PLANT SCIENCE TODAY
Vol 12(sp4): 01-07
https://doi.org/10.14719/pst.9491

eISSN 2348-1900

RESEARCH ARTICLE

Effect of seed priming on growth and yield attributing traits of okra (*Abelmoschus esculentus* L.)

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Received: 18 May 2025; Accepted: 07 August 2025; Available online: Version 1.0: 24 November 2025

Cite this article: Chenji AL, Rehan, Ankita S, Sunny S. Effect of seed priming on growth and yield attributing traits of okra (*Abelmoschus esculentus* L.). Plant Science Today. 2025;12(sp4):01-07. https://doi.org/10.14719/pst.9491

Abstract

Okra (*Abelmoschus esculentus*) is a significant vegetable crop grown for its tender pods. Despite the economic and nutritional importance, it faces challenges of poor seed germination and inconsistent seedling establishment. Seed priming aids in hastening and enhancing the consistency of plant growth and seed germination. It is an effective way of promoting seed germination and vigour of okra by alleviating seed dormancy. The study aims to address the gaps by systematically evaluating the effect of different seed priming treatments on germination trait, growth and yield of okra. A research trial was investigated at the vegetable field, Department of Horticulture, Lovely Professional University, Phagwara, Punjab during the period of 2024-2025 to assess the response of okra variety Pusa Sawani to seed priming. A total of 7 treatment combinations meticulously crafted comprising of salicylic acid, GA_3 and cow urine under varying concentrations. The experiment was structured in a Randomized Block Design (RBD) with three replications. Findings revealed that okra seeds primed with GA_3 at 200 ppm and those treated with GA_3 at 200 ppm combined with salicylic acid at 100 ppm exhibited the highest seedling length, number of branches per plant, number of leaves per plant, stem diameter, fruit yield, days to 50 % flowering, fruit length, fruit weight, number of fruits per plant and fruit yield. It can be inferred that out of all the priming treatments, seeds primed with GA_3 at 200 ppm performed the best, demonstrating quicker germination, enhanced growth, yield and quality.

Keywords: morphological traits; okra; plant growth regulators; seed priming; yield

Introduction

Okra (*Abelmoschus esculentus* L.) is the sole significant vegetable crop from the Malvaceae family, characterized by a chromosome count of 2n=130 and it enjoys great popularity in the Indo-Pak subcontinent. While it originated in Ethiopia and Sudan, two Northeastern African nations, India has the highest level of consumption of this vegetable. Rich in vital micro and macro-nutrients, okra holds considerable nutritional, medicinal and industrial importance (1).

Okra proves to be an invaluable crop, with its leaves, buds, flowers, pods, stems and seeds all rich in nutritional and medicinal qualities (2). It is cultivated across India, including in arid and semi-arid regions where water for germination and emergence is only available briefly. Hence, the successful establishment of crops relies on quick and uniform seed germination under conditions of limited water availability. The critical phases in the life cycle of every crop include germination and seedling establishment (3). Among the challenges for achieving high yields, a sparse plant population due to poor and asynchronous germination is particularly significant. Okra contributes importantly to human nutrition by providing fats, proteins, carbohydrates, vitamins and minerals. The optimal yield of okra is about 6.6 tonnes per hectare. The crop thrives in warm temperatures, ideally ranging from 20 to 30 °C, with minimum temperatures of 18 °C and a maximum of 35 °C. While okra is nutritious, it may experience issues with seedling emergence and vigour (4).

It is a versatile crop, the fresh leaves, buds, flowers, pods, stems and seeds of okra all have diverse uses. The young fruit (green seed pods) can be eaten unsalted. The immature pods are also harvested for pickling. Okra contains a substance with a viscous texture, especially when it is cooked. Above everything else, okra is admired for its tender and taste rich edible pods since they contain a lot of vitamins and minerals (5).

The green pods are dehydrated and used to thicken soups or as an ingredient in stews. Mucilage can be extracted from dry roots and stems by soaking them in water overnight and this extract is used for clarifying sugarcane juice in jaggery production (6). Various parts of the okra fruit, including mucilage, seeds and pods, contain significant bioactive compounds that provide medicinal benefits (7). The crude fibre obtained from fully matured okra fruits and stems can be used in the paper industry. Okra, a nutritious low-calorie vegetable, contains protein, vitamins, minerals and dietary fibre (8). It is an excellent source of A and C vitamins that are essential for the body. Besides vitamin A, okra contains carotene, which can be used to make vitamin A. In addition, Vitamin C present in 100 g of okra pods helps meet around 20 % of daily needs (9).

