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ORIGINAL RESEARCH ARTICLE

Seed priming and GA_3 field application enhanced growth, yield and postharvest quality of okra

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ABSTRACT

Highly nutritive and antioxidants-enriched okra (*Abelmoschus esculentus*) gets sub-optimal field yield due to the irregular germination coupled with non-synchronized harvests. Hence, the research aimed at assessing the combined impact of seed priming and field-level gibberellic acid (GA_3) foliar spray on the yield and post-harvest quality of okra. The lab studies were conducted using a complete randomized design (CRD), while the field trials were performed following a factorial randomized complete block design (RCBD) with three replications. Okra seeds were subjected to ten different priming methods to assess their impact on seed germination and seeding vigor. In the premier step, okra seeds were subjected to ten different priming methods, like hydro priming for 6, 12, and 18 h, halo priming with 3% NaCl at 35 °C, 45 °C, and 60 °C, acid priming with 80% H_2SO_4 for 2.5, 5, and 10 min. Based on the observation, hydro priming for 12 h exhibited the best germination rate (90%), followed by halo seed priming at 60 °C and acid priming for 5 min. Furthermore, the halo priming at 60 °C demonstrated the greatest seedling vigor index (1965), whereas acid priming for 5 min resulted in favorable outcomes in terms of early emergence in 2.66 days. In addition, varying concentrations of GA_3 (0, 100, 200, and 300 ppm) were also administered to the best three primed seedlings for evaluating their field performance. The findings indicated that applying GA_3 at a concentration of 300 ppm to seedlings raised through acid priming (80% H_2SO_4 for 5 min) resulted in improved leaf length, reduced time to flowering (first and 50%) and harvest, increased pod diameter, individual pod weight, and yield per plant (735.16 g). Additionally, the treatment involving GA_3 at 300 ppm with halo priming (3% NaCl) at 60 °C exhibited the longest shelf life (21 days) of okra with the lowest levels of rotting (6.73%) and color change (1.12) in the polyethylene storage condition.

Keywords: germination index; plant growth regulator; postharvest quality; seed priming; vegetables

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1. Introduction

Vegetables are the key suppliers of vitamins, minerals, and phytochemicals for humans. In the tropical and sub-tropical weather conditions of the south Asian countries, vegetables grow in plenty during the short winter, while the summer months are the dearth period for vegetables[1]. Okra (*Abelmoschus esculentus*), belonging to the *Malvaceae* family, is one of the important summer vegetables of south Asian countries, including Nepal and Bangladesh[2]. Consumption of young, immature okra pods is as important as fresh fruits, and it can be consumed in different forms as well. Fruits can be boiled, fried, or cooked[3]. Often, the extract obtained from the fruit is added to different recipes like soup, stews, and sauces to increase the consistency[4–6]. The green immature pods or fruits of okra contain proteins, fats, carbohydrates, β-carotene, vitamins (B1, B2, and B6), niacin, and vitamin C, as well as calcium and iron, which are beneficial in moderating blood pressure, fibrinogen concentration, and plasma viscosity in hypertension[7,8]. Okra originated in east Africa, quite possibly in Ethiopia[9] but its cultivation is widely distributed to the tropics and subtropics. In Nepal, the total production of okra was 122,101.60 MT under an area of 10,781.40 ha[10], whereas Bangladesh produced 55905 MT of okra from 11,539.86 ha of land in the year of 2019–2020[11]. However, the actual yield of okra in Nepal (11.33 t/ha) is far behind the different countries of the world (53.3 t/ha in Guyana, 36.36 t/ha in Senegal). Improper and irregular germination is one of the main problems that consequently hampers the growth, yield, and yield attributes of okra. In general, certified okra (*Abelmoschus esculentus* var. *Arka anamika*) seeds have a 75% germination rate. But at the field level, the germination percentage and productivity potential were not fully achieved. Germination percentage of okra seed was 61.79% only under controlled conditions[12].

Usually, the presence of hard and water impermeable seed coat and embryo dormancy have made the natural regeneration of some crops very difficult for farmers[13]. Okra seeds also have a slightly impermeable seed coat that leads to non-uniform germination in relatively longer time, even at optimum soil moisture and temperature. Seed priming is a very promising, efficient, and low-cost approach to increasing the germination, growth, and the productive capability of crops[14]. Furthermore, it can improve primary seedling vigor, especially under adverse conditions[15]. Several studies have been conducted on priming seeds to improve the germination rate and uniformity of growth, thereby reducing the emergence time of many horticultural and agricultural crops[16]. Germination percentage of okra increases up to 92.79% when seed is soaked in hot water[12] and 2% KNO_3 gives superior results in germination and seedling parameters in tomato[17]. However, previous research findings were not found to be fully satisfactory at ground level, especially at the experimental sites. In addition, plant growth, development, yield, and post-harvest qualities of okra after seed priming are still unnoticed. Okra plants at the field level also bear flowers and fruits non-homogenously, leading to an inefficient harvest index[18]. At the same time, farmers are also struggling to increase crop yield[19]. Therefore, an alternative means to address the existing problems has merits.

Moreover, plant growth regulators (PGRs) stimulate or retard the natural growth regulatory systems from germination to senescence in plants[20]. Foliar spray of growth regulator has been found effective in increasing vegetative growth, early and uniform fruiting, total yield, and quality of numerous vegetables[21,22]. In the market, the most felicitous PGR is GA_3 among the available PGR_s, which induces stem and internode elongation, fruit setting, and growth[23]. Growth parameters like number of branches per plant, number of fruits per plant, fruit yield per plant, etc. were found maximum on GA_3 sprayed okra plants compared to control[24]. Similarly, it was also revealed that the highest fruit length, fruit diameter, and weight were achieved with foliar application of 200 ppm GA_3 compared to lower concentrations of GA_3 (25, 50, and 100 ppm) in pointed gourd[23]. Meanwhile, okra is an indeterminate type of plant where vegetative and reproductive growth overlap and irregular flowering and fruit setting occur, which leads to improper harvest[24]. In addition, post-harvest storage of okra is also not free from problems. Low post harvest shelf life, weight loss, color change, low overall quality, etc. are the common problems associated with it. Fresh okra deteriorates quickly during storage due to tenderness and a high respiration rate[1]. Packaging and controlled atmosphere (CA) storage have been somewhat successful in extending okra shelf life[25] while the highest shelf life was experienced in GA_3 treated China aster[26]. GA_3 treatment was also found to maintain chlorophyll content during storage[27]. Priming can improve plant health to produce properly filled grain, thereby retaining superior seed quality in storage[28]. Numbers of research have been conducted to extend the shelf life of fruits and vegetables; however, impoverished people belonging to rural areas are still struggling to keep okra pods for a longer time. In this regard, GA_3 might be effective to enhance optimum vegetative flourishment and promote uniform flowering and fruiting that will further facilitate labor intensive harvest and improve the edible quality and postharvest storage life of okra. Therefore, the objectives of the study were to select suitable priming techniques for okra for maintaining better germination and seedling growth as well as to explore the combine effects of seed priming and GA_3 field application on growth, yield, yield attributes, and storage quality of okra.

2. Materials and methods

2.1. Plant materials and study location

Commercially famous variety of okra (*Ablemoschus esculaentus* var. *Arka anamika*, Pokhara seed) was collected from the local market and used as study materials. Seed germination experiment and post-harvest quality analysis were performed at room condition in the Black Diamond Agro Farm, Nepal, whereas the field experiment was carried out at the farmer's field in Pokhara-29 Naubise, Kaski, Nepal. The study area is located at 84.05º N Latitude and 48.16º E longitude with an elevation of 679 m above the sea level. The average temperature and RH of the study area during seed germination were recorded as 24.53 °C and 65.99%, respectively, whereas it was 25.73 °C and 64.93%, respectively during post-harvest study. Field experimental site was known for hot and partly cloudy summers where heavy rainfall prevailed during the months of June to September. Growing media for raising okra seedlings was made mixing peat moss and soil in 2:1 proportion. The soil of the experiment field was sandy loam within 50 cm from the surface with pH 5.90. The chemical composition of the soil was organic matter (2.82%), NO_3^- (0.14%), P_4O_5 (331.40 kg/ha) and K_2O (223 kg/ha).

2.2. Seed priming influence on germination and seedling growth of okra

2.2.1. Seed priming treatments

The priming experiment consisted of 10 treatments; in each treatment 50 okra seeds were subjected for priming. The treatments of the experiment were viz. hydro priming for 6 h (T_1), hydro priming for 12 h (T_2), hydro priming for 18 h (T_3), halo priming with 3% NaCl at 35 °C for 40 min (T_4), halo priming with 3% NaCl at 45 °C for 40 min (T_5), halo priming with 3% NaCl at 60 °C for 40 min (T_6), acid priming with H_2SO_4 (80%) for 2.5 min (T_7), acid priming with H_2SO_4 (80%) for 5 min (T_8), acid priming with H_2SO_4 (80%) for 10 min (T_9) and no priming or control (T_{10}). Completely randomized design (CRD) with three replications was followed during the study.

