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Synergistic Effects of Plant Population and Foliar Application of GA_3 on Growth and Flowering Performance of Cocksflower

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Accurate optimization of plant population and foliar application doses of growth regulators like GA_3 can play a crucial role in enhancing growth and flower dynamics of flowering plants under different climate scenarios. An experiment was conducted to investigate how different plant populations and foliar applications of GA_3 at different concentrations influenced the vegetative growth performance and flowering performance of cocksflower. The experiment followed a Randomized Complete Block

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Design (RCBD) with 3 replications and consisted of two factors. Factor A: Three levels of plant population: P_1: 12 plants plot^{-1} (160,000 plants ha^{-1}), P_2: 15 plants plot^{-1} (200,000 plants ha^{-1}), P_3: 18 plants plot^{-1} (240,000 plants ha^{-1}) and Factor B: G_0 = 0 ppm GA_3, G_1 = 50 ppm GA_3, G_2 = 100 ppm GA_3, and G_3 = 150 ppm GA_3, respectively. Plant population and GA_3 levels resulted significant variations for most of the parameters. P_1G_2 consistently showed superior growth across all stages. It recorded the tallest plants (33.16, 53.15, and 69.12 cm), the longest stems (13.28, 20.81, and 35.52 cm), and the longest spikes (9.18, 14.75, and 25.09 cm), highest spikelet numbers (2.46, 3.46, and 4.53 per spike), at 15, 30, and 45 DAT, respectively confirming its overall growth advantage. P_1G_2 produced the highest spikes per plant with 8.40, and this supported 100.80 spikes per plot and 1344000 spikes per hectare. The results demonstrated that optimum plant population and GA_3 usage of 100 ppm by foliar application give better results for growth and flowering performance of cocksflower.

Keywords: Plant population; GA3; flowering performance; Celosia plumosa.

1. INTRODUCTION

Cocksflower (*Celosia plumosa*) from the genus *Celosia*, family Amaranthaceae, and class Magnoliopsid (Priyadharsini et al*.,* 2025). The common names of *Celosia* are cockscomb, crested celosia, foxtail amaranth, fire-flame bush, yellow toreador, red cockscomb and Wood fordia. They are all herbaceous, hardy perennials with a height of between 6 cm and 1.5 m. It is quite common in Mexico, Northern regions of the South America, Tropical Africa, West India and Southeast Asia, where it is cultivated as a native wildflower (Bakonyi et al., 2020). Beyond its ornamental significance, cocksflower holds medicinal value, with its flowers traditionally used for their astringent properties and in the treatment of ailments such as pain and dysentery (Al-Fatlawi & Al-Bayati, 2021). Environmental conditions, such as light intensity, photoperiod, and temperature, further modulate growth dynamics and flowering time, with optimal conditions promoting robust development and ornamental quality (Lee et al*.,* 2023; Orlando et al*.,* 2022).

The population density of the plants is a very crucial agronomic parameter that affects the growth, development and reproductive success of most crop species (Abas et al*.,* 2025). The high densities of plants are often associated with high levels of biomass per square area along with a decrease in the size of the individual plants, their branching, and reproductive performance because of the common occurrence of increased competition, especially with light, on the other hand, low densities can encourage higher growth and flowering but low yield per unit area (Postma et al*.,* 2020). The gibberellic acid (GA_3) and other plant growth regulators have become significant horticultural tools in attempting to control the growth of plants, change vegetative vigour, and improve the reproductive characteristics (Sharma et al., 2024). Foliar application of GA_3 has been shown to stimulate cell elongation, enhance photosynthetic activity, and promote early and prolific flowering across a range of ornamental and crop species (Islam et al., 2023). Within the Amaranthaceae family, which includes both economically important crops and ornamentals, optimizing growth and flowering is essential for maximizing yield, quality, and ornamental value (Wadagave et al., 2024; Salachna et al., 2020).

Among these agronomic practices, population density and plant growth regulator application, such as that of gibberellic acid (GA_3), have become critical factors affecting the development of plants and their reproductive success (Karki et al., 2021). Plant population, or spacing, directly affects resource availability, including light, nutrients, and water, impacting plant architecture, biomass accumulation, and, ultimately, flowering characteristics (Mladenović et al*.,* 2020). While dense populations may lead to competition and reduce performance of individual plants, wider spacing can allow for better growth but might not maximize land use efficiency. Concurrently, the foliar application of GA_3 - a well-known plant growth regulator - has been widely reported to stimulate cell elongation, enhance vegetative growth, and promote earlier and more prolific flowering in several ornamental species (Chandel et al., 2023; Sharma et al., 2023). However, the interaction of plant population with GA_3 application is not well understood and remains largely unexplored in *Celosia plumosa.* Understanding the synergistic effects of these two factors is crucial for developing an integrated cultivation strategy that maximizes both growth and floral yield (Al-Fatlawi & Al-Bayati, 2021).

