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RESEARCH ARTICLE

Effects of mepiquat chloride and foliar nutrition on growth, yield, and fiber quality in High-Density Planting System (HDPS)

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Abstract

Increased plant density promotes taller growth and greater vegetative development, intensifying competition among plants for resources and consequently affecting the balance between the vegetative and reproductive stages of the cotton plant. To ensure improved square development, boll development, boll retention, and seed cotton yield under dense planting condition, this research was conducted at the Cotton Research Station, Veppanthattai. The study aimed to evaluate the effects of plant growth regulators (PGR) and foliar nutrition on the growth, yield, and fibre quality of compact cotton varieties suitable for dense populations and mechanical harvesting. The results revealed that the application of mepiquat chloride (100ppm at 45 and 60 DAS), NAA (40ppm at 60 and 90 DAS), KNO_3 (2% at 60 and 90 DAS), calcium borate (0.5% at 60 and 90 DAS), and a defoliant (Thidiazuron 240 g/L and Diuron 120 g/L at 200 ml/ha at the 60% boll bursting stage) achieved optimal growth attributes. These included plant height (98.7 cm), the number of functional leaves (07), leaf area index (3.9), seed cotton yield (2351 kg/ha), stalk yield (3286 kg/ha), lint yield (933 kg/ha), and harvest index (0.69), along with improvements in fiber quality parameters. In this study, potassium facilitated the efficient translocation of photosynthates from leaves to reproductive organs, contributing to enhanced biomass accumulation and yield.

Keywords

canopy management; foliar application; plant growth regulators (PGR); high -density planting system (HDPS)

Introduction

Cotton (*Gossypium* sp.), often referred to as "white gold" is a fiber crop of immense commercial importance, playing a crucial role in global agriculture and industry (1). It significantly contributes to the agricultural economy and industrial sectors, providing employment to over 50 million people and supporting the livelihoods of approximately 6 million farmers (2).

In India, cotton is cultivated over an area of 123.50 million hectares, producing 340.62 million bales with a productivity rate of 510 kg/ha. However, since 2015, total production has steadily declined from 40 million to 31 million bales, accompanied by stagnation in yield. This decline is attributed to pest resurgence and adverse climatic conditions. India's national average cotton productivity currently stands at 433 kg/ha, substantially lower than the global average of 768 kg/ha. These figures underscore the need for advancements in cotton genetic improvement and the adoption of effective agronomic practices.

To meet the projected demand of the Indian textile industry by 2026, approximately 45 million bales of cotton will be required. The substantial gap between cotton production and demand in the country necessitates the expansion of cotton cultivation areas and the enhancement of both production and productivity.

The High-Density Planting System (HDPS) employs narrower row spacing, typically ranging from 45 to 60 cm (18 to 24 inches), compare to traditional cotton spacing, which is wider at approximately 90 to 100 cm (35 to 40 inches). Narrow row spacing in HDPS increases planting density to about 90000 to 120000 plants per hectare, compared to the traditional 50000 to 70000 plants per hectare. This approach offers structural benefits such as uniform boll distribution, reduced canopy height, compact growth, and higher plant populations, all of which contribute to increased yield potential. Additionally, HDPS facilitates easier application of defoliants, making it globally recognized for its effectiveness in improving yields and enabling mechanization. HDPS has demonstrated the potential to increase yield by 30-40% and is well-suited for complete mechanization.

Major cotton-growing countries, including China, the USA, and Australia, practice HDPS with plant spacing as close as 90 x 10 cm or even narrower, allowing for compact varieties suitable for single harvests. The shorter plant height and denser branching achieved through the application of growth retardants create the ideal plant structure suitable for mechanized operations.

PGRs are widely employed in developed nations to enhance cotton production by modulating growth processes. Commonly used plant growth regulators include gibberellic acid (GA3), cytokinins, Ethephon, auxins, and mepiquat chloride, which improve lint yield and fiber quality. PGRs have been shown to increase yield by 100-200% under laboratory conditions and by 10-15% under field conditions (3). The plant response to PGR applications depends on factors such as growth stage, application rates, and environmental conditions (4).

One key PGR, mepiquat chloride, alters the source-sink balance by inhibiting gibberellic acid biosynthesis. This inhibition reduces cell division and enlargement while enhancing reproductive growth by redistributing assimilates between vegetative and reproductive structures. This process has been shown to increase yields per plant by 9.68% and per hectare by 9.72%. Beyond canopy manipulation, mepiquat chloride also promotes root growth by increasing lateral root development, root vigour, and respiratory activity. To sustain cotton productivity under HDPS while ensuring economic and environmental safety, it is essential to determine the optimal fertilizer doses and timing for split applications in combination with growth retardants.

