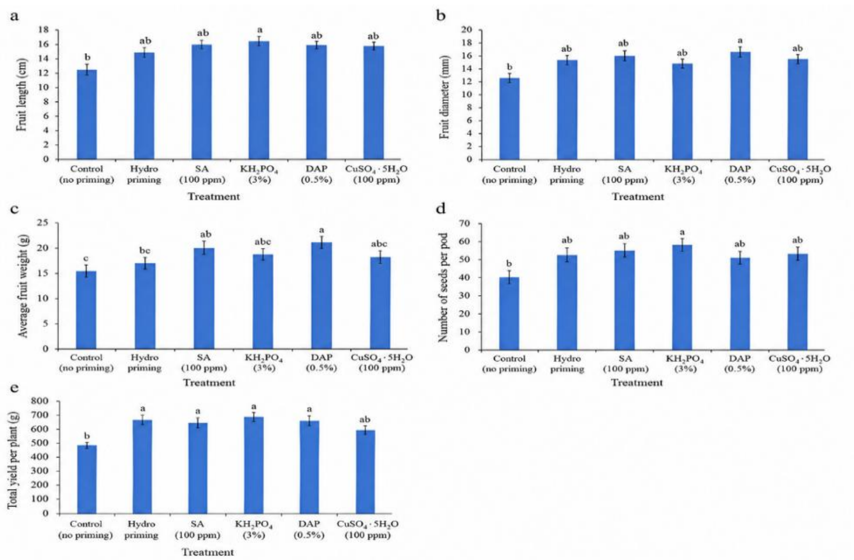

Fig. 3. Effects of different seed priming treatments on yield attributes of okra: (a) fruit length (cm), (b) fruit diameter (mm), (c) average fruit weight (g), (d) number of seeds per pod, and (e) total yield per plant (g). Values represent treatment means ± standard error (SE) based on three replications. Bars with different letters indicate significant differences among treatments according to Tukey's HSD test at $P \leq 0.05$. Treatments: Control (no priming), Hydropriming, Salicylic acid (SA, 100 ppm), KH_2PO_4 (3%), DAP (0.5%), and $CuSO_4 \cdot 5H_2O$ (100 ppm).

Fruit length was significantly different between treatments ($F = 4.10$, $P = 0.0276$). The highest fruit length was observed with KH_2PO_4 (16.65 cm), while the shortest was recorded with the control (13.10 cm). The treatments of hydropriming, salicylic acid, DAP, and $CuSO_4 \cdot 5H_2O$ yielded intermediate fruit lengths and were not significantly different from KH_2PO_4 (Figure 3a).

Fruit diameter showed a numerical increase in response to seed priming; however, the overall treatment effect was not significant at the 5% probability level ($F = 3.13$, $P = 0.0585$). However, DAP recorded the highest fruit diameter of 16.78 mm, while the control recorded the lowest fruit diameter of 12.89 mm (Figure 3b).

Seed priming treatments ($F = 5.60$, $P = 0.0102$) significantly affected the average fruit weight. The highest fruit weight (21.51 g) was achieved from DAP-primed plants and followed by salicylic acid (20.28 g). The lowest fruit weight was recorded in the control (15.44 g), followed by KH_2PO_4 and $CuSO_4 \cdot 5H_2O$ treatments (Figure 3c).

Seed priming generally did not significantly affect seed number per pod at $P \leq 0.05$ ($F = 3.02$, $P = 0.0646$), but the seed number per pod tended to increase after seed priming. KH_2PO_4 produced the highest seed number (57.89 seeds pod^{-1}), whereas the control produced the lowest value (40.33 seeds pod^{-1}) (Figure 3d).

Seed priming significantly enhanced total yield per plant ($F = 9.10$, $P = 0.0017$). The best yield was obtained from KH_2PO_4-primed plants (693.71 g plant^{-1}), followed by hydropriming (674.85 g plant^{-1}), DAP (673.65 g plant^{-1}), and salicylic acid (656.01 g plant^{-1}). The control treatment had the lowest yield (488.10 g plant^{-1}). Although hydropriming, salicylic acid, DAP, and KH_2PO_4 were statistically similar, all substantially outperformed the untreated control (Figure 3e).

DAP increased fruit diameter and fruit weight, and KH_2PO_4 (3%) increased fruit length, seed production, and total yield. This could be due to improved nutrient absorption, root development, and photosynthetic efficiency, leading to higher allocation of assimilates to fruits. This finding is also reported by Adhikari and Shrestha (2020), Khan *et al*. (2021), and Sheferie *et al*. (2023).

Post-Harvest Qualities

Post-harvest quality parameters of okra were significantly affected by different seed priming treatments under both storage conditions (Figure 4).