This study aims to investigate how varying plant population densities and application of GA_3 influence the vegetative growth performance and flowering performance of cocksflower and to find the best combination of plant population and GA_3 for the growth and flowering of cocksflower.

2. MATERIALS AND METHODS

2.1 Site Description of the Experiment

The study was placed at the Horticulture Farm, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh, at 90°22' E longitude and 23°41' N latitude and 8.2 m above sea level. The location falls within the Modhupur Tract Agro-Ecological Zones (AEZ-28), which is red clay loam soil that developed on top of the Modhupur clay and contains small hillocks that are enclosed by floodplains. The soil was sandy loam and moderately fertile and had a pH of 6.0.

2.2 Experimental Design

Randomized Complete Block Design (RCBD) considering three replications was selected in the following two-factor experiment. The blocks were divided by 12 plots with all the treatments randomly allotted. The total plots of the experiment were 36 units. Each plot size was 1 m × 0.75 m. Plots were made with the distance of 0.5 m between blocks and 0.5 m of drains.

2.3 Planting Materials and Seedbed Preparation of the Experiment

Flame-mix cocksflower seed had been taken at KRISHIBID NURSERY, Agargaon, Dhaka-1207. A single packet of cocksflower consisted of a thousand seeds. The broadcasting method was used to prepare the standard seedbed and plant cocksflower in the first week of February (Kharif-I season). After the seedling emergence, irrigation was applied as per requirements.

2.4 Fertilizers and Manures Application

Urea, Triple Super Phosphate (TSP) and Muriate of Potash (MoP), respectively were used in the experimental field. Full dose of cowdung (5 t ha^{-1}), Urea (68 kg), TSP (23 kg), MoP (17 kg) and Gypsum (4 kg) were used during final land preparation.

2.5 Selected Treatments

The treatments of the experiments were Factor A: Plant population; P_1: 12 plants $plot^{-1}$ (160,000 plants ha^{-1}), P_2: 15 plants $plot^{-1}$ (200,000 plants ha^{-1}), P_3: 18 plants $plot^{-1}$ (240,000 plants ha^{-1}) and Factor B: GA_3 concentration; G_0: Control, G_1: 50 ppm GA_3, G_2: 100 ppm GA_3, G_3: 150 ppm GA_3.

2.6 Preparation and Application of GA_3

GA_3 was procured from a local agricultural chemical supplier in Dhaka. A weighing of 50 mg of gibberellic acid was performed using an electric balance and dissolved in a small amount of 90% ethyl alcohol. A 50-ppm solution was then collected by transferring the solution to a 1000 ml volumetric flask and filling it up to 1000 ml with distilled water. Following the similar procedure, other solutions of 100 and 150 ppm were prepared. Each application was done by making a fresh solution. GA_3 was used in three splits at 10, 25 and 40 days following the transplantation process with the help of a hand sprayer.

2.7 Transplanting and Intercultural Operations

Plantlets at the height of 2.5-5.0 cm and 25 days old were transplanted to the experimental field during afternoon. Considering the plant population, thinning was done as required. Light overhead irrigation was provided. Weeding was done in all the plots if necessary to keep the plots free from any weeds and ensure easy soil aeration.

2.8 Data Collection

2.8.1 Vegetative characteristics

- **Plant height (cm)**
  Plant height was measured from the ground level up to the tip of the growing point of the plant. Plant height was recorded in centimeters (cm) from randomly selected ten plants at 15, 30 and 45 DAT by using a meter scale, and the average value was calculated.
- **Number of leaves per plant**
  The leaves number per plant was counted, and recorded from randomly selected ten plants at 15, 30 and 45 DAT, and the average value was calculated.
- **Number of branch**
  The number of branches was measured and recorded from randomly selected ten plants at 15, 30 and 45 DAT by using a scale and the average value was calculated.

- **Stem length (cm)**
  Stem length was measured in centimeters (cm) from randomly selected ten plants at 15, 30 and 45 DAT by using a scale, and the average value was calculated.
- **Dry weight of plant (g)**
  The plant dry weight was recorded using an electric oven drying of the entire cocksflower plant. The dry weight of the plant was measured in grams (g) from randomly selected 10 plants after harvesting using an electric balance, and the average value was calculated.

