Ye S *et al.* (2024)
Notulae Botanicae Horti Agrobotanici Cluj-Napoca
Volume 52, Issue 3, Article number 13393
DOI:10.15835/nbha52313393
Research Article

Effects of chemical regulation on the growth, yield and fiber quality of cotton varieties with different plant architectures

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Abstract

Chemical regulation has beneficial effects on the growth, yield, and fiber quality of cotton with different plant architectures. This study aimed to investigate the combined effects of chemical regulators such as mepiquat chloride (1,1-dimethyl-piperidiniuchloride, DPC), chlormequat chloride (CCC), thidiazuron (TDZ), and ethephon (ETH) during the growth period of cotton. Different combinations of chemical regulators were applied to examine the growth, development, yield, and quality of cotton. The results showed that the application of different chemical regulators had varying effects on the yields of the two cotton varieties with distinct plant architecture. Specifically, K1C1 (before and after topping with 1:1 25% DPC, 50% TDZ, and 40% ETH) and K2C2 (before topping with 25% DPC and after topping with 50% CCC, 50% TDZ, and 40% ETH) were sprayed on 'Wankemian-1' and 'Wanmian-191', thereby increasing the cotton yield. The K2C2 treatment increased the upper half mean length and fiber strength of the two varieties but decreased the fiber length uniformity index. The fiber strength, fiber length uniformity index, and spinning consistency index of 'Wankemian-1' were higher than those of 'Wanmian-191'. Based on comprehensive yield, quality, and economic benefits, K1C1 and K2C2 were determined to be the most effective chemical regulators of 'Wankemian-1' and 'Wanmian-191', respectively.

Keywords: cotton; chemical regulation; fiber quality; growth; yield

Introduction

Cotton has the inherent characteristic of infinite growth. Topping is a widely practiced method to restrain the unending growth of cotton plants and regulate their architectural structures (Zhu *et al*., 2020; Yu *et al*., 2021). Cotton topping can be performed manually or chemically. Manual topping is time-consuming

Received: 10 Sep 2023. Received in revised form: 28 May 2024. Accepted: 22 Aug 2024. Published online: 06 Sep 2024.
From Volume 49, Issue 1, 2021, Notulae Botanicae Horti Agrobotanici Cluj-Napoca journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

and labor-intensive, impeding the implementation and widespread adoption of light and simplified cotton cultivation techniques (Zou *et al*., 2014; Zhao *et al*., 2011). In contrast, chemical capping involves the use of plant growth regulators to restrict the growth of cotton tips, control plant height, and coordinate vegetative and reproductive growth of cotton plants (Zou *et al*., 2014). Chemical capping offers several advantages including high efficiency, rapid effects, and low cost. Consequently, it has become a key technology in large-scale cotton production (Zhu *et al*., 2020; Yu *et al*., 2021). Therefore, it is important to analyze the effects of chemical capping on cotton plant architecture regulation and yield and to identify suitable chemical control methods for light and simple cotton cultivation.