2.2.2. Priming procedure

In order to priming okra seeds T_1, T_2, and T_3 treatments were simply maintained in the separate beakers, whereas T_4, T_5, and T_6 treatments were performed in a water bath (DXY digital thermostat water bath) to maintain a constant temperature. 80% H_2SO_4 was prepared by the dilution of concentrated H_2SO_4 and the treatments T_7, T_8, and T_9 were performed in the separate beakers. Hydro-primed and halo-primed seeds were directly air dried whereas acid-primed seeds were rinsed with tap water then air dried. The treated seeds were kept inside the incubator chamber at the Black Diamond Agro Farm, Kaski Nepal. The same amount of seeds was also used for germination test without any priming as control treatment (T_{10}). Trays were irrigated regularly to maintain the optimum moisture for germination.

2.2.3. Data collection on seedling growth

Differently treated seeds were sown on different plastic trays filled with growing media (peat moss + soil) at a depth of 1 cm. Seedlings data were collected from each treatment by following both destructive testing (DT) as well as non-destructive testing (NDT) techniques. Number of days required to emergence was determined as the first appearance of seedling plumule above the soil media in the trays. While germination speed index (GSI) and seedling vigor index (SVI) were assessed using the following equation (Equation (1)) proposed by Farooq[29].

$$GSI = \frac{N1}{T1} + \frac{N1 + N2}{T2} + \cdots + \frac{N1 + N2 + \cdots + NK}{TK} \quad (1)$$

where,

N1, N2, N3, … , NK: Number of germinated seeds observed

T1, T2, T3, … , TK: Specific number of germinated seed at the specific time

K: Time intervals

SVI = Standard germination (%) × Seedling length (cm)

2.2.4. Seedling transplanting

Several trays of the best three priming treatments as well as control were again set-up in the same condition to grow a large quantity of seedlings for transplanting to the main field. Seedlings grown on trays which had three sets of true leaves were transplanted to the main field on 30 May 2021 in the late afternoon. Immediately after transplanting, light irrigation was given for their speedy adaptation. Remaining seedlings were kept in farm condition and used for gap filling. All the intercultural operations like irrigation, fertilization, weeding etc. were the same and cared faithfully to maintain their vigor.

2.3. Field performance of okra influenced by seed priming and GA_3

2.3.1. Treatments and layout

Upon the evaluation of seed priming efficiency on seedling emergence and vigor, a second study was performed by applying three different concentrations of GA_3 (G_1–100 ppm, G_2–200 ppm, G_3–300 ppm) to the standing okra plants those developed from the three best priming treatments (T_2-hydro priming for 12 h; T_6-halo priming at 3% NaCl at 60 °C; T_8-acid priming at 80% H_2SO_4 for 5 min) selected from the study findings-I and compared with control (no priming and no GA_3 applied). Therefore, the latter field experiment was comprised of sixteen treatment interactions which were laid out in a factorial randomized complete block design (RCBD) with three replications. A total of sixteen plots of 2.88 m^2 in size (2.4 m × 1.2 m) were prepared in three blocks. One meter distance was maintained between blocks, whereas 60 cm was set for line to line and 30 cm for plant to plant in each block. Based on layout, sixteen primed seedlings as well as non-primed seedlings (control) were maintained in each plot for each treatment. Here, GA_3 were sprayed twice at 15 days after transplanting (DAT) and 30 DAT.

2.3.2. GA_3 preparation and foliar application

Gibberellic acid is not soluble in water directly therefore, at first, weighed GA_3 (1000 mg) was dissolved in 10 mL sodium hydroxide (NaOH) solution. Prepared GA_3 solution was again diluted in the distilled water (990 mL) to get 1000 ppm stock solution. 100, 200, and 300 ppm GA_3 solutions were prepared from the stock solution by using the following formula[30] (Equation (2)). Different concentrations of GA3 solution were filled up in hand sprayer (KCI 85506504) separately. During daytime, two consecutive spraying (15 June and 1 July 2021) were applied on plants based on research design and layout. Plants leaves were sprayed on both sides.

$$V1N1 = V2N2 \quad (2)$$

where,

V_1: Volume of stock solution to be taken

N_1: Concentration of stock solution available

V_2: Volume of ultimate solution to be made

N_2: Concentration of ultimate solution

2.3.3. Data collection on plant growth and yield contributing characters

Five plants from each plot were selected and tagged for data collection. Fruits were harvested manually and sample pods were kept in polythene bags with tagging for further study. Plant height (cm), number of branches and leaves per plant and leaf length (cm) were measured at 90 DAT. Number of days required to the first flowering, 50% flowering and harvest were counted and recorded. Number of nodes before the first flower was also noted. Pods were harvested as green immature as noted by Rahman et al.[1]. Immediately after harvest, pod length was measured from the pod harvested at 30 DAT. Centimeter scale was used to measure the pod length. From stalk end to the pod tip was measured to record the data on pod. Pod diameter was measured from the pods of 1st harvest by average value of base diameter, intermediate diameter and apical diameter of mature okra pods measured by vernier caliper. Each fresh pod from the 1st harvest was weighed in the weighing balance. The average weight was recorded as the individual pod weight for further analysis. The number of seeds per pod of the selected plants was recorded separately at first and calculated to get an average number of seeds per pod. Sample pods from each treatment were rinsed with clean tap water then air dried. One gram of dried fresh okra was taken and crushed in mortar and pistil together with 1 mL of distilled water to produce juice. To record TSS percentage, 2 drops of juice were placed on the prism of aichose refractometer (COMINHKPR124469) and looked through the eyepiece to record the data. Separately, okra pods from the selected plants were weighed on each harvest; after the last harvest, total weight was calculated to determine the yield per plant.

2.3.4. Data collection on post-harvest qualities

Pods from different treatments were harvested at optimum maturity stage and stored with or without polyethylene (30 µm) packaging at atmospheric condition in the laboratory. The average temperature and relative humidity (RH) were recorded 45.73 °C and 64.93%, respectively. Ten harvested pods from each treatment were stored at room condition to investigate the shelf life. For measuring weight loss at room temperature, 10 mature okra pods from each treatment were kept in a separate paper plate with or without polyethylene packaging and observed for 14 days. In every alternative day pods were scrutinized separately and data were recorded. Color change of the pods was determined considering five scoring levels viz.1) Dark green, 2) Green, 3) Yellowish green, 4) More yellow than green, 5) Yellow. Based on the pod color, rating was done and recorded on the collaboration with five people to obtain actual data without any bias. In the storage pods started to decay after certain period and the percentage of rooting was calculated by dividing the rotten pods with the total pods used in each treatment and multiplying by 100.

2.3.5. Statistical analysis and interpretation

The average mean data obtained from the experiment were statistically analyzed by ANOVA (Analysis of variance) with the help of R program to find out the significance level among the treatments. The mean differences of the treatments were observed and compared by least significant difference (LSD) test ($p < 0.05$) level to determine the significance of difference. Correlations among different studied parameters along with dendrogram and principle component analysis (PCA) were also performed to reach a concrete recommendation. Results of the field performance were described based on the interaction effects of the selected seed priming and GA_3 doses.

3. Results

3.1. Seed priming influence on germination and seedling growth of okra

3.1.1. Days to emergence

Different priming techniques on okra seed show a significant difference on days to emergence (**Figure 1A**). All the primed seeds required significantly reduced number of days to emergence compared to control (T_{10}). Among the priming, acid-priming < hydro-priming < halo-priming performed in sequence for early emergence. T_8 provided the most positive impact on seed to emerge earlier (2.66 days) than the other treatments whereas T_{10} took maximum time (5.66 days) for emergence.