2.8.2 Floral characteristics

- **Length of spike (cm)**
  The length of the flower stalk was measured from the base to the tip of the spike at 15, 30 and 45 DAT, and the average value was calculated.
- **Number of spikelet per spike**
  All the spikelets of the spike were counted from randomly selected 10 plants, and their average value was calculated at 15, 30 and 45 DAT.
- **Number of spikes per plant**
  Total numbers of spikes were counted from randomly selected 10 plants, and their average value was calculated after harvesting.
- **Number of spikes per plot**
  The total number of spikes was counted from randomly selected 10 plants, and it was multiplied by the total number of plants in each plot.
- **Number of spikes per ha**
  Total numbers of spikes were counted from each plot of 0.75 m^2 area and were converted to ha.
- **Dry weight of spike (g)**
  The dry weight of spike was measured after electric oven drying of the cocksflower after separating with knife cutting at the basal of the stalk. The spike dry weight was recorded in grams (g) from randomly selected 10 plants after harvesting by using an electric balance, and the average value was calculated.

2.9 Statistical Analysis

The average values of all the selected parameters were evaluated, and analysis of variance was performed with the help of 'STATISTIX 10', CV% was calculated, and the LSD test was used at a 5% ($P < 0.05$) significance level.

3. RESULTS

3.1 Vegetative Characteristics of Cocksflower

3.1.1 Plant height (cm)

The plants grew taller under wider spacing and higher GA_3 levels. The highest plant height came from P_1G_2 at every stage, with 33.16 cm at 15 DAT, 53.15 cm at 30 DAT, and 69.12 cm at 45 DAT (Table 1). Narrow spacing reduced height and kept the canopy compact. GA_3 at 100 ppm supported cell elongation and leaf expansion, which helped the plants maintain rapid height growth. These trends agree with earlier findings on ornamental species where GA_3 promoted strong stem elongation (Abass et al., 2025).

3.1.2 Leaf number per plant

Leaf production increased under wider spacing along with 100 ppm GA_3. P_1G_2 kept the highest leaf counts at all observation points, with 46.66 leaves at 15 DAT, 88.15 at 30 DAT, and 114.34 at 45 DAT (Table 1). Crowded stands produced fewer leaves because competition reduced light and nutrient availability. GA_3 helped the plants maintain higher leaf initiation and expansion. This pattern aligns with reports on celosia and related ornamentals where GA_3 increased vegetative growth and leaf formation (Sendhilnathan et al., 2019).

3.1.3 Branch number per plant

Branching responded strongly to both spacing and GA_3 concentration. P_1G_2 produced the most branches at each stage, reaching 3.13 branches at 15 DAT, 5.73 at 30 DAT, and 8.40 at 45 DAT (Table 2). Higher plant density reduced branching because the plants faced stronger shade and crowding. GA_3 at 100 ppm encouraged axillary bud activity and supported higher branching. Similar responses were reported in GA_3-treated flowering ornamentals (Zhang et al., 2022).

3.1.4 Stem length (cm)

Stem length increased under wider spacing and higher GA_3 levels. P_1G_2 produced the longest stems at all stages, with 13.28 cm at 15 DAT, 20.81 cm at 30 DAT, and 35.52 cm at 45 DAT (Table 2). Stem elongation dropped sharply under high-density planting due to limited

Table 1. Effect of plant population and GA_3 on plant height (cm) and leaves number per plant of cocksflower at different days after transplanting

Treatment	Plant height (cm) at			Leaves number per plant at		
	15 DAT	30 DAT	45 DAT	15 DAT	30 DAT	45 DAT
P_1G_0	20.51 e	41.74 g	62.94 de	38.66 efg	76.25 f	102.62 gh
P_1G_1	24.38 cd	44.69 ef	64.60 cd	42.77 bc	81.31 cd	108.40 cd
P_1G_2	33.16 a	53.15 a	69.12 a	46.66 a	88.15 a	114.34 a
P_1G_3	28.64 b	48.63 bc	66.68 b	43.77 abc	84.46 b	108.85 cd
P_2G_0	19.33 e	41.62 g	60.50 fg	35.81 gh	75.51 fg	100.30 hi
P_2G_1	23.26 d	44.73 ef	63.92 cde	41.81 bcd	79.88 de	105.29 efg
P_2G_2	29.62 b	50.91 ab	66.73 b	44.44 ab	86.74 a	112.22 ab
P_2G_3	25.64 c	47.23 cd	64.74 bcd	42.44 bc	82.89 bc	107.98 cde
P_3G_0	19.00 e	42.55 fg	58.55 g	33.58 h	74.17 g	97.71 i
P_3G_1	23.65 cd	46.19 de	62.48 ef	37.17 fg	79.25 e	104.42 fg
P_3G_2	27.76 b	49.46 bc	64.98 bc	41.42 cde	84.29 b	110.63 bc
P_3G_3	24.24 cd	47.39 cd	63.63 cde	39.17 def	82.35 c	107.17 def
LSD $_{(0.05)}$	2.11	2.38	2.03	2.95	1.59	3.08
CV (%)	5.00	3.03	1.88	4.29	1.16	1.71