Seed priming can enhance emergence and synchronize the germination of seeds. Various techniques for seed priming come with numerous advantages, such as reducing fertilizer requirements, increasing agricultural yield through timely germination and fostering systemic resistance in plants, which can be both economically and environmentally advantageous (10).

Seed priming with plant growth regulators has been extensively studied as an effective strategy to improve germination, seedling vigour and yield performance in okra. Several research have demonstrated that hormonal priming with GA_3, NAA and salicylic acid significantly enhance the germination percentage and reduces the mean germination time, thus promoting robust early growth (11). Priming with GA_3 has improved the seedling dry weight, vigour indices, morphological traits and fruit characteristics in okra (12).

Also, GA_3priming promotes seedling sprouting, accelerates growth and activates cell-specific enzymes for carbohydrate metabolism, chlorophyll biosynthesis and other critical enzymes which contribute to embryo development, seed germination and seedling development. Seed priming with salicylic acid (SA) has improved the viability of okra. In similar way, application of SA enhances the biochemical traits and growth of okra plants (13). Seed priming and external application of SA improve seed germination and plant productivity by controlling the leaf water content, leaf pigments and photosynthetic characteristics (14). The purpose of this study was to assess the effect of seed priming with SA, GA_3 and cow urine on morpho-phenological parameters and quality of okra (*Abelmoschus esculentus* L.).

Materials and Methods

Location of experiment

The proposed research was carried out at the Vegetable Farm, Department of Horticulture, Lovely Professional University, Phagwara, Punjab from July to September 2024-2025 to determine how okra will react to seed priming under different treatments in var. Pusa Sawani.

Climatic conditions

The climate of the experimental field is subtropical climate ranges from 23 °C to 43 °C at its highest point in the summer to 7 °C to 19 °C at its lowest point in the winter. The usual range of relative humidity is 30 % to 85 %. Mid-June to early September is when there is the most rainfall, while winter rainfall is more sporadic. The region gets roughly 686 mm of rain on average every year.

Treatment details

The experiment consisted of one factor: 7 levels of seed priming with different solutions. viz. T_1: control (no priming), T_2: (GA_3 200 ppm), T_3: (cow urine 50 %), T_4: (SA 100 ppm), T_5: (GA_3 200 ppm + cow urine 50 %), (T_6:GA_3 200 ppm + SA 100 ppm), T_7: (Cow urine 50 % + SA 100 ppm). There were 7 treatments combinations. The experiment was laid out in RBD with three replications.

Variety

Pusa Sawani variety was selected for the experiment on seed priming. It was developed by cross of IC-1572 and Pusa Makhmali at IARI, Pusa New Delhi. It is a popular variety for growing in the plains of North India in spring summer with smooth dark green pods. The seeds were procured from New Delhi for the investigation.

Procedure for preparing the priming treatment

A solution comprising of GA_3 (200 ppm), SA (100 ppm) and cow urine 50 % was prepared in separate beakers as per the treatment. The seeds of okra were immersed for 24 hr in varied PGRs. Primed seeds of okra were then shade dried. Subsequently, the primed seeds were sown on the prepared land.

Agronomic management

Tractor drawn cross cultivation method was adopted to prepare uniform seed bed. Primed okra seeds were sown on the prepared beds in ridges with a spacing of 45 × 30 cm having 10 plants per plot. Light irrigation was given for proper germination followed by subsequent irrigation at 7-10 days interval depending on soil moisture. Fertilizers were applied as per the recommended dose. Intercultural operations were carried out to control weeds and improve soil aeration. Pest and disease management practices were adopted as per standard agronomic recommendations to maintain healthy plants.

Observations recorded

Three plants were tagged from each plot for observing the germination parameters, growth parameters, yield parameters and quality parameters.

The germination was observed visually by counting the number of germinated seedlings at an interval of seven days. The shoot length and root length were recorded using measuring scale. Morphological observations were recorded and plant height was noted using measuring scale. Among the floral parameters, days to 50 % flowering was noted as the number of days from sowing until half of the plants in the plots had produced flowers. Mucilage content was quantified using standardised gravimetric methods. Iodine concentration was assessed via dry ashing followed by colorimetric analysis. Total mineral content was estimated using gravimetric method of ash determination.

