Indian Journal of Experimental Biology
Vol. 60, July 2022, pp. 490-497

Validating the physiological potential of zero monopodial compact cotton TCH 1819 culture by chemical manipulation

B Rakavi[1], P Jeyakumar[1]*, CN Chandrasekhar[1], D Vijayalakshmi[1], M Kumar[2], L Arul[3] & N Manikanda Boopathi[3]

[1]Department of Crop Physiology; [2]Department of Plant Breeding and Genetics; [3]Department of Plant Biotechnology, Tamil Nadu Agricultural University (TNAU), Coimbatore, Tamil Nadu, India

Received 13 December 2021; *revised 14 June 2022*

Cotton is the most important global cash crop which controls economy of many nations. Global sustainability of cotton yield is one of the major challenges for meeting impending threats under climate change. Though India is one among the leading countries in cotton production, the supply is not enough considering the increasing demand. Scientists across the Globe are indulged in developing new lines and cultures with capacity to produce more yields. In this context, here, we have made an attempt to study the growth, physiology, and yield traits of cotton culture - TCH 1819 before its release (now released in the name of CO 17) by different chemical treatments. Observation on the leaf gas exchange traits, leaf parenchymal cells distinguished the source sink relationship of the culture. Chemical manipulation by growth retardants reduced the gibberellins content and modified the foliage structure. By characterizing the physiological potential through manipulation by growth retardant (Mepiquat chloride (0.015 %)) increased the yield by 30%. The traits identified in this study are potential indicators in breeding programme before releasing the variety.

Keywords: Abiotic stress, Chlorophyll index, Drought stress, Gibberellins, Leaf architecture, Mepiquat chloride, Source sink relationship

Cotton is an important textile crop serves the economy of many countries worldwide. Cotton requires sufficient water to produce yield and good fibre. India is the largest consumer and exporter of cotton.In, Tamil Nadu the supply is lesser than the demand. Hence, it is essential to produce more cotton to meet the demand. The indeterminate habit of cotton makes it difficult for farmers to cultivate it and researchers were attempting to study the growth stages for management practices. The management of plant density and the spatial arrangements of cotton plants, for attaining higher yield have been attempted by physiologists for several decades. Furthermore, cotton is responsive to management and changes in the environments and responds to any perturbations in its environment with a dynamic growth response that is often unpredictable. Physiological efficiency of the plant holds the key for ideal performance of the crop in terms of growth stages, yield and fibre quality. Managing the balance of vegetative and reproductive growth by using nutrients, hormones and retardants are the essence of managing a cotton crop. Researches in these areas are driven by the need to intensify production to obtain greater yields. In countries such as USA, Australia and Brazil, cotton is grown on larger, modernized farms using more mechanized technology.

In India, cotton cultivation practiced in small-scale with labour intensive operations like hand weeding and picking. The practice of high density planting system (HDPS) with chemical manipulation is now being conceived as an alternate production system for improving the productivity, profitability, increasing input use efficiency, reducing input costs and minimizing the risks associated with the current cotton production system in India for short duration varieties. Application of nutrients as foliar spray helps in many ways to improve crop physiological growth, when applied in a combined manner like potassium silicate or calcium silicate, the efficiency of plant is increased in both stability and growth. Several naturally occurring hormones work in the cotton plant to adjust plant growth normally, when applied through foliar the response of cotton is greater to the existing environmental condition. Growth retardants like mepiquat chloride influences cotton growth specifically by targeting gibberellic acid synthesis and, thereby, inhibiting cell expansion. The inhibition of cell elongation limits expansion of leaf and stem

*Correspondence:
E-Mail: rakavi.agri@gmail.com

tissues, resulting in reduced leaf area and shorter stem lengths. Mepiquat is thus a tool to manage cotton canopy growth and size. Also, testing indicated that mepiquat chloride is of low chronic toxicity and that it is negative for mutagenic effects. Mepiquat chloride generally is of low acute toxicity and has been classified in Group E (no evidence of carcinogenicity for humans). Use of growth retardants under high density planting system promotes synchronized maturity. Most decisions regarding production inputs depend upon plant growth stage and yield potential. Thus, efforts have been made in recent years to better predict cotton growth stages and development period for newly introduced varieties.

To sustain the cotton productivity with economic and environmental safety, there is a need to optimize the nutrient, hormones, growth retardant and nutrient consortium requirement for compact cotton types before release to farmers for commercial cultivation. In this context, here, we studied the growth and gas exchange potential, yield increment of cotton variety Co 17 under different chemical treatments before releasing the culture.