Foliar fertilization is an effective method to enhance crop growth, offering several advantages such as rapid plant response, ease of application, supplementation to soil fertilization, correction of nutritional deficiencies, reduction of input costs, and improved nutrient uptake (5). The foliar application of macro- and micronutrients, either alone or in combination, has been reported to significantly enhance growth parameters, seed cotton yield, and overall crop performance. For instance, Bt cotton exhibited higher growth attributes and seed cotton yield with three foliar applications of micronutrient along with recommended fertilizer dose (RDF).

Foliar nutrition enhances the efficiency of nutrient utilization, thereby improving crop growth, seed yield, and fiber quality characteristics in cotton. This article highlights the importance of applying growth retardants and foliar nutrition in cotton cultivation. However, foliar fertilization should supplement traditional soil-applied fertilizers to ensure an adequate and consistent nutrient supply for achieving optimal yields and fibre quality.

In general, foliar applications are most effective when performed during the early morning or late evening to maximize absorption and minimize evaporation losses. It is crucial to avoid foliar applications on water-stressed cotton to prevent potential damage to the crop. While some conflicting opinions exist regarding the benefits of foliar fertilization, substantial scientific evidence and extensive practical applications support its effectiveness in improving cotton productivity (6).

Materials and Methods

A field experiment was conducted at the Cotton Research Station, Veppanthattai, under Tamil Nadu Agricultural University, during February 2024 (summer season). The study aimed to evaluate the effects of plant growth regulators and foliar spray nutrients on the compact cotton variety VPT 2. The experimental design employed a Randomized Block Design (RBD), with three replications and twelve treatments (Table 1).

Table 1. Treatments details in the study

T1	Mepiquat chloride 100 ppm @ 45 & 60 DAS + Defoliant (Thidiazuron 240g/L & Diuron 120g/L at 200ml/ha) at the 60% boll bursting stage.
T2	Mepiquat chloride 100 ppm @ 45 and 60 DAS + NAA 40 ppm @ 60 and 90 DAS + Defoliant (Thidiazuron 240g/L & Diuron 120g/L at 200ml/ha) at the 60% boll bursting stage.
T3	Mepiquat chloride 100 ppm @ 45 and 60 DAS + Cotton plus 6 kg/ha @ 60 and 90 DAS + Defoliant (Thidiazuron 240g/L & Diuron 120g/L at 200ml/ha) at the 60% boll bursting stage.
T4	Mepiquat chloride 100 ppm @ 45 & 60 DAS +NAA 40 ppm @ 60 & 90 DAS + KNO_3 2% @ 60 and 90 DAS + Defoliant (Thidiazuron 240g/L & Diuron 120g/L at 200ml/ha) at the 60% boll bursting stage.
T5	Mepiquat chloride 100 ppm @ 45 and 60 DAS +NAA 40 ppm @ 60 and 90 DAS + SOP 2% @ 60 & 90 DAS + Defoliant (Thidiazuron 240g/L & Diuron 120g/L at 200ml/ha) at the 60% boll bursting stage.
T6	Mepiquat chloride 100 ppm @ 45 & 60 DAS + NAA 40 ppm @ 60 & 90 DAS + KNO_3 2% @ 60 and 90 DAS + Calcium borate 0.5% @ 60 and 90 DAS + Defoliant (Thidiazuron 240g/L & Diuron 120g/L at 200ml/ha) at the 60% boll bursting stage.
T7	Mepiquat chloride 100 ppm @ 45 and 60 DAS + NAA 40 ppm @ 60 and 90 DAS +SOP 2% @ 60 and 90 DAS +Calcium borate 0.5% @ 60 and 90 DAS + Defoliant (Thidiazuron 240g/L & Diuron 120g/L at 200ml/ha) at the 60% boll bursting stage.
T8	Control (No application)

The recommended dose of fertilizers, 100:50:50 NPK/ha, was applied in two split applications. Pre-emergence weed control was achieved using pendimethalin (Stomp) 30 EC at 1.0 kg a.i. ha⁻¹ and metolachlor 50% EC at 1.0 kg a.i. ha⁻¹. To manage sucking pests, imidacloprid 17.8% SL was applied at a rate of 250 ml/ha. Intercultural operations were performed using a power weeder at 45 days after sowing (DAS). Growth retardants were applied during the square and boll formation stages at 45 and 60 DAS. Foliar application of nutrients, including NAA, Cotton Plus, potassium nitrate, calcium borate, and sulphate of potash, were conducted during the flowering and boll development stages at 60 and 90 DAS. A defoliant mixture (Thidiazuron 240 g/L & Diuron 120 g/L at 200 ml/ha) was applied at the 80% boll-bursting stage.

Data collection encompassed a range of parameters, including growth parameters (plant height, functional leaves, dry matter production, and leaf area index), canopy management practices (number and length of sympodial branches), yield attributes (biological yield, harvest index, lint yield, boll weight, stalk yield, number of bolls per plant, number of bolls per m^2,and seed cotton yield), and fiber quality parameters (ginning percentage, lint index, seed index, upper half mean length, micronaire, uniformity index, tenacity, and elongation percentage).

