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INFLUENCE OF SEED PRIMING AGENTS ON GERMINATION AND EARLY SEEDLING GROWTH OF OKRA (*ABELMOSCHUS ESCULENTUS*)

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Abstract

An experiment was conducted at the laboratory of Plant Physiology Section of Horticulture Research Centre, Bangladesh Agricultural Research Institute during two consecutive years 2023 and 2024 (from 8 May to 16 May 2023 and 6 May to 15 May 2024) to investigate the effect of different priming agents on seed germination and early seedling growth of okra. The experiment was laid out in a completely randomized design with three replications. The treatments consisted of two okra varieties, namely BARI Dheros-2 and OK1820, and 11 priming agents *viz*., unprimed control, DH_2O (distilled water), 150 ppm GA_3 (gibberellic acid), 200 ppm GA_3, 40 ppm SA (salicylic acid), 50 ppm SA, 0.25% KNO_3 (potassium nitrate), 0.50% KNO_3, 40 mM H_2O_2 (hydrogen peroxide), 100 ppm HA (humic acid) and 200 ppm HA. Seed germination percentage, T_{50} (time required for 50% germination) value, speed of germination and germination value were enhanced significantly in both the varieties of okra at 40 mM H_2O_2 followed by 200 ppm HA and distilled water. Seedling growth expressed by seedling length and seedling dry weight, and seedling vigour (seedling vigour index-I and seedling vigour index-II) were also increased at 40 mM H_2O_2, 200 ppm HA and distilled water. Therefore, it was concluded that for obtaining better germination and vigorous seedlings in okra the seeds may be soaked in either 40 mM H_2O_2 or 200 ppm HA or distilled water for 18 hours

Keywords: Okra, *Abelmoschus esculentus*, seed priming, germination, growth, seedling vigour.

Introduction

Lady's finger or okra [(*Abelmoschus esculentus* (Moench)], a nutritious vegetable of the family Malvaceae, is popularly known as 'dheros'/'bhendi' in Bangladesh. It is also called 'bhindi' in India and Pakistan. It is one of the most significant vegetable crops which are grown throughout the tropical, subtropical and temperate region of the world. The immature, young green seed pods are the edible part which are consumed as vegetable. The fresh okra fruit consists of water 90.19%, energy 33 Kcal, carbohydrate 7.45 g, protein 2 g, fat 0.19g, dietary fiber 1.48 g, Ca 82 mg, Mg 57 mg, Fe 0.62 mg, Zn 0.58 mg, K 299 mg, vitamin A 36

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ug, thiamine 0.2 mg, riboflavin 0.06 mg, niacin 1 mg, ascorbic acid 23 mg, vitamin E 0.2 mg, vitamin K 31.3 ug per 100g fresh weight of edible portion (Kumar *et al*., 2013).

Okra seeds germinate very slowly and unevenly in the field though the seeds are viable. Poor, reduced, delayed, and erratic emergence is a serious problem in okra cultivation which is caused by seed hardness (Barupal *et al.,* 2022; Poudel *et al*., 2015). The hard seed coat restricts the water imbibition, and thus germination, uniform growth and development of the embryo are hindered. (Mohammadi *et al*., 2011). Chan *et al*. (2018) observed that limited permeability can be detrimental as it leads to non-uniform germination. Hard seed coat is reported as the major reason for okra seed dormancy that interferes with seed germination (Mohammadi *et al*., 2011). Seed priming is considered as a solution to the okra hard seed coat-related low germination issue (Thakur *et al*., 2023).

Seed germination is very crucial among all growth stages because low germination rate lowers the population density per unit area that ultimately reduced the yield (Rahman *et al*., 2020). Seed germination is a complex process involves three main phases such as water imbibition, activation of physiological processes and gene expression, and radicle emergence (Tuan *et al*., 2019). Water uptake by cytoplasmic compounds and macromolecules hydrolysis occurs in initial 24 h that triggers the ATP and protein synthesis followed by radicle emergence after 48 to 72 h of imbibition (Carrera-Castaño *et al*., 2020).

Seed priming is the process of controlled hydration of seeds which is potentially able to promote rapid and more uniform seed germination and plant growth. Dawood (2018) opined that priming is a controlled process of soaking seeds in water or a low osmotic potential solution and drying them to a stage where germination processes are initiated, allowing early seedling growth under various conditions, but without radicle protrusion. Seed priming is a simple, inexpensive, and effective method for synchronized germination and early seedling growth. It increases the speed of germination and seedling vigor by overcoming dormancy, and better stand establishment under stressful and stress-free environmental conditions (Ventura *et al*., 2012; Parella *et al*.,2015; Hussein, 2015).

Priming allows some of the metabolic processes necessary for germination to occur. Seed priming induced synchronized germination, increased seed vigor, and growth of seedlings under stressful conditions (Bajehbaj, 2010). Different seed priming methods have been used to enhance germination and seed vigor of okra. Among them, hydro-priming, hormonal priming, osmo-priming, halo-priming, etc. are commonly used seed priming methods. Accelerated germination, seed growth, and uniform field establishment can be achieved through priming (Yadav *et al*., 2012). Sheferie (2023) used gibberellic acid and tap water as seed hormonal and hydro-priming agents for improving germination and germination parameters in okra seed. Lamichhanea *et al*. (2024) obtained the maximum germination percentage using150 ppm GA_3. Cowpea seedling emergence and field establishment were enhanced by hydropriming and sodium chloride (NaCl) priming (Eskandari and Kazemi, 2011). Hussein (2015) used salicylic acid for priming okra seeds. Rehman *et al*. (2024) reported that seed priming with 50 mM of KNO_3 can be an effective strategy to improve germination in okra. Ebrahim and Miri (2016) used 30 g l^{-1} humic acid (60%) as seed priming agent to obtain the highest germination rate. Despite the benefits of priming are well documented for uniform and smooth germination, the practice has not yet been widely accepted by the farmers in Bangladesh. This is because there is no easily available and affordable priming agent in the common market. Keeping the above facts in view, the present investigation was conducted to study the effect of various priming treatments on overcoming the germination hindrance of okra seeds.