Material and Methods

Field experiment was conducted at Department of Cotton, Tamil Nadu Agricultural University, Coimbatore, located in the Western Agro-climatic zone of Tamil Nadu (11° 02' N latitude, 76° 93' E longitude and at an altitude of 428.5 metres above mean sea level) during winter season (August-February) of 2018-2019 and 2019-2020. The soil of the experimental site was sandy clay loam in texture, which comes under Typic Ustropept series. Compact Cotton Co 17 (TCH 1819 Culture) was taken as test crop. Crop was supplied with fertilizers and other cultivation operations including plant protection measures as per recommended package of practices of Tamil Nadu Agricultural University, Coimbatore. There were eight treatments *viz.*, T_1, Control; T_2,Mepiquat chloride (0.015%); T_3, Potassium silicate (0.5%); T_4, Potassium schoenite (0.5%); T_5, Borax (0.3%); T_6, Salicylic acid (0.01%); T_7, Calcium silicate (0.5%); and T_8, TNAU Cotton Plus (1.25%). Foliar spray of treatments were given at peak vegetative [45 days after sowing (DAS)] and flowering (60 DAS) stage of the crop. The observations on growth, physiology were recorded and yield attributes were taken at the time of harvest of crop. Cotton crop was raised in raised beds and the major cultivation practices were carried out from sowing to harvest in timely manner. The weather prevailed during the cropping period are recorded from meteorological observatory of Tamil Nadu Agricultural University, Coimbatore. Harvesting was done manually and the observations on growth, morphology, anatomical and physiological with yield attributes like seed Cotton yield were taken at the time of harvest of crop.

Plant height as the length of main stem from the cotyledonary node to the base of the last opened leaf was measured and the mean was expressed in cm. Leaf area per plant was measured using a Leaf area meter (LICOR, Model LI 3000) and expressed as cm^2 $plant^{-1}$. Leaf thickness was measured using the instrument, vernier caliper and expressed in mm. Chlorophyll index was recorded using a portable chlorophyll meter[1]. Photosynthetic gas exchange was measured from non-detached young and fully expanded leaves using a portable photosynthetic system (PPS) (ADC Bio-Scientific). Leaf samples were extracted with standard HPLC grade methanol for hormonal analysis of giberrelins in treated plants. Samples (50 µL) were then analyzed by HPLC – electrospray ionisation/MS-MS using an Agilent [1]100 HPLC coupled to an Applied Biosystems Q-TRAP 000 (Applied BIOSYSTEMS, California, USA). Chromatographic separation was carried out on a phenomenex Luna 3 µm C18 (2) 100×2.0 mm column, at 35°C. The solvent gradient used was 100%A (94.9% H_2O: 5% CH3CN: 0.1% CHOOH) to 100%B (5% H_2O: 94.9% CH_3CN: 0.1% CHOOH) over 20 min. Solvent B was held at 100% for 5 min. Analysis of the compounds was based on appropriate Multiple Reaction Monitoring. Data were acquired and analyzed using Analyst 1.4.2 software (Applied Biosystems). Hormones were determined in three leaf samples treated under different chemicals at flowering stage.

For anatomical studies examination areas ranging from approximately 1 cm to 5 microns in width was imaged in a scanning mode using conventional SEM techniques (magnification ranging from 20X to approximately 30,000X, spatial resolution of 50 to 100 nm). The leaf samples were collected from respective plots at 60 and 90 DAS and frozen with liquid nitrogen. For taking images of samples, the leaf samples were placed on the carbon conducting tape and sputter coated. The tape was mounted on sample stage and the images were taken in 200X, 800X and

1600X etc., magnification and 15 KV and 20 KV using FET SEM Model "QUANTA 250". Yield traits like cotton yield, ginning out turn, lint and seed index were recorded.

The data recorded on various parameters during the course of investigation and the summed up data were statistically analyzed following the analysis of variance for randomized block design through SPSS software. Wherever the treatment differences were found significant (`F` test), critical difference was worked out at 0.05 probability level. Treatment differences that were non-significant were denoted by "NS". The multiple linear regression analysis was made between growth parameters, and yield.

Results and Discussion

Growth and morphology

The data on plant height of CO 17 recorded during 2018-2019 and 2019-2020 are presented in Fig. 1. There were significant differences in plant heights of the cotton plants subjected to different treatments during two cropping periods. Foliar application of TNAU Cotton Plus (1.25%) resulted in the maximum plant height of 104.9, 109.2 and 112.9 cm on 60, 90 and 120 DAS, respectively during 2018-19. Similarly during 2019-20, the plant height was higher in the plants subjected to TNAU Cotton Plus (1.25%). Cotton plants treated with mepiquat chloride (0.015%) showed the least plant height of 80.10, 88.8 and 92.6 cm during 60, 90 and 120 DAS as in 2018-19. While during 2019-20, a plant height of 84.5, 91.7 and 93.7 cm on 60, 90 and 120 DAS was recorded respectively. However, plants applied with mepiquat chloride (0.015%) had lesser plant height than the control during both the cropping period.

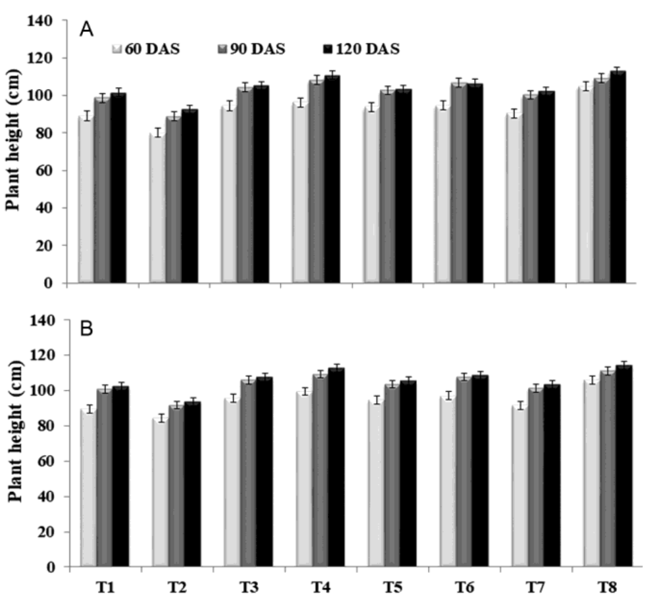

Fig. 1 — Effect of chemical manipulation on plant height (cm) in CO 17 during 2018-19 and 2019-20.