Statistical analysis

The data generated from the present investigation will be subjected to statistical analysis using MS Excel and OP STAT. Critical Difference (CD) at a 5 % level was used for testing the significant difference among the treatment means.

Results

Germination parameters

Germination parameters are crucial for successful crop establishment and yield. The data regarding the gemination parameters influenced by seed priming with different treatments like GA_3, SA and cow urine is presented in Table 1, which demonstrates a significant effect. The seeds of okra with treatment T_2(priming with GA_3 200 ppm) exhibited a maximum germination percentage of 91.60 % whereas T_5consisting of priming with GA_3 200 ppm and cow urine 50 % showed 87.47 % germination. The minimum germination percentage (68.48 %) was deduced from T_1 (control) and T_4 (SA 100 ppm) treatment (68.48). The data further demonstrate that different priming treatments showed significant effect on shoot length of okra. Different priming treatments lead to a varying shoot length. The longest shoot length of 17.36 cm was recorded in treatment T_3 embodying priming with SA which is statistically similar to treatment combination T_6 (GA_3 200 ppm and

Table 1. Seed priming effect on germination parameters of okra

Treatment	Germination percentage (%)	Shoot length (cm)	Root length (cm)	Seedling length (cm)
T_1	66.43	9.65	8.11	18.16
T_2	91.60	16.15	9.24	22.19
T_3	66.89	17.36	9.60	17.94
T_4	68.48	14.51	8.27	18.40
T_5	87.47	15.82	8.89	18.53
T_6	76.63	17.01	8.50	19.87
T_7	76.51	12.90	8.49	19.03
C.D. 5 %	6.02	3.26	N/A	2.41
SE(m)	1.93	1.04	0.72	0.77

SA 100 ppm). Minimum shoot length of 9.65 cm was recorded from T_1 (control). Hence, seed priming with different concentrations can be successfully used to improve the germination and seedling growth in okra seeds. Seedling length is a critical parameter that reflects the overall vigour and early growth potential of a crop. It is an integrative measure that combines the elongation of both shoot and roots, indicating the seed's ability to establish successfully under field conditions. In terms of the seedling length, the data tabulated in Table 1 revealed that T_2 (GA_3 200 ppm) showed maximum seedling length of 22.19 cm in okra which was statistically superior over other priming treatments and the minimum seedling length of 18.16 cm was observed in T_1 (control).

Growth parameters

Growth parameters such as plant height, number of leaves, primary branches, node number are vital indicators of the physiological status and productivity potential of okra. Seed priming significantly enhances various plant growth parameters leading to better plant performance. The data concerning the impact of seed priming on growth parameters is presented in Table 2. The data clearly shows that the plant height of okra responded significantly due to different seed priming treatments at all growth stages. Plant height was recorded at 30, 45, 60 and at final harvesting day (cm). Taller plants of 30.47, 57.00, 65.00, 79.66 cm okra were produced from the plots comprising of the treatment T_2 with GA_3 200 ppm which exhibited significant superiority at 30, 45, 60 DAS and at final harvesting. The plant height of okra was minimum 22.73, 41.66, 51.33, 70.00 cm under the treatment T_1 (control) at 30, 45, 60 DAS at harvest, respectively.

Number of leaves is a key growth parameter that directly influences the synthetic capacity and assimilate production of okra. The data attributing to number of leaves per plant at 30, 45, 60 DAS and at final harvesting is presented in Table 1. More number of 9.33, 20.33, 21.33, 23.66 leaves were noted from the plot with the application of GA_3 200 ppm (T_2) which was at par with treatment combination GA_3 with 200 ppm and SA 100ppm (T_6) with 8.66, 18.66, 19.33, 21.33 leaves recorded at the crop growth stage of 30,45,60 DAS and at final harvesting. Minimum number of 5.66, 14.33, 16.33, 19.33 leaves were transcribed from T_1 (control) at 30, 45, 60 DAS and at final harvesting, respectively, the results were consistent with those reported in a previous study (14). GA_3 at 300 ppm with acid-priming provided a better result concerning the number of leaves and leaf length.

