Biological Forum
an International Journal 18(1): 54-59(2026)
ISSN No. (Print): 0975-1130
ISSN No. (Online): 2249-3239

Influence of Growth Retardants on Canopy Dynamics and Yield Under High-Density Planting in Upland Cotton (*Gossypium hirsutum* L.)

Narendra G.[1], Raghavendra T.[2*], Mohan Vishnu Vardhan K.[3], Venkatesh Babu D.[4] and Latha P.[5]
[1]PG Research Scholar, Department of Crop Physiology,
S.V. Agricultural College, Tirupati (Andhra Pradesh), India.
[2]Scientist (Crop Physiology), Regional Agricultural Research Station, Nandyal (Andhra Pradesh), India.
[3]Scientist (Genetics and Plant Breeding),
Regional Agricultural Research Station, Nandyal (Andhra Pradesh), India.
[4]Scientist (Crop Physiology), Regional Agricultural Research Station, Chinthapalli (Andhra Pradesh), India.
[5]Professor and Head (Crop Physiology), S.V. Agricultural College, Tirupati (Andhra Pradesh), India.

(Corresponding author: Raghavendra T.)*

(Received: 14 October 2025; Revised: 02 December 2025; Accepted: 04 January 2026; Published online: 17 January 2026)
(Published by Research Trend)

DOI: https://doi.org/10.65041/BiologicalForum.2026.18.1.9

ABSTRACT: The experiment was conducted to examine the influence of plant spacing and growth regulators on physiological traits, growth attributes, and yield of upland cotton under high-density planting system. Treatments were comprised with three spacings (90 × 60 cm, 90 × 30 cm, and 90 × 15 cm) and four canopy-management practices (control, de-topping at the 20th node, mepiquat chloride at 50% squaring, and mepiquat chloride at 50% squaring plus 50% flowering. Wider spacing significantly enhanced photosynthetic rate, transpiration, and stomatal conductance because of improved canopy aeration and reduced competition, whereas the closest spacing produced the highest seed-cotton and lint yields owing to greater plant population, more sympodia, and better boll retention despite lower physiological efficiency. Among canopy treatments, mepiquat chloride at 50% squaring achieved the greatest photosynthetic rate and yield by moderating vegetative growth, improving canopy structure, and strengthening the source–sink relationship. Correlation analysis showed strong positive association among photosynthetic rate, stomatal conductance, transpiration, and boll weight, whereas, excessive plant height and leaf area index were negatively associated with seed cotton yield. The findings highlighted that combining close spacing with application of mepiquat chloride at squaring offers a synergistic strategy for effective canopy management and improved productivity of upland cotton under high-density planting conditions.

Keywords: Upland cotton, Canopy management, Plant spacing, Growth regulators, Seed cotton yield.

INTRODUCTION

Cotton (*Gossypium hirsutum* L.) is an important fibre and cash crop that sustains the textile industry worldwide. In recent years, the high-density planting system (HDPS) has been promoted as a strategy to improve productivity and resource-use efficiency. High density planting system involves accommodating a higher plant population per unit area by reducing intra- and inter-row spacing. This system helps in realizing higher yields per hectare. However, it also faces challenges such as excessive vegetative growth, mutual shading, poor light penetration, delayed maturity, and reduced boll retention (Bhalerao *et al.*, 2019). To overcome these limitations, canopy management through growth retardants has gained significant attention. Growth retardants such as mepiquat chloride (MC), chlormequat chloride (CCC), and cycocel inhibit gibberellin biosynthesis, resulting in reduced internode elongation, controlled plant height, and compact plant architecture (Reddy *et al.*, 2018). The compact canopy allows for better light distribution, improved photosynthetic efficiency, and greater assimilate partitioning towards reproductive organs (Ahuja *et al.*, 2014). Several studies have demonstrated the efficacy of growth retardants in highdensity planting system of cotton. The application of mepiquat chloride under high density planting system significantly reduced plant height while increasing boll number per unit area and seed cotton yield (Ahuja *et al.*, 2014). Similarly, canopy management through growth retardants improves boll development and harvest index (Bhalerao *et al.*, 2019). In addition, that closer spacing combined with canopy regulation enhances light interception which directly improves boll setting and lint yield (Ali *et al.*, 2009).

Thus, the integration of high density planting system with growth retardants offers a promising approach for canopy manipulation leading to higher productivity, synchronized maturity, better harvest index, and enhanced economic returns. This practice is particularly relevant in regions adopting Bt cotton hybrids under resource-constrained and rainfed conditions, where balanced vegetative and reproductive growth is critical for yield sustainability.

