The Journal of Agricultural Science

cambridge.org/ags

Evaluating the effects of defoliant spraying time on fibre yield and quality of different cotton cultivars

Liyuan Wang[1], Yongsheng Deng[2], Fanjin Kong[2], Bing Duan[2], Muhammad Saeed[3], Ming Xin[4], Xiaoge Wang[2], Liying Gao[2], Guifang Shen[2], Jinghui Wang[2], Zongfu Han[2], Zongwen Wang[2] and Xianliang Song[4]

[1]Crop Research Institute, Shandong Academy of Agricultural Sciences, Jinan 250100, China; [2]Institute of Industrial Crops, Shandong Academy of Agricultural Sciences, Jinan 250100, China; [3]Department of Botany, Faculty of Life Sciences, Government College University Faisalabad, Faisalabad 38000, Pakistan and [4]State Key Laboratory of Crop Biology/Agronomy College, Shandong Agricultural University, Taian 271018, China

Crops and Soils Research Paper

Cite this article: Wang L *et al* (2023). Evaluating the effects of defoliant spraying time on fibre yield and quality of different cotton cultivars. *The Journal of Agricultural Science* **161**, 205–216. https://doi.org/10.1017/S0021859623000151

Received: 2 May 2022
Revised: 8 December 2022
Accepted: 8 February 2023
First published online: 17 February 2023

Key words:
Boll opening; fibre related traits; leaf defoliation; seed cotton yield

Author for correspondence:
Zongwen Wang, E-mail: wangzw66@163.com;
Xianliang Song, E-mail: songxl999@163.com

Abstract

Chemical defoliants are widely used in cotton (*Gossypium* L.) to accelerate leaf abscission and boll maturation, as well as, to facilitate mechanical harvesting. The current study was conducted to determine the interactive effect of cotton cultivars and spraying time of defoliant on defoliation, boll opening, fibre yield and quality. An experiment was performed with four cultivars and three defoliant spraying time during 2019 and 2020 in split plot design with three replications. At harvest, the defoliation and boll opening rate of all treatments after spraying defoliant was 94.6 and 85.4%, while the blank control (water) was 73.9 and 79.1%, respectively. After spraying defoliant, the effects of defoliation rate, boll opening rate, fibre yield and quality were different among cultivars, indicating that different cultivars had different responses to defoliant. Among them, L7619 was the most sensitive to defoliant, with the average defoliation rate of 95.6% and a seed cotton yield reduction of 882.9 kg/ha. Among the different time of applications, late spraying (17 September, B3) of defoliant recorded the highest defoliation rate (97.3%), boll opening rate (89.8%), seed cotton yield (3991 kg/ha) and steadily increased the fibre strength by 0.59 cN/tex compared with the control. Late spraying of defoliant had little or even no adverse effect on the remaining fibre quality traits (length, uniformity, micronaire and elongation). In general, these results suggested that the appropriate time for spraying defoliant can be determined based on the sensitivity of the cotton cultivar, the weather conditions at the field and the harvest time.

Introduction

Cotton is a major economic crop cultivated all over the world, providing renewable textile fibre, seed oil and high protein meals (Chen *et al*., 2007). China's cotton consumption is the largest in the world. Cotton in China is grown relatively concentrated, mainly distributed in three regions with different ecological environments in Xinjiang, the North China Plain and the Yangtze River Basin. With the development of textile technology and the growth of human living standards, the requirements for fibre quantity and quality are ever-increasing. However, due to the high labour costs and low profits, cotton planting area in China has decreased rapidly according to the data from the National Bureau of Statistics in the past five years.

The application of large mechanical equipment can improve field efficiency by reducing operational time and save labour and financial resources at the same time. Along with this, mechanical harvesting of cotton requires leaf abscission and boll dehiscence before harvesting to ensure fibre cleanliness and maximize harvesting efficiency (Awg-Adeni *et al*., 2010; Singh *et al*., 2014). Defoliation is a natural physiological process in the growth of cotton; however, it cannot meet the requirements of mechanical harvesting timely and fully (Ashraf *et al*., 2021). Therefore, applying chemicals such as defoliants, desiccants and growth-regulators is an effective auxiliary method, which can make cotton leaves fall off earlier than normal (Siebert and Stewart, 2006; Ashraf *et al*., 2020). Several popular types of chemicals have been tested in the world. Thidiazuron, a cytokinin activity analogue, was widely used to promote leaf abscission through a variety of ways, such as affecting the balance among ethylene, auxin and abscisic acid and changing reactive oxygen species metabolism and photosynthetic efficiency (Xu *et al*., 2019; Jin *et al*., 2020, 2021; Chandrasekaran *et al*., 2021; Liu *et al*., 2021). Spraying paraquat had a significant influence on the plant height, leaf-area index, dry-matter production, growth attributes and the per cent of leaf fall (Ashraf *et al*., 2020). However, the application of paraquat was limited to the opening of all mature cotton bolls. The plant growth regulators such as ethephon, mepiquat chloride, cyclanilide and dimethipin were applied to accelerate boll dehiscence and leaf fall to aid harvesting and divert the nutrients towards the immure bolls so as to improve the seed cotton yield and quality (Ashraf *et al*., 2020, 2021; Kaur *et al*., 2021; Sravanthi *et al*., 2022). The mixture of chemicals such as thidiazuron and diuron (known as drop ultra), thidiazuron and ethephon, endothall and ethephon, tribufos and ethephon, cyclanilide and ethephon, ethephon and triiodbenzoic acidhas also had been proved to accelerate defoliation and boll opening at the same time (Snipes and Baskin, 1994; Du *et al*., 2013; Mrunalini *et al*., 2019; Ashraf *et al*., 2021; Chandrasekaran *et al*., 2021; Meng *et al*., 2021; Sravanthi *et al*., 2022).