The number of primary branches in okra is an important morphological trait that contributes to the plant's architecture, flowering site and ultimately the yield potential. More number of primary branches means greater surface area for leaves to capture sunlight for photosynthesis, which is essential for the growth and food production. Maximum number of 7.00 primary branches (7.00) was obtained in okra plants seed primed with GA_3 200 ppm (T_2). Contrastingly, minimum number of 4.66 primary branches was documented from T_1 (control). The effect can be explained by the role of gibberellic acid in stimulating cell division and elongation in meristematic tissues, promoting lateral bud growth and apical dominance, which collectively encourages branching.

The nodes serve as a potential site for leaf initiation, flower bud formation and fruit development. An increased number of nodes enhances the plant's capacity to bear a greater number of leaves and reproductive structures, ultimately contributing to higher yield. The number of nodes per plant ranged from 10.33 to 15.66. Notably, the highest count of nodes per plant, which was (15.66), occurred in T_6 (priming with GA3 200 ppm and 100 ppm of SA), comparable to T_2(priming with GA3 200 ppm). In contrast, the less count was noted in T_1 (control) treatment at (10.33). The treatment of GA_3 (200 ppm) indicates the effectiveness in modulating plant architecture for better growth and yield potential.

Stem diameter is an important growth parameter that reflects the structural strength and vigour of plant. A thicker stem provides better mechanical support for leaves, floral primordia and fruits, while serving as a conduit for efficient transport of water and nutrient assimilates. The maximum magnitude of stem diameter (2.24 cm) was recorded when the seed riming was done with GA_3 200 ppm (T_2) whilst, minimum stem diameter (1.39 cm) was calibrated from T_1 (control).

Earliness in fruit harvest ensures an extended harvesting period, earl market availability and higher economic returns for growers. Time of first picking is influenced by the plant's vegetative growth rate, flowering initiation and fruit development. Early picking of the fruit of okra at 38.33 days was achieved from plots with seed priming with GA_3 200 ppm (T_2) for 24 hr, demonstrating a

Table 2. Impact of seed priming on growth attributing traits of okra

Treatment	PH at 30 days (cm)	PH at 45 days (cm)	PH at 60 days(cm)	PH at final harvest (cm)	NOL at 30 days	NOL at 45 days	NOL at 60 days	NOL final harvest	NOPB	NON	SD	DTFP	DTFI	NOF	Days to 50 % flowering	DTFtI	IL
T_1	22.73	41.66	51.33	70.00	5.66	14.33	16.33	19.33	4.66	10.33	1.39	47.33	39.33	14.33	45.33	51.33	4.44
T_2	30.47	57.00	65.00	79.66	9.33	20.33	21.33	23.66	7.00	14.00	2.24	38.33	35.33	16.88	37.66	42.66	6.50
T_3	23.50	45.33	54.00	71.00	7.66	17.66	18.66	19.33	5.33	13.00	1.65	45.00	36.33	16.03	39.33	45.66	6.08
T_4	25.82	47.33	56.66	71.33	8.00	18.33	18.33	19.00	4.66	13.66	1.49	41.33	38.66	15.39	41.00	47.66	5.55
T_5	28.00	48.66	58.00	75.66	7.33	17.00	18.66	20.00	5.33	11.33	1.81	40.66	36.66	16.44	40.66	46.66	5.86
T_6	29.73	49.66	60.33	78.66	8.66	18.66	19.33	21.33	5.66	15.66	1.88	39.33	38.00	16.83	42.33	48.66	6.11
T_7	23.00	42.00	53.33	70.66	6.00	15.33	16.66	19.66	5.00	12.66	1.66	44.33	39.00	14.84	43.00	50.33	5.79
C.D. 5 %	4.94	3.28	4.72	1.89	1.62	2.16	1.68	1.36	1.12	1.93	0.23	5.90	1.69	1.59	2.06	1.12	1.15
SE(m)	1.58	1.05	1.51	0.60	0.52	0.69	0.54	0.43	0.36	0.61	0.07	1.89	0.54	0.51	0.66	0.36	0.37

PH- Plant Height; NOL- Number of Leaves; NOPB- Number of Primary Branches; NON- Number of Nodes per plant; SD- Stem Diameter; DTFP- Days to First Picking; DTFI- Days to Flower Initiation; NOF- Number of Flowers per plant; DTFtI- Days to Fruit Initiation; IL- Internode Length statistically significant advantage over all treatments. Conversely, T_1 (control) recorded the longest duration to the first harvest at 47.33 days. The results along with the findings in previous research, indicates that the application of plant growth regulators like GA_3 enhances the interval between flowering and harvesting (11). Earliest fruit picking in T_2 is attributed to its ability to stimulate early vegetative growth, promote faster transition from vegetative to reproductive growth.