MATERIAL AND METHODS

Experimental Site and Design

The field experiment entitled "Influence of Growth Retardants on Canopy Dynamics and Yield Under High-Density Planting in Upland Cotton" was carried out during *kharif,* 2024-25 season at Regional Agricultural Research Station, Nandyal, Andhra Pradesh. The study followed a split-plot design with three replications. The Main-plot treatments (crop geometry) were:M_1: 90 cm × 60 cm; M_2: 90 cm × 30 cm; and M_3: 90 cm × 15 cm and the Sub-plot treatments (canopy management) were:S_1: Control; S_2: Detopping at the 20th node; S_3: Mepiquat chloride @ 45 ppm at 50 % squaring; and S_4: Mepiquat chloride @ 45 ppm at 50 % squaring and 50 % flowering. The Bt cotton hybrid which was used for this experiment was Navaneet BG II, a Bt-cotton hybrid with 155 days duration from Nuziveedu Seeds Pvt. Ltd., grows tall with an erect and open canopy structure, supporting better air circulation and ease of field operations.The leaves are medium-sized, green, and slightly hairy, with a medium inter-nodal distance, produces large, ovate bolls. This hybrid possesses certain level of resistance to boll-worms and sucking pests, contributing to crop health and stability under field conditions and also showed tolerance to drought.

Observations and Measurements

Plant Height (cm)

Plant height was recorded at maturity stage. Five randomly selected and tagged plants in each net plot were measured from base of the plant to the tip of the growing point and average was calculated and expressed in centimeters.

Number of Monopodia per Plant

Number of monopodial branches were counted from five selected tagged plants at harvesting stage. Average of five plants was taken as number of monopodial branches per plant.

Number of Sympodia per Plant

The branches that are formed from above portions of main stem, which bear flowers at each node and later bolls, were counted from selected tagged plants of the net plot and averaged as number of sympodial branches per plant at harvesting stage.

Number of Bolls per Plant

The number of bolls per plant was recorded by counting the total bolls from five tagged plants at harvest. The data was then expressed as the average number of bolls per plant.

Ginning Out Turn (G.O.T) (%)

The seed cotton obtained from net plot area in different pickings was mixed thoroughly (treatment-wise) and 350 g sample was drawn and hand cleaned for dried leaves, sticks and insect damaged bolls.

$$\text{Ginning percentage } = \frac{\text{Weight of lint}}{\text{Weight of seed cotton}} \times 100$$

Seed Cotton Yield (kg ha^{-1})

Seed cotton was picked from the plants in the net plot area and weighed. The yield obtained from five tagged plants was also added to this and expressed as seed cotton yield in kg ha^{-1}.

Lint Yield (kg ha^{-1})

Lint yield refers to the amount of fibre obtained after the ginning process, where lint is separated from the seed cotton, and is expressed in kilograms per hectare (kg/ha). At crop maturity, seed cotton was harvested from each plot and weighed to determine the total yield. A representative sample were collected from each plot was then subjected to ginning to separate the lint from the seed.

$$\text{Lint yield} = \frac{\text{Seed cotton yield}\left(\text{kg ha}^{-1}\right) \times \text{Ginning percentage}(\%)}{100}$$

Boll Weight (g)

The weight of a single mature boll obtained by taking an average weight of ten randomly collected bolls, usually expressed in grams. Boll weight includes both the lint (fiber) and the seed contained within the boll.

Physiological Parameters

Photosynthetic rate (µmol CO_2 m^{-2} s^{-1})

The photosynthetic rate was measured using an Infrared Gas Analyzer (IRGA) model CI-340, targeting recently fully expanded leaves. This technique enables the estimation of short-term photosynthetic rates. The net CO_2 exchange between the leaf and the surrounding atmosphere was determined by placing the leaf inside a closed chamber and measuring the rate of change in CO_2 concentration over a brief time period.

Transpiration rate (mmol H_2O m^{-2} s^{-1})

The transpiration rate was measured using an Infrared Gas Analyser (IRGA) model CI-340 from recently fully expanded leaves. This method enables the estimation of short-term water vapour loss from the leaf surface. The measurement involved enclosing the selected leaf in a closed chamber and recording the rate of increase in water vapour concentration within the chamber over a brief period. This setup reflects the net water vapour exchange between the leaf and the atmosphere, providing an accurate assessment of the transpiration process.