Materials and Methods

The present investigation was conducted under natural conditions in the laboratory of Plant Physiology Section of Horticulture Research Centre (HRC), Bangladesh Agricultural Research Institute (BARI) during two consecutive years of 2023 and 2024 (in May for 10 days each year) to evaluate the effects of priming agents on germination, germination properties and early seedling growth in okra. The seeds of BARI Dheros-2 and OK1820 were obtained from Olericulture Division of HRC and bought from local market, respectively. The study consisted of two okra varieties namely, V_1 = BARI Dheros-2 and V_2 = OK1820 and eleven priming treatments *viz*., T_0 = unprimed control, T_1 = DH_2O (Hydropriming), T_2 =150 ppm GA_3, T_3 = 200 ppm GA_3, T_4 = 40 ppm SA (salicylic acid), T_5 = 50 ppm SA, T_6 = 0.25% KNO_3, T_7 = 0.50% KNO_3, T_8 = 40 mM Hydrogen Peroxide (H_2O_2), T_9 = 100 ppm HA (humic acid, as potassium humate), T_{10} = 200 ppm HA. The priming of seeds was done in the lab at 35±2℃ for 18 hours.

Required number of healthy seeds for each variety (20× 3×11; about 50 g) totaling about 100 g was counted based on two varieties, 11 treatments and 3 replications. Considering each variety and replication total seeds were divided into 11 groups. All seeds were sterilized with 0.1 % Hg_2Cl_2 for 5 min. Then the sterilized seeds were washed well with distilled water to remove the chemicals adhered to seed surface. The sterilized seeds were dried in shade for 30 min. Then, except one group (for unprimed control), 10 groups of seeds were soaked for 18 hrs (Khan *et al*., 2023) in the respective priming solutions prepared by dissolving calculated amount of priming chemicals in the required amount of distilled water. The ratio of seed weight to solution volume (w/v) was 1:5. After 18 hours, the primed seeds were washed with water for 3-4 times and dried in shade at 35±2℃ until the moisture content was decreased to initial moisture content (20%). Required number of petri dishes, each with a diameter of 9 cm were used in the experiment and arranged in a completely randomized design (CRD) moistened with respective treatment in three replications. Three layers of commercial tissue paper were used in each Petri dish for retaining required amount of water for imbibition of seeds. Twenty equal sized seeds of each variety were selected and placed on sterilized Petri dish lined with filter paper on 8 May 2023 and 6 May 2024. The pert dishes with seeds of the selected varieties of okra were kept in normal room temperature (35±2 ℃) for germination.

The 5 ml of prime solutions were added separately in the petri dishes. For unprimed control, 5 ml distilled water was added to the Petri dishes. The Petri dishes were covered with glass cover to prevent the loss of moisture by evaporation. The respective priming solutions and distilled water (for unprimed control) were added to the Petri dishes when required. Number of seeds germinated was counted daily and data recording were continued up to 10 days. On 10^{th} day, 10 seedlings (shoot + root) were weighed by the electrical balance and this weight was considered as fresh weight (g) of seedling, and these seedlings (air dried for 01 day) were kept in an oven at 72^0c for 02 days (48 hrs) for recording dry weight (mg) of seedling. On 10^{th} day of each year, the shoot and the root length of ten randomly selected seedlings from each replicate were measured. Seeds were considered germinated upon emergence of radicles (≥ 2 mm) (Sharma and Sharma, 2010). From these germination counts, several germination attributes were calculated such as germination percentage (GP), days required for 50% germination (T_{50}), speed of germination (SoG), germination value (GV) by different formulae proposed by different authors and scientists given below:

Germination percentage

Germination percentage was calculated from the daily counted seeds (ISTA, 2014) give as follows:

Germination percentage (GP) = (No. of seeds germinated/Total No. of seeds placed in petridish) × 100

T_{50} (Time to 50 percent germination): It was the time required to achieve 50% of final/maximum germination (Coolbear *et al*., 1984).

$$T50 = ti + [(N/2 - ni)\ (tj - ti)]/\ (nj - ni)$$

Where, T_{50} is the median germination time (time to 50% germination), N is the final number of germinated seeds and n_i and n_j are the total number of seeds germinated in adjacent counts at time t_i and t_j, respectively, when where $n_i<N/2<n_j$

Speed of Germination:

The number of germinated seeds was counted every two days until the end of the germination test. An index was calculated by dividing the number of seeds that germinated each day by the number of days that were in the petri dish (Sahib *et al*., 2014).

Speed of Germination: $N1/\,C1\ +\ N2/\,C2 + \ldots + NF/\,CF$

Where N1 (number of germinated seeds at first count), N2 (Number of germinated seeds at the second count), Nf (number of germinated seeds at the final count), C1 (days to first count), C2 (days to the second count), and Cf (days to the final count).

Germination value (GV): It was calculated as (Djavanshir and Pourbeik, 1976)

$$GV\ =\ \Sigma DGS/N\ \times (GP\ \times 10)$$

Where GV is germination value, DGS is daily germination speed which is computed by dividing cumulative germination percent by the number of days since beginning the test.

Seedling Vigour Index: The seedling vigour index I and seedling vigour index-II was calculated as per the method prescribed by Abdul-Baki and Anderson (1973) and expressed in whole number.