For plant height, measurements were taken from the base of the plant to the tip of the growing point, expressed in cm. Dry matter productions included the separate recording of dry weights of stem, leaves and reproductive parts, expressed in $kgha^{-1}$. The leaf area index (LAI) was calculated by dividing the leaf area per plant by the land area occupied by that plant. The Lint index (g) was determined using 100 seeds of cotton, expressed as the lint index in grams, which provides a quantitative measure of lint production. Harvest index expressed as the ratio of seed cotton yield to biological yield and expressed in percent. Biological yield was determined by summing the seed cotton yield (kg ha^{-1}) and stalk yield (kg ha^{-1}). Ginning percentage of various treatments was calculated by ginning 500 g of seed cotton picked from the first picking. The lint index defined as the ratio between lint and seed, expressed as the weight of lint obtained per seed of cotton

LAI = Leaf area per plant / Land area per plant

Harvest index (%) =Economic yield/ Biological yield x 100

Ginning (G) % = weight of lint (g) / weight of seed cotton (g) *100

Lint index = weight of 100 seeds * ginning percentage /100.

Results

Growth and canopy management

Growth parameters, including plant height, number of functional leaves, and leaf area index, varied significantly depending on the application of plant growth regulators and nutrients (Table 2). The control treatment (T8) recorded the tallest plant height (110 cm), the highest number of functional leaves (89.7 Nos.), and the greatest leaf area index (4.5). Following this was treatment T6, which involved the application of mepiquat chloride (100 ppm at 45 and 60 DAS), NAA (40 ppm at 60 and 90 DAS), KNO_3 (2% at 60 and 90 DAS), calcium borate (0.5% at 60 and 90 DAS), and a defoliant mixture (Thidiazuron 240 g/L and Diuron 120 g/L at 200 ml/ha at the 60% boll bursting stage). This (T6) resulted in a plant height of 98.7 cm, fewer functional leaves (07 Nos.), and a leaf area index of 3.9, considered optimal for mechanical harvesting. The lowest plant height (82.4 cm), fewest functional leaves (10 Nos.), and the lowest leaf area index (3.0), were recorded in treatment T1.

Regarding canopy management, significant differences

Table 2. Effect of PGR and foliar nutrition on growth parameter

Treatment	Plant height (cm)	No. of. Leaves at harvest	LAI stage of harvest	No. of. sympo-dial branches	Length of sympodia
T1: Mepiquat chloride 100 ppm @ 45 & 60 DAS + Defoliant @ 60% boll bursting stage	82.4	10	3.1	12.7	16.4
T2: Mepiquat chloride 100 ppm @ 45 & 60 DAS + NAA 40 ppm @ 60 & 90 DAS + Defoli-ant @ 60% boll bursting stage	83.8	13	3.0	13.6	17.6
T3: Mepiquat chloride 100 ppm @ 45 & 60 DAS + Cotton Plus 6 kg/ha @ 60 & 90 DAS + Defoliant @ 60% boll bursting stage	92.5	09	3.2	14.2	18.0
T4: Mepiquat chloride 100 ppm @ 45 & 60 DAS + NAA 40 ppm @ 60 & 90 DAS + KNO_3 2% @ 60 & 90 DAS + Defoliant @ 60% boll bursting stage	96.9	09	3.7	14.4	18.7
T5: Mepiquat chloride 100 ppm @ 45 & 60 DAS + NAA 40 ppm @ 60 & 90 DAS + SOP 2% @ 60 & 90 DAS + Defoliant @ 60% boll bursting stage	87.4	10	3.1	13.8	17.9
T6: Mepiquat chloride 100 ppm @ 45 & 60 DAS + NAA 40 ppm @ 60 & 90 DAS + KNO_3 2% @ 60 & 90 DAS + Calcium borate 0.5% @ 60 & 90 DAS + Defoliant @ 60% boll bursting stage	98.7	07	3.9	17.8	20.6
T7: Mepiquat chloride 100 ppm @ 45 & 60 DAS + NAA 40 ppm @ 60 & 90 DAS + SOP 2% @ 60 & 90 DAS + Calcium borate 0.5% @ 60 & 90 DAS + Defoliant @ 60% boll bursting stage	94.6	08	3.3	15.7	19.6
T8: Control (No application)	110	89.7	4.5	10.5	25.8
SED	1.8	0.6	0.3	0.7	0.4
CD (0.05)	4.0	1.3	0.5	1.6	0.9

were observed across the treatments. The control treatment (T8) recorded the lowest number of sympodial branches (10.5) and the longest branch length (25.8 cm). In contrast, treatment T6 exhibited the highest number of sympodial branches (17.8) and the lowest sympodial branch length (20.6 cm).Treatment T7, which involved the application of mepiquat chloride (100 ppm at 45 and 60 DAS) + NAA (40 ppm at 60 and 90 DAS) + SOP (2% at 60 and 90 DAS) + calcium borate (0.5% at 60 and 90 DAS) + defoliant (Thidiazuron 240 g/L & Diuron 120 g/L at 200 ml/ha at the 60% boll bursting stage) followed with 15.7 sympodial branches and a branch length of 19.6 cm. These findings are summarized in Table 2 and depicted in Fig. 1.