Stomatal conductance (mol H_2O m^{-2} s^{-1})

Stomatal conductance was measured using an Infrared Gas Analyser (IRGA) model CI-340 on recently fully expanded leaves. This method allows the estimation of the rate at which carbon dioxide enters and water vapour exits through the stomata of the leaf. The measurement was carried out by enclosing the leaf in a sealed chamber and monitoring the flux of gases, which provides an accurate indication of stomatal opening and gas exchange activity. This approach reflects the physiological status of the plant in terms of water use efficiency and gas regulation.

Leaf Area Index (LAI)

The leaf area index was calculated at different growth stages by dividing the leaf area per plant by land area occupied by the plant and is defined as the assimilatory surface area per unit land area.

RESULTS AND DISCUSSION

Photosynthetic Rate

Plant spacing significantly influenced the photosynthetic rate (Table 1). The widest spacing recorded the highest rate (34.75 µmol CO_2 m^{-2} s^{-1}), which was superior to 90 × 30 cm (31.39 µmol CO_2 m^{-2} s^{-1}) and 90 × 15 cm (28.26 µmol CO_2 m^{-2} s^{-1}). The advantage of wider spacing is attributed to reduced inter-plant competition for light and improved canopy aeration, which enhanced leaf gas exchange. Closer spacing (90 × 15 cm) caused internal shading and restricted radiation interception, lowering photosynthesis. Among growth regulator treatments, mepiquat chloride @ 45 ppm at 50 % squaring (S3) produced the highest photosynthetic rate (31.89 µmol CO_2 m^{-2} s^{-1}), followed by mepiquat chloride at both squaring and flowering (S4, 31.28 µmol CO_2 m^{-2} s^{-1}). Control (30.39 µmol CO_2 m^{-2} s^{-1}) and detopping (30.89 µmol CO_2 m^{-2} s^{-1}) recorded lower values. Mepiquat chloride improved photosynthetic efficiency by moderating vegetative growth, maintaining an optimal source–sink balance, and prolonging leaf functional activity, consistent with Reddy *et al.* (2022).

Transpiration Rate

Transpiration also varied significantly with spacing. Wider spacing registered the highest rate (5.63 mmol H_2O m^{-2} s^{-1}), followed by 90 × 30 cm (5.45 mmol H_2O m^{-2} s^{-1}), while 90 × 15 cm recorded the lowest (4.61 mmol H_2O m^{-2} s^{-1}). Enhanced leaf exposure to sunlight and greater stomatal opening likely accounted for the higher values in wider spacing.Among growth regulators, mepiquat chloride at squaring (S3) showed the greatest transpiration (5.45 mmol H_2O m^{-2} s^{-1}), closely followed by the control (5.33 mmol H_2O m^{-2} s^{-1}). The lowest value occurred in mepiquat chloride at squaring and flowering (S4, 4.97 mmol H_2O m^{-2} s^{-1}), reflecting reduced vegetative growth and smaller leaves. These findings align with Kiran *et al.* (2020), who reported lower transpiration with mepiquat chloride due to minimized leaf area and canopy expansion.

Stomatal Conductance

Spacing significantly affected stomatal conductance, with the widest spacing achieving the highest value (591.1 mmol H_2O m^{-2} s^{-1}) and the closest spacing the lowest (482.7 mmol H_2O m^{-2} s^{-1}). Reduced conductance at high density may result from canopy shading and limited photosynthetically active radiation (PAR), causing partial stomatal closure.Mepiquat chloride at squaring (S3) recorded the greatest stomatal conductance (546.3 mmol H_2O m^{-2} s^{-1}), whereas the control showed the lowest (530.9 mmol H_2O m^{-2} s^{-1}). Growth-retardant treatments likely improved source–sink relationships, promoting efficient stomatal regulation, as reported by Dharshini *et al.* (2021).

Yield and Yield attributes

Plant spacing markedly influenced seed cotton and lint yields (Table 2). The closest spacing (M3) achieved the highest seed cotton yield (1943 kg ha^{-1}) and lint yield (729 kg ha^{-1}), significantly exceeding wider spacings. Greater productivity under closer spacing resulted from higher plant population, more bolls per plant (38.9), and more sympodia (22.2). The leaf area index (4.75) was also highest here, reflecting better canopy development and solar interception. Plant height was comparatively lower (91.5 cm), indicating that dense planting restricted vertical growth but enhanced reproductive development. Wider spacing produced the tallest plants (97.9 cm) and heaviest bolls (6.2 g) but the lowest seed cotton yield (1723 kg ha^{-1}) due to fewer plants and bolls (24.6 $plant^{-1}$). Intermediate spacing yielded 1853 kg ha^{-1} with moderate growth and yield traits.