The data on leaf area of CO 17 recorded during 2018-2019 and 2019-2020 are presented in Fig. 2A. There were significant differences in leaf area of the cotton plants subjected to different treatments during two cropping seasons. Foliar application with TNAU Cotton Plus (1.25%) resulted in the maximum leaf area of 2759.69, 5880.99 and 5552.12 (cm^2/plant) on 60, 90 and 120 DAS respectively during 2018-19. Similarly during 2019-20, the leaf area was maximum in the plants subjected to TNAU Cotton Plus (1.25%). Cotton plants treated with mepiquat chloride (0.015%) showed the least leaf area of 2008.89, 4863.64 and 3419.56 (cm^2/plant) during 60, 90 and 120 DAS as in 2018-19. While during 2019-20 they showed a leaf area of 1893.29, 4724.29 and 3821.87 (cm^2/plant) on 60, 90 and 120 DAS, respectively. Plants applied with mepiquat chloride (0.015%) had lesser leaf area than the control during both the seasons. Significant variations in the leaf thickness of CO 17 were recorded during various treatments and the values are given in the Fig. 2B. Leaves were found thicker (0.61, 0.85 and 0.83 (mm) on 60, 90 and 120 DAS) as in mepiquat chloride (0.015%) applied plants during 2018-19 trial and the same trend was found in the 2019-2020 trial.

Gas exchange traits

The photosynthetic rate recorded during 2018-19 and 2019-20 in chemically manipulated CO 17 plants are given in Table 1. The photosynthetic rate was found maximum of 34.87, 35.39, 37.89 and 36.10, 37.95, 39.25 μmol $CO_2m^{-2}s^{-1}$ at 60, 90,120 DAS during 2018-19 and 2019-20 cropping period respectively in TNAU Cotton Plus (1.25%) treated cotton plants. Mepiquat chloride (0.015%) applied plants had least photosynthetic rate of 27.32, 30.62 and 31.28 μmol $CO_2m^{-2}s^{-1}$at 60, 90 and 120 DAS during 2018-19 and a similar trend was seen in the next year trial. The photosynthetic rate was less in the untreated plant leaves with a value of 31.34, 33.04, 32.10 and 32.14, 34.16, 33.17 μmol CO_2 $m^{-2}s^{-1}$ at 60, 90, 120 DAS during the 2018-19 and 2019-20, respectively. The data on stomatal conductance of CO 17 recorded during 2018-2019 and 2019-2020 are presented in Table 1. Significant differences were observed in stomatal conductance of the cotton plants