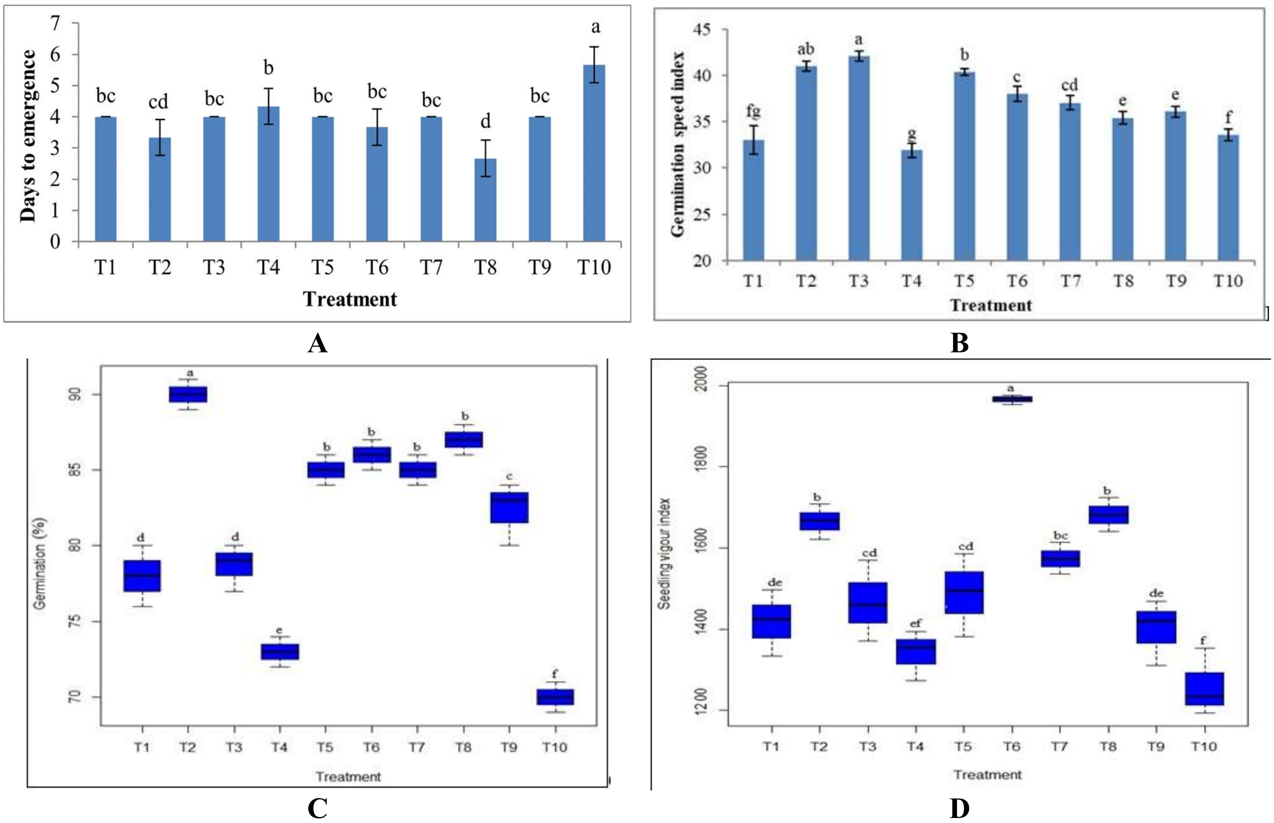


Figure 1. Effect of seed priming on days to emergence **(A)**, germination percentage **(B)**, germination speed index **(C)** and seedling vigor index **(D)** of okra. Vertical bars indicate ± SD of three replications, same lowercase letters do not differ significantly by LSD at 5% level.
T_1, T_2 and T_3 denote hydro priming for 6 h, 12 h and 18 h, respectively; T_4, T_5, and T_6, denote halo priming with 3% NaCl for 40 min at 35 °C, 45 °C, and 60 °C, respectively; T_7, T_8, and T_9 denote acid priming with H_2SO_4 (80%) for 2.5 min, 5 min and 10 min, respectively and T_{10} denote no priming or control.

3.1.2. Germination speed index (GSI)

The priming of seed depicts significant effects on the germination speed index (**Figure 1B**). The highest GSI (42.10) was found in T_3 followed by T_2 with 40.99 values. The lowest germination speed index (31.91) was found in T_4. T_{10} had 33.53 GSI which was better than T_1 and T_4.

3.1.3. Germination percentage

Priming treatments of seeds significantly affected germination percentage (**Figure 1C**). Among the seed priming technique tested, acid-priming was better followed by halo-priming with higher temperature. Hydro-priming also performed better than control. The highest germination percentage (90%) was exceptionally recorded in T_2 compared to other treatments. Better germination percentages were detected in T_8 and T_6. The lowest germination percentage was found in T_{10} (70%).

3.1.4. Seedling vigor index (SVI)

Results revealed that the SVI was positively influenced by priming of the okra seeds (**Figure 1D**). The highest seedling vigor (1965) was recorded in T_6 followed by T_2 and T_8. On the other hand, the lowest (1260) seedling vigor was obtained in T_{10} having statistical parity with T_4 priming technique.

3.2. Field performance of okra as influenced by seed priming and GA_3

Besides the seed priming influence on seedling emergence and early vigor, distinguished results were obtained when four levels of GA_3 (0 ppm, 100 ppm, 200 ppm, and 300 ppm) was applied as foliar spray to the standing okra plants developed from the best three priming treated seeds (hydro priming for 12 h; halo priming at 3% NaCl at 60 °C, and acid priming at 80% H_2SO_4 for 5 min) besides control or plants from non-primed seeds. Therefore, results of the sixteen treatments on growth, yield and quality traits of okra are described below.

3.2.1. Plant height, number of branches and leaves, leaf length (cm)

Plant height was significantly influenced by foliar application of GA_3 on primed seedling after transplanting and at 90 days after transplanting (DAT), a wide fluctuation on plant height was noticed (**Table 1**). T_7 (243.33 cm) and T_8 (242.67 cm) were at the peak whereas minimum plant height was recorded in T_1 (137.23 cm) at 90 DAT. The number of branches of okra was influenced by the application of different priming treatments and GA_3. T_5 and T_9 were exceptional but quite similar to control which indicated hydro- and halo-priming alone was unable to increase branch without GA_3. At 90 DAT, the highest number of branches was observed in T_{12} (2.73) followed by T_{13}, T_{15}, T_{16} (2.40) and the lowest number of branches was seen in T_1 (0.66). Results revealed that GA_3 either single or in combination with priming increased leaves of okra. At 60 DAT, the maximum number of leaves was found in T_8 (29.13) followed by T_{13} (27.87). Meanwhile the lowest number of leaves was found in T_1 (18.53) followed by T_5 (20.53). Leaf length was also significantly affected by the priming and the foliar application of GA_3 on okra. At 60 DAT, T_{16} (30.53 cm) and T_1 (15.83 cm) provided the highest and the lowest leaf length respectively. Acid-priming > halo-priming > hydro-priming sequentially influenced the leaf length, while GA_3 at higher dose of 200/300 ppm performed the best.

Table 1. Effect of seed priming and foliar application of GA_3 on plant height, number of branches, number of leaves and leaf length at 90 days after transplanting.

Treatments	Plant height (cm)	Number of branches	Number of leaves	Leaf length (cm)
T_1	137.23 ± 1.14 k	0.93 ± 0.31 i	18.53 ± 1.10 g	15.83 ± 0.56 i
T_2	154.33 ± 0.50 j	1.67 ± 0.42 fg	23.13 ± 0.76 def	18.63 ± 0.47 h
T_3	182.67 ± 2.00 ij	2.20 ± 0.40 b–e	22.27 ± 2.14 ef	23.00 ± 0.40 f
T_4	180.33 ± 0.92 ef	2.00 ± 0.20 c–g	24.07 ± 0.99 cde	21.23 ± 0.80 g
T_5	142.33 ± 0.76 hi	0.80 ± 0.40 i	20.53 ± 1.92 fg	20.33 ± 0.98 g
T_6	170.00 ± 0.99 hi	1.60 ± 0.35 gh	25.53 ± 1.17 bcd	24.73 ± 0.94 d
T_7	243.33 ± 1.02 b	1.87 ± 0.42 d–g	23.93 ± 0.61 cde	25.60 ± 1.00 cd
T_8	242.67 ± 1.15 cd	2.33 ± 0.12 a–d	29.13 ± 1.62 a	23.40 ± 0.40 ef
T_9	148.67 ± 9.02 hij	1.13 ± 0.31 hi	24.20 ± 1.51 cde	24.50 ± 0.43 de
T_{10}	191.67 ± 0.99 gh	1.77 ± 0.25 efg	25.53 ± 1.72 bcd	24.60 ± 1.05 de
T_{11}	236.67 ± 1.03 e	2.13 ± 0.23 b–f	25.67 ± 2.52 bcd	23.06 ± 0.64 f
T_{12}	224.33 ± 1.21 a	2.73 ± 0.31 a	24.93 ± 0.99 b–e	26.96 ± 0.40 b
T_{13}	160.67 ± 1.36 de	2.53 ± 0.21 ab	27.87 ± 2.14 ab	25.00 ± 0.80 d
T_{14}	238.33 ± 1.74 bc	2.40 ± 0.40 abc	25.60 ± 1.31 bcd	26.33 ± 1.02 bc
T_{15}	218.33 ± 0.61 bc	2.53 ± 0.12 ab	27.00 ± 5.37 abc	27.10 ± 1.30 b
T_{16}	201.67 ± 0.53 fg	2.53 ± 0.12 ab	25.73 ± 1.30 bcd	30.53 ± 0.50 a
CV (%)	1.72	15.68	7.89	3.23

Values are means ± standard errors of three replications. Different letters within the column indicate statistically significant differences among the treatments according to a Fisher's protected LSD (least significance difference) test at $p < 0.05$. Here, T_1: no priming + no GA_3, T_2: GA_3 at 100 ppm, T_3: GA_3 at 200 ppm, T_4: GA_3 at 300 ppm, T_5: hydro priming for 12 h, T_6: hydro priming for

12 h + GA_3 at 100 ppm, T_7: hydro priming for 12 h + GA_3 at 200 ppm, T_8: hydro priming for 12 h + GA_3 at 300 ppm, T_9: halo priming at 60 °C, T_{10}: halo priming at 60 °C + GA_3 at 100 ppm, T_{11}: halo priming at 60 °C + GA_3 at 200 ppm, T_{12}: halo priming at 60 °C + GA_3 at 300 ppm, T_{13}: acid priming for 5 min, T_{14}: acid priming for 5 min + GA_3 at 100 ppm, T_{15}: acid priming for 5 min + GA_3 at 200 ppm, and T_{16}: acid priming for 5 min + GA3 at 300 ppm.