Seeding vigor index I: It was calculated as follows:

$$Seedling\ vigor\ index\ I = Germination\ percentage\ (\%)\ \times\ seedling\ length\ (cm)$$

Seedling Vigor Index II*:* It was calculated as follows:

$$Seedling\ vigor\ index\ II = Germination\ percentage\ \times\ seedling\ dry\ weight\ (g)$$

The data of both 2023 and 2024 with pooled analyses on germination per cent (GP), speed of germination (SoG), germination value (GV), total seedling length, seedling dry weight and seedling vigour index-I, seedling vigour index-II were subjected to one-way analysis of variance (ANOVA) to establish the significance of differences between the treatments ($p \leq 0.05$) by Tukey HSD test using MSTATC software.

Results and Discussion

Germination Percentage

Seed germination percentage is the measure of how many seeds in a batch successfully sprout into healthy seedlings, indicating their viability and potential for successful planting under ideal conditions. Germination percentage was significantly influenced by the different priming agents (Table 1). The maximum germination percentage was recorded when seeds were primed with 40 mM H_2O_2 (98.87% in 2023, 97.79% in 2024 with pooled mean 98.33% in BARI Dhereos-2 and 94.01% in 2023, 95.33% in 2024 with pooled mean 94.67% in OK1820) closely followed by 100 ppm HA (92.98% in 2023, 93.68% in 2024 with pooled mean 93.33% in BARI Dhereos-2 and 89.99% in2023, 92.67% in 2024 with pooled mean 91.33% in OK1820) , 200 ppm HA (93.35% in 2023, 93.31% in 2024 with pooled mean 93.33% in BARI Dheros-2 and 94.01% in 2023, 93.33% in 2024 with pooled mean 93.67% in OK1820) and hydropriming (85.0% in 2023, 95.00% in 2024 with pooled mean 90.00% in OK1820) and the lowest germination percentage was obtained from 0.50% KNO_3 (62.54% in 2023, 60.80% in 2024 and pooled 61.67% in BARI Dhereos-2 and 53.22% in 2023, 50.12% in 2024 with pooled 51.57% in OK1820) which was almost identical with unprimed control (69.52% in2023, 71.14% in 2024 with pooled 70.33% in BARI Dheros-2 and 70.01% in 2023, 72.23% in 224 with pooled 71.12% in OK1820) (Table 1). After HA, hydropriming with distilled water showed better results in respect of germination percentage and in both the varieties, hydro-priming gave higher per cent germination than unprimed control.

It is presumed that H_2O_2 e helped increase okra seed germination by acting as a signaling molecule that helps to break seed dormancy, improve oxygen bioavailability. Rehman *et al*. (2024) reported that increased seed germination may be attributed to KNO_3 which acted as a nutrient source, a signaling molecule, and an osmotic agent that breaks dormancy and activates essential metabolic processes. Hussein (2015) opined that salicylic acid (SA) may boost okra germination by acting as a signaling molecule that activates protective responses, repairing cellular damage (like DNA/RNA), improving water uptake, and regulating key enzymes, leading to faster, more uniform germination and helps overcome seed dormancy and hard seed coats, kickstarting metabolic processes crucial for germination. Hydropriming may increase okra germination due to hydropriming which helped overcome its hard seed coat, allowing controlled water intake that activates pre-germinative metabolism (like enzyme activity) without the radical emerging, thus speeding up and synchronizing germination (Sheferie, 2023).

The results for germination obtained from hydropriming corroborate the results of Khan *et al.* (2023) who obtained maximum germination percentage through hydropriming by distilled water in okra for 18 hrs. The results of H_2O_2 are in partial agreement with Alam *et al.* (2024) who obtained maximum per cent germination 2% H_2O_2 primed seeds in okra. The results of DH_2O, 0.5% NaCl, 0.5% KNO_3 and 100 ppm GA_3 are in consonance with Thapa *et al*. (2025) in okra. The results of HA were in agreement with Hussein (2015) who obtained the highest germination % (98%) from 100 ppm SA primed seeds of okra.

Table 1. Effect of different priming agents on seedling length of two okra varieties

Treatment	Germination Percent					
	BARI Dheros-2			OK1820		
	2023	2024	Pooled	2023	2024	Pooled
T_0	69.52cd	71.14c	70.33b	70.01d	72.23f	71.12b
T_1	85.00ab	95.00a	90.00a	87.12ab	89.54a-d	88.33a
T_2	91.12a	85.54abc	88.33a	85.02abc	84.98b-e	85.00a
T_3	87.41ab	85.93abc	86.67a	86.56abc	86.78a-e	86.67a
T_4	84.58abc	85.42abc	85.00a	79.67bcd	80.33def	80.00a
T_5	89.68ab	90.32ab	90.00a	86.01abc	87.33a-e	86.67a
T_6	75.89bcd	77.45b	76.67ab	75.67cd	77.67ef	76.67ab
T_7	62.54d	60.80d	61.67b	53.22e	50.12g	51.67c
T_8	98.87a	97.79a	98.33a	94.01a	95.33a	94.67a
T_9	92.98a	93.68a	93.33a	89.99ab	92.67ab	91.33a
T_{10}	93.35a	93.31a	93.33a	94.01a	93.33ab	93.67a
CV (%)	8.54	9.65	9.00	8.96	8.59	7.23