[In every column means consist of similar letter(s) are statistically similar and means consist of dissimilar letter(s) differ significantly at 0.05 level of probability. Here, P_1: 12 plants plot^{-1} (160,000 plants ha^{-1}), P_2: 15 plants plot^{-1} (200,000 plants ha^{-1}), P_3: 18 plants plot^{-1} (240,000 plants ha^{-1}) and G_0 = 0 ppm GA_3, G_1 = 50 ppm GA_3, G_2 = 100 ppm GA_3, and G_3 = 150 ppm GA_3]

Table 2. Effect of plant population and GA_3 on branch number per plant and stem length (cm) at different days after transplanting and dry weight of cocksflower

Treatment	Branch number per plant at			Stem length (cm) at			Dry weight of plant (g)
	15 DAT	30 DAT	45 DAT	15 DAT	30 DAT	45 DAT	
P_1G_0	1.53 f	2.33 e	3.53 g	8.66 cdef	11.70 e	25.31 fg	184.86 e
P_1G_1	2.13 b	2.93 d	4.26 ef	9.89 c	14.85 d	28.80 e	189.44 bc
P_1G_2	3.13 a	5.73 a	8.40 a	13.28 a	20.81 a	35.52 a	193.46 a
P_1G_3	2.20 b	3.66 c	5.60 d	11.63 b	18.34 b	32.16 c	191.49 ab
P_2G_0	1.80 de	1.93 ef	2.80 h	7.29 fg	10.15 f	23.49 h	182.20 fg
P_2G_1	1.80 de	2.20 ef	3.53 g	8.37 def	14.12 d	26.78 f	187.60 cd
P_2G_2	2.20 b	4.66 b	7.33 b	11.58 b	18.22 b	33.77 b	191.56 ab
P_2G_3	2.13 b	3.40 cd	4.53 e	9.10 cde	16.54 c	30.45 d	189.92 bc
P_3G_0	1.46 f	1.73 f	2.40 h	6.28 g	9.15 f	22.16 h	180.44 g
P_3G_1	1.86 cd	2.33 e	3.73 fg	7.86 ef	12.53 e	25.25 g	184.21 ef
P_3G_2	2.06 bc	4.66 b	6.66 c	9.73 cd	16.71 c	31.22 cd	188.64 c
P_3G_3	1.60 ef	3.26 cd	4.26 ef	8.40 cdef	14.31 d	28.79 e	185.98 de
LSD $_{(0.05)}$	0.23	0.52	0.57	1.51	1.41	1.50	2.40
CV (%)	6.91	9.61	7.12	9.57	5.64	3.11	0.76

[In every column means consist of similar letter(s) are statistically similar and means consist of dissimilar letter(s) differ significantly at 0.05 level of probability. Here, P_1: 12 plants plot^{-1} (160,000 plants ha^{-1}), P_2: 15 plants plot^{-1} (200,000 plants ha^{-1}), P_3: 18 plants plot^{-1} (240,000 plants ha^{-1}) and G_0 = 0 ppm GA_3, G_1 = 50 ppm GA_3, G_2 = 100 ppm GA_3, and G_3 = 150 ppm GA_3]

light penetration. GA_3 improved internode extension through its effect on cell elongation, which agrees with earlier studies on GA_3 and stem development in ornamental crops (Zhang et al., 2022).

3.1.5 Dry weight of plant (g)

Dry matter accumulation rose under wider spacing and moderate GA_3 levels. P_1G_2 produced the highest plant dry weight at 193.46 g (Table 2). Higher density lowered dry matter accumulation because of strong competition for assimilates. GA_3 at 100 ppm supported dry weight through improved leaf area development and better source strength. Comparable patterns were reported in GA_3 studies on biomass formation in ornamentals (Wadagave et al., 2024).