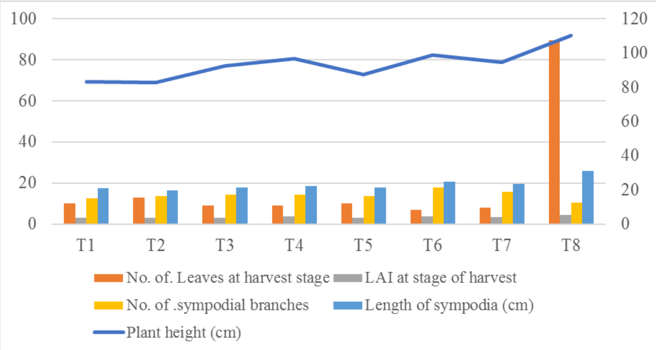

Fig. 1. Effect of foliar nutrition on growth canopy management.

Yield and yield attributes

Yield attributes of cotton at different growth stages exhibited significant differences across all treatments (Table 3). The highest seed cotton yield (2351 kg/ha), lint yield (933 kg/ha), and harvest index (0.69) were recorded in treatment T6. This was followed by treatment T7, which achieved a seed cotton yield of 2265 kg/ha, lint yield of 847 kg/ha, and a harvest index of 0.67. The lowest seed cotton yield (1495 kg/ha), lint yield (516 kg/ha), and harvest index (0.6) were observed in the control treatment (T8).

The highest stalk yield was recorded in the control (T8) at 3971 kg/ha, while the lowest stalk yield (3286 kg/ha) was observed in Treatment (T6). Regarding boll weight and the number of bolls per plant and per square meter, treatment T6 also produced the best results. It recorded a boll weight of 4.9 g and 79.8 bolls/m^2. This was followed by treatment T7, which recorded a boll weight of 4.2 g, and 77.0 bolls/m^2. In contrast, the control (T8) had the lowest values for these parameters, with a boll weight of 3.9 g, and 49.8 bolls/m^2 (Table 3 and Fig. 2).

Fiber quality parameters

Fiber quality parameters of cotton at different growth stages showed significant differences in ginning percentage, seed index, and lint index across all treatments (Table 4). However, parameters such as upper half mean length, uniformity index (%), micronaire value, tenacity (3.2 mm), and elongation (%) did not exhibit significant differences among the treatments. Treatment T6 recorded the highest ginning percentage (39.6%), seed index (8.1), and lint index (3.0), closely followed by Treatment T7, which achieved values of 38.2%, 8.1, and 3.0, respectively. The control treatment (T8) showed the lowest values**,** with a ginning percentage of 34.5%, a seed index of 7.3, and a lint index of 2.5.

For fiber quality traits, Treatment T6 also achieved the best results, recording an upper half mean length of 29.4 mm, uniformity index of 85.6%, micronaire value of 3.8, tenacity of 31.9 g/tex, and elongation of 6.0% .This was followed by Treatment T7, which recorded an upper half mean length of 29.3 mm, uniformity index of 85.3%, micronaire value of 3.8, tenacity of 31.8 g/tex, and elongation of 6.0%. In contrast, the control Treatment (T8) demonstrated the lowest values for fiber quality parameters, with an upper half mean length of 28.6 mm, uniformity index of 84.6%, micronaire value of 3.6, tenacity of 30.0 g/tex, and elongation of 5.8% (Table 4).