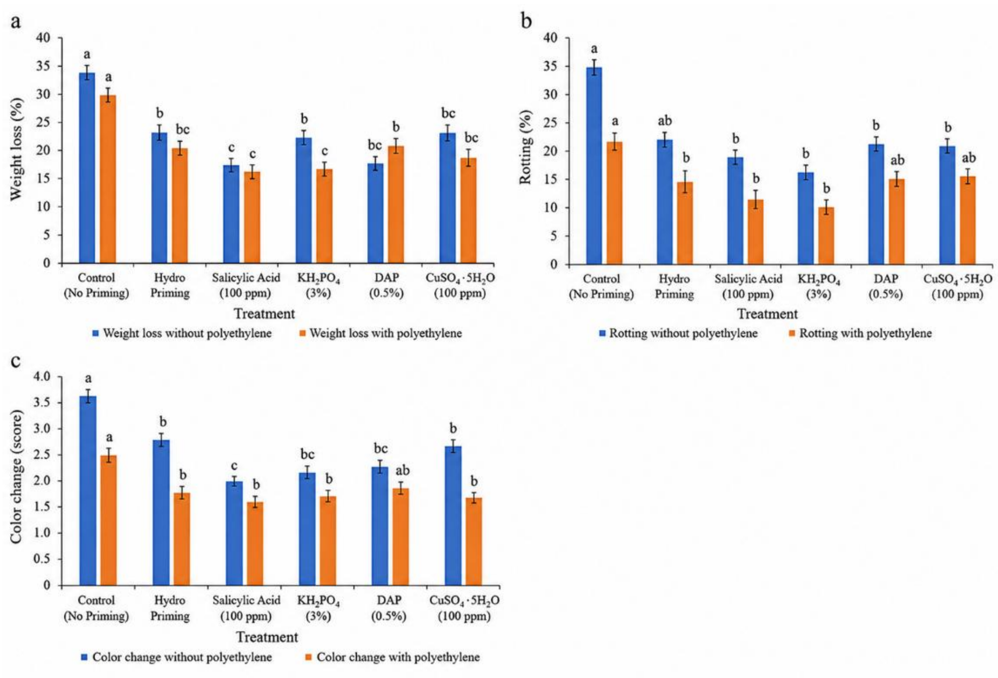

Fig. 4. Effects of different seed priming treatments on post-harvest quality attributes of okra stored under open and polyethylene packaging conditions for 12 days: (a) weight loss (%), (b) rotting (%), and (c) color change score. Values represent treatment means ± standard error (SE) based on three replications. Bars with different letters indicate significant differences among treatments according to Tukey's HSD test at $P \leq 0.05$. Treatments: Control (no priming), Hydropriming, Salicylic acid (SA, 100 ppm), KH_2PO_4 (3%), DAP (0.5%), and $CuSO_4{\cdot}5H_2O$ (100 ppm).

Different seed priming treatments affected post-harvest quality parameters of okra significantly and in both open and polyethylene storage conditions (open storage: $F = 19.44$, $P < 0.001$; polyethylene storage: $F = 36.84$, $P < 0.001$). The data indicate (Figure 4a) that significant differences in percentages of weight loss were found between treatments. The maximum weight loss occurred in the control (T1) (33.68%), and the minimum weight loss occurred in T3 (15.94%), under open conditions of storage. The intermediate values were observed between treatments T2 (23.18%), T4 (22.16%), T5 (17.15%), and T6 (22.90%) but much lower than the control. This trend was also realized in the case of polyethylene storage, where T1 had the most weight loss (29.94%), T3 the least (15.75%), followed by T4 (16.09%), T6 (18.22%), and T2 (19.70). These results suggest that salicylic acid (100 ppm) is effective when reducing the loss of moisture in both storage conditions.

A notable difference in rotting percentage was also observed across treatments (Figure 4b). The highest rotting was observed in T1 (34.67 %) in the open storage, and the lowest rotting was observed in T4 (15.67 %). In the storage of polyethylene, the lowest rotting percent was obtained in T4 (10.33%) and T3 (11.33%), and the highest was obtained in T1 (21.67%). Intermediate rotting was found in treatments T2, T5, and T6 but less than in the control. The outcomes of these experiments are that KH_2PO_4 (3%) and salicylic acid (100 ppm) were helpful in suppressing decay in storage.

Seed priming treatments had a significant influence on color change score (Figure 4c). T1 (3.67) and T3 (2.00) showed the greatest and the least color change during 12 days of open storage, respectively. In polyethylene storage, again T1 (2.53) was the best point in color change; T3 (1.73), T6 (1.73), T2 (1.80), and T4 (1.80) exhibited little color deterioration. All in all, primed treatments were effective in retarding the degradation of color in comparison to unprimed seeds. These findings are a clear indication that post-harvest shelf life and storage quality were enhanced by seed priming, especially through the use of salicylic acid and KH_2PO_4.