The earliest onset of flowering occurred in T_2 (priming with GA_3 200 ppm), T_3(priming with cow urine 50 %) and T_5(GA_3 200 ppm + cow urine 50 %), respectively which were at par with each other i.e., 35.33, 36.33 and 36.66 days. However, treatment T_1 (control) exhibited delayed flowering time of 39.33 days. Seed priming for the treatment $T_2$with seed priming with GA_3 200 ppm produced maximum number of 16.88 flowers juxtaposed to other treatments. It is also evident that T_1(control) gave minimum number of 14.33 flowers per plant. The shortest duration to reach 50 % flowering was recorded at 37.66 days when seed priming with the T_2(GA_3 200 ppm), which was at par with the T_4 (SA @ 100 ppm) treatment at 39.33days. The longest duration to achieve 50 % flowering (45.33) were found in T_1(control).

Fruit initiation in okra depends on the rate of vegetative growth, timely floral induction and successful pollination. Number of days to fruit initiation is a critical parameter in okra cultivation as early fruiting not only extends the harvesting period but also allows farers to capture premium market prices. Early days (42.66) to fruit initiation were found in seed priming with GA_3 200 ppm (T_2) treatment closely followed by T_4(SA 100 ppm) at 45.66 days. The longest duration to fruit initiation (51.33) were measured from plot with treatment T_1(control) comparable to T_7.

Internodal length directly affects the plant height, canopy structure and light interception. Seed priming significantly influences internodal length by enhancing early growth and physiological activity. The maximum internodal length of 6.50 cm was documented from plots with $T_2$when done with GA_3 200 ppm). Shortest internodal length of 4.44 cm was recorded from T_1 (control) treatment. Studies have reported that primed seeds produce plants with greater internodal length compared to untreated controls, contributing to improved plant architecture and potentially better yield performance in okra.

Yield parameters

Seed priming treatment had a notable difference in the number of fruits, fruit length, fruit diameter and fruit weight produced per plant in okra. Seed priming enhances the number of fruits per plant by promoting uniform and vigorous growth in okra. T_2 treatment comprising of seed priming with GA_3at 200 ppm resulted in an average of 14.33 fruits per plant, which was comparable to the T_6 treatment when priming with GA_3 at 200 ppm. Plant growth regulators result in better root and shoot development, leading to robust plants capable of producing more flowers and subsequently a higher number of fruits. In contrast, the less average number of 8.66 fruits per plant were recorded in the control treatment T_1.

Length of okra pod is important yield and market quality parameter. Longer pods are preferred in markets for better appearance, higher consumer appeal and greater edible portion per fruit. Seed priming done with GA_3 200 ppm (T_2) showed longest fruit length of 11.38 cm, on the other hand, shortest fruit length of 8.35 cm was found from T_1 (control). The findings encompassing the fruit diameter of okra showed that treatment T_2 consisting of priming with GA_3 200 ppm resulted in maximum fruit diameter of okra of 1.66 cm. This was closely followed by T_6 with seed priming with GA_3 200 pm along with SA 100 ppm yielding a diameter of 1.33 cm. The minimum fruit diameter of 0.76 cm was recorded in T_1 control group which was comparable to treatment combination T_7encompassing cow urine 50 % and SA 100 ppm produced a diameter of 0.79 cm. In regard to the fruit weight of okra, it could be compounded from the set of observations that seeds priming with GA_3 200 ppm showed maximum fruit weight of okra (11.13 g), while the control group (T_1) recorded lowest 8.50 g. GA_3 improves the translocation of photosynthates towards developing fruits increasing fruit weight and diameter. Studies have shown that okra seeds primed with GA_3 produce longer, thicker and heavier fruits compared to unrimed seeds.