3.2.2. Flowering and harvesting

GA_3 at 100 to 200 ppm did better in combination with priming in sequence of acid-priming > halo-priming > hydro-priming in respect of flowering on earlier nodes. T_{14} and T_{15} influenced earlier blooming at 4.26 nodes compared to other treatments. Whereas T_1 needed a higher number of nodes (6.86) to experience the first bloom (2A). In terms of duration from transplanting, the highest number of days to the first flowering was taken by T_1 (33 days) whereas the lowest number of days to flowering was observed in T_{16} (25.06 days) (2B). Importantly, T_{16} (28.66) and T_9 (29) required the minimum days to 50% flowering. To the contrary, T_1 required maximum days (38) to 50% flowering (2C). Finally, the lowest days to first harvest was observed in T_{16} (32.33 days). Contrary, the highest days to first fruit harvest was observed in T_1 (40.73 days) (2D).

3.2.3. Pod characters

Pod length, pod diameter and individual pod weight of okra was significantly influenced by the priming and foliar application of GA_3 (**Table 2**). Results revealed that the highest pod length was in T_{14} (22.13 cm) followed by T_{13} (20.27 cm) during the first harvest. At the first harvest, the highest pod diameter (16.6 mm) was secured by T_{16} which was closely followed by T_{15} (16.26 mm). It indicated that GA_3 at higher concentration (300 ppm) boosted the pod diameter alone compared to control and while in combination with priming higher GA_3 did the best. Treatment T_9 (13.2 mm) had the lowest pod diameter. Fresh pod weight at first harvest was maximum (26.06 g) in T_{16} followed by T_{14} (24.4 g), while the lowest was recorded in T_7 (14.4 g). The highest number of seeds per pod was recorded in T_5 (50.66) and T_{13} (50.93) whereas the lowest number of seeds was found in T_1 (41) and T_8 (41.06). GA_3 with higher dose (200 and 300 ppm) independently or in combination with priming stored the maximum TSS in okra. Maximum TSS was recorded in T_3 (4.75%), T_{12} (4.72%), T_{13} (4.67%) and T_{16} (4.53%). Inversely, minimum TSS was recorded in T_1 (2.50%).

Table 2. Effect of seed priming and foliar application of GA_3 on pod length, pod diameter and individual pod weight, number of seeds/pod, total soluble solid (°Brix).

Treatments	Pod length (cm)	Pod diameter (mm)	Individual pod weight (g)	Number of seeds/pod	Total soluble solid (°Brix)
T_1	13.50 ± 0.26 h	13.86 ± 0.50 gh ^{x}	16.20 ± 0.52 jk	41.00 ± 1.40 h	2.50 ± 0.19 d
T_2	17.53 ± 0.76 fg	13.93 ± 0.57 f–h	20.46 ± 1.28 efg	44.20 ± 0.91 efg	3.87 ± 0.18 b
T_3	18.67 ± 0.42 c–f	15.40 ± 0.34 a–d	18.80 ± 1.83 gh	42.53 ± 2.73 fgh	4.75 ± 0.01 a
T_4	17.53 ± 0.76 fg	15.13 ± 0.90 c–g	19.20 ± 1.24 fgh	43.00 ± 1.63 fgh	3.68 ± 0.02 bc
T_5	18.67 ± 0.42 c–f	14.46 ± 0.80 d–h	19.66 ± 1.22 fgh	50.66 ± 1.22 a	3.73 ± 0.22 bc
T_6	18.87 ± 0.64 cde	15.26 ± 0.80 b–e	21.80 ± 0.87 de	49.13 ± 1.10 ab	3.87 ± 0.11 b
T_7	17.80 ± 0.35 efg	15.66 ± 1.10 a–c	14.40 ± 0.52 k	48.13 ± 1.10 bc	3.69 ± 0.24 bc
T_8	19.13 ± 1.03 b–d	15.40 ± 1.20 a–d	23.73 ± 1.00 bc	41.06 ± 0.50 h	3.81 ± 0.46 b
T_9	19.63 ± 0.80 bc	13.20 ± 1.00 h	16.72 ± 1.19 ij	47.26 ± 1.20 bcd	4.04 ± 0.11 b
T_{10}	19.67 ± 0.42 bc	15.20 ± 0.50 b–f	20.73 ± 1.10 ef	46.20 ± 0.87 cde	3.35 ± 0.11 c
T_{11}	18.20 ± 0.35 d–g	14.06 ± 0.70 efg	18.20 ± 0.91 hi	45.60 ± 1.05 de	3.99 ± 0.28 b
T_{12}	17.40 ± 0.72 g	14.33 ± 0.83 efg	23.60 ± 1.20 bcd	43.06 ± 1.50 fgh	4.72 ± 0.32 a
T_{13}	20.27 ± 0.14 b	15.20 ± 0.91 b–g	24.06 ± 0.80 b	50.93 ± 2.54 a	4.67 ± 0.16 a
T_{14}	22.13 ± 0.70 a	15.26 ± 0.41 b–e	24.40 ± 1.05 ab	42.40 ± 2.02 fgh	3.78 ± 0.38 b
T_{15}	18.67 ± 0.83 c–f	16.26 ± 0.23 ab	22.13 ± 1.22 cde	44.73 ± 1.20 ef	4.00 ± 0.16 b
T_{16}	17.20 ± 0.92 g	16.60 ± 0.60 a	26.06 ± 0.46 a	41.80 ± 1.56 gh	4.53 ± 0.35 a
CV (%)	3.89	5.41	5.41	3.28	5.91

Values are means ± standard errors of three replications. Different letters within the column indicate statistically significant differences among the treatments according to a Fisher's protected LSD (least significance difference) test at $p < 0.05$. Here, T_1: no priming + no GA_3, T_2: GA_3 at 100 ppm, T_3: GA_3 at 200 ppm, T_4: GA_3 at 300 ppm, T_5: hydro priming for 12 h, T_6: hydro priming for 12 h + GA_3 at 100 ppm, T_7: hydro priming for 12 h + GA_3 at 200 ppm, T_8: hydro priming for 12 h + GA_3 at 300 ppm, T_9: halo priming at 60 °C, T_{10}: halo priming at 60 °C + GA_3 at 100 ppm, T_{11}: halo priming at 60 °C + GA_3 at 200 ppm, T_{12}: halo priming at 60 °C + GA_3 at 300 ppm, T_{13}: acid priming for 5 min, T_{14}: acid priming for 5 min + GA_3 at 100 ppm, T_{15}: acid priming for 5 min + GA_3 at 200 ppm, and T_{16}: acid priming for 5 min + GA3 at 300 ppm.

3.2.4. Yield/plant

GA_3 and different priming treatments significantly influenced the yield/plant of okra (**Figure 2E**). It was observed that GA_3 at 200 ppm did better compared to control and others. GA_3 at 200 ppm was more effective in respect of yield/plant when sprayed on acid primed seedlings. In case of halo-priming, GA_3 at 300 ppm was found to be better for yield. The highest yield per plant was observed in T_{15} (735.16 g) followed by T_{12} (729.87 g), whereas the lowest yield per plant was observed in T_{16} (564.62 g) and T_1 (572.47 g).