Chemical capping is widely used in cotton-producing regions. Currently, mepiquat chloride (1,1-dimethyl-piperidiniuchloride, DPC) is the most commonly used chemical capping agent in cotton production (Zhu *et al*., 2020; Zhao *et al*., 2018; Liu *et al*., 2018a; He *et al*., 2021). The effective chemical regulation of mepiquat improves cotton plant architecture, coordinates vegetative and reproductive growth, and enhances cotton yield and quality (Zhang *et al*., 2021). Nicotin reduces gibberellin activity in plants, inhibits cell elongation and stem internode compactness, reduces the height of the first fruit node, and increases lodging resistance (Liu *et al*., 2015). The appropriate dosage and frequency of application should be determined based on factors such as variety, climatic conditions, and planting density to achieve the desired increase in yield; otherwise, production may be reduced. Chlormequat chloride (CCC) is a typical plant growth inhibitor that prevents the excessive growth of cotton plants and hinders plant architecture (Li *et al*., 2016; Wang *et al*., 2018). Spraying a 50% dilution of CCC with water can control cotton plant height and fruit branch length, make cotton plants more compact, improve field ventilation and light conditions, increase the number of pre-frost flowers and yield, and increase the total seed cotton yield (Fan *et al*., 2007). In addition to chemical capping, chemical ripening agents have been used in cotton production to promote ripening. Common ripening agents include thidiazuron (TDZ) and ethephon, and there are both single and compound ripening agents (Wang *et al*., 2015). The TDZ is particularly effective in inducing defoliation properties, as it causes the leaves to fall off in a green state, thereby resolving the problem of withering without reducing cotton production (Wang *et al*., 2015). Research has shown that the combination of TDZ and ethephon (ETH) significantly improves ripening (Jiang *et al*., 2013), and that the combination of defoliants and ripening agents can significantly reduce costs and improve efficiency (Wang *et al*., 2015). In the cotton-growing region of the Yellow River Valley, mixed application of 50% TDZ wettable powder and 40% ETH diluted with water has been found to have a positive effect on both defoliation and ripening (Dai *et al*., 2013).

The present study aimed to investigate the effects of combining different chemical capping agents (DPC and CCC) and ripening agents (TDZ and ETH) on the growth and development, agronomic characteristics, yield, and quality of different cotton plant architectures in the primary cotton production regions of Anhui. This research was conducted to simplify chemical regulation, reduce costs, and enhance efficiency, with the ultimate goal of providing technical support for high-quality and efficient production of cotton. Although there are limited reports on suitable chemical control methods for these regions, this study provides essential insights into achieving optimal cotton production outcomes.

Materials and Methods

Overview of the experimental field

This experiment was conducted at the Cotton Research Institute of the Anhui Academy of Agricultural Sciences (Yingjiang district, Anqing city) test base (30° 31'N, 117° 06'E) in 2018 (Figure S1). The local area is characterized by a subtropical, monsoon humid climate along the river, with annual precipitation ranging from 1300 to 1500 mm and average temperatures between 14.5 °C~16.6 °C. The topsoil at the test site was composed of sandy loam, and its basic physical and chemical properties are listed in Table S1.

Experimental design

Based on the characteristics of the main cotton-producing regions in the Anhui Province, two early maturing cotton varieties were tested: 'Wankemian-1', a variety with a finite fruit branch type, and 'Wanmian-191', a variety with an infinite fruit branch type (Figure S2). The experiment employed a split-zone design, with two cotton varieties in the main zone and four chemical regulation levels in the split zone, as shown in Table 2. The plot area was 20 m^2 (3.9 m × 5.13 m, 6 row area), and each treatment had three replicates, resulting in a total of 24 cells.

Based on the results of a previous study, the nitrogen, phosphorus, and K fertilization levels for the two varieties were 160 kg N/hm^2, 40 kg P_2O_5/hm^2, and 80 kg K_2O/hm^2, respectively. The selected fertilizer comprised urea (with a nitrogen content of 46%), cotton-specific slow-release fertilizer (18-9-18), and rapeseed cake fertilizer, which was applied as a topdressing at the early flowering stage. The planting densities of 'Wankemian-1' and 'Wanmian-191' were 112,500 plants/hm^2 and 82,500 plants/hm^2, respectively, and the row spacing of 'Wankemian-1' was 65 cm × 13.7 cm and that of 'Wanmian-191' was 65 cm × 18.7 cm. The seeds were sown on May 21, 2018, and field management was performed according to local conventional cultivation techniques.

Index measurement

The plot was used as a unit to analyze the growth period, specifically recording the emergence, budding, initial flowering, and full flowering periods. The main agronomic traits, including plant height, first fruit branch node, number of fruit branches, number of internodes, and length of internodes, were measured in 10 cotton plants with relatively consistent growth in each plot at the peak of flowering and boll development (85 d after emergence).