Table 3. Effect of PGR and foliar nutrition on yield and yield attributes

Treatment	No. of bolls/m^2	Boll Weight	Seed Cotton Yield (kg/ha	Lint yield (kg/ha)	Stalk Yield (kg/ha)	Harvest index
T1: Mepiquat chloride 100 ppm @ 45 & 60 DAS + Defoliant @ 60% boll bursting stage	62.2	4.0	1527	561	3406	0.46
T2: Mepiquat chloride 100 ppm @ 45 & 60 DAS + NAA 40 ppm @ 60 & 90 DAS + Defoliant @ 60% boll bursting stage	66.6	4.0	1718	637	3258	0.42
T3: Mepiquat chloride 100 ppm @ 45 & 60 DAS + Cotton Plus 6 kg/ha @ 60 & 90 DAS + Defoliant @ 60% boll bursting stage	67.6	4.1	1806	780	3128	0.52
T4: Mepiquat chloride 100 ppm @ 45 & 60 DAS + NAA 40 ppm @ 60 & 90 DAS + KNO_3 2% @ 60 & 90 DAS + Defoliant @ 60% boll bursting stage	70.3	4.1	2047	781	3122	0.66
T5: Mepiquat chloride 100 ppm @ 45 & 60 DAS + NAA 40 ppm @ 60 & 90 DAS + SOP 2% @ 60 & 90 DAS + Defoliant @ 60% boll bursting stage	66.6	4.1	2018	742	3134	0.59
T6: Mepiquat chloride 100 ppm @ 45 & 60 DAS + NAA 40 ppm @ 60 & 90 DAS + KNO_3 2% @ 60 & 90 DAS + Calcium borate 0.5% @ 60 & 90 DAS + Defoliant @ 60% boll bursting stage	79.8	4.2	2351	933	3186	0.69
T7: Mepiquat chloride 100 ppm @ 45 & 60 DAS + NAA 40 ppm @ 60 & 90 DAS + SOP 2% @ 60 & 90 DAS + Calcium borate 0.5% @ 60 & 90 DAS + Defoliant @ 60% boll bursting stage	75.0	4.2	2265	847	3060	0.67
T8: Control (No application)	49.8	3.9	1495	516	3671	0.37
SED	1.7	0.2	73.6	56.1	71.3	0.1
CD (0.05)	3.7	NS	148.6	103.3	153.0	NS

Discussion

Growth canopy management

The study highlights the significant impact of different treatments on cotton growth attributes, particularly plant height, functional leaves, leaf area index, and total dry matter production. The application of potassium nitrate (KNO_3) at 2% during 60 and 90 DAS was pivotal in enhancing dry matter accumulation, leaf area index, and overall plant growth. Potassium plays a crucial role in several physiological processes, including photosynthesis, chlorophyll synthesis, water retention, and carbon metabolism. Additionally, it facilitates the efficient translocation of photosynthates from leaves to reproductive organs, thereby contributing to better biomass accumulation and yield (7).

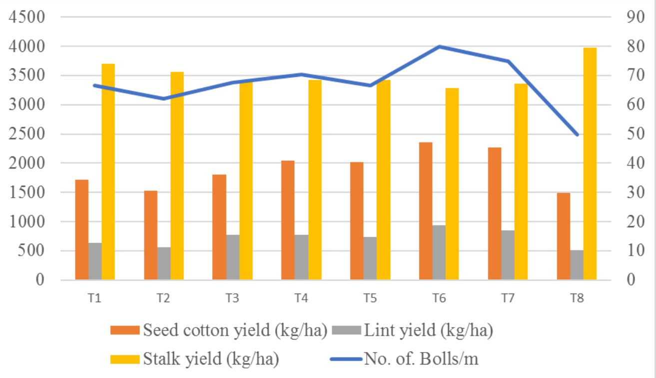

Fig. 2. Effect of foliar nutrition on yield and yield attributes.

The application of PGRs, such as mepiquat chloride at 45 and 60 DAS, effectively controlled excessive vegetative growth while optimizing the canopy structure. This effect was further complemented by the use of NAA at 60 and 90 DAS, which promoted cell elongation and differentiation, resulting in a balanced vegetative and reproductive growth pattern. In contrast, the control treatment (T8), which lacked PGRs and defoliants, exhibited the tallest plants (110 cm) and the highest number of functional leaves (89.7), suggesting vigorous growth but potentially excessive vegetative growth. In contrast, Treatment (T6), which included mepiquat chloride, NAA, KNO_3, calcium borate, and defoliant, achieved an optimal plant height (98.7 cm), fewer functional leaves (07), and an adequate leaf area index (3.9). This balanced growth pattern rendered the plants more suitable for mechanical harvesting.

The application of defoliants (Thidiazuron and Diuron at the 60% boll bursting stage) in treatments like T6 significantly improved harvest efficiency by inducing leaf drop and exposing bolls, thereby facilitating mechanical picking. Moreover, canopy management in T6 treatment showed the highest number of sympodial branches (14.8) and optimal sympodial branch length (20.6 cm), indicating that the combined use of PGRs and foliar nutrients promoted both reproductive branching and optimal branch extension. The inclusion of calcium borate at 0.5% further improved the structural integrity of the plants, as calcium is crucial for strengthening cell walls, while boron supports carbohydrate metabolism and supports pollen tube growth, ensuring successful fertilization and boll development.

Overall, the combination treatment (T6) effectively balanced vegetative growth, optimized canopy architecture, and enhanced physiological processes, leading to improved cotton yield and better suitability for mechanical harvesting. The results underscore the importance of precise nutrient management and the strategic use of growth regulators to optimize plant morphology and productivity in cotton cultivation.