Fruit yield in okra refers to the total weight of marketable pods produced per plant or per unit area over growing period. Okra fruit yield is influenced by fruit size, fruit weight, plant density and number of fruits per plant. Higher yield is associated with vigorous plant growth, optimal flowering and efficient fruit set. The results of the array of observations recorded for fruit yield per plant substantiated that the treatment T_2(priming with GA_3 200 ppm) yielded more 115.66 g exhibiting significant superiority and was followed treatment combination T_6 consisting of priming with GA_3 200 pm with SA 100 ppm possessing 109.33 g fruit weight per plant. The lowest fruit yield per plant of 71.33 g was evinced from treatment T_1(control) which was comparable to T_3involvingpriming with 50 % cow urine yielding 90.66 g. In contrast, treatment T_2 in which priming with GA_3 200 ppm was done achieved the highest fruit yield of 6.60 kg per plot closely preceded by T_6 which combined priming with GA_3 200 pm and SA 100 ppm, yielding 6.36 kg fruit yield. The control group (T_1) exhibited lowest fruit yield 3.66 kg per plot which at par with the T_3(priming with cow urine 50 %) treatment (4.16 kg). The array of observation appertaining to the fruit yield per hectare tabulated in Table 3. The plots with treatment T_2 encompassing of seed priming with GA_3 200 ppm recorded the highest fruit yield of 16.40 q ha^{-1} depicting significant superiority. T6 comprising of priming with GA_3 200 pm along with SA 100 ppm produced a fruit yield of 15.03 q, while the lowest yield (9.36 q ha^{-1}) was observed in the control (T_1). A similar study observed that GA_3 at 200 ppm out preformed both the control and other treatments (14).

Quality parameters

Mucilage is a gel-like substance responsible for slimy texture in the fruit of okra. Ash content indicates mineral richness and nutritional quality. Seed priming treatment had a significant difference on mucilage content in okra (Table 3). The plots with treatment T_6comprising of priming with GA_3 200 ppm reported highest mucilage content i.e. (5.56 %). The treatment T_1(Control) disclosed a minimum mucilage content of 4.12 %. Dry matter content influences the nutritional and sensory characteristic and determines the texture, flavour and shelf life of fruit. In regard to the dry matter content, T_2consisting ofGA_3 200 ppm gave a maximum magnitude of 7.58 % which was preceded by T_5 encompassing GA_3 200 ppm with cow urine 50 % giving a value of 6.66 %. The treatment T_1(control) had the lowest magnitude (6.15 %) for dry matter content.

Table 3. Impact of seed priming on yield and quality attributing traits of okra

Treatment	Number of fruits per plant	Fruit length (cm)	Fruit diameter (cm)	Fruit weight (g)	Fruit yield per plant (g)	Fruit yield per plot (kg)	Fruit yield per hectare (q)	Mucilage content (%)	Dry matter (%)	Total minerals (Ash content) (%)	Iodine content (mg)
T_1	8.66	8.35	0.76	8.30	71.33	3.66	9.36	4.12	6.15	1.92	7.14
T_2	14.33	11.38	1.66	11.13	115.66	6.60	16.40	5.56	7.58	2.92	12.99
T_3	9.00	10.00	0.91	8.50	90.66	4.16	11.56	4.13	6.18	1.93	8.76
T_4	12.33	9.47	0.85	9.06	95.66	5.36	13.06	4.23	6.23	2.04	9.63
T_5	13.66	9.39	0.90	9.43	101.66	5.40	13.63	5.42	6.66	2.53	12.54
T_6	13.33	10.15	1.33	9.96	109.33	6.36	15.03	4.50	6.46	2.41	11.10
T_7	9.66	8.48	0.79	8.83	95.00	4.90	12.06	4.30	6.38	2.32	10.20
C.D. @5 %	1.68	0.42	0.56	1.13	6.92	0.59	1.43	0.09	0.46	0.05	0.60
SE(m)	0.54	0.13	0.18	0.36	2.22	0.19	0.46	0.03	0.15	0.01	0.19

Total ash content is an indicator of mineral composition of okra, directly influencing the nutritional values. The set of data revealed that plots with treatment T_2(GA_3 200 ppm) showed the maximum total minerals (ash content) (2.92 %) at par with the T_5 (GA_3 200 ppm + cow urine 50 %) treatment (2.53 %) followed by T_6 (GA_3 200 ppm and SA 100 ppm) treatment (2.41 %). The minimum total minerals (ash content) (1.92 %) were obtained from T_1(control). Iodine content in okra contributes to the overall quality and nutritional profile of crop. Iodine content showed the maximum value of 12.99 mg in plot T_2 with $GA_3$200 ppm which was succeeded by treatment combination T_5 with application of $GA_3$200 ppm and cow urine 50 % (12.54 mg). Minimum value of 7.14 mg iodine was recorded from T_1(control). Therefore, seed priming serves as an effective pre-sowing technique not only to boost yield but also improve the postharvest quality and nutritional characteristics of okra, making it beneficial for growers and consumers.