During the mature stage of cotton from September to October, the plants in each plot were artificially harvested three times to calculate the boll number per plant, boll weight, harvest boll rate, lint percentage, and yield using established methods (Zhi *et al*., 2016). Fiber quality indices, such as upper half mean length, fiber strength, Micronaire value, fiber length uniformity index, and spinning consistency index, were determined using previously described methods (Zhang *et al*., 2016; Zhang *et al*., 2006).

The total output value is calculated as the combined income from cotton products and planting subsidies, whereas the total input cost includes the material and management costs. All material and labor costs were evaluated based on their current prices.

Data analysis

Microsoft Excel 2013 software was used for data calculation and mapping and SPSS software (version 19.0) was used for variance analysis. Differences in processing were compared by using the least significant range method.

Results

Effects of chemical regulation on the growth characteristics of cotton varieties with different plant architectures

As shown in Table 1, the application of different chemical regulations had a negligible impact on the growth and development of the two cotton varieties with distinct plant architectures. The treatments had no significant effect on emergence, bud emergence, flowering time and boll opening of cotton, as well as on the growth period of the infinite fruit branch type variety 'Wanmian-191'. The two treatments, K2C1 and K2C2, shortened the growth period of the finite fruit branch type variety 'Wankemian-1'. In general, the growth period of 'Wanmian-191' is longer than that of 'Wankemian-1'.

Table 1. Effects of different chemical regulations on plant growth stages and periods of two cotton varieties

Varieties	Treatment	Growth stage of the developmental process				Growth period (d)
		Emergence (month-day)	Days from emergence to squaring (d)	Days from squaring to first bloom (d)	Days from first bloom to boll opening (d)	
Wankemian-1	K1C1	05-21	36.3a	21.1a	52.0a	109.3a
	K1C2	05-21	37.0a	20.7a	51.1a	108.7ab
	K2C1	05-21	36.3a	20.3a	51.1a	107.7b
	K2C2	05-21	36.7a	21.1a	52.0a	108.0b
	mean		37.58	20.8	51.55	108.4
Wanmian-191	K1C1	05-21	38.7a	21.1a	51.0a	110.7a
	K1C2	05-21	38.3a	20.7a	51.3a	110.3a
	K2C1	05-21	39.0a	20.7a	50.7a	110.3a
	K2C2	05-21	38.7a	21.1a	50.0a	109.7a
	Mean		38.675	20.9	50.75	110.2

The effects of different chemical regulation treatments on the agronomic traits of the two cotton varieties with different plant architecture are shown in Table 2. The treatments had no significant effect on the first fruit branch nodes of the two cotton varieties. Compared to the K1C1 and K1C2 treatments, the K2C1 and K2C2 treatments significantly reduced the number of fruit branches in both varieties. The number of fruit branches in 'Wankemian-1' decreased from 12.2 and 12.5 to 9.6 and 10.1 (20.3% reduction), while that of 'Wanmian-191' decreased by 8.6%. Compared to the K1C1 and K1C2 treatments, the K2C1 and K2C2 treatments significantly reduced the plant height of both cultivars. The first fruit branch node and fruit branch number in 'Wanmian-191' were greater than those in 'Wankemian-1', and there was no significant difference in plant height between the two varieties.

Table 2. Effects of different chemical regulations on agronomic traits of two cotton varieties

Varieties	Handling treatment	First fruit branch node	Number of fruit branches	Plant height (cm)
Wankemian-1	K1C1	5.1a	12.5a	92.2a
	K1C2	5.1a	12.2a	93.5a
	K2C1	5.1a	10.1b	88.0b
	K2C2	5.0a	9.6b	89.1b
	mean	5.1b	11.1b	90.7a
Wanmian-191	K1C1	5.6a	12.3a	105.2a
	K1C2	5.5a	12.2a	104.4a
	K2C1	5.6a	11.3b	100.2b
	K2C2	5.6a	11.1b	98.5b
	mean	5.6a	11.7a	102.1a

Effects of chemical regulation on the yield of cotton varieties with different plant architectures