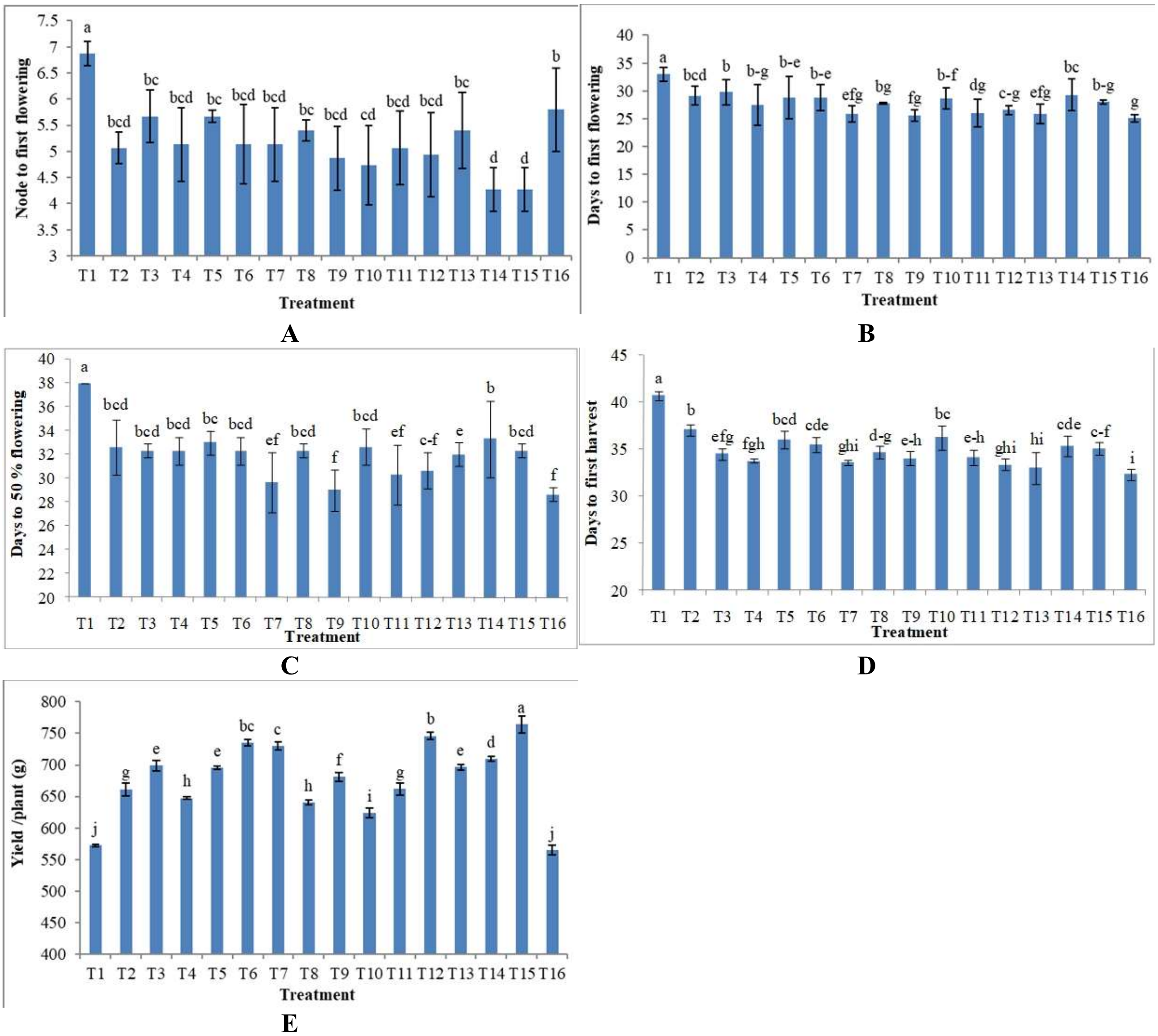


Figure 2. Effect of seed priming and foliar application of GA_3 on node number to the first flower appearance **(A)**, days to first flowering **(B)**, days to 50% flowering **(C)**, days to first harvest **(D)** and yield per plant **(E)**. Similar letter (s) in figure does not differ significantly by LSD at 5% level.

T_1: no priming + no GA_3, T_2: GA_3 at 100 ppm, T_3: GA_3 at 300 ppm, T_4: GA_3 at 400 ppm, T_5: hydro priming for 12 h + no GA_3, T_6: hydro priming for 12 h + GA_3 at 100 ppm, T_7: hydro priming for 12 h + GA_3 at 300 ppm, T_8: hydro priming for 12 h + GA_3 at 400 ppm, T_9: halo priming at 3% NaCl at 60 °C + no GA_3, T_{10}: halo priming at 3% NaCl at 60 °C + GA_3 at 100 ppm, T_{11}: halo priming at 3% NaCl at 60 °C + GA_3 at 300 ppm, T_{12}: halo priming at 3% NaCl at 60 °C + GA_3 at 400 ppm, T_{13}: acid priming at 80% H_2SO_4 for 5 min + no GA_3, T_{14}: acid priming at 80% H_2SO_4 for 5 min + GA_3 at 100 ppm, T_{15}: acid priming at 80% H_2SO_4 for 5 min + GA_3 at 300 ppm, and T_{16}: acid priming at 80% H_2SO_4 for 5 min + GA_3 at 400 ppm.

3.3. Seed priming and GA_3 influence on the post-harvest qualities of okra

3.3.1. Weight loss (%)

Weight loss due to priming and foliar application of GA_3 during post-harvest storage was statistically significant (**Table 3**). During the first 6 days of open storage, the highest weight loss was found in T_1 (33.67%) where the lowest weight loss was observed in T_{15} (12.09%). But in the last 6 days of open storage, weight loss seems quite different. T_9 (44.92%) lost the maximum weight during storage whereas the lowest weight lost was observed in T_2 (26.30%), T_6 (24.83%), T_{11} (26.46%), T_{12} (26.25%), T_{14} (25.71%), and T_{16} (24.54%). Therefore, GA_3 along with priming treatment restricted weight loss noticeably. In polyethylene storage, there was negligible weight loss at the first 6 days of storage but in overall 12 days course of storage the maximum weight loss was observed in T_1 (10.98%) followed by T_{10} (10.27%) and the lowest weight loss was observed in T_3 (1.62%) and T_7 (1.65%).

Table 3. Effect of seed priming and foliar application of GA_3 on weight loss (%) and rotting rate (%) of okra pod up to 12 days in open and polythene storage conditions.

Treatment	Weight loss (%)			Rotting rate (%)		
	Open storage		Polyethylene storage up to 12 days	Open storage		Polyethylene storage up to 12 days
	First 6 days	Last 6 days		First 6 days	Last 6 days	
T_1	33.67 ± 0.67 a	31.61 ± 0.45 de	10.98 ± 0.35 a	2.50 ± 0.28 c	19.61 ± 0.92 ab	7.34 ± 0.05 g
T_2	20.41 ± 1.69 d	26.30 ± 1.11 g	7.25 ± 0.39 g	1.52 ± 0.05 e	18.95 ± 0.42 bcd	4.54 ± 0.38 l
T_3	30.55 ± 0.93 a	28.86 ± 0.24 f	1.62 ± 0.22 i	1.79 ± 0.08 d	14.23 ± 1.88 fg	5.19 ± 0.05 k
T_4	18.74 ± 1.33 de	41.42 ± 1.45 b	2.44 ± 0.24 h	1.48 ± 0.05 e	19.20 ± 0.37 bc	3.22 ± 0.04 m
T_5	16.00 ± 2.31 ef	35.53 ± 2.30 c	8.34 ± 0.22 f	0.00 ± 0.00 f	15.69 ± 0.91 f	5.14 ± 0.11 k
T_6	26.97 ± 0.42 b	24.83 ± 1.62 g	9.37 ± 0.30 cd	2.48 ± 0.06 c	17.91 ± 0.09 cde	4.50 ± 0.11 l
T_7	25.81 ± 1.75 b	29.73 ± 1.94 ef	1.65 ± 0.14 i	4.31 ± 0.29 a	13.46 ± 1.08 gh	9.56 ± 0.01 c
T_8	21.24 ± 0.86 cd	30.00 ± 0.42 ef	1.98 ± 0.18 hi	0.00 ± 0.00 f	19.55 ± 0.5 ab	6.16 ± 0.08 i
T_9	20.87 ± 1.31 d	44.92 ± 1.23 a	8.99 ± 0.29 de	0.00 ± 0.00 f	15.36 ± 1.18 f	5.55 ± 0.10 j
T_{10}	15.88 ± 6.42 ef	30.16 ± 1.67 ef	10.27 ± 0.78 b	0.00 ± 0.00 f	20.99 ± 1.77 a	8.76 ± 0.10 d
T_{11}	24.38 ± 1.25 bc	26.46 ± 0.81 g	9.67 ± 0.34 bc	1.61 ± 0.15 de	18.66 ± 0.91 b-e	7.83 ± 0.03 f
T_{12}	25.03 ± 1.57 b	26.25 ± 1.02 g	7.42 ± 0.62 g	2.53 ± 0.03 c	12.56 ± 0.44 h	6.73 ± 0.04 h
T_{13}	13.21 ± 0.95 fg	33.83 ± 0.85 cd	8.69 ± 0.58 ef	0.00 ± 0.00 f	19.07 ± 0.64 bc	10.63 ± 0.04 b
T_{14}	21.24 ± 1.64 cd	25.71 ± 1.31 g	8.54 ± 0.48 ef	3.92 ± 0.07 b	17.59 ± 0.82 de	7.73 ± 0.12 f
T_{15}	12.09 ± 0.28 g	41.30 ± 1.78 b	7.32 ± 0.32 g	0.00 ± 0.00 f	17.19 ± 0.36 e	12.08 ± 0.10 a
T_{16}	12.63 ± 0.56 fg	24.54 ± 0.89 g	7.63 ± 0.14 g	4.23 ± 0.39 a	18.05 ± 0.58 cde	8.23 ± 0.08 e
CV (%)	9.87	4.33	5.33	9.56	5.06	1.99