3.2 Floral Characteristics of Cocksflower

3.2.1 Spike length (cm)

Spike growth responded strongly to both spacing and GA_3. The longest spikes came from P_1G_2, with 9.18 cm at 15 DAT, 14.75 cm at 30 DAT, and 25.09 cm at 45 DAT (Table 3 and Fig 1.). High-density planting lowered spike length because of limited photoassimilate supply. GA_3 increased spike elongation and promoted floral axis development. These findings support earlier reports on GA_3 influence on floral growth in celosia and similar species (Zhang et al*.,* 2022).

3.2.2 Spikelets per spike

Spikelet formation increased under wider spacing and 100 ppm GA_3. P_1G_2 recorded the highest spikelet numbers, reaching 2.46 at 15 DAT, 3.46 at 30 DAT, and 4.53 at 45 DAT (Table 3). Plants in crowded plots produced fewer spikelets due to restricted floral initiation. GA_3 supported spikelet formation through its effect on floral meristem activity. Comparable increases were reported in GA_3-treated inflorescences of ornamental plants (Wadagave et al., 2024).

3.2.3 Spike number per plant, per plot, and per hectare

Spike number improved under lower density and higher GA_3 concentration. P_1G_2 produced the highest spikes per plant with 8.40, and this supported 100.80 spikes per plot and 1344000 spikes per hectare (Table 4), which was close to the highest number of spikes per plot and spikes per hectare (118.00 and 1569778) even with low plant population. Dense stands produced fewer spikes per plant, but total spikes per hectare increased under very high density with GA_3 because of the larger plant count.

Table 3. Effect of plant population and GA_3 on spike length (cm) and spikelet number per spike of cocksflower at different days after transplanting

Treatment	Spike length (cm) at			Spikelet number per spike at		
	15 DAT	30 DAT	45 DAT	15 DAT	30 DAT	45 DAT
P_1G_0	4.10 gh	6.86 e	15.89 efg	1.06 b	1.00 e	1.26 d
P_1G_1	5.66 def	9.28 cd	19.53 cd	1.06 b	1.33 d	2.40 c
P_1G_2	9.18 a	14.75 a	25.09 a	2.46 a	3.46 a	4.53 a
P_1G_3	7.02 bc	12.54 b	23.10 ab	1.06 b	2.13 b	3.53 b
P_2G_0	3.45 hi	4.93 f	14.23 fg	1.06 b	1.00 e	1.26 d
P_2G_1	5.36 ef	7.75 de	14.93 fg	1.06 b	1.20 de	2.06 c
P_2G_2	7.28 b	12.26 b	21.73 bc	1.26 b	2.06 b	3.46 b
P_2G_3	6.17 cde	8.84 d	16.86 def	1.06 b	1.33 d	2.40 c
P_3G_0	2.93 i	4.12 f	12.81 g	0.66 c	1.00 e	1.00 d
P_3G_1	4.8 fg	6.60 e	16.78 def	1.06 b	1.66 c	2.46 c
P_3G_2	6.52 bcd	10.51 c	19.54 cd	1.06 b	1.93 bc	3.33 b
P_3G_3	5.39 ef	8.85 d	18.73 cde	1.06 b	1.13 de	2.40 c
LSD $_{(0.05)}$	1.09	1.60	3.10	0.30	0.30	0.66
CV (%)	11.43	10.60	10.04	15.72	11.20	15.71

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Table 4. Effect of plant population and GA_3 on flowering characteristics of cocksflower after harvesting

Treatment	Spike number plant^{-1}	Spike number plot^{-1}	Spike number ha^{-1}	Dry weight of spike (g)
P_1G_0	3.53 g	42.40 f	565333 e	16.53 d
P_1G_1	4.27 ef	57.47 e	766222 d	18.40 c
P_1G_2	8.40 a	100.80 c	1344000 b	22.36 a
P_1G_3	5.60 d	67.20 d	896000 c	19.73 b
P_2G_0	2.80 h	41.33 f	551111 e	14.66 e
P_2G_1	3.53 g	55.20 e	736000 d	16.40 d
P_2G_2	7.33 b	109.33 b	1422222 b	21.26 a

Treatment	Spike number plant^{-1}	Spike number plot^{-1}	Spike number ha^{-1}	Dry weight of spike (g)
P_2G_3	4.53 e	69.13 d	920000 c	18.60 bc
P_3G_0	2.40 h	43.20 f	576000 d	12.73 e
P_3G_1	3.73 fg	59.20 e	789333 d	14.50 e
P_3G_2	6.67 c	118.00 a	1569778 a	18.70 bc
P_3G_3	4.27 ef	73.47 d	979556 c	16.03 d
LSD $_{(0.05)}$	0.57	6.85	96214	1.17
CV (%)	7.12	5.80	6.13	3.97