The findings confirm that closer spacing improves yield by increasing bolls and sympodia number per unit area, while wider spacing favors vegetative growth and larger boll size (Dharshini *et al.*, 2021; Reddy *et al.* 2022). Growth regulator treatments also affected yield. Mepiquat chloride @ 45 ppm at 50 % squaring (S3) produced the highest seed cotton yield (1988 kg ha^{-1}) and lint yield (705 kg ha^{-1}). This treatment maintained optimum plant height (92.1 cm), greater boll number (33), and more sympodia (22.4), improving the source–sink relationship. Application at both squaring and flowering (S4) gave a moderate yield (1864 kg ha^{-1}), while detopping yielded 1792 kg ha^{-1}. The control recorded the lowest yield (1715 kg ha^{-1}), with taller plants (102.1 cm) and fewer bolls (28 $plant^{-1}$). These results support the findings of Priyanka *et al.* (2021) on the benefits of mepiquat chloride for boll retention and yield enhancement.

Overall, combining closer spacing with a single mepiquat chloride spray at 50 % squaring consistently achieved the highest productivity, demonstrating a synergistic advantage of high-density planting and chemical canopy management in cotton.

Correlation Analysis of Growth and Yield Attributes

Pearson correlation analysis (Fig. 1) revealed distinct positive and negative associations among physiological traits and yield components in cotton. Stomatal conductance (ST), transpiration rate (TR), and photosynthetic rate (PR) were strongly and positively correlated ($r = 0.94$–0.98), highlighting the close physiological linkage of canopy gas-exchange processes. Enhanced stomatal activity therefore supports higher CO_2 fixation and transpiration, improving assimilate supply. A similar trend was also noted by Raghvendra *et al.* (2023) in cotton.

Boll weight (BW) showed significant positive correlations with PR ($r = 0.78$), TR ($r = 0.72$), and ST ($r = 0.77$), indicating that greater canopy photosynthesis directly promotes boll development through better assimilate partitioning. Seed cotton yield (SCY) was strongly correlated with lint yield (LY) ($r = 0.93$) and ginning out-turn (GI) ($r = 0.75$), and positively associated with boll number ($r = 0.67$), underscoring the importance of boll retention for final yield.

Conversely, plant height (PH) was negatively correlated with SCY (r = –0.69) and GI (r = –0.45), suggesting that excessive vegetative growth under dense planting limits assimilate allocation to reproductive sinks. Leaf area index (LAI) correlated positively with ST (r = 0.90) and TR (r = 0.84) but negatively with SCY and boll number (both r = –0.64). While a larger canopy enhances gas exchange, excessive leaf area can cause self-shading and greater intra-row competition, reducing reproductive efficiency.

Overall, seed cotton yield was most strongly influenced by boll number, lint yield, and ginning percentage, whereas excessive plant height and high LAI had adverse effects. These findings emphasize the need for canopy management through optimal plant spacing and judicious growth regulator use to balance vegetative and reproductive growth for maximum yield.

Table 1: Influence of plant spacing and growth regulator treatments on gas exchange characteristics in cotton.

Parameters	Photosynthetic Rate (μmol CO_2 m^{-2} s^{-1})	Transpiration Rate (mmol $H_2Om^{-2}s^{-1}$)	Stomatal Conductance (mmol H_2O $m^{-2}s^{-1}$)
Main plots (Different spacings)			
M1 : 90 ×60 cm	34.75	5.63	591.1
M2: 90 × 30cm	31.39	5.45	548
M3: 90 × 15cm	28.26	4.61	482.7
S.E(m)±	0.16	0.02	0.97
CD(P=0.05)	0.63	0.11	3.81
CV(%)	1.77	1.84	0.61
Subplots (Treatments)			
S1:Control	30.39	5.33	530.9
S2: Dettoping at 20th node	30.89	5.23	535.3
S3: Mepiquatchloride@45ppm at 50% Squaring	31.89	5.45	546.3
S4: Mepiquatchloride@45 ppm at 50% Squaring and 50% Flowering	31.28	4.97	540.0
S.E(m)±	***0.16***	***0.03***	***1.88***
CD(P=0.05)	***0.48***	***0.10***	***5.58***
CV(%)	***1.54***	***1.97***	***1.03***

Table 2: Influence of plant spacing and growth regulator treatments on yield-attributing characteristics in cotton.