Values are means ± standard errors of three replications. Different letters within the column indicate statistically significant differences among the treatments according to a Fisher's protected LSD (least significance difference) test at $p < 0.05$. Here, T_1: no priming + no GA_3, T_2: GA_3 at 100 ppm, T_3: GA_3 at 200 ppm, T_4: GA_3 at 300 ppm, T_5: hydro priming for 12 h, T_6: hydro priming for 12 h + GA_3 at 100 ppm, T_7: hydro priming for 12 h + GA_3 at 200 ppm, T_8: hydro priming for 12 h + GA_3 at 300 ppm, T_9: halo priming at 60 °C, T_{10}: halo priming at 60 °C + GA_3 at 100 ppm, T_{11}: halo priming at 60 °C + GA_3 at 200 ppm, T_{12}: halo priming at 60 °C + GA_3 at 300 ppm, T_{13}: acid priming for 5 min, T_{14}: acid priming for 5 min + GA_3 at 100 ppm, T_{15}: acid priming for 5 min + GA_3 at 200 ppm, and T_{16}: acid priming for 5 min + GA3 at 300 ppm.

3.3.2. Rotting (%)

Rotting percentage in storage was highly reduced by priming and foliar application of GA_3 on okra (**Table 3**). There was a significant difference in rotting percentage due to the treatments effect. In the initial six days of open storage, the highest rotting percentage was experienced in T_7 (4.31%) and T_{16} (4.23%) whereas T_5, T_4, T_9, T_{10}, T_{13}, and T_{15} did not experience any rotting. But at the last 6 days of open storage, rotting percentage seems quite common in almost all the treated samples and it seems comparatively lower with GA_3 at 200 ppm when applied independently or in combination. However, T_{10} (20.99%) showed the highest percentage of rotting followed by T_1 (19.61%) and the lowest percentage of rotting was experienced by T_{12} (12.56%) ,which was the combination of GA_3 at 300 ppm and halo-priming. In polyethylene storage, rotting was not visible in any pods for up to 6 days. But in overall 12 days of storage, in most of the cases GA_3 at 100 ppm with priming exhibited reduced rotting (%). The highest rotting percentage (12.08%) was experienced in T_{15} followed by T_{13} (10.63%) whereas the lowest rotting percentage was found in T_4 (3.22%).

3.3.3. Color change

All the treatments restricted more color change compared to control (**Table 4**). In the course of first 6 days of open storage, maximum color change was observed in T_1 (2.55) where minimum color change was observed in T_{13} (1). In the last 6 days of open storage, the highest color change (4.66) was again observed in T_1 followed by T_{11} (3.88). The lowest color change was experienced in T_{13} (2.32) in the same storage condition. In polyethylene storage, reverse phenomenon was observed in respect of color change where higher concentration of GA_3 (300 ppm) with halo-priming performed better. Meanwhile, other priming was better to keep the color of okra with GA_3 at 100 ppm. The highest color change was observed in T_{13} (2.03) closely followed by T_{11} (1.84) while minimum color change was observed in T_{12} (1.12). Here, the lowest color changing treatment in open storage becomes the highest color changing treatment.

Table 4. Effect of seed priming and foliar application of GA_3 on color change and shelf life of okra pod under open and polythene storage conditions.

Treatment	Color change			Shelf life	
	Open storage		Polyethylene storage up to 12 days	Open storage	Polyethylene storage
	First 6 days	Last 6 days			
T_1	2.55 ± 0.19 a	4.66 ± 0.33 a	1.47 ± 0.03 def	14.00 ± 1.00 gh	16.00 ± 1.00 e
T_2	1.55 ± 0.19 cde	3.11 ± 0.19 c–f	1.59 ± 0.03 cd	15.00 ± 1.00 d–g	17.66 ± 1.52 de
T_3	1.33 ± 0.00 efg	3.22 ± 0.69 cde	1.33 ± 0.03 g	15.66 ± 0.57 c–f	17.53 ± 0.57 de
T_4	1.55 ± 0.19 cde	3.33 ± 0.33 bcd	1.28 ± 0.07 g	15.00 ± 1.00 d–g	20.00 ± 1.00 abc
T_5	1.11 ± 0.19 gh	2.55 ± 0.50 fg	1.56 ± 0.05 cde	15.66 ± 0.57 c–f	17.66 ± 0.57 de
T_6	1.76 ± 0.20 bc	3.66 ± 0.33 bc	1.38 ± 0.16 fg	13.33 ± 0.57 h	17.66 ± 2.08 de
T_7	1.55 ± 0.19 cde	3.55 ± 0.19 bc	1.55 ± 0.05 cde	16.00 ± 1.00 b–e	19.66 ± 1.52 abc
T_8	1.22 ± 0.19 fgh	2.66 ± 0.33 efg	1.54 ± 0.08 cde	14.33 ± 0.57 fgh	19.00 ± 1.00 bcd
T_9	1.33 ± 0.33 efg	2.77 ± 0.19 d–g	1.28 ± 0.03 g	17.66 ± 0.57 a	20.66 ± 2.08 ab
T_{10}	1.33 ± 0.00 efg	3.44 ± 0.19 bc	1.37 ± 0.05 fg	16.66 ± 0.57 abc	19.66 ± 0.57 abc
T_{11}	1.66 ± 0.00 cd	3.88 ± 0.19 b	1.84 ± 0.05 b	14.66 ± 2.08 e–h	18.33 ± 1.52 cd
T_{12}	1.98 ± 0.01 b	2.77 ± 0.38 d-g	1.12 ± 0.11 h	16.33 ± 0.57 a–d	21.00 ± 0.00 a
T_{13}	1.00 ± 0.00 h	2.32 ± 0.31 g	2.03 ± 0.06 a	17.66 ± 0.57 a	20.66 ± 1.15 ab
T_{14}	1.44 ± 0.19 def	2.66 ± 0.33 efg	1.28 ± 0.03 g	16.00 ± 1.00 b–e	18.66 ± 0.57 cd
T_{15}	1.33 ± 0.33 efg	3.55 ± 0.38 bc	1.66 ± 0.10 c	17.33 ± 0.57 ab	20.66 ± 0.57 ab
T_{16}	1.55 ± 0.19 cde	3.11 ± 0.11 c–f	1.46 ± 0.05 ef	16.33 ± 0.57 a–d	20.66 ± 0.70 ab
CV (%)	12.71	10.71	5.18	5.45	5.86

Values are means ± standard errors of three replications. Different letters within the column indicate statistically significant differences among the treatments according to a Fisher's protected LSD (least significance difference) test at $p < 0.05$. Here, T_1: no priming + no GA_3, T_2: GA_3 at 100 ppm, T_3: GA_3 at 200 ppm, T_4: GA_3 at 300 ppm, T_5: hydro priming for 12 h, T_6: hydro priming for 12 h + GA_3 at 100 ppm, T_7: hydro priming for 12 h + GA_3 at 200 ppm, T_8: hydro priming for 12 h + GA_3 at 300 ppm, T_9: halo priming at 60 °C, T_{10}: halo priming at 60 °C + GA_3 at 100 ppm, T_{11}: halo priming at 60 °C + GA_3 at 200 ppm, T_{12}: halo priming at

60 °C + GA_3 at 300 ppm, T_{13}: acid priming for 5 min, T_{14}: acid priming for 5 min + GA_3 at 100 ppm, T_{15}: acid priming for 5 min + GA_3 at 200 ppm, and T_{16}: acid priming for 5 min + GA_3 at 300 ppm.