Seed priming improved the post-harvest quality by minimizing weight loss, rotting, and color change during storage. However, salicylic acid (100 ppm) was especially effective in pod quality, probably due to the delay of senescence and the enhancement of pod membrane stability. Furthermore, polyethylene packaging caused less open-storage loss. These findings agree with previous studies on the role of salicylic acid in extending shelf life and preserving quality (Siddiqui *et al*., 2014; Rokaya *et al*., 2016).

Correlation Analysis among Studied Traits

Pearson's correlation analysis was conducted between treatment mean values ($n = 6$) to determine the correlation values related to germination, growth, yield, and post-harvest quality traits (Table 3). The results are based on treatment means, not experimental observations, and should therefore be viewed with caution.

Several growth and yield traits exhibited strong positive associations. Germination percentage was highly correlated with the height of the plants (r = 0.82) and productivity/plant (r = 0.88), suggesting that the better the germination and establishment of the crop, the better the productivity. Average fruit weight (r = 0.85) and total yield per plant (r = 0.91) were positively correlated with plant height, emphasizing the effect of vegetative growth on yield. Average fruit weight was most correlated with total yield (r = 0.94), indicating that fruit biomass was a larger factor in yield variability than fruit size. Fruit diameter was also strongly correlated with average fruit weight (r = 0.89).

Growth and yield, however, were negatively correlated with post-harvest deterioration traits. Total yield per plant was negatively correlated with weight loss under open storage conditions at a moderate level (r= −0.70). Likewise, negative correlations were found between rotting percentage and germination percentage (r= −0.65) and plant height (r= −0.60). From these results, it can be concluded that treatments that resulted in vigorous plant growth and increased production also generally led to increases in post-harvest stability.

The overall correlation analysis shows that better germination and vegetative growth were closely related to yield performance and better crop vigor to reduced post-harvest losses and storage quality.

Table 3. Pearson correlation coefficients among selected traits (based on treatment means, n= 6)

Trait	Germ %	Plant Height	Fruit Weight	Total Yield	Weight Loss	Rotting %
Germination %	1	0.82*	0.79ns	0.88*	-0.63ns	-0.65ns
Plant Height	0.82*	1	0.85*	0.91*	-0.58ns	-0.60ns
Fruit Weight	0.79ns	0.85*	1	0.94**	-0.55ns	-0.57ns
Total Yield	0.88*	0.91*	0.94**	1	-0.70ns	-0.68ns
Weight Loss	-0.63ns	-0.58ns	-0.55ns	-0.70ns	1	0.81*
Rotting %	-0.65ns	-0.60ns	-0.57ns	-0.68ns	0.81*	1

Significance levels: $P \leq 0.05$; $P \leq 0.01$; ns = not significant. Correlation analysis was performed using treatment means (n = 6); therefore, the results should be interpreted with caution due to the limited sample size.

The significant positive correlation among germination, growth, and yield traits was observed. Correlation between germination percentage and plant height ($r = 0.82$, $P \leq 0.05$) and total yield ($r = 0.88$, $P \leq 0.05$) showed a positive relationship between better germination and productivity. Plant height was positively associated with fruit weight ($r = 0.85$, $P \leq 0.05$) and total yield ($r = 0.91$, $P \leq 0.05$). The strongest correlation was observed between fruit weight and total yield ($r = 0.94$, $P \leq 0.01$), highlighting fruit biomass as a key determinant of yield. Rotting percentage was positively related to weight loss ($r = 0.81$, $P \leq 0.05$), which indicated that moisture loss is a factor in postharvest deterioration. In general, better germination and vegetative growth correlated with higher production and superior post-harvest performance.

Conclusion

This study demonstrates that seed priming is an effective strategy to improve germination, plant growth, yield characteristics and post-harvest quality of okra. All priming treatments performed better than the untreated control, which confirms the importance of seed physiological conditioning in improving overall crop performance. Among the tested treatments, DAP (0.5%) was most effective in promoting rapid emergence, high germination and vigorous vegetative growth, whereas KH_2PO_4 (3%) produced the highest seedling vigor, yield and seed production. Salicylic acid (100 ppm) was particularly effective in minimizing post-harvest weight loss, reducing quality deterioration and extending storage life. Taken together, these results highlight seed priming as a simple technology for improving okra production and post-harvest quality. Further studies across different growing environments are needed to validate the consistency of these benefits in various agro-ecological settings.

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