As shown in Table 3, the application of a chemical regulator significantly affected the yield of cotton in both plant architectures. For 'Wankemian-1', the highest seed cotton and lint yields were achieved with the K1C1 treatment, whereas the highest boll number per plant was observed with the K1C1 treatment. However, lower boll weights and harvest boll rates were achieved. The K1C1 treatment significantly increased the seed cotton and lint yield of 'Wankemian-1' by 11.4% and 10.5%, respectively, compared to the K2C2 treatment. In contrast, K2C2 treatment significantly increased the seed cotton yield, lint yield, boll weight, and harvest boll rate of 'Wanmian-191', and the seed cotton and lint yields increased by 13.6% and 13.3%, respectively, compared to the K1C1 treatment. Generally, the regulatory mechanisms of different chemical regulators on the yield of the two cotton varieties with different plant architectures were inconsistent, and the methods of increasing the yield were also different. The application of K1C1 to 'Wankemian-1' increased the number of bolls per plant, whereas the application of K2C2 to 'Wanmian-191' increased boll weight and harvest boll rate. The boll number per plant, boll weight per boll, seed cotton yield, and lint yield of 'Wanmian-191' were significantly higher than those of 'Wankemian-1'.

Table 3. Effects of different chemical regulations on the yields of the two cotton varieties

Varieties	Handling treatment	Boll number (boll/ plant)	Boll weight (g/boll)	Harvest boll rate (%)	Ratio of dead cotton (%)	Lint percentage (%)	Seed cotton yield (kg/hm^{-2})	Lint yield (kg/hm^{-2})
Wankemian-1	K1C1	12.6a	4.5b	96.5b	0.5a	39.1 bc	36644.2a	1432.7a
	K1C2	12.0ab	4.4b	98.4ab	0.5a	39.6a	3494.6ab	1383.8ab
	K2C1	11.0b	5.1a	97.2ab	0.4a	38.9c	3412.1ab	1327.4ab
	K2C2	11.3b	4.9a	98.9a	0.4a	39.4ab	3289.7b	1296.2b
	Mean	11.7b	4.3b	97.8a	0.5b	39.3b	3465.2b	1360.0b
Wanmian -191	K1C1	15.5a	5.2ab	90.5c	0.7a	40.5a	3759.5c	1522.8b
	K1C2	15.8a	5.1b	95.6a	0.7a	40.6a	3862.8 bc	1568.1b
	K2C1	14.2b	5.5a	93.5b	0.5b	40.3a	4132.6ab	1665.4ab
	K2C2	14.5b	5.4ab	97.6a	0.5b	40.4a	4272.0a	1725.9a
	Mean	15.0a	5.3a	94.3b	0.6a	40.5a	4006.7a	1620.6a

Effect of chemical regulation on fiber quality of cotton varieties with different plant architectures

The effects of different chemical regulators on the fiber quality of the two cotton varieties with distinct plant architectures are shown in Table 4. The highest upper-half mean length and fiber strength of the two varieties were observed when treated with K2C2, whereas the lowest length uniformity index was recorded when treated with K2C2. The chemical regulatory treatments had no significant effect on either the spinning consistency index of the two plant architectures of cotton fibers or the cotton fiber Micronaire value of 'Wanmian-191'. In general, K2C2 treatment increased the upper half mean length and fiber strength but reduced the length uniformity index. The fiber strength, fiber length uniformity index, and spinning consistency index of 'Wankemian-1' were higher than those of 'Wanmian-191'.

Table 4. Effects of different chemical regulations on the fiber quality of the two cotton varieties

Varieties	Handling treatment	Upper half mean length (mm)	Fiber strength (cN, Tex^{-1})	Micronaire value	Fiber length uniformity index (%)	Spinning consistency index (SCI)
Wankemian-1	K1C1	30.8b	30.9a	5.2ab	85.5bc	140 a
	K1C2	30.3bc	29.9a	5.3a	87.0a	142 a
	K2C1	29.7c	30.5a	5.0b	86.3ab	140 a
	K2C2	32.0a	31.0a	5.0b	85.0c	143 a
	Mean	30.7a	30.6a	5.1a	86.0a	141.3a
Wanmian-191	K1C1	29.9b	29.6ab	5.2a	85.9b	136 a
	K1C2	30.7ab	29.3b	5.2a	85.9a	134 a
	K2C1	30.0b	29.6ab	5.0a	85.9a	136 a
	K2C2	30.9a	29.8a	5.1a	85.5b	138 a
	Average	30.4a	29.6b	5.1a	85.8b	136.0b