Figures within a column, having different letter (s) do not differ significantly at $P<0.05$ by Tukey W test. T_0 (unprimed control), T_1 (Hydropriming), T_2 (150 ppm GA_3), T_3 (200 ppm GA_3), T_4 (40 ppm SA), T_5 (50 ppm SA), T_6 (0.25% KNO_3), T_7 (0.50% KNO_3), T_8 (40 mM H_2O_2), T_9 (100 ppm HA), T_{10} (200 ppm HA); GA_3 = Gibberellic Acid, SA = salicylic Acid, HA = Humic Acid

Time required for 50% germination (T_{50})

Time required for 50% Germination (T_{50}), essentially measuring the speed of germination, not just the final percentage. It indicates how quickly seeds start sprouting under specific conditions (like temperature), with a lower T_{50} suggesting faster germination, making it vital for assessing seedling vigor and predicting crop establishment. T_{50} value was significantly affected by different priming agents (Table 2). The lowest T_{50} value was obtained from 200 ppm GA_3 (2.50 days in 2023, 2.58 days in 2024 with pooled 2.54 days) which was statistically similar to 40 mM H_2O_2 (2.49 days in 2023, 2.61 days in 2024 with pooled 2.55 days) in case of BARI Dheros-2, whereas in case of OK1820, the lowest T_{50} value was obtained from 50 ppm SA (3.50 days in 2023, 3.56 days in 2024 with pooled 3.53 days) closely followed by all treatments except control (3.96 days in 2023, 4.02 days in 2024 with pooled 3.99 days) and 0.50% KNO_3 (pooled 3.66 days of 2023 and 2024). In case of BARI Dheros-2, all priming agents performed better except control (3.31 days in 2023, 3.27 days in 2024 with pooled 3.29 days) and 50 ppm SA (2.71 days in 2023, 2.73 days in 2024 with pooled 2.72 days) with regard to T_{50} value.

Table 2. Effect of different priming agents on time to 50% germination of two okra varieties

Treatment	Time to 50% germination (T_{50})					
	BARI Dheros-2			OK1820		
	2023	2024	Pooled	2023	2024	Pooled
T_0	3.31a	3.27a	3.29a	3.96a	4.02a	3.99a
T_1	2.50cd	2.82b	2.66bc	3.47cd	3.63bc	3.55bc
T_2	2.55cd	2.57d	2.56bc	3.56bc	3.52d	3.54 bc
T_3	2.50cd	2.58d	2.54c	3.56bc	3.52d	3.54bc
T_4	2.65bc	2.59d	2.62 bc	3.44d	3.68b	3.56bc
T_5	2.71b	2.73bc	2.72b	3.50cd	3.56cd	3.53c
T_6	2.58bcd	2.54d	2.56bc	3.56bc	3.54cd	3.55bc
T_7	2.65bc	2.53d	2.59bc	3.64b	3.68b	3.66a
T_8	2.49d	2.61cd	2.55c	3.54bcd	3.56cd	3.55bc
T_9	2.57bcd	2.55d	2.56bc	3.51cd	3.57c	3.54bc
T_{10}	2.64bc	2.54d	2.59bc	3.56bc	3.54cd	3.55bc
CV (%)	2.30	2.14	2.18	2.59	2.58	2.57

Figures within a column, having different letter (s) do not differ significantly at $P<0.05$ by Tukey W test. T_0 (unprimed control), T_1 (Hydropriming), T_2 (150 ppm GA_3), T_3 (200 ppm GA_3), T_4 (40 ppm SA), T_5 (50 ppm SA), T_6 (0.25% KNO_3), T_7 (0.50% KNO_3), T_8 (40 mM H_2O_2), T_9 (100 ppm HA), T_{10} (200 ppm HA); GA_3 = Gibberellic Acid, SA = salicylic Acid, HA = Humic Acid

Hydropriming of okra seeds leads to a decrease in the T_{50} value because the process accelerates the initial metabolic events of germination, leading to faster and more uniform sprouting of seedlings. Potassium nitrate (KNO_3) treatment may help to decrease T_{50} value because it accelerates the metabolic processes required for germination. The decrease in T_{50} value means faster and more uniform germination. Hydrogen peroxide may cause a decrease in the T_{50} value in okra because it acts as a signaling molecule that promotes germination by enhancing oxygen supply to the embryo and breaking dormancy. Salicylic acid treatment might accelerate okra seed germination by influencing several physiological and biochemical processes. Khan *et al.* (2023) obtained T_{50} value through hydropriming by distilled water in okra for 18 hrs. Mauro *et al.* (2020) obtained a notable decrease in average germination time from KNO_3 (0.75 %) seed priming

Speed of germination (SoG)

The speed of germination (SoG) refers to how quickly seeds sprout after planting under favorable conditions. It is essentially a measure of the time it takes for a seed to begin the growth process, typically by an index that combines the number of germinated seeds and the time taken. SoG was significantly influenced by different

Table 3. Effect of priming agents on speed of germination and germination value of two okra varieties