Parameters	Seed cotton yield (kg/ha)	Lintyield (kg/ha)	Leaf area index	Number of sympodia per plant	Plant Height (cm)	Boll weight	Ginning %	Number of monopodia per plant	Number of Bolls per plant
Main plots (Different spacings)									
M1- 90 ×60 cm	1723	537	3.72	20.9	97.9	6.2	31.2	1.4	24.6
M2- 90×30cm	1853	622	4.08	21.5	94.7	5.8	33.5	1.7	27.3
M3 -90×15cm	1943	729	4.75	22.2	91.5	5.5	37.5	1.8	38.9
S.E(m)±	**16.05**	**9.72**	**0.08**	**0.14**	**1.2**	**0.39**	**0.48**	**0.05**	**1.023**
CD(P=0.05)	**63.02**	**38.17**	**0.23**	**0.57**	**3.5**	**1.56**	**1.42**	**NS**	**4.019**
C.V(%)	**3.02**	**5.34**	**5.4**	**2.36**	**5.2**	**2.35**	**3.7**	**6.8**	**11.702**
Subplots (Treatments)									
S1- Control	1715	568	4.32	21.5	102.1	5.6	33.2	1.7	28
S2 –Dettoping at 20th node	1792	600	4.36	19.8	96.1	5.7	33.5	1.6	29.7
S3- Mepiquatchloride@45ppmat 50% Squaring	1988	705	4.18	22.4	92.1	6.1	35.5	1.6	33
S4- Mepiquatchloride@45ppm at 50% Squaring and 50% Flowering	1864	645	3.86	23.4	90.1	5.9	34.6	1.5	30.3
S.E(m)±	**17.90**	**10.46**	**0.07**	**0.31**	**1.4**	**0.45**	**0.44**	**0.04**	**0.95**
CD(P=0.05)	**53.19**	**31.10**	**0.21**	**0.94**	**4.0**	**1.35**	**1.31**	**NS**	**2.83**
CV(%)	**2.919**	**4.98**	**5.1**	**4.43**	**5.6**	**2.32**	**3.5**	**6.2**	**9.44**

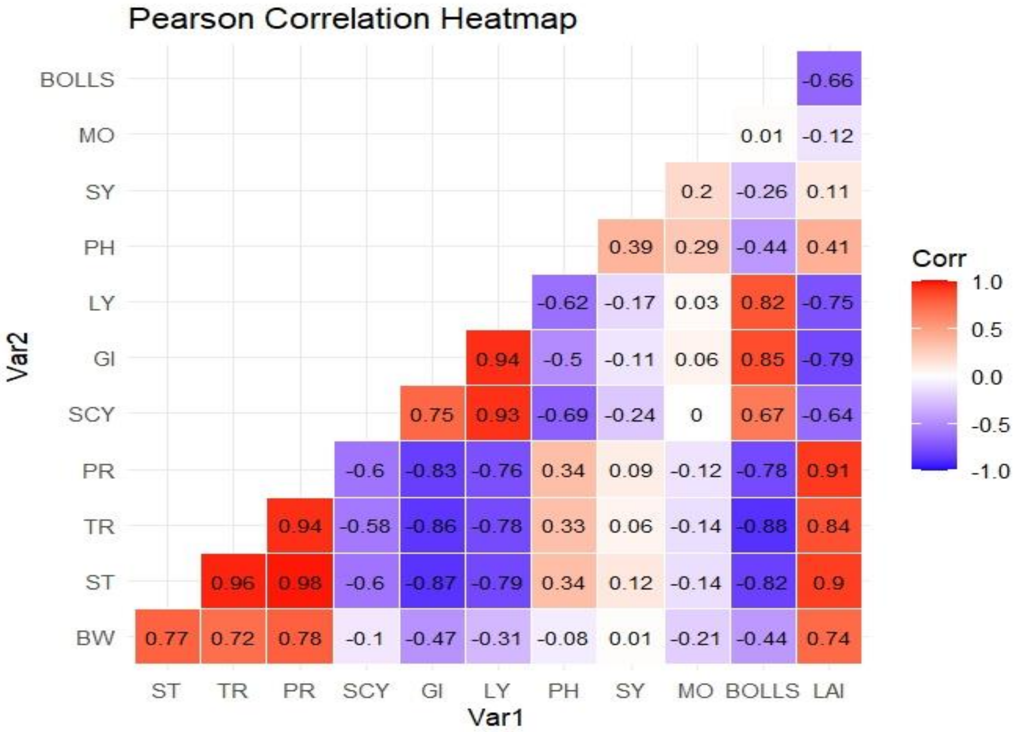

Fig. 1. Correlation Analysis of Growth and Yield Attributes of Cotton as Influenced by Spacing and Growth Regulators.