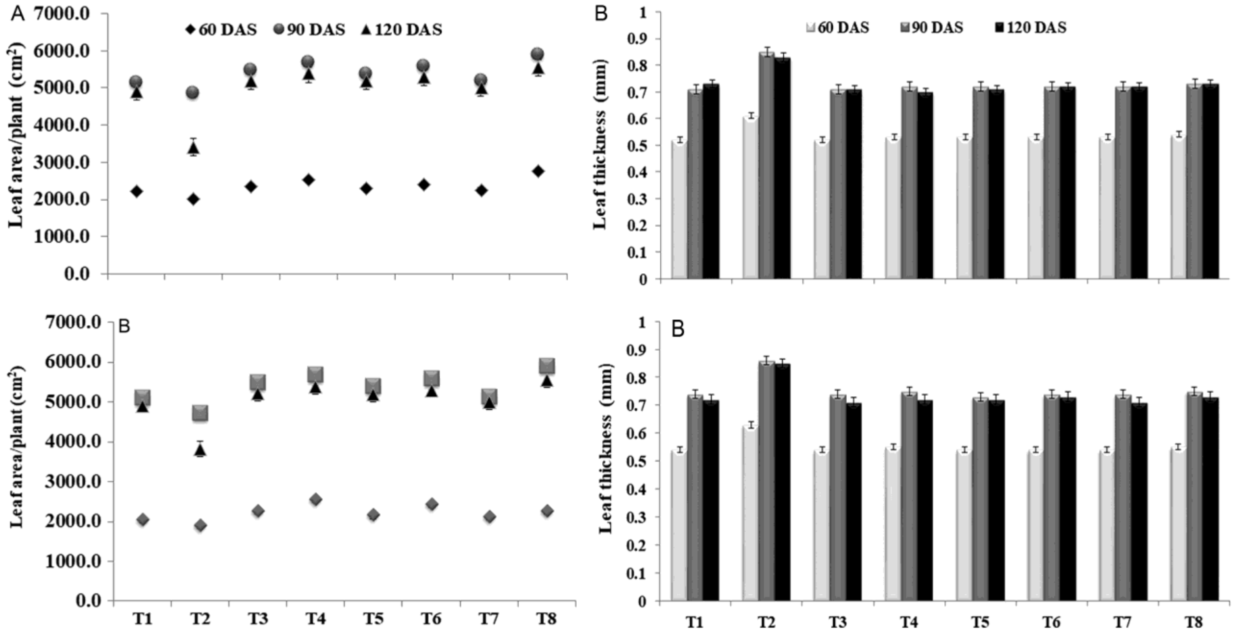

Fig. 2 — Effect of chemical manipulation on (A) leaf area per plant (cm^2); and (B) leaf thickness (mm) in CO 17 during 2018-19 and 2019-20.

Table 1 — Effect of chemical manipulation on Photosynthetic rate (μmol $CO_2 m^{-2}s^{-1}$) and Stomatal conductance (mol H_2O $m^{-2}s^{-1}$) of cotton during 2018-2019 and 2019-2020

Treatments	Pn				g_s (s is subscript)			
	30 DAS	60 DAS	90 DAS	120 DAS	30 DAS	60 DAS	90 DAS	120 DAS
			2018-2019					
T1 Control	28.85±0.441	31.34±0.479	33.04±0.505	32.1±0.490	0.42±0.006	0.68±0.010	0.73±0.011	0.51±0.008
T2 Mepiquat chloride (0.015%)	28.95±0.427	27.32±0.509	31.28±0.529	30.62±0.524	0.43±0.007	0.62±0.012	0.7±0.013	0.49±0.010
T3 Potassium silicate (0.5%)	27.64±0.961	32.17±1.160	33.78±1.218	33.57±1.210	0.46±0.017	0.75±0.027	0.77±0.028	0.6±0.022
T4 Potassium schoenite (0.5%)	27.47±0.727	33.63±0.916	34.97±0.925	34.68±0.918	0.47±0.012	0.81±0.021	0.83±0.022	0.64±0.017
T5 Borax (0.3%)	28.33±0.283	31.27±0.313	32.28±0.323	31.13±0.311	0.4±0.004	0.7±0.007	0.77±0.008	0.54±0.005
T6 Salicylic acid (0.01%)	26.48±0.404	32.57±0.498	33.59±0.513	32.28±0.493	0.41±0.006	0.77±0.012	0.8±0.012	0.61±0.009
T7 Calcium silicate (0.5%)	28.75±0.924	31.78±1.022	32.77±1.053	31.76±1.021	0.45±0.014	0.67±0.021	0.74±0.024	0.52±0.017
T8 TNAU Cotton Plus (1.25%)	27.21±0.566	34.87±0.726	37.89±0.758	35.39±0.789	0.41±0.009	0.85±0.018	0.86±0.018	0.73±0.015
Mean	27.96	31.87	33.31	33.09	0.43	0.73	0.78	0.58
SEd	0.4907	0.584	0.6071	0.6044	0.0083	0.0134	0.0139	0.0108
CD ($P \leq 0.05$)	1.0524	1.2526	1.3022	1.2964	0.0177	0.0287	0.0298	0.0232
			2019-2020					
T1 Control	29.01±0.443	32.14±0.491	34.16±0.522	33.17±0.507	0.43±0.007	0.69±0.011	0.73±0.011	0.51±0.008
T2 Mepiquat chloride (0.015%)	28.97±0.443	27.04±0.549	30.88±0.563	31.94±0.564	0.44±0.007	0.62±0.013	0.69±0.013	0.48±0.011
T3 Potassium silicate (0.5%)	27.67±0.998	34.03±1.227	35.47±1.279	34.67±1.250	0.47±0.017	0.77±0.028	0.8±0.029	0.62±0.022
T4 Potassium schoenite (0.5%)	28.65±0.758	35.18±0.931	36.57±0.968	35.47±0.938	0.48±0.013	0.83±0.022	0.85±0.022	0.66±0.017
T5 Borax (0.3%)	29.53±0.295	33.99±0.340	34.92±0.349	33.93±0.339	0.41±0.004	0.73±0.007	0.78±0.008	0.59±0.006
T6 Salicylic acid (0.01%)	27.66±0.423	34.33±0.524	35.89±0.548	35.08±0.536	0.42±0.006	0.79±0.012	0.82±0.013	0.64±0.010
T7 Calcium silicate (0.5%)	29.68±0.954	33.03±1.062	34.53±1.110	33.61±1.080	0.46±0.015	0.7±0.023	0.76±0.024	0.54±0.017
T8 TNAU Cotton Plus (1.25%)	28.48±0.593	36.1±0.751	39.25±0.811	37.95±0.817	0.42±0.009	0.87±0.018	0.9±0.019	0.74±0.015
Mean	28.71	33.59	35.05	34.64	0.44	0.75	0.79	0.6
SEd	0.5091	0.6084	0.6376	0.6243	0.0084	0.0138	0.0144	0.0111
CD ($P \leq 0.05$)	1.0919	1.3051	1.3676	1.339	0.0181	0.0296	0.0309	0.0238