Treatment	Speed of germination						Germination value					
	BARI Dheros-2			OK1820			BARI Dheros-2			OK1820		
	2023	2024	pooled	2023	2024	pooled	2023	2024	pooled	2023	2024	pooled
T_0	5.15de	4.55ef	4.85bc	3.75c	3.69cd	3.72b	85.69f	94.73e	90.21b	95.79d	98.23ef	97.01b
T_1	5.75bc	5.45cd	5.60ab	4.25abc	4.37abc	4.31ab	145.25de	149.19cd	147.22ab	132.40abc	120.58cde	126.49ab
T_2	5.69bcd	5.81bc	5.75ab	4.15abc	4.19a-d	4.17ab	170.21bcd	167.09bc	168.65ab	118.15bcd	120.25cde	119.20ab
T_3	5.78abc	5.56c	5.67ab	4.23abc	4.29a-d	4.26ab	164.54bcd	166.42bc	165.48ab	124.75abc	122.87bcd	123.81ab
T_4	5.37cde	5.45cd	5.41abc	3.98bc	3.86bcd	3.92ab	150.12cde	149.28cd	149.70ab	108.39cd	100.25def	104.32ab
T_5	5.43cde	5.65c	5.54abc	4.25abc	4.31a-d	4.28ab	148.21cde	147.33cd	147.77ab	124.46abc	128.52abc	126.49ab
T_6	4.93e	5.01de	4.97abc	3.87bc	3.65d	3.76b	126.54e	124.26d	125.40ab	97.51d	95.65f	96.58b
T_7	3.98f	4.06f	4.02c	1.08d	0.98d	1.033c	89.25f	85.36e	87.303b	55.02e	58.54g	56.783c
T_8	6.34a	6.50a	6.42a	4.72a	4.68a	4.70a	212.25a	209.17a	210.71a	146.85a	148.23a	147.54a
T_9	6.02ab	6.10ab	6.06ab	4.52ab	4.46ab	4.49ab	184.56ab	186.86ab	185.71a	137.24ab	135.54abc	136.39ab
T_{10}	6.02ab	5.98abc	6.00ab	4.54ab	4.66a	4.60a	176.59c	180.55ab	178.57a	143.38ab	145.62ab	144.50a
CV (%)	5.65	5.74	9.64	6.74	7.01	7.11	10.51	9.87	13.54	12.04	11.53	13.94

Figures within a column, having different letter (s) do not differ significantly at $P<0.05$ by Tukey W test. T_0 (unprimed control), T_1 (Hydropriming), T_2 (150 ppm GA_3), T_3 (200 ppm GA_3), T_4 (40 ppm SA), T_5 (50 ppm SA), T_6 (0.25% KNO_3), T_7 (0.50% KNO_3), T_8 (40 mM H_2O_2), T_9 (100 ppm HA), T_{10} (200 ppm HA); GA_3 = Gibberellic Acid, SA = salicylic Acid, HA = Humic Acid.

priming agents (Table 3). In BARI Dheros-2, priming with 40 mM H_2O_2 gave maximum values of SoG (6.34 in 2023, 6.50 in 2024 with pooled 6.42) which were statistically similar to other priming treatments except 0.50% KNO_3 (3.98 in 2023, 4.06 in 2024 with pooled mean 4.02) and unprimed control (5.15 in 2023, 4.55 in 2024 with pooled 4.85) (Table 3). In Okra1820, the maximum SoG was recorded from 40 mM H_2O_2 (4.72 in 2023, 4.68 in 2024 with pooled 4.70) identical with all other priming treatments except 0.50% KNO_3 (1.08 in 2023, 0.98 in 2024 with pooled mean 1.033) and control (3.75 in 2023, 3.69 in 2024 with pooled 3.72). The lowest SoG was recorded from 0.50% KNO_3 followed by control.

Hydropriming may speed up okra germination by initiating key metabolic processes like enzyme activation and food reserve mobilization, softening the hard seed coat, and preparing the embryo for rapid emergence, overcoming the natural delays caused by okra's tough seed coat and leading to faster, more uniform seedling growth and establishment. This controlled hydration activates systems that break dormancy and energize the seed, essentially giving it a head start. Hydrogen peroxide may increase the speed of okra seed germination by acting as a signaling molecule that helps break seed dormancy, enhancing metabolic activity, and providing crucial oxygen to the embryo. Potassium nitrate priming might increase the speed of okra germination primarily by breaking seed dormancy and activating key metabolic processes through several mechanisms such as hormonal regulation, improving water uptake, enhancing metabolic activities viz., DNA replication, RNA and protein synthesis, and greater ATP (energy) availability (Rehman *et al*., 2024). Alam *et al.* (2024) obtained speed of germination by using 2% H_2O_2 in okra. Hussein (2015) obtained the highest germination speed index (47.6) from 100 ppm SA primed seeds of Okra.

Germination value (GV)

Germination value (GV) is a single-value index that combines both the speed and the completeness (total percentage) of seed germination. It is used to provide a comprehensive measure of a seed lot's overall quality and vigor. A higher germination value indicates that a seed lot has a high total percentage of viable seeds and that those seeds germinate quickly and uniformly over time. Different priming agents significantly affected germination value (Table 3). In BARI Dheros-2, the highest GV (212.25 in 2023, 209.17 in 2024 with pooled 210.71) was observed from 40 mM H_2O_2 which was statistically similar to 100 ppm HA (184.56 in 2023, 186.86 in 2024 with pooled 185.71), 200 ppm HA (176.59 in 2023, 180.55 in 2024 with pooled 178.57) and other priming treatments except 0.50% KNO_3 (89.25 in 2023, 85.36 in 2024 with pooled 87.30) and control (85.69 in 2023, 94.73 in 2024 with pooled 90.21). In OK1820, the maximum GV was obtained from 40 mM H_2O_2 (146.85 in 2023, 148.23 in 2024 with pooled 147.54) closely followed by 200 ppm HA (143.38 in 2023, 145.62 in 2024 with pooled

144.50) and other treatments except 0.50% KNO_3 (55.02 in 2023, 58.54 in 2024 with pooled 56.78) and control (95.79 in 2023, 98.23 in 2024 with pooled 97.01). The lowest GV value was recorded from 0.50% KNO_3 which was statistically similar to control (Table 3).