3.3.4. Shelf life of okra pod

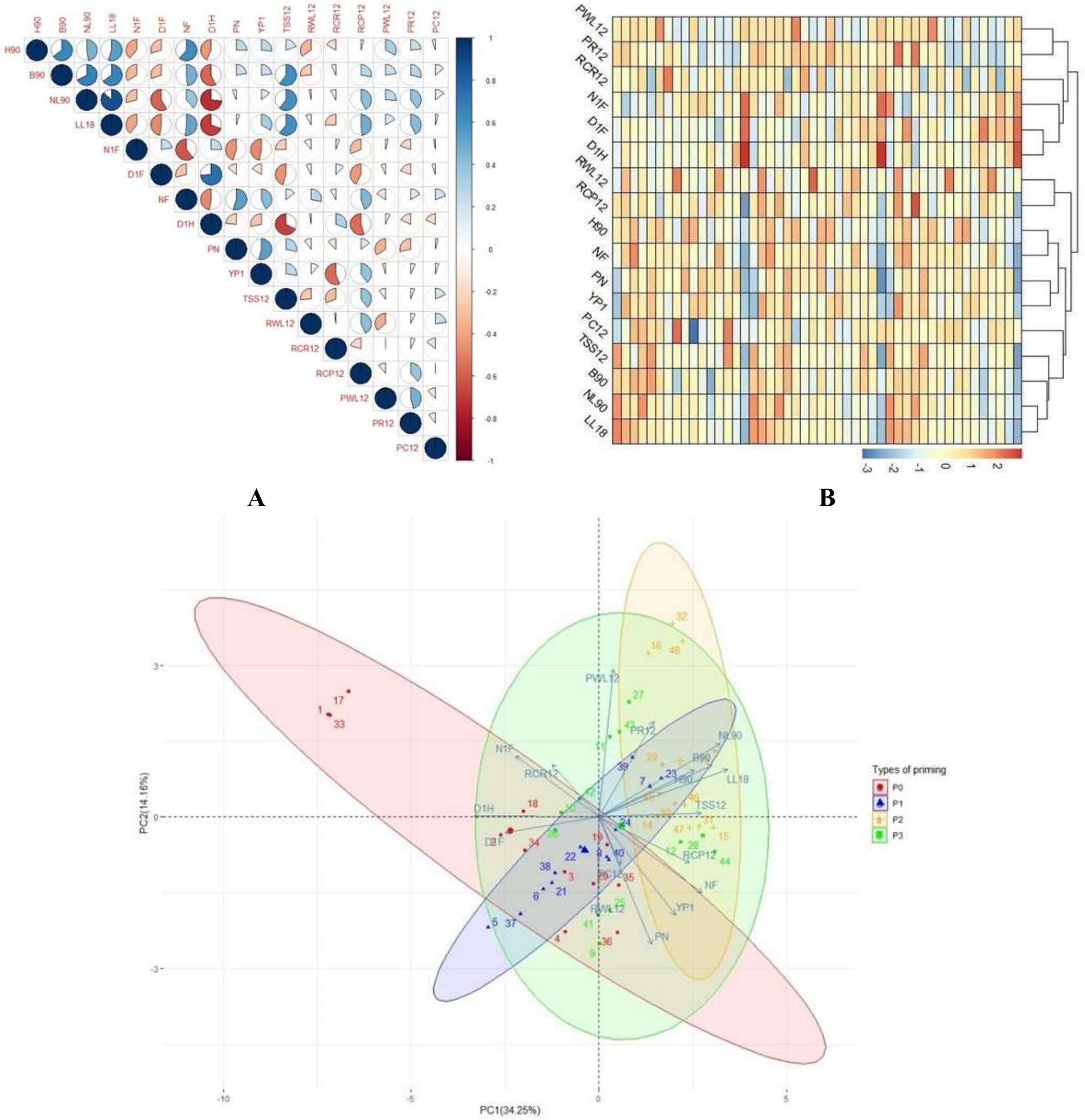
Post-harvest shelf life of okra pod was highly improved by priming and foliar application of GA_3 (**Table 4**). Higher concentration of GA_3 (200 to 300 ppm) either alone or in combination with different priming provided higher shelf life under polyethylene storage. Meanwhile in open storage, there was no concrete result but GA_3 at 100 to 200 ppm was good for long storage life. The highest post-harvest shelf life of okra was found in T_9 (17.66) and T_{13} (17.66) whereas the lowest post-harvest shelf life was found in T_6 (13.33) at open storage. T_{12} (21) and T_1 (16) gave the maximum and minimum post-harvest shelf life in polyethylene and open storage respectively.

3.4. Correlation coefficient analysis of seventeen variables related to growth, yield, yield attributes and post-harvest storage traits

In the study, parameters were interlinked and their interaction was complicated (**Figure 3**). Understanding of the complexity is important for characterization of priming and foliar application of GA_3 on growth, yield, yield attributes and post-harvest storage qualities of okra.

Among growth traits (**Figure 3A**), the number of branches (B90) was positively correlated with plant height (H90) at 65% whereas the number of leaves (NL90) had a strong positive correlation with B90, viz., 67%. Similarly, leaf length (LL18) had positively correlated with H90, B90 and NL90, viz., 55%, 65%, and 87%. In generative and yield related traits, days to first harvest (D1H) was negatively correlated with B90, NL90, LL18, viz., 57%, 74%, and 69% whereas strong positive correlation (74%) was exhibited for days to first flowering (D1F). Besides, other reproductive parameters like number of flowers (NF) were positively correlated with H90 and LL18 at 62% and 52% respectively whereas it had strong negative correlation (61) with node to first flowering (N1F). Likewise, pod number (PN) and yield per pod (YP1) were positively correlated with NF and PN at 55% and 54%, respectively. Days to first harvest (D1H) showed a different result than the other traits. It had positive correlation with D1F at 74% but at the same time it had negative correlation with B90, NL and LL18 at 57%, 74%, and 69%, respectively. **Figure 3A** revealed that the total soluble solid (TSS) of okra pod was positively correlated with B90, NL90, and LL18 at 60%, 61%, and 61%, respectively whereas it had strong negative correlation (68%) with D1H. Differently, most post-harvest storage parameters had moderate or low correlation with other traits. Considering all, growth, yield and yield attributing parameters were found highly interlinked with each other whereas post-harvest related traits were less influenced by growth, yield and yield attributing variables.

Heatmap cluster presented in **Figure 3B** showed two major clusters; cluster 1 divided into two sub-clusters. In first sub cluster, weight loss and rotting percentage were closely related to each other in polyethylene storage therefore they belong to the same cluster whereas rest of the variable (RCR12, N1F, D1F, and D1H) were in sub cluster 2. It was also further divided into small clusters because the extent of the variation was not the same among the variables. In major cluster 2, there were also two sub-clusters which were further divided into some small clusters as their interrelationships were not similar to those in the same sub-cluster.



A

B

C

Figure 3. Correlation coefficient analysis **(A)**, cluster analysis **(B)** and principle component analysis (PCA) **(C)** of various growth, yield, yield attributes and post-harvest quality of okra as influenced by seed priming and GA_3 field application.
H90: Plant height, B90 : Number of branches, NL90 : Number of leaves, LL18 : Leaf length, N1F : Node to first flowering, D1F : Days to first flowering, NF : Number of flowers, D1H : Days to first harvest, PN : Pod number, YP1 : Yield per plant, TSS : Total soluble solid, RWL12 : Weight loss at open storage, RCR12 : Rotting (%) at open storage, RCP12 : Consumable pod at open storage, PWL12 : Weight loss in polyethylene storage, PR12 : Rotting (%)in polyethylene storage, PC12 : Consumable pod in polyethylene storage.

3.5. Principle component analysis (PCA) of seventeen variables related to growth, yield, yield attributes and post-harvest storage traits

It is a method of transforming a large set of data into a concise frame with important information. To know the relationship among the traits, PCA was performed on 17 dependent variables with the major two contributors of Dim1 (34.25%) and Dim2 (14.16%) (**Figure 3C**). In PCA study for PC1, PR12, NL90, B90, H90, LL18, TSS12, PWL12, RCP12, NF, YP1, and PN were positive contributors. Meanwhile major contributions were given by PWL12, NL90, LL18, and PN. Similarly, four variables namely RCR12, N1F, D1H, and D1F were negative contributors. Of them, D1H contributes more than the other variables. In PC2 variables D1H, RCR12, N1F, PWL12, PR12, NL90, B90, H90, LL18, and TSS were in the positive side where their influence was positive. Out of 17 variables, only six variables (D1F, RWL12, PN, YP1, NF, and RCP12) were in the negative side where their relation was negative. As the effect of priming concentration, four clusters were formed for the priming effects where P3 (H_2SO_4) formed a distinct cluster covering the many variables from each quarter whereas clusters for P2 overlapped with P3 of the positive side of PC1. Priming P0 and P1 covers both the positive and negative side of PC2.

In GA_3 concentration four clusters were also formed for four GA_3 concentrations. All clusters cover both the positive and negative side of PC1 and PC2 however clusters of G3 looked superior to others. Therefore, H_2SO_4 priming and GA_3 at 300 ppm found to be the best in overall concern.