On the other hand, the timing of spraying defoliant is an important factor to be taken into consideration (Ashraf *et al*., 2021). Delaying defoliation allows the development of immature bolls, which may potentially increase yield (Snipes and Baskin, 1994). However, delaying defoliation also increases the risks of late season rainy weather, light deficiency, lower temperatures or early frost, which will lead to yield loss (Bange and Milroy, 2000; Mo *et al*., 2018; Wang *et al*., 2019; Raghavendra and Reddy, 2020). Appropriate defoliation timing may balance the rate of increase in fibre yield and loss in fibre quality (Faircloth *et al*., 2004). Therefore, it is recommended to spray defoliants when about 60% of cotton bolls are open (Mrunalini and Rekha, 2018; Mrunalini *et al*., 2018; Haliloglu *et al*., 2020; Jajoria *et al*., 2020; Raghavendra and Reddy, 2020; Chandrasekaran *et al*., 2021). Studies have shown that early defoliation resulted in losses of yield, quality and profitability, while the use of defoliants in the later period had the opposite effects (Bednarz *et al*., 2002; Faircloth *et al*., 2004; Singh and Rathore, 2015; Ashraf *et al*., 2020; Long *et al*., 2021). When the spraying time is delayed to approximately 70–80% of the boll opening, the greatest return was produced (Larson *et al*., 2002; Sravanthi *et al*., 2022).

Since fibre yield and quality related traits are controlled by genotype, environment and genotype × environment interaction, cultivar selection is another important factor to be considered (Long *et al*., 2021). For example, 75% of the variation in fibre length comes from the variety, while the variation in micronaire is mostly due to weather and management, and only 25% is determined by genetics (Faircloth *et al*., 2004). In the current study, four commercial cultivars with different yield and quality traits were selected to study the effects of cultivars sprayed with defoliant on fibre yield and quality. Observations were made after spraying defoliant at three different periods in the early, middle and late stages. In addition, the changes in the bolls from different fruiting branch positions after spraying defoliant were also observed.

Therefore, the overall objectives of the current experiment were to study the impact of cotton genotypes and defoliant spraying times on leaf defoliation, boll opening rate, fibre yield and quality and to screen the optimum defoliant spraying time. These results might provide guidance for determining the appropriate spraying time that was conducive to mechanical harvesting.

Materials and methods

Materials

Four cotton cultivars were used in the current study. The seeds of cotton cultivars LMY21, LMY36, K836 and L7619 were provided by Institute of Industrial Crops, Shandong Academy of Agricultural Sciences. These cultivars were approved by the Shandong Province from 2005 to 2013, suitable for cultivation in the North China Plain cotton area, and have been commercially cultivated. The defoliant used in the experiment was Tuotulong from Bayer Crop Science (Germany), which was a mixed suspension concentrate of 360 g/l thidiazuron and 180 g/l diuron.

Study site and experimental design

The experiment was conducted in Linqing (36°53' N and 115°41' E), Shandong province, China in 2019 and 2020. The soil of the experimental site was sandy loam in texture, with moderately higher soil fertility and good drainage and irrigation conditions. During deep ploughing in both years, 450 kg per hectare of nitrogen, phosphorus and potassium compound fertilizer (25% N, 10% P_2O_5 and 18% K_2O) were used as the basal fertilizer to prepare for cotton planting. Cotton seeds were sown on 26 April 2019 and 27 April 2020, respectively. The experiment was conducted by means of split plot design with three replications. The main plot comprised of four cultivars LMY21 (A1), LMY36 (A2), K836 (A3) and L7619 (A4) and the sub plot consisted of three times of defoliant spraying. Three treatments of spraying defoliant were carried at 26 August (B1, early spraying), 6 September (B2, middle spraying) and 17 September (B3, late spraying) respectively in 2019 and 2020. Each plot was divided into four rows with equal row spacing of 76.0 cm and a total area of 34.2 m^2. In each treatment, two rows were sprayed with defoliant and two rows with water as blank control. All the other cultural and field management practices such as irrigation, weeding and pest management followed the normal local managements.