Hydropriming may increase the germination value (GV) of okra seeds by initiating crucial pre-germinative metabolic processes, which leads to faster and more uniform seedling growth and other mechanism such as protein synthesis, DNA repair, and ATP generation, upgrade imbibition, enhanced enzyme activation, improved membrane integrity and breaking dormancy (Tania *et al*., 2020). Maximum germination value was attributed to H_2O_2 treatment which acted as a signaling molecule that breaks seed dormancy, improves metabolic activity, enhances antioxidant capacity, and provides extra oxygen (Ellouzi *et al*., 2021). Potassium nitrate may increase the germination value (GV) in okra by acting as a nutrient and a signaling molecule that breaks seed dormancy, enhances water uptake, regulates hormones, and improves antioxidant defenses (Rehman *et al*., 2024). Negi *et al*. (2024) used the germination parameter 'germination value (GV) to evaluate the seeds of *Oroxylum indicum* collected from four different sources in India. Geethanjali *et al*. (2025) reported that GA_3 @ 750 ppm (among 500, 600 ppm and 750 ppm GA_3) recorded highest germination value.

Table 4. Effect of different priming agents on seedling length of two okra varieties

Treatment	Seedling length (cm)					
	BARI Dheros-2			OK1820		
	2023	2024	Pooled	2023	2024	Pooled
T_0	1.46g	1.50h	1.48f	5.65c	5.49bc	5.57b
T_1	12.45a	11.87a	12.16a	9.95ab	9.99a	9.97a
T_2	2.74f	2.50g	2.62f	5.21cd	4.35d	478b
T_3	2.06fg	2.36g	2.21f	4.90cd	4.94c	4.92b
T_4	4.08e	4.14f	4.11e	4.82cd	4.76cd	4.79b
T_5	6.02d	5.90e	5.96d	4.18d	4.24d	4.21b
T_6	9.87c	9.79c	9.83c	1.35e	1.43e	1.39c
T_7	6.70d	6.74d	6.72d	1.20e	1.16e	1.18c
T_8	11.54ab	11.42ab	11.48ab	10.54a	10.40a	10.47a
T_9	10.82bc	10.88b	10.85bc	6.10c	6.30b	6.20b
T_{10}	11.62ab	11.50ab	11.56ab	9.15ab	9.33a	9.24a
CV (%)	6.84	7.25	8.87	8.89	9.52	9.12

Figures within a column, having different letter (s) do not differ significantly at $P<0.05$ by Tukey W test. T_0 (unprimed control), T_1 (Hydropriming), T_2 (150 ppm GA_3), T_3 (200 ppm GA_3), T_4 (40 ppm SA), T_5 (50 ppm SA), T_6 (0.25% KNO_3), T_7 (0.50% KNO_3), T_8 (40 mM H_2O_2), T_9 (100 ppm HA), T_{10} (200 ppm HA); GA_3 = Gibberellic Acid, SA = salicylic Acid, HA = Humic Acid.

Seedling length

Seedling length was significantly influenced by different priming agents (Table 4). In BARI Dheros-2, the highest seedling length was recorded from hydro-priming (12.45 cm in2023, 11.87 cm in 2024 with pooled 12.16 cm) identical with 40 mM H_2O_2 (11.54 cm in 2023, 11.42 cm in 2024 with pooled 11.48 cm) and 200 ppm HA (11.62 cm in 2023, 11.50 cm in 2024 with pooled 11.56 cm) and unprimed control gave the lowest seedling length (1.46 cm in 2023, 1.50 cm in 2024 with pooled 1.48 cm) (Fig. 4). In OK1820, priming with 40 mM H_2O_2 gave the maximum seedling length (10.54 cm in 2023, 10.40 cm in 2024 with pooled 10.47 cm) which was statistically similar to hydro-priming (9.95 cm in 2023, 9.99 cm in 2024 with pooled mean 9.97 cm) and 200 ppm HA (9.15 cm in 2023, 933 cm in 2024 with pooled mean 9.24 cm) and the lowest seedling recorded from 0.50% KNO_3 (1.20 cm in 2023, 1.16 cm in 2024 with pooled 1.18 cm) closely followed by 0.25% KNO_3 (1.35 cm in 2023, 1.43 cm in 2024 with pooled 1.39 cm). Hydrogen peroxide might increase okra seedling length because, at appropriate low concentrations it acts as a signaling molecule that breaks seed dormancy, strengthens the antioxidant system, and promotes vital early growth processes (Badsha *et al*., 2022). Okra seedling length increase was attributed to potassium nitrate application that supplies two essential nutrients, nitrogen (N) and potassium (K), which work together to promote cell division, cell elongation, and overall robust vegetative growth. Results are supported by the results of Geethanjali *et al*. (2025) who obtained highest plumule length, radicle length in *Lisianthus using* GA_3 @ 750 ppm (among 500 and 600 ppm GA_3) and 0.3% KNO_3, Karta *and Abebie* (2012) who obtained the highest shoot length, root length from 0.155 M KNO_3 and 0.310 M KNO_3 in *Vicia villosa.* Ebrahim and Miri (2016) who obtained the highest radical length in *Borago officinalis* and *Cichorium intybus* from 15-30 g/l HA and Hussein (2015) who found maximum shoot length (18 cm) and root length (11 cm), seedling length (29 cm), using 100 ppm SA in okra.