[Pn denotes photosynthetic rate, g_s denotes stomatal conductance **denote significance level at P <0.05 and NS denote non-significant, respectively]

subjected to different treatments during two cropping periods. Among them, stomatal conductance was found maximum in TNAU Cotton Plus (1.25%) treated plants with a value of 0.85 and 0.86 at 60 DAS, 0.87 and 0.90 at 90 DAS, 0.73 and 0.74 (mol H_2O $m^{-2}s^{-1}$) at 120 DAS during 2018-19 and 2019-20 cropping period, respectively. The control plant leaves with a value of 0.68 and 0.69 at 60 DAS, 0.73 and 0.73 at 90 DAS, 0.51 and 0.51 (mol H_2O $m^{-2}s^{-1}$) at 120 DAS recorded during the 2018-19 and 2019-20, respectively. Mepiquat chloride (0.015 %) applied plants had lesser stomatal conductance (0.62 and 0.62 at 60DAS, 0.70 and 0.69 at 90 DAS, 0.49 and 0.48 mol H_2O $m^{-2}s^{-1}$ at 120 DAS during 2018-19 and 2019-20 cropping period when compared to all other treatments during both the cropping periods.

Chlorophyll index

The data on chlorophyll index measured in CO 17 samples are given in the Fig. 3. Maximum chlorophyll index value was measured in mepiquat chloride (0.015%) applied plants with 44.45 and 45.74 at 60 DAS, 47.57 and 46.39 at 90 DAS, 42.56 and 42.28 at 120 DAS during 2018-19 and 2019-20, respectively. TNAU Cotton Plus (1.25%) applied plants recorded a chlorophyll index of 39.85, 40.48 and 36.59 on 60, 90 and 120 DAS, but comparatively lesser than mepiquat chloride (0.015%) applied plants. The same trend was observed in the next season trial during 2019-20. The trend line holds the untreated plants with the least chlorophyll index values in both the cropping seasons with 37.41, 39.89, 35.25 and 39.54, 40.75, 36.26 on 60, 90, 120 DAS during 2018-2019 and 2019-2020, respectively.

Gibberellin content (µg g^{-1})

The HPLC analyzed gibberellic acid (GA) content (µg g^{-1}) are given in Fig. 4. Regarding GA analysis, mepiquat chloride applied plants recorded very less GA content (1.82 µg g^{-1} and 1.87 µg g^{-1} at 60 DAS, 1.95 µg g^{-1} and 1.99 µg g^{-1} at 90 DAS during the years 2018-2019 and 2019-2020). Whereas in control plants (3.77 µg g^{-1} and 3.83 µg g^{-1} at 60 DAS, 3.99 µg g^{-1} and 4.04 µg g^{-1} at 90 DAS during the years 2018-2019 and 2019-2020) and TNAU Cotton Plus (4.64 µg g^{-1} and 4.69 µg g^{-1} at 60 DAS, 4.89 µg g^{-1} and 4.94 µg g^{-1} at 90 DAS during the years 2018-2019 and 2019-2020) applied plants the GA content was higher in both the years indicating higher GA synthesis.

Effect of chemical manipulation on yield traits

Foliar application of nutrients, growth hormones, growth retardants and nutrient consortium had effect on the yield traits of CO 17. The data on number of sympodia per plant as influenced by various treatments are presented in Fig. 5. The variety performed well under foliar application of TNAU Cotton Plus by recording increased seed cotton yield (2269 kg/ha and 2332 kg/ha) during both 2018-2019 and 2019-2020. Followed by mepiquat chloride (0.015 %) (seed cotton yield: 2165 and 2274 kg ha^{-1} during 2018-19 and 2019-20).

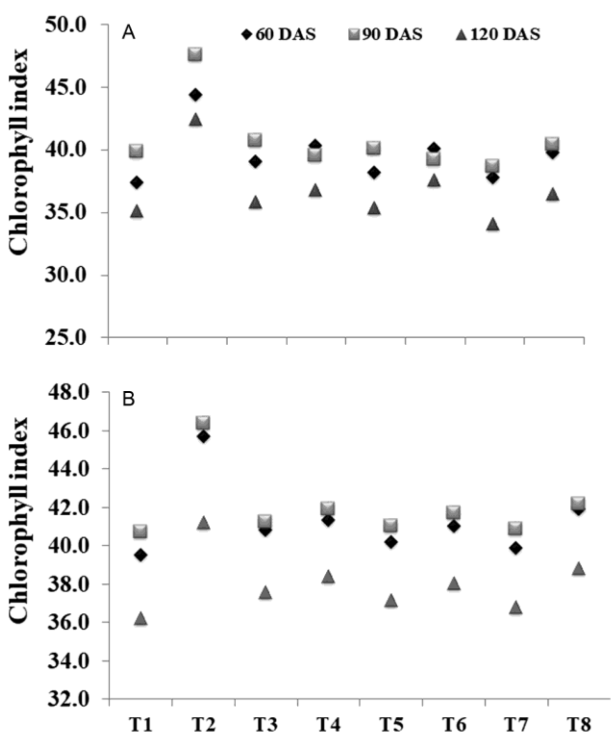

Fig. 3 — Effect of chemical manipulation on chlorophyll index in CO 17 during (A) 2018-19; and (B) 2019-20