Data scoring

Ten cotton plants were chosen at random and tagged from two rows at the centre of each treatment to evaluate the effect of defoliant on leaf defoliation, boll opening, yield and quality. All leaves on the fruiting nodes in a plant were counted separately at 0 (on the day before treatment), 5, 10, 15, 20, 25 days after defoliant spraying. The total number of opened bolls and unopened bolls of 10 tagged plants were also measured for 6 times. And then the rate of leaf defoliation and the percentage of opened bolls were calculated.

At harvest time, all the fully opened bolls were picked from the 10 tagged plants to investigate fibre yield and quality traits. Besides, all fruiting branches were divided from bottom to top into three parts: 1–4 fruiting branches were the lower part, 5–8 fruiting branches were the middle part, and 9 or more fruiting branches were the upper part. In order to understand the effect of defoliant on different parts of cotton fruiting branches, 20 fully opened bolls were harvested in the upper, middle and the lower parts in each plot. Firstly, the yield-related traits such as the yield, boll weight and lint percentage of the mixed sample and the samples of the upper, middle and lower parts were weighed and calculated by conventional methods. Soon afterwards, these samples were sent to the Supervision, Inspection and Test Center of Cotton Quality, Ministry of Agriculture of China (Anyang, China) to detect quality-related traits through the HVI900 fibre testing system, including fibre length, fibre uniformity, fibre strength, micronaire and fibre elongation.

Statistical analysis

The statistical results of main plot (cultivar, A), subplot (spraying time, B) and their interaction (A × B) effects on leaf defoliation, percentage of opened bolls, fibre yield and quality were performed by SPSS 21.0 and DPS 7.05. The Duncan's new complex polar difference method was used for multiple comparisons and significant differences ($P < 0.05$) test on the averages of each treatment. Finally, figures and tables were drawn using GraphPad Prism 9 and Excel software, respectively.

Results

The data of temperature and rainfall were obtained for each year from the Linqing Statistical Yearbook. The average monthly temperatures and rainfall during the cotton growing period (from April to October in 2019 and 2020) are shown in Fig. 1. The average monthly temperatures between the two years were basically the same, however, there were differences in rainfall, with the total rainfall during the cotton growing period in 2020 being higher than that in 2019. Due to the environmental differences between years, the statistical results of all survey indicators were listed separately in the subsequent analysis.

The interactive effect of cotton cultivars and spraying time on leaf defoliation

On the day of spraying, there was no obvious difference in the initial number of plant leaves between the defoliant (33.1 leaves per plant) and blank control (33.2 leaves per plant) across two years. The effects on defoliation were the same in 2019 and 2020 (Fig. 2). In 2019 and 2020, five days after spraying, the average defoliation rates of the defoliant treatments were 61.9 and 41.4%, respectively, and the average defoliation rates of the blank control group were 23.7 and 19.6%, respectively. The defoliation rate of the defoliant treatments was more than twice that of the blank control group, and the difference reached a very significant level ($P < 0.001$). The defoliant effectively promoted the shedding of cotton leaves. Twenty-five days after spraying, the mean number of defoliation rates for all the defoliant treatments in 2019 was 96.4%, while the blank control was 82.0%, and the corresponding results in 2020 were 92.8 and 65.9%, respectively.

The changing trend of defoliation of each variety after treatment with different spraying time is shown in Fig. 3. All treatments showed the fastest rate of defoliation at 5 days after

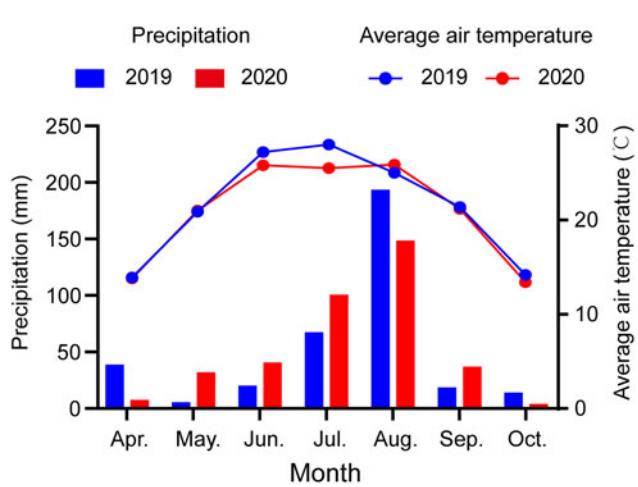

Fig. 1. The average monthly temperatures and monthly total rainfall during the cotton growing season in 2019 and 2020.

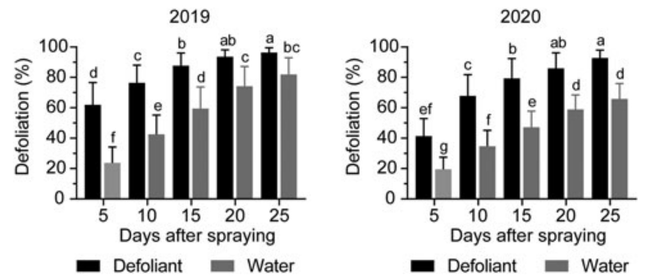

Fig. 2. The comparison of average defoliation rate between defoliant and water after defoliant treatments for 2019 and 2020. The data are the mean and standard error of all the treatments in each year. The same letter indicates no significant difference at 0.05 level.

spraying defoliant, and then the increase in rate of leaf falling slowed down. After spraying defoliant, the defoliation effect of B1 and B2 treatment at 25 days was equivalent to that of B3 treatment at 15 days, and the average defoliation rates were 92.2, 93.3 and 93.8%, respectively. The defoliation rate of four cotton cultivars did not differ much at 15, 20 and 25 days after spraying for the B3 treatment. Among them, the average defoliation rate of the L7619 (A4) variety was the largest, which was 95.5, 97.1 and 98.3%, respectively.