Effects of chemical regulation on the planting benefits of cotton varieties with different plant architectures

The effects of different chemical regulations on the planting benefits of the two cotton varieties was observed (Table 5). The material inputs for each treatment were similar. 'Wankemian-1' and 'Wanmian-191' achieved the highest net income when treated with K1C1 and K2C2. This increase in net income is attributed to high product income. Compared with the lowest product income, the K1C1 treatment of 'Wankemian-1' and K2C2 treatment of 'Wanmian-191' resulted in an increase in net income by 11.4% and 12.0%, respectively. In terms of labor input, the K1C1 treatment of 'Wankemian-1' and the K2C2 treatment of 'Wanmian-191' ranked the highest.

Table 5. Effects of different chemical regulations on planting benefits of two cotton varieties

Variety	Handling treatment	Cost of materials (Yuan/ hm²)	Cost of Labor (Yuan/ hm²)	Total cost (Yuan/ hm²)	Product income (Yuan/ hm²)	Planting subsidy (Yuan/ hm²)	Net income (Yuan/ hm²)
Wankemian-1	K1C1	6906	12000	18906	22718.0	4135	7947.0a
	K1C2	6945	11250	18195	21666.5	4135	7606.5a
	K2C1	6903	11250	18153	21155.0	4135	7137.0a
	K2C2	6942	10500	17442	20396.1	4135	7089.1a
	Mean	6924	11250	18174	21483.9	4135	7444.9b
Wanmian-191	K1C1	6681	12000	18681	23308.9	4135	8762.9a
	K1C2	6720	12750	19470	23949.4	4135	8614.4a
	K2C1	6678	13500	20178	25622.1	4135	9579.1a
	K2C2	6717	14250	20967	26486.4	4135	9654.4a
	Mean	6699	13125	19824	24841.7	4135	9152.7a

Discussion

Effects of chemical regulation on the growth period and agronomic characteristics of cotton

Cotton is a perennial plant that is usually cultivated and managed as an annual crop; topping is required to control its unlimited growth. The plant architecture significantly influences the adaptability, yield, and economic benefits of cotton cultivation (Zhu *et al*., 2020). The chemical capping technique plays a crucial role in shaping plant architecture and regulating the cotton canopy structure (Yang *et al*., 2016). Previous studies demonstrated that chemical topping treatment had an effect similar to that of manual topping treatment, and the two indices of internode length and upper fruit branch length were superior to those of manual topping treatment (Zhu *et al*., 2020). This study revealed that the chemical regulator had a minimal effect on the growth period of two cotton varieties with different plant architectures. The ripening agent (TDZ combined with ETH) showed a better ripening effect but had a minimal impact on the growth and development process of cotton, mainly promoting defoliation and centralized ripening of cotton. This is conducive to mechanical harvesting and spraying, which is consistent with the findings of previous studies (Wang *et al*., 2015; Jiang *et al*., 2013). Additionally, the chemical regulators K2C1 and K2C2 significantly decreased the plant height and fruit branch number of both cotton varieties with different plant architecture. Treatment with 25% DPC and 50% CCC was effective in reducing plant height, and was more effective than the application of DPC alone (once before topping and once after topping).