[In every column means consist of similar letter(s) are statistically similar and means consist of dissimilar letter(s) differ significantly at 0.05 level of probability. Here, P_1: 12 plants plot^{-1} (160,000 plants ha^{-1}), P_2: 15 plants plot^{-1} (200,000 plants ha^{-1}), P_3: 18 plants plot^{-1} (240,000 plants ha^{-1}) and G_0 = 0 ppm GA_3, G_1 = 50 ppm GA_3, G_2 = 100 ppm GA_3, and G_3 = 150 ppm GA_3]

Fig. 1. Effect of plant population and GA_3 on spike length of cocksflower

3.2.4 Dry weight of spike (g)

Spike dry weight increased with wider spacing and 100 ppm GA_3. P_1G_2 produced the highest spike dry weight at 22.36 g (Table 4). Narrow spacing reduced spike mass because competition limited assimilate availability for floral structures. GA_3 improved spike mass through enhanced spike elongation and improved spikelet development. Similar increases in floral dry mass were reported in earlier GA_3 studies on flowering species (Sharma et al., 2024).

4. DISCUSSION

Proper plant-to-plant spacing was ensured through wider spacing; it favored taller plants as the canopy faced more sunlight and less competition, and vegetative growth was further enhanced when the plants were treated with 100 ppm GA_3. The previous experiment on *Celosia* and other ornamentals obtained the same reaction, where GA_3 led to an increase in stem lengths and vegetative vigour (Sravya et al., 2024). The high density lowered the height by limiting light access and retarding expansion of roots. The same trend was observed in the production of leaves as the height of the plant (Postma et al., 2020). The increased distance resulted in a greater number of leaves since the plants were getting lighter and more efficient with nutrients, and 100 ppm GA_3 kept the growth of leaves high (Abass et al., 2025). The PGR (GA_3) aided the emergence of new leaves and augmented the development of the leaf area. Research on annual ornamentals also revealed an increase in the number of leaves with GA_3, which facilitated vigorous photosynthesis and biomass development (Angitha et al., 2022). Plots with high plant population had fewer leaves, as the amount of assimilates was less. The high plant population density and 100 ppm GA_3 foliar application lowered per-plant performance of the plants since the plants experienced less light and increased competition for nutrients.

When the plants were grown in wider spacing, branching was enhanced. It occurred due to the fact that the shading of the plants was minimized and branching was further enhanced by GA_3 at 100 ppm. The PGR (GA_3) aided the activity of axillary buds and made the plants retain additional branches. *Celosia* and chrysanthemum also show similar results, as GA_3 enhanced canopy productivity and branching (Zhang et al., 2022). There was inhibited branching due to dense planting, as the plants used the resources on growth upwards instead of growing laterally. The findings demonstrated that GA_3 increased the length of stems of all planting densities, as the stems were the longest with GA_3 at 100 ppm. The similar findings were found in marigold, verbena, and salvia (Sharma et al., 2024). The high-density plots experienced shorter stem length because of intense competition for light. Extended interspersal allowed the plants to be more robust in the stem structure. Spike length was greater in the case of increased spacing and 100 ppm foliar application of GA_3. This reaction was in line with previous studies which showed that floral structures grow more effectively when plants are provided with more photosynthates and enhanced hormonal provisions. GA_3 induced lengthening of the spikes and favored the development of the floral axis. Zinnia (*Zinnia elegans* L.) was studied, and it was found that flowering parameters were improved with in the presence of 100-150 ppm GA_3 (Abass et al., 2025). Compact strands had short spikes due to the limitation of resources the plants had.

Low plant population density and the foliar application of 100 ppm GA_3 produced spikelet formation at best. GA_3 stimulated floral meristem, which enhanced the number of spikelets. The increased plant-to-plant distance also contributed to an increased supply of the plants to reproductive organs. Field experiments on GA_3 observed that GA_3 enhanced the number of spikelets and enhanced the quality of the floral (Wadagave et al., 2024). The high-plant-population-density plots constrained the spikelet development by insufficient nutrient and carbohydrate supply. The number of spikes per plant also went up with increased spacing and 100 ppm GA_3. There is an increase in per-plant productivity with an increase in spacing (Tyrus et al., 2023). Low plant population density and 100 ppm GA_3 stimulated spike introduction and facilitated the existence of additional floral arrangements per plant.