In this study, the defoliation was not significantly affected by cultivar and cultivar × spraying time interaction (Table 1). After spraying defoliant, the defoliation of all cultivars exceeded 90%, which was higher than that of the control. Among them, L7619 (A4) was the most sensitive to defoliant than other cultivars. L7619 had the highest defoliation, with an average of 95.6% across two years, while natural defoliation without defoliant was only 71.4%. The effect of spraying time on defoliation was significant ($P < 0.05$ in 2019 and ≤ 0.001 in 2020). With the delay in spraying time, the defoliation rate increased and reached the maximum for the 3 treatments.

The interactive effect of cotton cultivars and spraying time on boll opening

In 2019, the average percentage of opened bolls on the day of B1, B2 and B3 treatments were 16.8, 34.9 and 64.4%. However, the value was lower in 2020 than the same period in 2019, with the average values being 3.52, 21.6 and 46.9%. The reason might be that the rainfall in the middle of cotton growing period (June and July) in 2020 was higher than that in 2019, and the plant's vegetative growth was vigorous, and the overall boll opening rate was delayed. The comparison between the boll opening rate of each treatment is shown in Fig. 4. Compared with the blank control, spraying defoliant for the B1 treatment increased the boll opening rate of all cultivars.

The cultivar and its interaction with spraying time had no significant effect on the boll opening rate (Table 1). There was no significant difference among all cultivars in the control group (water) across two years ($P = 0.934$ in 2019 and 0.789 in 2020). After spraying defoliant, the average boll opening rate was higher than that of the blank control. Among them, the boll opening rate of LMY36 (A2) increased after spraying defoliant in two years. The spraying time had a significant effect on the boll opening rate in 2019 ($P = 0.042$). As the spraying time was delayed, the boll opening rate increased gradually. The average value of the boll opening rate investigated for the B3 treatment (89.81%) was higher than the other treatments.

https://doi.org/10.1017/S0021859623000151 Published online by Cambridge University Press