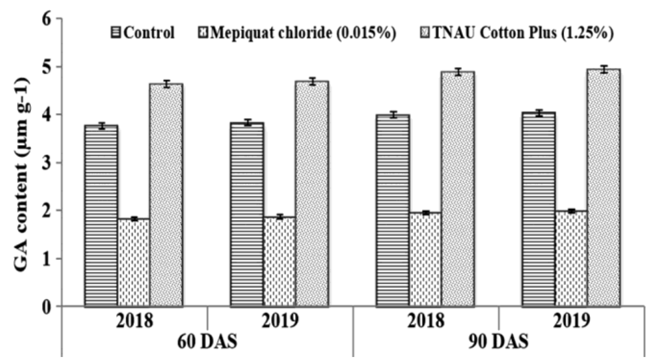

Fig. 4 — Effect of chemical manipulation on gibberellic acid (GA) content in best treatments.

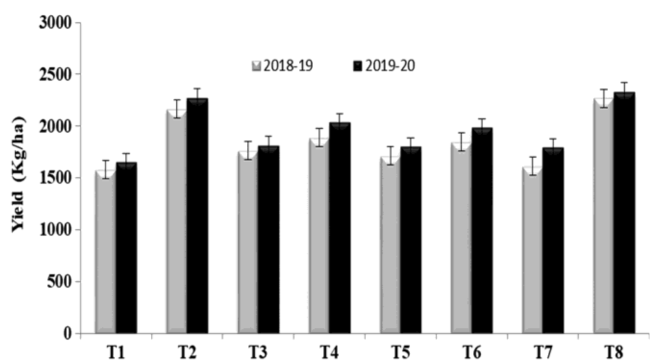

Fig. 5 — Effect of chemical manipulation on yield (kg/ha) in CO 17 (2018-19 and 2019-20)

Plant height is an important morphological character in cotton by providing sites for nodes and internodes from where sympodial branches emerge, and thus plays an important role in defining the morphological structure work relating to productivity. In the present investigation, chemical manipulation experiment in cotton variety CO 17 increased the plant height. Foliar application of different treatments increased the plant height than control. The growth retardant such as mepiquat chloride (Pix), reduced the plant height in cotton and the reduction increased with the increasing concentration[2]. Ren *et al.*[3] suggested that mepiquat chloride application may reduce intraspecific competition due to a more compact plant structure. The mechanism of reducing the gibberellin (GA) biosynthesis and production of high amount of IAA oxidase activity was the reason for reduced plant height under mepiquat application. Similarly, Rademacher[4] reported that onium compounds, such as chloromequat chloride and mepiquat chloride, which blocked the copalyl-diphosphate synthase and ent-kaurene synthase involved in the early steps of GA biosynthesis is responsible for reduced GA production and reduced plant height.

Leaf area is a vital factor that is closely connected to the physiological process controlling dry matter production and yield. Leaf area was found higher in TNAU Cotton plus (1.25%) (24.47 and 30% at 60 DAS; 14.15 and 15.0% increase at 90 DAS) and lesser in mepiquat chloride (0.015 %) (9.42 and 7.11% at 60 DAS; 5.59%, and 7.20% decrease at 90 DAS) than other treatments during 2018-2019 and 2019-2020, respectively. It has been stated that foliar application of boosters containing multi-nutrients increases the growth of foliage size. Nutrients like nitrogen and magnesium increases the leaf growth by increasing the cell division and differentiation at cell level. Hussain *et al.*[5] and Shahzad *et al.*[6] reported that 1% potassium, boron and magnesium sulphate in cotton can increase yield by increasing the expansion of leaf area and CO_2 assimilation capacity[7]. Though mepiquat chloride (0.015 %) reduced leaf area, it recorded the highest leaf thickness trait (17.30 % and 16.66 % at 60 DAS; 16.43%, 16.21% increase at 90 DAS) than other treatments during 2018-2019 and 2019-2020, respectively. Leaf area reduction is owing to the plant growth regulator effect suppressing cell elongation and smaller cells result in leaf area reduction. Growth retardants like mepiquat chloride (100 ppm) and Cycocel (40 ppm) reduced leaf area and resulted in more production of leaves and thicker leaves[8]. Gwathmey & Clement[9] reported the leaf area reduction under mepiquat chloride in cotton, which is due to the partition of assimilates to developing flowering parts to shorten the vegetative stage.