The dry weight of plants under low plant population density was higher since the plants had more leaves and branches, and GA_3 at 100 ppm boosted the growth of dry matter since it enhanced the activity of the sources and led to an increase in the rate of organ growth (Wadagave et al., 2024). The same outcome in the case of other ornamental crops revealed that the GA_3 treatment enhanced the biomass generation and a general enhancement in the plant architecture (Janowska & Andrzejak, 2023). Dense plant population decreased the dry matter due to heavy competition, but the dry weight of spikes grew with the broadened spacing and 100 ppm GA_3. The enhancement was associated with the elongation of spikes and increased spikelets. 100 ppm GA_3 aided the plants in distributing assimilates to reproductive structures. Researchers of flowering plants found that using GA_3 increased the mass of the spikes and the market value of inflorescences (Sharma et al., 2023). Synergic effect of low plant population and foliar application of 100 ppm GA_3 demonstrated the best outcome for cocksflower (*Celosia plumosa*) in terms of vegetative growth and flowering performance.

5. CONCLUSION

Lower plant population density led to an increase in stems, leaves, and branches, and the plants also yielded more dry matter, and the dose of GA_3 foliar application enhanced the elongation of the stems, increased the formation of the branches and the leaves, and also improved the formation of spikes, spike length, spikelet count, and spike dry weight. The overall results indicate that an optimal plant population combined with a GA_3 foliar application of 100 ppm leads to improved vegetative growth and flowering performance in Cocksflower (*Celosia plumosa*).

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology.

Details of the AI usage are given below:

1. During the preparation of this work, the author(s) used *ChatGPT 5.0 & DeepSeek* for grammar correction and language editing.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Abas, S. A., Abdulhamed, Z. A., & Abood, N. M. (2025). Impact of climate change on the growth, yield, and sunflower cultivar performance under the influence of plant density. *Iraqi Journal of Agricultural Sciences, 56*, 10-19. https://doi.org/10.36103/9z5web62

Abass, M., Wani, A. H., & Malik, K. M. (2025). Effect of growth regulator and nutrient spray to improve the growth, flowering, and seed production of zinnia (Zinnia elegans Jacq.). *Plant Archives*. https://doi.org/10.51470/PLANTARCHIVES.2025.v25.no.1.308

Al-Fatlawi, K. A. I., & Al-Bayati, M. Y. I. (2021). Response of Celosia argentea (Plumosa) to spraying with growth regulars (ABA and GA3). *IOP Conference Series: Earth and Environmental Science*. https://doi.org/10.1088/1755-1315/910/1/012018

Angitha, S., Singh, D., & Fatmi, U. (2022). Effect of plant growth regulators giberellic acid (GA3) and salicylic acid (SA) on growth and yield of carnation (Dianthus caryophyllus) under naturally ventilated polyhouse. *International Journal of Plant & Soil Science*. https://doi.org/10.9734/ijpss/2022/v34i2231392

Bakonyi, N., Kisvarga, S., Barna, D., Toth, I. O., El-Ramady, H., Abdalla, N., Kovacs, S., Rozbach, M., Feher, C., Elhawat, N., Alshaal, T., & Fari, M. G. (2020). Chemical traits of fermented alfalfa brown juice: Its implications on physiological, biochemical, anatomical, and growth parameters of Celosia. *Agronomy, 10*(2), 247. https://doi.org/10.3390/agronomy10020247

Chandel, A., Thakur, M., Rakwal, A., Chauhan, S., & Bhargava, B. (2023). Exogenous applications of gibberellic acid modulate the growth, flowering and longevity of calla lily. *Heliyon, 9*(5): e16319. https://doi.org/10.1016/j.heliyon.2023.e16319

Islam, M. S., Hasan, M. K., Islam, M. R., Chowdhury, M. K., Pramanik, M. H., Iqbal, M. A., Rajendran, K., Iqbal, R., Soufan, W., Kamran, C., Liyun, L., & Sabagh, E. A. (2023). Water relations and yield characteristics of mungbean as influenced by foliar application of gibberellic acid (GA3). *Frontiers in Ecology and Evolution, 11*, 1-12. https://doi.org/10.3389/fevo.2023.1048768

Janowska, B., & Andrzejak, R. (2023). Plant Growth Regulators for the Cultivation and Vase Life of Geophyte Flowers and Leaves. *Agriculture, 13*(4), 855. https://doi.org/10.3390/agriculture13040855

Karki, P., Atreya, P. N., & Shrestha, S. (2021). Effect of maleic hydrazide and gibberellic acid on growth and yield of African marigold (Tagetes erecta L.) cv. Calcuttia Orange. *Fundamental and Applied Agriculture, 6*(3), 272-278. https://doi.org/10.5455/faa.103177