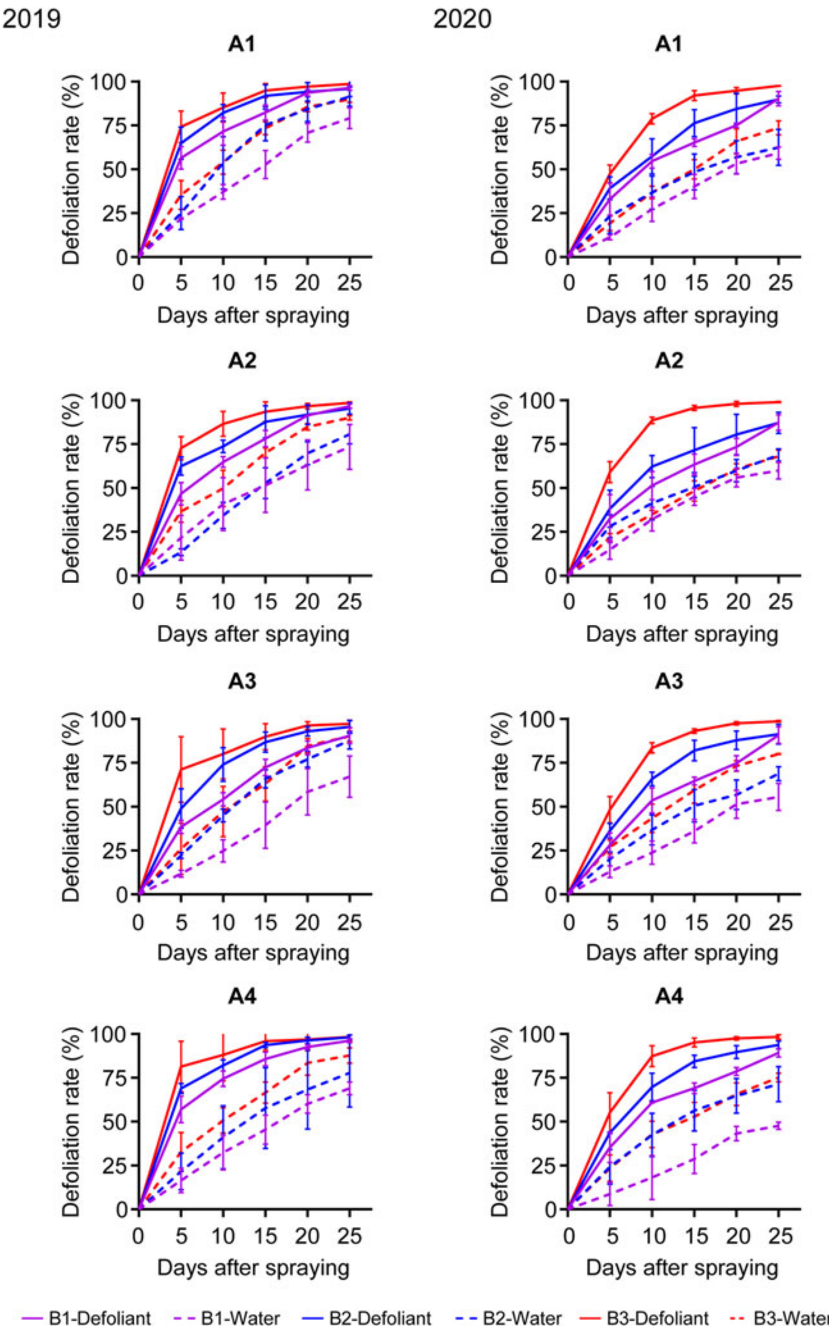

Fig. 3. The defoliation rate after defoliant treatments in 2019 and 2020. A1, A2, A3 and A4 represent LMY21, LMY36, K836 and L7619. B1, B2 and B3 stand for the spraying time on 26 August, 6 September and 17 September. The solid line and dotted line with different colours represent the spraying of defoliant and water at different spraying time. The data are the mean and standard error of three replications.

The interactive effect of cotton cultivars and spraying time on fibre yield and quality in mixed samples

The seed cotton yield, lint percentage and fibre elongation decreased in 2020, and the difference between the two years was extremely significant ($P < 0.001$) as shown in Table 2. Meanwhile, the fibre strength and uniformity increased significantly in 2020 ($P = 0.004$ and 0.024, respectively). These traits were greatly affected by the environment. The fibre length and micronaire did not differ significantly between two years ($P = 0.770$ and 0.624, respectively).

As evident from data presented in Table 2, the difference in the fibre yield and quality mainly came from cultivars, except for the fibre uniformity in 2019. Compared with the blank control, the seed cotton yield was reduced after spraying defoliant. Among the four cultivars, L7619 (A4) had the highest seed cotton yield, but suffered the most adverse effect after spraying defoliant, with a reduction of 679.9 and 989.9 kg/ha in two years. After spraying defoliant, the average seed cotton yield was the lowest for the B1 treatment (3353 kg/ha) and the highest for the B3 treatment (3991 kg/ha). The early spraying of defoliant (B1) had the greatest adverse effect on the yield of seed cotton, with an average reduction of 945.1 kg/ha. The lint percentage was stably higher after spraying defoliant for the B3 treatment than that of the water in two years. For the treatments of B1 and B2, spraying defoliant in 2019 reduced the lint percentage, but the result in 2020 was the opposite. Therefore, the effect of defoliant on the lint may be related to the environment, which should be investigated further.

https://doi.org/10.1017/S0021859623000151 Published online by Cambridge University Press

Table 1. Effects of cotton cultivars and spraying time on defoliation and boll opening at harvest time

	Defoliation (%)				Opened bolls (%)			
	2019		2020		2019		2020	
Treatments	Defoliant	Water	Defoliant	Water	Defoliant	Water	Defoliant	Water
Cultivars								
LMY21 (A1)	97.06 ± 2.91 ab	86.79 ± 7.1 a	92.55 ± 4.41 a	65.12 ± 8.74 a	84.72 ± 14.56 a	86.72 ± 12.22 a	82.14 ± 14.59 b	72.24 ± 21.11 a
LMY36 (A2)	96.81 ± 2.23 ab	81.36 ± 10.05 a	91.14 ± 6.98 a	65.61 ± 5.47 a	89.41 ± 9.22 a	84.18 ± 11.83 a	96 ± 3.27 a	74.61 ± 16.26 a
K836 (A3)	94.4 ± 4.34 b	81.69 ± 12.78 a	93.59 ± 5.3 a	68.11 ± 11.48 a	88.83 ± 6.93 a	82.28 ± 14.82 a	75 ± 10.81 b	76.82 ± 17.49 a
L7619 (A4)	97.5 ± 1.88 a	78.14 ± 13.02 a	93.76 ± 4.33 a	64.71 ± 13.93 a	86.95 ± 9.42 a	84.48 ± 13.97 a	79.75 ± 12.36 b	71.81 ± 27.78 a
Spraying time								
26 August (B1)	94.9 ± 3.42 b	72.15 ± 9.33 b	90.5 ± 4.55 b	55.6 ± 6.65 c	82.8 ± 6.92 b	76.32 ± 15.26 b	79.36 ± 15.59 a	51.42 ± 12.24 c
6 September (B2)	98.11 ± 1.43 a	84.4 ± 10.82 a	89.4 ± 3.65 b	67.84 ± 7.37 b	86.01 ± 11.73 ab	85.64 ± 6.65 ab	84.27 ± 11.15 a	79.5 ± 14.11 b
17 September (B3)	96.32 ± 3.38 ab	89.44 ± 2.63 a	98.39 ± 0.82 a	74.22 ± 5.11 a	93.61 ± 8.59 a	91.28 ± 10.88 a	86.04 ± 12.84 a	90.69 ± 8.46 a
Source of variance								
Cultivars (A)	0.1956	0.4163	0.1726	0.6213	0.7508	0.9338	0.0537	0.7892
Spraying time (B)	0.038	0.0002	0.0001	0.0001	0.0418	0.0303	0.3098	0.0001
AxB	0.4525	0.6288	0.6553	0.0063	0.4276	0.8214	0.3734	0.0010