Effects of chemical regulation on cotton yield and economic benefits

One of the main indicators used to assess the feasibility of cotton chemical control technologies is their impact on the yield. Studies have shown that cotton yield can be improved by applying chemical regulators such as DPC, which can lead to enhanced cotton yield by increasing the boll number per plant and boll weight of cotton (Xue *et al*., 2015; Song *et al*., 2015). Furthermore, both DPC and CCC have been shown to increase the boll number per plant and boll weight of cotton under specific conditions as well as improve the prefrost yield rate to enhance the prefrost lint yield (Wang *et al*., 2018). However, some studies have reported that the application of DPC has no significant effect on yield increase or decrease (Pettigrew *et al*., 2005). Zhu et al. (2020) also found that spraying methyl pionium did not have a significant effect on cotton yield compared with artificial topping. The findings revealed significant differences in the yield responses of different plant architectures to chemical regulators. 'Wankemian-1' had the highest seed cotton and lint yield with the K1C1 treatment, while 'Wanmian-191' had the highest seed cotton and lint yield with the K2C2 treatment. The increase in 'Wankemian-1' yield was primarily attributed to the increase in boll number per plant, whereas the increase in 'Wanmian-191' yield was mainly attributed to the increase in harvest boll rate. In conclusion, the results indicate that the influence of chemical regulators on cotton yield varies depending on the variety and region, and this variability was attributed to the difference in dosage and environmental conditions after spraying, particularly the difference in rainfall or dry climate. Therefore, it is crucial to effectively determine the time and dosage of these chemical regulators in cotton production, and ensure their appropriate use according to climate, soil, and other conditions, as well as cotton growth conditions, to ensure high-quality and high-yield cotton production (Wang *et al*., 2018). Moreover, further research is needed to investigate the dosage and spraying time of chemical regulators in cotton from different production areas to increase the cotton yield in this region. In general, the appropriate chemical regulators for 'Wankemian-1' and 'Wanmian-191' were K1C1 and K2C2, respectively, resulting in higher net cotton profits.

Effects of chemical regulation on cotton yield and economic benefits

The findings of studies on the influence of chemical regulators on cotton fiber quality are inconsistent. Some studies have indicated that DPC enhances the fiber quality, significantly increases the fiber strength, and improves the fiber uniformity index through proper regulation (Zhao *et al*., 2018; Liu *et al*., 2018b). Spraying DPC at the budding and flowering stages has been shown to significantly improve fiber length and uniformity (Ren *et al*., 2013; Han *et al*., 2019). On the other hand, Xu et al. found that high chemical control treatments tended to decrease cotton fiber strength and increase the Micronaiere value (Xu *et al*., 2006). In this study, K2C2 treatment increased the upper half mean length and fiber strength, but reduced the fiber length uniformity index. Cotton fiber quality is influenced by factors such as light, temperature, water and fertilizer, and chemical regulation, which can result in different effects of DPC on fiber quality under different experimental conditions (Zhao *et al*., 2018). Therefore, further investigation is needed to understand the effects of chemical regulators on cotton fiber quality and their underlying mechanisms.

Conclusions

In summary, the results revealed that the effects of different chemical regulators on the production of the two plant architectures differed. Specifically, the application of K1C1 and K2C2 to 'Wankemian-1' and 'Wanmian-191' increased the cotton yield. K2C2 treatment enhanced the fiber strength and upper half mean length of the two cotton varieties but decreased the fiber length uniformity index. Compared to 'Wanmian-191', 'Wankemian-1' exhibited higher values for fiber strength, fiber length uniformity index, and spinning consistency index. In terms of yield, fiber quality, and economic benefits, K1C1 and K2C2 were determined to be the most effective chemical regulators of 'Wankemian-1' and 'Wanmian-191', respectively.

Authors' Contributions

Conceptualization: SY, BW and WW; Data curation: PZ; Formal analysis: SJ and GJ; Funding acquisition: SY; Investigation, Methodology, Resource, Software, and Visualization: LF, DX, WH and HY; Writing-original draft: SY; Writing-review and editing: BW and WW. All authors have read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

Acknowledgements

This study was funded by Natural Science Foundation Project of Xinjiang Production and Construction Corps (2024DA027), Key Research and Development Project of Jiangsu Province, China (Modern Agriculture, BE2022382), Achievement Transformation Project of Anhui Academy of Agricultural Sciences (2024YL038) and State Key Laboratory of Cotton Biology Open Fund (CB2023A08).

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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