CONCLUSIONS

The investigation established that canopy manipulation through plant spacing and growth-regulator application is a decisive factor for enhancing the physiological efficiency and yield of Bt cotton under high-density planting. Wider spacing (90 × 60 cm) improved gas-exchange parameters photosynthetic rate, transpiration, and stomatal conductance by reducing shading and improving canopy aeration. In contrast, closer spacing (90 × 15 cm) reduced these physiological traits but achieved the highest seed-cotton and lint yields owing to greater plant population, higher boll number, and more sympodia per unit area. Among canopy-management treatments, a single foliar spray of mepiquat chloride (45 ppm) at 50 % squaring was most effective in moderating vegetative growth, sustaining leaf functional activity, and improving boll retention, thereby maximizing yield. De-topping provided only marginal benefits, while repeated mepiquat chloride sprays caused excessive growth suppression and moderate yields.

Correlation analysis confirmed that seed-cotton yield is primarily driven by boll number, lint yield, and ginning percentage, whereas excessive plant height and leaf area index negatively affect productivity. Gas-exchange traits were strongly interrelated and positively associated with boll development and yield efficiency.

Overall, integrating closer spacing (90 × 15 cm) with a single mepiquat chloride spray at 50 % squaring optimizes canopy architecture, balances vegetative and reproductive growth, and enhances resource-use efficiency. This combined strategy represents a technically sound approach for maximizing the productivity of Bt cotton in high-density planting systems.

FUTURE SCOPE

Future studies should examine the sustainability, economic returns and environment impact using the high density planting system along with growth regulators following climate resilient techniques such as moisture conservation, pest management and precision farming, further enhancing cotton productivity and system resilience.

REFERENCES

Ahuja, S L., Ghosh, S., Kumar, A. and Kumar, V. (2014). Influence of plant growth regulators on canopy architecture, light interception and yield of Bt cotton under high density planting system. *Indian Journal of Agronomy*, *59*(3), 421–426.

Ali, M., Singh, V. V., Kairon, M. S. and Bhatnagar, P. S. (2009). Effect of closer spacing and canopy regulation on productivity of upland cotton. *Journal of Cotton Research and Development*, *23*(1), 47–52.

Bhalerao, P. D., Pawar, P. P., Patil, R. P. and Patil, D. S. (2019). Canopy management practices for improving productivity and fibre quality in high density planting system of cotton. *Journal of Pharmacognosy and Phytochemistry*, *8*(4), 1189–1194.

Dharshini, T., Reddy, D. M. and Rao, K. N. (2021). Effect of plant geometry on canopy microclimate, gas exchange, and productivity of Bt cotton. *Journal of Cotton Research and Development*, *35*(2), 125–132.

Kiran, K., Ramesh, B. and Suresh, J. (2020). Influence of mepiquat chloride on water relations, transpiration, and productivity of cotton under different planting systems. *International Journal of Current Microbiology and Applied Sciences*, *9*(7), 1123–1131.

Priyanka, K., Rani, B. S. and Reddy, P. V. (2021). Effect of mepiquat chloride on growth and yield of cotton under irrigated conditions. *Journal of Pharmacognosy and Phytochemistry*, *10*(1), 187–190.

Raghvendra, D., Pandey, B. K., Sawant, S. V. and Shirke, P. A. (2023). Drought stress inhibits stomatal development to improve water use efficiency in cotton. *Acta Physiologiae Plantarum*, *45*(30), 1-12.

Reddy, P. V., Naik, R. S. and Rao, K. R. (2018). Role of growth retardants in manipulating canopy architecture of Bt cotton under high density planting. *Journal of Cotton Research and Development*, *32*(2), 239–246.

Reddy, P. V., Naik, R. S. and Rao, K. R. (2022). Canopy management through plant growth regulators under high-density planting system in Bt cotton. *Journal of Cotton Research*, *5*, 18–26.

How to cite this article: Narendra G., Raghavendra T., Mohan Vishnu Vardhan K., Venkatesh Babu D. and Latha P. (2026). Influence of Growth Retardants on Canopy Dynamics and Yield Under High-Density Planting in Upland Cotton (*Gossypium hirsutum* L.). *Biological Forum, 18*(1): 54-59.