The data were the mean and standard error of three replications. The same letter indicated no significant difference at 0.05 level.

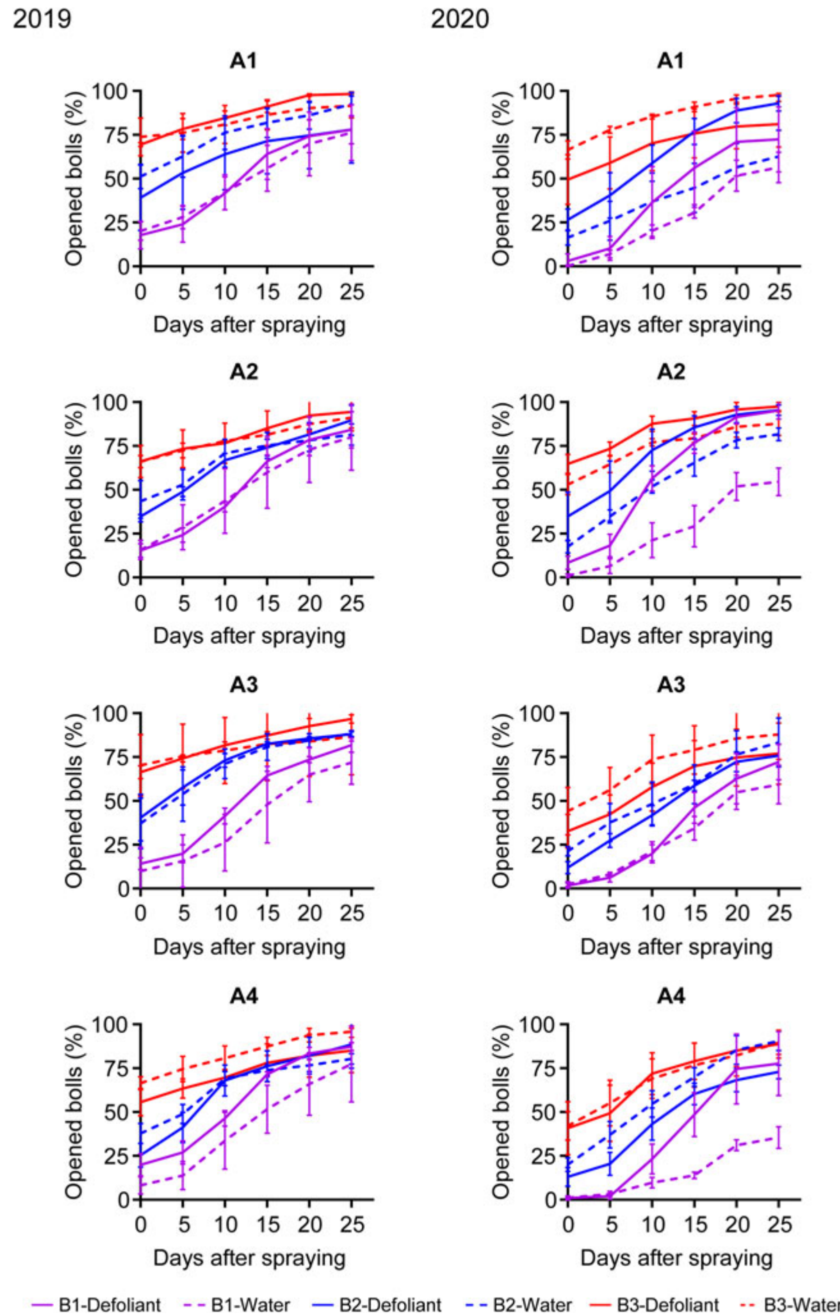

Fig. 4. The percentage of opened bolls after defoliant treatments in 2019 (top) and 2020 (bottom). The meanings represent by A1-4 and B1-3 are as shown above. The data are the mean and standard error of three repetitions.

The effect of spraying time on fibre quality was not significant. However, as the spraying time was delayed, the performance of each trait was improved. For the B3 treatment, after spraying defoliant, the fibre strength was steadily higher than control for two years, increasing by 0.99 and 0.18 cN/tex, respectively.