Seedling dry weight

Seedling dry weight was significantly influenced by different priming agents (Table 5). In BARI Dheros-2, maximum seedling dry weight was observed in 40 mM H_2O_2 (35.21 mg in 2023, 35.59 mg in 2024 with pooled 35.40 mg) closely followed by hydro-priming (30.29 mg in 2023, 30.51 mg in 2 024 with pooled30.40 mg), 150 ppm GA_3 (30.20 mg in 2023, 30.06 mg in 2024 with pooled mean 30.13 mg), 40 ppm SA (30.74 mg in 2023, 30.86 mg in 2024 with pooled 30.80 mg) and its minimum value was obtained when seeds were primed with 200 ppm GA_3 (1654 mg in 2023, 16.40 mg in 2024 with pooled 16.47 mg) (Table 5). In OK1820, maximum seedling dry weight was observed in 40 mM H_2O_2 (35.45 mg in 2023, 35.73 mg in 2024 with pooled 35.59 mg) which was identical with 200 ppm HA (35.68 mg in 2023, 35.30 mg in 2024 with pooled mean of 35.49 mg) and other priming treatments control (20.42 mg in 2023, 20.24 mg in 2024 with pooled 20.33 mg). Hydropriming may help increase okra seedling length by accelerating the metabolic processes required for germination and promoting cell division and elongation during early growth. The increased okra seedling dry weight may be attributed to hydropriming which helped accelerate the seed's metabolic activity, enhancing enzyme function, and promoting the rapid development of an efficient root and shoot system. This improved vigor allows the plant to accumulate more biomass compared to unprimed seeds. Hydrogen peroxide may enhance nutrient and water uptake, increased antioxidant activity, activation of growth-related genes/proteins, improved histological components that improve the plant's physiological efficiency and support greater dry weight accumulation. Essentially, the right concentration of H_2O_2 might help seedling to grow more vigorously by optimizing its metabolic and defensive functions, leading to a more robust plant with higher dry weight. Potassium nitrate may increase okra seedling dry weight primarily by supplying two essential nutrients, nitrogen (N) and potassium (K), which play critical roles in core plant physiological processes like water regulation, and protein synthesis and increase seedling length.

Khan *et al.* (2023) obtained maximum seedling dry weight through hydropriming by distilled water in okra for 18 hrs. Results of seedling growth are in line with Dursan *et al.* (2002) who obtained better seedling growth using 100-200 ppm HA in both eggplant and tomato. With regard to seedling dry weight, the present experimental results are in partial agreement with Debbarma *et al*. (2018) who reported that hydropriming and GA_3 (50 ppm) priming in bitter gourd. Results are supported by the results of Geethanjali *et al*. (2025) who obtained highest seedling dry weight in *Lisianthus using* GA_3 @ 750 ppm (among 500 and 600 ppm GA_3) and 0.3% KNO_3, Karta *and Abebie* (2012) who obtained the highest seedling dry weight from 0.155 M KNO_3 and 0.310 M KNO_3 in *Vicia villosa*, Ebrahim and Miri (2016) who obtained the highest radical length in *Borago officinalis* and *Cichorium intybus* from 15-30 g/l HA and Hussein (2015) who found maximum seedling fresh weight (0.9988g) and seedling dry weight (0.0603 g) using 100 ppm SA in okra.

Table 5. Effect of different priming agents on seedling length of two okra varieties

Treatment	Seedling dry weight (mg)					
	BARI Dheros-2			OK1820		
	2023	2024	Pooled	2023	2024	Pooled
T_0	24.01b	24.31bc	24.16bc	20.42e	20.24b	20.33b
T_1	30.29ab	30.51ab	30.40ab	27.68a-e	28.20ab	27.94ab
T_2	30.20ab	30.06ab	30.13ab	21.21e	20.91b	21.06ab
T_3	16.54c	16.40c	16.47bc	23.21e	23.45b	23.33ab
T_4	30.74ab	30.86ab	30.80ab	24.36de	24.56b	24.46ab
T_5	24.05b	24.21bc	24.13bc	33.87a-d	34.13a	34.00a
T_6	24.38b	24.42bc	24.40abc	34.12abc	34.00a	34.06a
T_7	23.32b	23.48bc	23.40bc	28.36a-e	28.18ab	28.27b
T_8	35.21a	35.59a	35.40a	35.45ab	35.73a	35.59a
T_9	25.98b	26.16b	26.07abc	28.85a-e	29.15ab	29.00ab
T_{10}	29.02ab	29.24ab	29.13ab	35.68a	35.30a	35.49a
CV (%)	6.54	8.85	6.42	7.56	8.87	8.56

Figures within a column, having different letter (s) do not differ significantly at $P<0.05$ by Tukey W test. T_0 (unprimed control), T_1 (Hydropriming), T_2 (150 ppm GA_3), T_3 (200 ppm GA_3), T_4 (40 ppm SA), T_5 (50 ppm SA), T_6 (0.25% KNO_3), T_7 (0.50% KNO_3), T_8 (40 mM H_2O_2), T_9 (100 ppm HA), T_{10} (200 ppm HA); GA_3 = Gibberellic Acid, SA = salicylic Acid, HA = Humic Acid

Seedling vigour

Seedling vigour was presented by two indexes *viz.*, Seedling Vigour Index-I and Seedling Vigour Index-II (Table 6). Seedling Vigour Index-I (SVI-I) is a crucial measure of seed quality, showing how well seeds not only sprout but also develop strong, long seedlings, indicating good overall performance for planting. It's a way to see a seed lot has strong growth potential beyond just germination, helping farmers choose seeds for better crop establishment. Whereas, Seedling Vigour Index-II (SVI-II) is a key measure of seed quality providing a strong indicator of a seed's ability to produce strong, healthy, high-biomass seedlings, reflecting its stored food reserves and overall performance potential beyond just germination.