Discussion

Germination parameters

Seed priming significantly improves okra germination by overcoming dormancy and enhancing seed quality. Okra seeds can be slow to germinate owing to the hard seed coat. Seed priming helps to break down the dormancy, allowing the seed to germinate more quickly. It could be evinced from the experimental findings that priming with GA_3 200 ppm exhibited superiority which was preceded by the seed priming with GA_3 200 ppm and cow urine 50 %. A previous study used SA, the specific concentrations and application methods differed, leading to variations in the observed shoot length (15). This significant increase may be attributed to enhanced metabolic activities in the treated seeds. Increasing the concentration of SA used in seed priming appears to correlate with longer seedling length. The possible reason of this increment might be due to increased cell division within the apical meristem, cell division, or its role in cell elongation of seedling shoots and roots, which caused an increase in plant growth. In terms of the seedling length, maximum value was noted from seed priming with GA_3@ 200 ppm. This may be attributed due to enhanced enzymatic activities responsible for germination that increased the seedling length. These improvements can be attributed to the activation of metabolic processes during the priming phase, which prepares the seed for rapid and uniform germination upon sowing (16). Among the various priming treatments, GA_3showed pronounced effect, likely due to its role in breaking dormancy and stimulating enzymatic activity involved in mobilizing seed reserves. Enhanced germination of treated seeds than the untreated seeds also contributed to the seedling length (17), the findings also align with previous studies (18-22).

Growth parameters

Growth parameters of okra akin to the plant height, number of leaves, number of primary branches, number of nodes, stem diameter and the phenological attributes such as days to first picking, days taken to first flower initiation, number of flowers per plants revealed that the okra seeds primed with illustrated better results. The improvement in growth with the application of GA_3 might be attributed to their function in stimulation of metabolic activities and hormonal regulation. GA_3 that stimulates the growth of plant tissues there by enhancement in cell multiplication and cell elongation resulting in increased growth and flowering. The observations agree with the findings of another study which suggest that GA_3 primed seeds results in highest number of branches, internodes per plant and fruit length, which may be due to GA_3, that promotes seedling establishment and increased meristematic cell activity in seedlings, which is essential for plant vigour growth and fruit size (4). GA_3stimulates the metabolic activities and hormonal regulation. Stem diameter correlates positively with plant height, number of fruits and fruit weight. Thicker the stem, stronger and healthier the plant. A higher leaf count enhances the plant's ability to capture sunlight, synthetize carbohydrates and support the vigorous vegetative and reproductive growth. The treatment led to considerable increase in leaf count, suggesting a synergistic effect of the organic nutrient as GA_3 promotes cell division and leaf initiation. The increase can be attributed to the role of gibberellic acid in enhancing cell elongation and tissue differentiation through activation of cambial activity. GA_3 promotes expansion of vascular tissues, thereby increasing the girth of the stem and improving nutrient translocation within plant.

More number of flowers in okra were noted from seed primed with GA_3, this outcome could be linked to the vigorous vegetative growth observed in the plants treated with GA_3, leading to a greater accumulation of assimilates and enabling higher flower production, as noted in the study by (23).

Priming allows the plants to reach maturity more quickly. It improves the physiological quality of seeds making them less susceptible to stress during germination and produce early growth, which further contributes to faster flowering. In accordance with the early days to flowering, a greater number of 50 % flowering, it was acknowledged that GA_3 may promote an increased number of flowers by transforming axillary buds into new shoots, thereby providing more sites for blooming, as a result, a larger number of flowers contributing to a higher fruit yield. Additionally, GA_3 enhances the efficient movement of photosynthesis (11). This effect may be attributed to GA_3capacity to maximize the number of flowering plants by hastening the development of axillary buds into new shoots, thus providing more sites for flowers and enhancing flower production, which ultimately results in a higher fruit yield. Furthermore, GA_3 facilitates improved translocation of photosynthates. Similar findings were documented in previous studies (19, 22, 24-27). Early days to fruit initiation and internodal length of okra plant transcribed from the plots with okra seed priming with GA_3 200 ppm. Seed priming leads to increased internodal length in okra leading to faster and more robust plant growth. The observed growth enhancement owing to GA_3 could be associated with its role in promoting metabolic processes and hormonal regulation. GA_3 contributes to the stimulation of plant tissue growth, leading to increased cell division and elongation, which in turn fosters greater growth and flowering. SA contrastingly is used to improve flower retention and reduce flower drop by stabilizing plant hormone and antioxidant system. Similar findings were documented in previous studies (19, 22, 24-27).