Yield and yield attributes

The results demonstrate that the highest seed cotton yield and associated attributes were achieved in Treatment T6, which involved the application of mepiquat chloride at 100 ppm at 45 and 60 DAS, combined with NAA at 40 ppm at 60 and 90 DAS, KNO_3 at 2% at 60 and 90 DAS, calcium borate at 0.5% at 60 and 90 DAS, and a defoliant (Thidiazuron 240 g/L & Diuron 120 g/L) at the 60% boll bursting stage. This treatment recorded a seed cotton yield of 2351 kg/ha, a

Table 4. Effect of PGR and foliar nutrition on fiber quality parameters

Treatment	Ginning percentage (%)	Seed index (g)	Lint index (g)	UHML (mm)	Uniformity Index (%)	Mic	Tenacity 3.2 mm (g/tex)	Elongation (%)
T1: Mepiquat chloride 100 ppm @ 45 & 60 DAS + Defoliant @ 60% boll bursting stage	37.0	7.7	2.69	28.8	84.6	3.7	30.3	5.8
T2: Mepiquat chloride 100 ppm @ 45 & 60 DAS + NAA 40 ppm @ 60 & 90 DAS + Defoliant @ 60% boll bursting stage	36.7	7.5	2.92	28.7	84.6	3.7	30.1	5.8
T3: Mepiquat chloride 100 ppm @ 45 & 60 DAS + Cotton Plus 6 kg/ha @ 60 & 90 DAS + Defoliant @ 60% boll bursting stage	37.7	7.8	2.23	29.1	85.0	3.7	30.4	5.9
T4: Mepiquat chloride 100 ppm @ 45 & 60 DAS + NAA 40 ppm @ 60 & 90 DAS + KNO_3 2% @ 60 & 90 DAS + Defoliant @ 60% boll bursting stage	38.1	7.9	3.08	29.3	85.3	3.7	30.9	5.9
T5: Mepiquat chloride 100 ppm @ 45 & 60 DAS + NAA 40 ppm @ 60 & 90 DAS + SOP 2% @ 60 & 90 DAS + Defoliant @ 60% boll bursting stage	37.1	7.7	2.81	29.1	84.6	3.7	30.3	5.8
T6: Mepiquat chloride 100 ppm @ 45 & 60 DAS + NAA 40 ppm @ 60 & 90 DAS + KNO_3 2% @ 60 & 90 DAS + Calcium borate 0.5% @ 60 & 90 DAS + Defoliant @ 60% boll bursting stage	39.6	8.1	3.09	29.4	85.6	3.8	31.9	6.0
T7: Mepiquat chloride 100 ppm @ 45 & 60 DAS + NAA 40 ppm @ 60 & 90 DAS + SOP 2% @ 60 & 90 DAS + Calcium borate 0.5% @ 60 & 90 DAS + Defoliant @ 60% boll bursting stage	38.2	7.9	3.04	29.3	85.3	3.8	31.8	6.0
T8: Control (No application)	34.5	7.3	2.54	28.6	84.6	3.6	30.0	5.8
SED	0.6	0.18	0.07	20.2	59.1	2.6	21.4	4.1
CD (0.05)	1.3	NS	NS	NS	NS	NS	NS	NS

lint yield of 933 kg/ha, and a harvest index of 0.69. These results highlights the significant role of potassium, especially in the form of foliar application of KNO_3, in promoting boll retention, increasing boll weight, and improving overall yield per plant (8). Potassium helps in mitigating drought stress and maintaining plant turgor, thereby reducing boll shedding under adverse environmental conditions (9). Additionally, potassium facilities the translocation of photosynthates to developing bolls, contributing to higher boll numbers and increased boll weight.

The foliar application of KNO_3 at critical stages of boll formation was instrumental in promoting boll retention and development, thereby significantly boosting seed cotton yield (10). This finding aligns with previous studies indicating that potassium nitrate, regardless of soil potassium status, can boost seed cotton yield by ensuring a sufficient supply of potassium during the boll development stage (11–14). The ability of potassium to support critical physiological functions, including photosynthesis, water regulation, and nutrient translocation, makes it essential for enhancing cotton productivity (15–17). The synchronization of nutrient supply with key developmental stages (18–20), as seen in T6, ensured optimal growth and yield by providing plants with the necessary nutrients at the critical times.

Moreover, T6 outperformed other treatments in terms of boll weight (4.9 g), and the number of bolls per square meter (79.8). The combination of plant growth regulators and nutrients applied in (T6) optimized both vegetative and reproductive growth, leading to higher yield parameters. In contrast, the control (T8) without the application of PGRs, KNO_3, and defoliants recorded the lowest seed cotton yield (1495 kg/ha), lint yield (516 kg/ha), and harvest index (0.6). The control treatment also showed the lowest boll weight (3.9 g), and the fewest bolls per square meter (49.8), demonstrating the critical role of foliar potassium application in maximizing cotton yield. The superior performance of (T6) in yield attributes further emphasizes the importance of providing adequate potassium, along with other growth regulators, to ensure higher productivity in cotton.