Lee, Z., Kim, S., Choi, S., Joung, E., Kwon, M., Park, H., & Shim, J. (2023). Regulation of flowering time by environmental factors in plants. *Plants, 12*(21), 3680. https://doi.org/10.3390/plants12213680

Mladenović, E., Cvejić, S., Jocić, S., Ćuk, N., Čukanović, J., Jocković, M., & Marjanović Jeromela, A. (2020). Effect of plant density on stem and flower quality of single-stem ornamental sunflower genotypes. *Horticultural Science, 47*(1), 45-52. https://doi.org/10.17221/10/2019-HORTSCI

Orlando, M., Trivellini, A., Incrocci, L., Ferrante, A., & Mensuali, A. (2022). The inclusion of green light in a red and blue light background impact the growth and functional quality of vegetable and flower microgreen species. *Horticulturae*. https://doi.org/10.3390/horticulturae8030217

Postma, J. A., Hecht, V. L., Hikosaka, K., Nord, E. A., Pons, T. L., & Poorter, H. (2020). Dividing the pie: A quantitative review on plant density responses. *Plant, Cell & Environment, 44*(4), 1072-1094. https://doi.org/10.1111/pce.13968

Priyadharsini, R., Rajadurai, K. R., Beaulah, A., Madhan Mohan, M., Venkatesan, K., & Rajesh, S. (2025). Genetic variability and trait association studies in Celosia accessions for growth and yield characters. *Plant Science Today, 12*(2), 1-10. https://doi.org/10.14719/pst.7281

Salachna, P., Mikiciuk, M., Zawadzińska, A., Piechocki, R., Ptak, P., Mikiciuk, G., Pietrak, A., & Łopusiewicz, Ł. (2020). Changes in growth and physiological parameters of ×Amarine following an exogenous application of gibberellic acid and methyl jasmonate. *Agronomy, 10*(7), 980. https://doi.org/10.3390/agronomy10070980

Sendhilnathan, R., Balaraman, E., Rajkumar, M., & Sureshkumar, R. (2019). Effect of organic nutrients and bioregulators on flowering and yield attributes of *Celosia* (*Celosia cristata* L.). *Plant Archives, 19*(1): 938-940. https://www.plantarchives.org/PDF%20SUPPLEMENT%202019/152__938-940_.pdf

Sharma, A., Dilta, B. S., Sharma, C. L., Kumar, M., Koundal, A., & Sharma, S. (2023). Effect of foliar application of gibberellic acid on plant growth, flowering and yield attributes in pansy (Viola × Wittrockiana Gams.). *International Journal of Plant & Soil Science, 35*(17), 403-410. https://doi.org/10.9734/ijpss/2023/v35i173222

Sharma, A., Dogra, S., Pandey, R. K., Sinha, B. K., Singh, A., & Laishram, N. (2024). Effect of gibberellic acid (GA3) and benzyl adenine (BA) on vegetative growth and flower induction in gladiolus (Gladiolus grandifloras). *International Journal of Plant & Soil Science, 36*(3), 362-368. https://doi.org/10.9734/ijpss/2024/v36i34434

Sravya, K., Dilta, B. S., Verma, R., Bhatia, S., Jnanesha, A.C., Ranjith S. K., Kumar, S. B., & Lal, R. K. (2024). The impact of varying levels of gibberellic acid (GA_3) on plant growth, flowering, flower quality, seed yield, and quality of petunia (*Petunia × hybrida* Vilm.). *Ecological Genetics and Genomics, 33*: 100301. https://doi.org/10.1016/j.egg.2024.100301

Tyrus, M., Lykhochvor, V., Dudar, I., Stefaniuk, S., & Andrushko, O. (2023). Amaranth yield depending on the sowing rate. *Scientific Horizons, 26*(8), 33-41. https://doi.org/10.48077/scihor8.2023.33

Wadagave, A. R., Sateesh, R. P., Jhanavi, D. R., & Pujar, D. U. (2024). Role of GA3 in Commercial Flower Crops. *International Journal of Current Microbiology and Applied Sciences, 13*(2), 36-41. https://doi.org/10.20546/ijcmas.2024.1302.006

Zhang, X., Zhao, B., Sun, Y., & Feng, Y. (2022). Effects of gibberellins on important agronomic traits of horticultural plants. *Frontiers in Plant Science, 13*, 978223. https://doi.org/10.3389/fpls.2022.978223

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