Maximum seedling vigour index-I was recorded from 40 mM H_2O_2 (1128.3 in BARI Dheros-2 and 956.83 in OK1820) closely followed by 200 ppm HA (1078.2 in BARI Dheros-2 and 847.63 in OK 1820) and hydropriming (1095.6 in BARI Dheros-2 and 883.1 in OK1820). In BARI Dheros-2, the lowest seedling vigour index-I was noted from control (130.82) closely followed by T_3 and T_2. The highest seedling vigour index-II was recorded from 40 mM H_2O_2 (3.48) closely followed by hydropriming (2.74) and 200 ppm HA (2.72) and the lowest value was obtained

Table 6. Effect of priming agents on seedling vigour index-I and seedling vigour index-II of two okra varieties

Treatment	Seedling Vigour Index I						Seedling Vigour Index II					
	BARI Dheros-2			OK1820			BARI Dheros-2			OK1820		
	2023	2024	pooled	2023	2024	pooled	2023	2024	pooled	2023	2024	pooled
T_0	154.65f	106.99g	130.82e	395.56e	572.80c	484.18b	1.67de	1.73def	1.70de	1.68de	1.50e	1.59d
T_1	1058.25a	1132.95a	1095.60a	866.84b	899.36a	883.10a	2.57bc	2.90ab	2.74ab	2.41bcd	2.53bcd	2.47ab
T_2	249.67e	212.07f	230.87de	442.95d	370.29f	406.62b	2.75ab	2.57bc	2.66b	1.80cde	1.78de	1.79d
T_3	209.06ef	231.24f	220.15de	424.14de	426.60d	425.37b	1.45e	1.41e	1.43e	2.01cde	2.03cde	2.02bc
T_4	345.09d	359.71e	352.40cd	384.01f	395.25de	389.63b	2.60bc	2.64c	2.62b	1.94cde	1.97cde	1.96c
T_5	539.87c	532.87d	536.37c	359.52f	371.74ef	365.63b	2.16b-e	2.19b-e	2.17b-e	2.91ab	2.98ab	2.95ab
T_6	749.03b	752.57c	750.80b	102.15g	112.11g	107.13c	1.85cde	1.89c-f	1.87cde	2.58ab	2.64abc	2.61ab
T_7	419.02d	411.64e	415.33c	63.86g	57.68h	60.77d	1.46e	1.43ef	1.44e	1.51e	1.41e	1.46e
T_8	1140.96a	1115.64a	1128.30a	990.87a	922.79a	956.83a	3.46a	3.50a	3.48a	3.33a	3.41a	3.37a
T_9	1006.04a	1014.16b	1010.10a	548.94c	605.92c	577.43b	2.42bcd	2.45bcd	2.43bcd	2.60abc	2.70abc	2.65bc
T_{10}	1084.73a	1071.67ab	1078.20a	860.19b	835.07b	847.63ab	2.71abc	2.73ab	2.72ab	3.35a	3.29ab	3.32a
CV (%)	7.89	7.87	6.85	7.41	7.56	6.95	7.45	5.87	6.25	9.92	8.95	8.54

Figures within a column, having different letter (s) do not differ significantly at $P<0.05$ by Tukey W test. T_0 (unprimed control), T_1 (Hydropriming), T_2 (150 ppm GA_3), T_3 (200 ppm GA_3), T_4 (40 ppm SA), T_5 (50 ppm SA), T_6 (0.25% KNO_3), T_7 (0.50% KNO_3), T_8 (40 mM H_2O_2), T_9 (100 ppm HA), T_{10} (200 ppm HA); GA_3 = Gibberellic Acid, SA = salicylic Acid, HA = Humic Acid.

from 200 ppm GA_3 (1.43) being identical with 0.50% KNO_3 (1.44) in BARI Dheros-2. Whereas, in OK1820, the maximum seedling vigour index-II was fond in 40 mM H_2O_2 (3.37) closely followed by 200 ppm HA (3.32), and its lowes value was noticed in 0.50% KNO_3 (0.94). Hydropriming might boost okra seedling vigor by initiating pre-germination metabolic processes, activating DNA repair, strengthening antioxidants, and breaking seed dormancy from hard coats, leading to faster, more uniform germination, quicker water uptake, and robust root/shoot growth, ultimately improving crop establishment and yield, especially under stress (Tania *et al*., 2020). Maximum seedling vigour was attributed to hydrogen peroxide treatment (priming) that helped increase okra seedling vigour by acting as a signaling molecule that breaks seed dormancy, improves the mobilization of stored nutrients, and enhances the antioxidant defense system of the plant (Ellouzi *et al*., 2021). Potassium nitrate may increase seedling vigour in okra by acting as both an essential nutrient and a vital signaling molecule, can improve early growth by accelerating metabolic activities, enhancing water uptake, modulating hormone level.

Results of seedling vigour index-I was supported by by Alam *et al.* (2024) using 2% H_2O_2, Khan *et al.* (2023) through hydropriming in okra for 18 hrs, Karta and Abebie. (2012) from 0.155 M KNO_3 and 0.310 M KNO_3 in *Vicia villosa,* Ebrahim and Miri (2016) in *Borago officinalis* and *Cichorium intybus* from 15-30 g/l HA, and Hussein (2015) using 100 ppm SA in okra. Results of seedling vigour index-II corroborate the results of Debbarma *et al*. (2018) who obtained best results from hydropriming and GA_3 (50 ppm) priming for 12 hours in bitter gourd and Karta and Abebie (2012) who obtained maximum seedling vigour index-II using KNO_3.

Conclusion

The results of the experiment revealed that H_2O_2, humic acid and distilled water were found to be the most important priming agents to increase seed germination, germination speed, seedling length and seedling dry weight and seedling vigour index. It is suggested that prior to sowing seeds of okra, okra seeds should be soaked in either 40 mM H_2O_2 or 200 ppm HA or distilled water for 18 hours to obtain better germination and vigourous seedlings by overcoming poor and erratic germination due to the presence of hard seed coat.

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