4. Discussion

Seed priming techniques have been found to have a significant influence on the germination and seedling growth of okra. These techniques have been shown to reduce the days to emergence, increase the germination percentage, speed index of germination and overall reliability of germination. Various priming treatments like acid priming have been employed to reduce the days required for emergence[31]. Similarly, our research has revealed that seed soaked in 50% H_2SO_4 for 5 min (T_8) displays same trend of results. This could be attributed to the activation of several enzymes that are involved in lipids, proteins and carbohydrates mobilization, which are essential in the breakdown of macromolecules for the development and growth of the embryo and ultimately result in early and higher seedling emergence[32–34]. Numerous priming treatments have been used to enhance the germination percentage. For instance, authors reported that the highest germination percentage was obtained from acid-priming[23,35], while better germination was noticed in halo priming[36,37]. Our results also showed an increasing trend in germination percentage in halo priming with NaCl (3%) at 60 °C for 40 min and acid priming with H_2SO_4 (80%) for 5 min compared to the control group. Therefore, the aforementioned research results directly correlate with our present findings. It was also found that hydro-priming improves the GSI when compared to unprimed seeds[38]. Our study also revealed that hydro-priming for 12 and 18 h significantly improved the germination index of okra seed. Priming can lead to the significant improvement in shoot and root length[39]. In our investigation an increase in shoot and root length of okra seedlings resulting in higher seedling vigor from various priming treatments was observed. The result aligns with the published findings, with the exception of T_5 and T_3. In general, halo-priming aids in nuclear replication in both root and shoot, resulting in a noticeable increase in root length. However, T_3, T_5, and T_{10} may not produce a similar effect on nuclear replication due to the creation of stress conditions caused by an overdose. Seed priming effect on plants can lead to increased seedling height[40,41] which supports our research outcome that showed all treatments were effective to increase seedling height compared to control. Halo-priming also resulted in an increase in the seedling vigor index. This may be due to early nutrient mobilization[42]. Furthermore, priming might encourage hormonal activity, resulting in early emergence of plumule and leaf, which lead to a higher seedling vigor index.

Our study has noted that foliar application of GA_3 on primed seedlings at different time intervals after transplanting can lead to significantly enhanced field performance of okra seedlings. GA3 at 200–300 ppm, along with hydro-priming, has been found to increase plant height. Reports of authors[43,44] stating that GA_3 was effective in increasing plant height align with our findings. GA_3 at 300 ppm was reported to give the highest length of edible leaves[45]. Our study also gave similar results, where, GA_3 at 200/300 ppm, along with halo-priming, provided increased number of branches and GA_3 at 300 ppm with acid-priming provided a better result concerning the number of leaves and leaf length.

GA_3 was reported to significantly reduce the number of nodes where the first flower appeared[46–48]. Our study has shown that the interaction effect of acid-priming and foliar application of GA_3 (100 and 200 ppm) manifested early node flowering in plants. Clearly, our results were in line with previous findings, which might be due to an increased number of leaves.

In this study, all treatments of GA_3 and priming individually or in combination significantly reduced the number of days to first flowering compared to the control. The combined effects of acid-priming and foliar application of GA_3 (300 ppm) in lowering the number of days of first flowering were in line with previous reports[49–51] where beneficial effects of seed priming have been demonstrated by authors which might be due to high dry matter accumulation in plants[52]. GA_3 at 300 ppm with H_2SO_4 provided better results in respect of days to 50% flowering, and days to 1st harvest.

Our study has shown that GA_3 at100 ppm along with acid priming gave increased pod length. Authors have reported that 50 ppm and 100 ppm of GA_3 were not effective in increasing pod length, which was against our findings, which might be due to the priming effect[44]. The increase in pod length might be the reason for cell elongation and cell division at the apical region by GA_3, which accelerates translocation and photosynthetic activity[53]. GA_3 at 300 ppm with H_2SO_4 provided better results for enhanced pod diameter and individual pod weight. A reduced number of seeds/pod was observed as the concentration of GA_3 increased. This trend was visible whether GA_3 was applied individually or along with different priming. GA_3 with a higher dose (200 and 300 ppm) in combination with priming stored the maximum TSS in okra. In conformity, authors[54] reported that GA_3 concentrations up to 200 mg/L increased TSS content of okra pods. The increase in TSS with priming and foliar application of GA_3 might be due to the increased ability of seeds to concentrate and accumulate sugar on okra pods.

The combined or individual effect of GA_3 and different priming treatments on the yield/plant of okra was significant. It was observed that GA_3 at 200 ppm did better compared to control and others. Tomar and Ramgiry[55] found the best effect of GA_3 application on yield per plant was at the concentration of 125 ppm in tomato while another author[56] found a gradual increase in the yield per plant with higher concentration (200 ppm) of GA_3. Studies reported that GA_3 100 ppm followed by GA_3 150 ppm in bitter gourd produced the maximum fruit weight[57], application of 100 ppm GA_3 led to the maximum yield in cucumber[58]. Our present result also supports the authors' depiction of higher yield with a higher concentration of GA_3. The variation in yield could be due to the concentration of GA_3 ranging from 200 to 300 ppm along with the impacts of different priming treatments.

Our study examined the influence of seed priming and GA_3 on the post-harvest storage qualities of okra, considering the perishable nature of okra pods. Our study showed that GA_3, along with priming treatment, significantly restricted weight loss during open storage which conforms with the reports from Sams[59] who experienced a similar result to ours and revealed that the lower weight loss observed in the GA_3 treated rocket leaves might be attributed to the maintenance of tissue integrity due to lower activity of enzymes responsible for decomposing cellular structure. In contrast, gibberellic acid (GA_3) in mangoes led to rapid weight loss compared to untreated mangoes[60] and different doses of GA3 did not significantly affect the weight loss in cherry[61]. Results of polythene storage revealed that GA_3 treated pods experienced lowest weight loss. Our research results are directly supported by the previous findings[62]. Packaging atmosphere reduces oxygen and increases carbon dioxide for fresh fruits and vegetables, reducing respiration rates[63]. Priming may negatively associate with this mechanism; therefore, only foliar application of 200 ppm GA_3 was found superior to the allotted treatment. Use of plant growth regulating bio-stimulants for improved vegetable qualities and shelf life was also noticed by Ray et al.[21] in onion and Khanam et al.[64] in broccoli.

Regarding color change, acid priming caused the lowest color change in open storage. Delay in the accumulation of carotenoids might be the reason for the small color change in GA_3 experienced treatments where acid-priming was found supportive to the foliar application of GA_3 to reduce the accumulation of carotenoids up to 6 days of storage. Halo-priming was also found supportive in the last 6 days of open storage to reduce the accumulation of carotenoids, which might be responsible for the reduction of color change in okra. In polyethylene storage, higher concentration of GA_3 (300 ppm) with halo-priming performed better. The fluctuation in results might be due to the packaging materials/conditions. In polyethylene storage, halo-priming along with foliar application of 300 ppm GA_3 might maintain the function of enzyme chlorophyllase and photo degradation than the other treatment, therefore it looks superior among the treatments.

Priming and foliar application of GA_3 on okra highly reduced the rotting percentage in storage. The lowest percentage of rotting was experienced by the combination of GA_3 at 300 ppm and halo-priming. Our findings are consistent with findings of previous studies conducted by Amir et al.[65], Rokaya et al.[66], and Jawandha et al.[67], who demonstrate the effectiveness of GA_3 in reducing post-harvest losses in various fruits. Interestingly, our research reveals that polyethylene storage outperforms open storage in terms of rotting percentage, but priming does not appear to provide a supportive effect in this type of storage due to packaging factors. However, the lowest rotting percentage was achieved with an increased GA_3 concentration of 300 ppm without priming treatment. Aligned with the findings of Kuppusamy and Ranganathan[28], treatments that employ higher concentrations of GA_3 (200 to 300 ppm) either alone or in conjunction with different priming techniques consistently yield better results in terms of maintaining higher shelf life under polyethylene storage conditions. Conversely, no significant results were observed in open storage.

5. Conclusions

The current experiment concludes that acid priming of seeds with H_2SO_4 (80%) for 5 min was found superior among the treatments; however, halo priming [60 °C hot brine water (3% NaCl) for 40 min] and hydro priming for 12 h were also found beneficial for germination enhancement and seedling growth of okra. Combination of acid priming (seed soaked in 80% H_2SO_4 for 5 min) and foliar application of GA_3 at 300 ppm was found superior among the treatments, especially on growth, yield, and yield attributes of okra on field performance as well as in post-harvest storage quality of okra pods. From PCA, it was found that acid-priming and GA_3 at 300 ppm contributed maximum to the growth, yield, yield attributes, and postharvest contributing parameters.

Author contributions

Conceptualization, JH and SD; methodology, JH, SD and JG; software, JH; validation, JH, SD, MSB, MMRR and TKG; formal analysis, JH; investigation, SD; JH and MSB; resources, SD; data curation, JH and SD; writing—original draft preparation, SD, JH, SHS and JG; writing—review and editing, JH, YO, MMR and JG; visualization, JH and SD; supervision, JH, MMRR and TKG; project administration, JH; funding acquisition, JH. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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