Fiber quality parameters

The study results on cotton fibre quality and yield attributes reveal notable distinctions in the effects of various treatments on yield-related parameters compared to fibre quality traits. Significant improvements were observed in yield attributes, such as ginning percentage, seed index, and lint index, across the treatments. However, the core fibre quality traits—upper half mean length, uniformity index, micronaire value, tenacity, and elongation—did not exhibit significant differences among the treatments.

In terms of yield attributes, (T6) recorded the highest values for ginning percentage (39.6%), seed index (8.1), and lint index (3.0). The ginning percentage refers to the proportion of usable fiber separated from seed cotton, with higher values indicating more efficient fibre production. The seed index reflects the weight of seeds produced, while the lint index represents the weight of lint per unit of seed cotton, both of which are critical for assessing overall yield quality. The success of T6 is attributed to the foliar application of mepiquat chloride, NAA, KNO_3, calcium borate, and a defoliant, which ensured a balanced nutrient supply during critical growth stages. Potassium, in particular, played a crucial role in enhancing boll retention and minimizing shedding, contributing to better cotton yields. Treatment (T7), which used SOP (Sulphate of Potash) instead of KNO_3, also recorded high values for yield parameters, though slightly lower than T6, indicating that efficacy of both forms of potassium. In contrast, the control (T8), which lacked foliar nutrient applications, the lowest ginning percentage (34.5%), seed index (7.3), and lint index (2.5), highlighting the critical role of added nutrients and growth regulators in maximizing productivity. The lower performance of T8 underscores the importance of potassium and other nutrients in achieving higher yields.

Despite the notable improvements in yield, the fibre quality traits, including upper half mean length (fibre length), uniformity index, micronaire value, tenacity, and elongation, remained relatively unchanged across treatments. T6 exhibited slightly better fibre quality results, with a fibre length of 29.4 mm, uniformity index of 85.6%, micronaire value of 3.8, tenacity of 31.9 g/tex, and elongation of 6.0%. However, these values were only marginally higher than those observed in other treatments, including the control (T8), which showed a fiber length of 28.6 mm, uniformity index of 84.6%, micronaire value of 3.6, tenacity of 30.0 g/tex, and elongation of 5.8%. This minimal variation in fiber quality suggests that nutrient applications have limited influence on intrinsic fiber characteristics. Potassium and calcium, although essential for plant growth, do not significantly affect cotton fiber structure (21, 22). Fiber traits such as micronaire (which reflects fibre fineness and maturity) and tenacity are primarily governed by genetic factors and environmental conditions rather than nutrient management practices (23, 24). While potassium is vital for overall plant health and productivity, its role in altering the physical properties of cotton fibre is minimal (25–27), which aligns with the findings of this study (28-30).

Interpretation of pearson correlation analysis of variables along with correlation matrix and heatmap

The study explored the relationships between various plant traits, revealing that plant height exhibited a positive and significant correlation with the leaf area index (LAI), sympodia length, and the number of leaves, while showing non-significant and weak associations with traits such as stalk yield, seed cotton yield, and lint yield. Similarly, the number of leaves had significant positive correlations with sympodia length and stalk yield but was negatively associated with the number of bolls and boll weight. LAI showed a strong positive relationship with sympodia length and leaf count but showed no significant associations with several other traits. Sympodial branches were positively correlated with boll weight, seed cotton yield, and harvest index, but negatively associated with stalk yield and leaf count. Boll weight demonstrated significant positive correlations with seed cotton yield, lint yield, and harvest index, while stalk yield exhibited strong negative correlations with several yield-related traits, including boll weight and lint yield. Finally, the harvest index showed significant positive associations with seed cotton yield and lint yield, but a notable negative correlation with stalk yield (Fig. 3).