Gas exchange parameters, *i.e.*, net photosynthetic rate, transpiration rate and stomatal conductance increased by foliar application of different treatments. Highest increased percentage was recorded in TNAU Cotton Plus (1.25%) (photosynthetic rate - 11.05 and 12.32% at 60 DAS; 10.13%, 10.02% increase at 90 DAS, stomatal conductance – 25.0 and 26.0% at 60 DAS; 19.44%, 20.48% increase at 90 DAS) applied plants over control during 2018-2019 and 2019-2020, respectively. The increase in stomatal conductance increased CO_2 diffusion into the leaf and accelarated the photosynthetic rates which consequently manifested in terms of increased biomass and crop yields. The increase in chlorophyll index and content is responsible for the increased photosynthetic rate. Increase in photosynthetic rate and conductance increases the translocation efficiency of assimilates fixed by carboxylation process. Among the treatments, least was observed under mepiquat chloride (0.015%) (photosynthetic rate – 12.8 and 15.9% decrease at 60 DAS; 7.1%, 9.6% decrease at 90 DAS, stomatal conductance – 8.0 and 10.0% decrease at 60 DAS; 4.0%, 5.40% decrease at 90 DAS) treated plants over control during 2018-2019 and 2019-2020. Application of Mepiquat chloride (0.015%) reduced single leaf photosynthesis, stomatal conductance but increased the assimilate production from source to sink in cotton[10]. Though there was reduction in leaf area, Mepiquat chloride increased the number of leaves in CO 17. The reduction in single leaf photosynthesis was compensated by presence of more number of leaves and by shortening the vegetative phase and increasing the reproductive phase with effective partitioning of assimilates to the sink portions (bolls) for production of bigger period. Furthermore, Mepiquat chloride partially closed the stomata that led to reduction in transpiration rate.

Chlorophyll index determined the photosynthetic capacity of the cotton and influenced the rate of photosynthesis, dry matter production and the yield. In the present study, mepiquat chloride (0.015%) (18.81 and 15.68% decrease at 60 DAS; 10.22%, 13.84% increase at 90 DAS over control during 2018-2019 and 2019-2020) recorded the highest percent increase in chlorophyll index over control. The variation in chlorophyll content due to growth retardants might be attributed to decreased chlorophyll degradation and increased chlorophyll synthesis. Increased chlorophyll index might be because of increased concentration of leaf pigments. Bhatt and Andal[11] inferred that the application of growth retardants produced thicker leaf blades, whereas the application of cycocel resulted in significantly increased the total chlorophyll content.

Effect of growth retardants on anatomy of leaves

Foliar application of mepiquat chloride reduced the leaf area and increased the thickness by altering the anatomical structures in CO 17 (Fig. 6). Leaves portion of mepiquat chloride applied plants and control plants were sampled and examined under scanning electron microscope. It has been shown that mepiquat chloride can induce more compact plants by decreasing leaf expansion in cotton. This phenomenon was confirmed by present data, which showed an inhibition of plant height, leaf area, more thickness (SEM). Mepiquat chloride (0.015%) treated leaves exhibited relatively thicker and longer palisade parenchyma and smaller spongy parenchyma in leaf tissues, whereas in the control, small palisade parenchyma was observed. Leaf cells of mepiquat chloride applied plants became more compact and thicker compared to control. Leaf midrib cross section showed the compact structural change of xylem and phloem vessels. The results are in harmony with the findings of Fukazawa *et al.*[12] in cotton plants treated under mepiquat chloride. Khan *et al.*[13] reported that plant growth regulator (*i.e.*, mepiquat chloride) at the rate of 200 ppm was sprayed in cotton (vegetative phase) resulted in darker and thicker leaves.

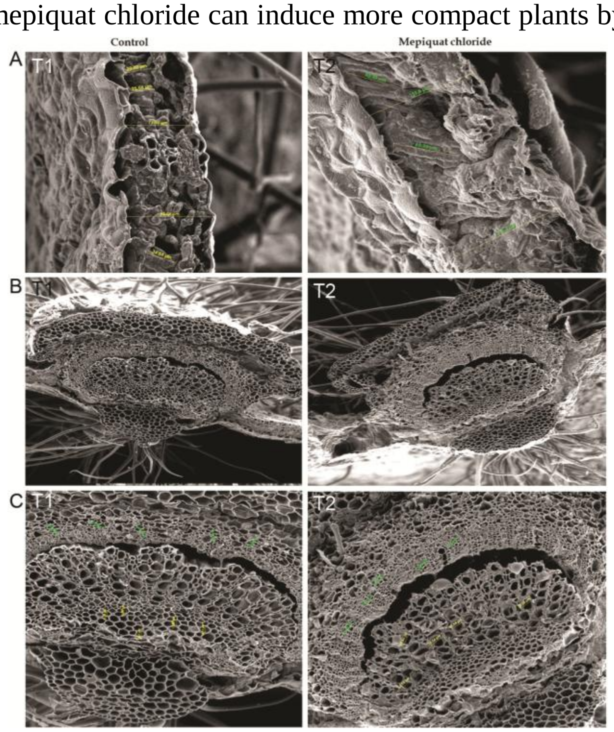

Fig. 6 — Cross sections of control and mepiquat chloride treated leaves. Yellow arrow indicates (A) Leaf cross section: thickening of palisde parenchyma cells, (B) Leaf midrib cross section: changes in vessel size; and (C) Measurement of xylem and pholem vessels.

Effect of growth retardants on hormones (GA content)

Leaves of mepiquat chloride (0.015%) and TNAU Cotton Plus (1.25%) applied plants and control plants were sampled and examined for hormonal study. Mepiquat chloride (0.05%) applied leaves exhibited a decrease in gibberellin content than TNAU Cotton Plus (1.25%) and control plants. Gibberellin inhibition might have resulted in reduced vegetative period by setting an early stage for reproductive phase to ensure better partitioning efficiency from source to sink[15]. This might have led to increased seed cotton yield in CO 17. The mechanism of reducing the gibberellin biosynthesis by mepiquat chloride is still need to be explored.