The interactive effect of cotton cultivars and spraying time on fibre yield of different parts of cotton fruiting branches

The statistical results show that due to environmental influences, the lint percentage of all cultivars in 2020 was lower than that of the same part in 2019 (Table 3). Regardless of spraying defoliant or water, the lower fruiting branches of all cultivars had the highest lint percentage, the middle part had the highest boll weight, and the upper fruiting branches had the lowest lint percentage and boll weight. In 2019 and 2020, spraying defoliant had a positive effect on the lint percentage of the middle part, which was 0.12 and 0.82 higher than that of water, respectively. In contrast, compared with water, spraying defoliant showed a negative effect and reduced the boll weight of all fruiting branches. Among them, the boll weight of upper part in two years decreased by 0.77 and 1.27 g, respectively, and the difference reached a significant level ($P < 0.001$).

There was a significant difference among cultivars for lint percentage and boll weight of all fruiting branches, while the spraying time had no significant effect on them. The effect of defoliant on different cultivars varied from year to year. However, after spraying defoliant, the lint percentage of the upper, middle and lower parts of L7619 (A4) increased in two years. Compared with the water, spraying defoliant in all periods steadily increased the

https://doi.org/10.1017/S0021859623000151 Published online by Cambridge University Press

Table 2. Effects of cotton cultivars and spraying time on yield and quality in mixed samples