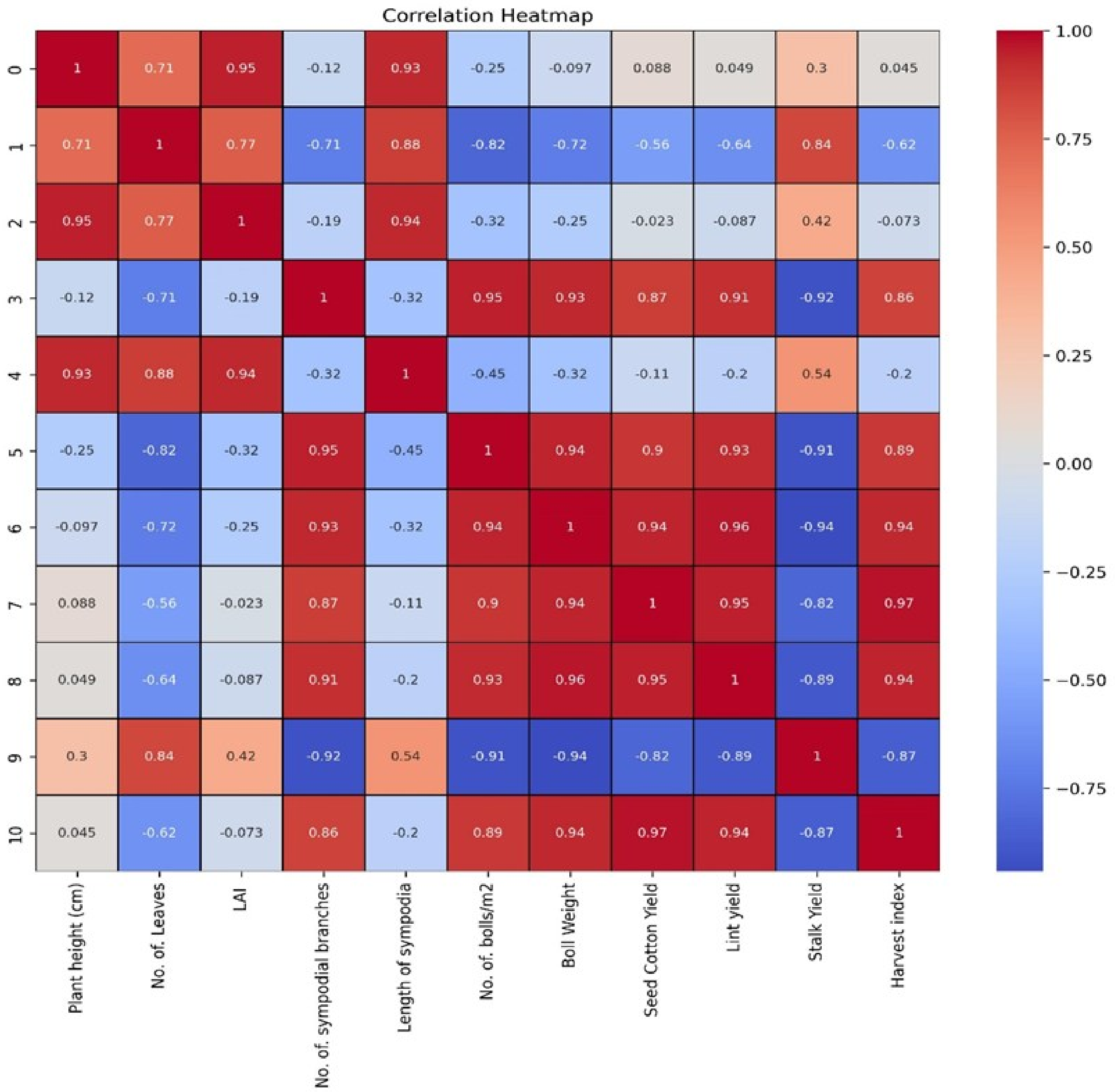

Fig. 3. Interpretation of Pearson Correlation Analysis of variables along with correlation matrix and heatmap.

Future research could focus on optimizing nutrient and growth regulator combinations to enhance fiber quality, as well as exploring genetic or environmental factors to improve the synergy between cotton yield and quality.

In conclusion, treatment T6 (Mepiquat chloride 100 ppm @ 45 & 60 DAS + NAA 40 ppm @ 60 & 90 DAS + KNO_3 2% @ 60 & 90 DAS + Calcium borate 0.5% @ 60 & 90 DAS + Defoliant at the 60% boll bursting stage) yielded the most favorable results for growth parameters, yield attributes, and fiber quality in cotton. The combination of growth regulators and foliar nutrients enhanced boll retention, reduced shedding, and improved yield components such as ginning percentage, seed index, and lint index. While fiber quality traits like fiber length and strength remained consistent across treatments, T6 exhibited slight improvements in uniformity and tenacity, indicating its potential to support high-yield production without negatively affecting fiber quality. This balanced approach highlights T6 as a promising treatment option for farmers seeking to maximize cotton yield and efficiency while maintaining fiber quality.

Conclusion

The application of mepiquat chloride (100 ppm) @ 45 and 60 DAS + NAA (40 ppm) @ 60 and 90 DAS + KNO_3 (2%) @ 60 and 90 DAS + Calcium borate (0.5%) @ 60 and 90 DAS + Defoliant @ the 60% boll bursting stage recorded the highest growth and yield parameters, as well as the maximum seed cotton yield, compared to other treatments. This treatment also achieved the desired plant architecture, making it well-suited for mechanical harvesting. Therefore, it may be recommended as an effective strategy for enhancing cotton productivity and profitability.

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Authors' Contributions

RV conducted the experiment, recorded data, and performed data analysis. SS supervised the experiment, formulated the experimental design, provided assistance, and contributed to manuscript corrections and data analysis. RT, AP and AR offered guidance for conducting the experiment and made corrections to the manuscript. All authors reviewed and approved the final version of the manuscript.

Compliance with Ethical Standards

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

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