Yield traits

With regards to chemical manipulation, TNAU Cotton Plus (1.25%) recorded higher percent increase in seed cotton yield (43 and 42%) during 2018-2019 and 2019-2020 followed by Mepiquat chloride (0.015%) seed cotton yield (36.0 and 37.4%) during 2018-2019 and 2019-2020. TNAU Cotton plus applied plants had higher boll weight and numbers due to efficient utilization of nutrients and thereby reduced boll shedding and increase in yield. Improvement in seed cotton yield and quality is due to nutrients involvement in several metabolic processes of cotton plants[15]. This helps in increasing photosynthesis and mobilization of photosynthates to reproductive sink, which in turn increased boll size and seed cotton yield. Foliar application of potassium sulphate increased the cotton yield (15% over control). Mepiquat chloride (0.015%) applied plants had increased yield due to effective distribution of assimilates by reduction in single leaf photosynthesis, by altering leaf anatomy (thicker and more leaves) and by prolonging reproductive phase to yield higher biomass. Also it increased the number of bolls by reducing the distance between the bolls when compared to other treatments. Similarly, Kumar *et al.*[15] reported that application of mepiquat chloride 50 ppm at flowering phase improved biomass, boll weight, boll diameter and seed cotton yield (21%). The increase in boll weight is due to better partitioning of photo-assimilates into reproductive structures. The results were in accordance with Gwathmey & Clement[9]. Limiting and regulating the excessive vegetative growth of cotton due to several factors besides, high density planting through application of mepiquat chloride was found encouraging in the current study.

Conclusion

Results from the above study indicate that chemical manipulation by mepiquat chloride (0.015%) reduced the foliage size and altered the plant structure in a compact way which was easy for management and suitable for synchronized maturity in this zero monopodia short sympodia TCH 1819 culture.

Conflicts of interest

Authors declare no competing interests.

References

1 Minolta C, Manual for Chlorophyll meter SPAD-502. (Minolta Cameraco., Osaka, Japan), 1989.

2 Gu S, Evers JB, Zhang L, Mao L, Zhang S, Zhao X, Liu S, van der Werf & Li Z, Modelling the structural response of cotton plants to mepiquat chloride and population density. *Ann Bot*, 114 (2014) 877.

3 Ren X, Zhang L, Du M, Evers JB, van der Werf W, Tian X & Li Z, Managing mepiquat chloride and plant density for optimal yield and quality of cotton. *Field Crops Res*, 149 (2013) 1.

4 Rademacher W, Growth retardants: effects on gibberellin biosynthesis and other metabolic pathways. *Ann Rev Plant Biol*, 51 (2000) 501.

5 Hussain M, Tariq AF, Nawaz A, Nawaz M, Sattar A, Ul-Allah S & Wakeel A, Efficacy of fertilizing method for different potash sources in cotton (*Gossypium hirsutum* L.) nutrition under arid climatic conditions. *PLoS ONE*, 15 (2020) 0228335

6 Shahzad AN, Rizwan M, Asghar MG, Qureshi MK, Bukhari SAH, Kiran A & Wakeel A, Early maturing Bt cotton requires more potassium fertilizer under water deficiency to augment seed-cotton yield but not lint quality. *Sci Rep*, 9 (2019) 1.

7 Bradow JM & Davidonis GH, Quantitation of fiber quality and the cotton production-processing interface: a physiologist's perspective. *J Cotton Sci*, 4 (2000) 34.

8 Hodges H, Reddy V & Reddy K, Mepiquat chloride and temperature effects on photosynthesis and respiration of fruiting cotton. *Crop Sci*, 31 (1991) 1302.

9 Gwathmey C & Clement J, Alteration of cotton source–sink relations with plant population density and mepiquat chloride. *Field Crops Res*, 116 (2010) 101.

10 Zhao D, Oosterhuis, D & Bednarz C, Influence of potassium deficiency on photosynthesis, chlorophyll content, and chloroplast ultrastructure of cotton plants. *Photosynthetica*, 39 (2001) 103.

11 Bhatt J & Andal R, Variations in foliar anatomy of cotton, Proceedings of the Indian Academy of Sciences-Section B. Part 2, *Plant Sci*, 88 (1979) 451.

12 Fukazawa JT, Sakai, Ishida S, Yamaguchi I, Kamiya K & Takahashi Y, Repression of shoot growth, a bZIP transcriptional activator, regulates cell elongation by controlling the level of gibberellins. *Plant Cell*, 12 (2000) 901.

13 Khan A, Najeeb U, Wang L, Tan DKY, Yang G, Munsif F, Ali S & Hafeez A, Planting density and sowing date strongly influence growth and lint yield of cotton crops. *Field Crops Res*, 209 (2017) 129.

14 Kumar A, Karunakar A, Nath A & Meena BR, The morphological and phenological performance of different cotton genotypes under different plant density. *J Appl Nat Sci*, 9 (2017) 2242.