Yield attributes

Priming okra seeds with GA_3 and SA, improved the yield attributes as the synergy of hormonal balance and stress resilience make seed priming a valuable pre-sowing treatment for maximizing okra productivity. More number of fruits per plant noted under the treatment of priming with GA_3 are in proximity with the results obtained in previous studies which recorded that more yield in plant growth regulators enhanced the yield of bottle gourd as it produced a greater number of fruits per plant thus proving the highest fruit yield (20). However, least number of fruits per plant were produced under control thus providing the lowest yield. Plants treated with GA_3 showed increased physiological activity, which led to a greater number of branches and fruiting sites, thereby enhancing their ability to capture sunlight to produce more photo assimilates. This improved accumulation and distribution of photo assimilates resulted in a higher quantity and longer length of fruits in GA_3 treated plants. Results from another study also show a significantly higher number of fruits in the GA_3 treatment (25). Plants treated with GA_3 became physiologically more active, resulting in an increased number of branches and fruiting points, which enhanced the utilization of sunlight for the formation of more photo assimilates. Because of better accumulation and distribution of this photo assimilates, the maximum number of fruits and fruit length were obtained in GA_3 treated plants. GA_3 at 200 ppm was more effective in respect of yield/plant when sprayed on acid primed seedlings. Comparable results were indicated in another studies (28-30).

Quality parameters

The physical quality of okra from various genotypes was evaluated after the implementation of priming treatment. Mineral content was significantly affected by seed priming treatment and soaking durations. Effect of seed priming treatments and soaking duration on crude protein was statistically at par in okra fruit. It has been opined by many scientists that the dry matter values increase in the primed seeds. Mucilage are water soluble polysaccharides found in wide variety of plants and their contents in okra varied with the primed seeds. Improvement in the content of iodine may be attributed to hydration and imbibition. Similar results were shown in another study which concluded that seed priming with plant growth regulators had the positive effect on quality (28). Similar findings were documented in other studies (9,19,20,22,25).

Conclusion

Seed priming is one method that could aid in hastening and enhancing the consistency of plant growth and seed germination. It is a seed treatment in which the seeds are partially hydrated by soaking them in a specific solution so that almost all seed metabolic processes take place before germination and then redried to restore the original seed moisture content. Seed priming treatments improve seed root emergence, germination speeds, seed vigour, seedling vigour and uniform seedling establishment in the field by altering numerous physiological activities. Seed priming had a significant effect on the germination, growth, yield and quality parameters of okra. In the present study, priming seeds with gibberellic acid resulted in notable enhancements across a range of vegetative and reproductive traits. Findings indicated that okra seeds treated with GA_3at 200 ppm and combination of GA_3at 200 ppm along with SA at 100 ppm exhibited the highest seedling length, branches per plant, leaves per plant, stem diameter, days to 50 % flowering, fruit length, fruit weight, number of fruits per plant and overall fruit yield. It can be inferred that among all the priming methods, seeds primed with GA_3 at 200 ppm proved to be the most effective, as they exhibited earlier germination, superior growth, yield and quality. The practical utility of this study lies in its potential to increase yield and quality using this technique, thereby supporting high efficiency vegetable production, in resource limited farming system. Future research may explore the interactive effect of $GA_3$with bio stimulants or micronutrients under varied agro-climatic conditions to optimize the protocol.

Acknowledgements

We would like to thank Lovely Professional University for providing the necessary facility to carried out the research.

Authors' contributions

LCA conducted the experiment. R designed the study, developed the methodology, performed the statistical analysis and supervised the research. AS contributed to the study design and statistical analysis. SS conceived the study and participated in its design and coordination. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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