Treatments	See cotton (kg/ha)		Lint percentage (%)		Fibre length (mm)		Fibre uniformity (%)		Fibre strength (CN/tex)		Micronaire		Fibre elongation (%)	
	Defoliant	Water	Defoliant	Water	Defoliant	Water	Defoliant	Water	Defoliant	Water	Defoliant	Water	Defoliant	Water
2019														
Cultivars														
LMY21 (A1)	4507.32 ± 505.73a	4696.26 ± 480.34 c	42.81 ± 0.73 b	42.89 ± 0.5 b	29.97 ± 0.58 a	30.24 ± 0.46 a	84.6 ± 1.52 a	84.87 ± 0.7 a	30.17 ± 1.37 a	29.9 ± 1.37 a	4.11 ± 0.4 b	4.2 ± 0.25 b	6.8 ± 0.07 a	6.79 ± 0.06 a
LMY36 (A2)	4483.88 ± 486.75 a	5103.19 ± 251.8 b	44.09 ± 0.55 a	44.23 ± 0.5 a	29.47 ± 0.98 a	29.28 ± 0.76 b	84.91 ± 1.57 a	85.21 ± 0.99 a	29.36 ± 1.53 a	29.17 ± 1.56 a	4.56 ± 0.39 a	4.78 ± 0.32 a	6.8 ± 0.09 a	6.79 ± 0.08 a
K836 (A3)	4599.16 ± 887.97 a	5037.85 ± 360.05 b	41.74 ± 0.72 c	41.98 ± 0.46 c	29.51 ± 0.57 a	29.96 ± 0.79 ab	85.13 ± 0.7 a	85.1 ± 0.84 a	30.67 ± 1.7 a	30.6 ± 1.65 a	4.86 ± 0.29 a	5.01 ± 0.31 a	6.8 ± 0.05 a	6.82 ± 0.08 a
L7619 (A4)	4918.73 ± 520.78 a	5598.69 ± 538.66 a	42.38 ± 0.6 bc	43.03 ± 0.87 b	27.94 ± 0.48 b	28.33 ± 0.84 c	84.53 ± 0.93 a	84.28 ± 1.03 a	27.28 ± 1.34 b	27.72 ± 1.1 b	4.72 ± 0.28 a	4.7 ± 0.33 a	6.72 ± 0.07 b	6.76 ± 0.09 a
Spraying time														
26 Aug (B1)	4409.42 ± 518.65 a	4969.63 ± 583.81 a	42.63 ± 1.04 a	43.37 ± 1.08 a	28.97 ± 1.04 a	29.26 ± 1 a	84.49 ± 1.46 a	85.25 ± 0.69 a	29.07 ± 2.14 a	29.53 ± 1.75 a	4.42 ± 0.52 a	4.68 ± 0.45 a	6.75 ± 0.08 b	6.78 ± 0.07 a
6 Sep (B2)	4657.15 ± 462.26 a	5117.35 ± 597.54 a	42.75 ± 1.21 a	43.02 ± 0.85 ab	29.25 ± 1.14 a	29.73 ± 0.93 a	84.62 ± 1.25 a	84.86 ± 1.16 a	29.12 ± 2.01 a	29.59 ± 1.83 a	4.58 ± 0.39 a	4.72 ± 0.44 a	6.77 ± 0.07 b	6.8 ± 0.07 a
17 Sep (B3)	4409.42 ± 808.42 a	5240.01 ± 347.97 a	42.88 ± 1.04 a	42.71 ± 1.03 b	29.44 ± 0.88 a	29.37 ± 1.14 a	85.27 ± 0.78 a	84.48 ± 0.8 a	29.92 ± 1.69 a	28.93 ± 1.73 a	4.69 ± 0.38 a	4.63 ± 0.4 a	6.83 ± 0.06 a	6.78 ± 0.09 a
Source of variance														
Cultivars (A)	0.2956	0.0031	0.0081	0.0001	0.0122	0.0433	0.8090	0.2688	0.0173	0.0306	0.0006	0.0130	0.1973	0.7452
Spraying time (B)	0.1600	0.2310	0.5879	0.0105	0.0972	0.1699	0.2549	0.1466	0.3455	0.4841	0.2269	0.7960	0.0077	0.7744
AxB	0.0193	0.0444	0.4150	0.0256	0.0630	0.6503	0.5026	0.6979	0.7908	0.5224	0.4655	0.9453	0.1426	0.2802
2020														
Cultivars														
LMY21 (A1)	2694.62 ± 606.91c	3755.74 ± 220.64 ab	40.16 ± 0.87 b	39.67 ± 0.61 b	30.11 ± 0.84 a	30.36 ± 0.72 a	85.7 ± 0.64 a	86.23 ± 0.6 a	30.33 ± 1.23 b	30.51 ± 1 a	4.12 ± 0.44 b	4.52 ± 0.19 b	6.7 ± 0.05 a	6.72 ± 0.08 a
LMY36 (A2)	3007.77 ± 556.27 b	3583.45 ± 267.73 b	45.01 ± 8.91 a	41.47 ± 0.95 a	28.32 ± 0.69 b	28.97 ± 0.63 c	84.58 ± 0.91 b	85.76 ± 0.52 a	29.17 ± 0.89 c	29.12 ± 1.38 b	4.52 ± 0.44 a	5 ± 0.3 a	6.62 ± 0.07 b	6.68 ± 0.07 a
K836 (A3)	3307.93 ± 545.64 a	3890.08 ± 243.03 a	38.65 ± 0.71 b	38.5 ± 0.66 c	29.8 ± 0.68 a	29.66 ± 0.64 b	84.88 ± 1.24 ab	84.86 ± 0.63 b	32.1 ± 0.98 a	31.47 ± 1.31 a	4.29 ± 0.6 ab	4.99 ± 0.29 a	6.72 ± 0.07 a	6.72 ± 0.08 a
L7619 (A4)	2911.23 ± 778.52 bc	3901.17 ± 395.55 a	39.84 ± 0.93 b	38.87 ± 0.93 c	28.68 ± 1.03 b	28.41 ± 0.65 c	84.9 ± 1.38 ab	84.89 ± 0.68 b	29.49 ± 1.17 bc	29.24 ± 1.02 b	4.2 ± 0.54 b	4.98 ± 0.23 a	6.67 ± 0.07 ab	6.69 ± 0.08 a
Spraying time														
26 Aug (B1)	2297.5 ± 407.17 c	3627.42 ± 202.73 b	42.86 ± 8.25 a	39.57 ± 1.29 a	29.64 ± 1.03 a	29.32 ± 0.87 a	84.77 ± 0.79 a	85.43 ± 0.75 a	30.6 ± 1.65 a	30.24 ± 1.16 a	3.71 ± 0.34 b	4.85 ± 0.37 a	6.66 ± 0.05 a	6.7 ± 0.07 a
6 Sep (B2)	3070.24 ± 429.01 b	3891.15 ± 309.78 a	40.28 ± 1.56 a	39.88 ± 1.46 a	28.86 ± 1.02 b	29.46 ± 1.03 a	85.13 ± 1.4 a	85.61 ± 0.92 a	29.78 ± 1.38 a	29.77 ± 1.56 a	4.53 ± 0.34 a	4.87 ± 0.33 a	6.67 ± 0.06 a	6.69 ± 0.08 a
17 Sep (B3)	3573.41 ± 241.55 a	3901.17 ± 395.55 a	39.6 ± 1.28 a	39.44 ± 1.5 a	29.18 ± 1.17 ab	29.27 ± 1.08 a	85.14 ± 1.14 a	85.26 ± 0.85 a	30.43 ± 1.6 a	30.25 ± 1.8 a	4.61 ± 0.23 a	4.9 ± 0.29 a	6.7 ± 0.1 a	6.72 ± 0.08 a
Source of variance														
Cultivars (A)	0.0044	0.2966	0.1099	0.0069	0.0075	0.0046	0.0999	0.0013	0.0065	0.0026	0.3421	0.0320	0.0254	0.3620
Spraying time (B)	0.0001	0.0154	0.1791	0.1763	0.0650	0.7489	0.5871	0.3371	0.1557	0.5846	0.0001	0.9127	0.3848	0.7729
AxB	0.3190	0.5563	0.4206	0.2394	0.3297	0.5420	0.1626	0.1948	0.5664	0.3398	0.2783	0.9147	0.6756	0.6060

The data were the mean and standard error of three replications. The same letter indicated no significant difference at 0.05 level.

https://doi.org/10.1017/S0021859623000151 Published online by Cambridge University Press

Table 3. Effects of cotton cultivars and spraying time on yield components in three parts of fruiting branches

	Lint percentage-Lower part (%)		Lint percentage-Middle part (%)		Lint percentage-Upper part (%)		Boll weight-Lower part (g)		Boll weight-Middle part (g)		Boll weight-Upper part (g)	
Treatments	Defoliant	Water	Defoliant	Water	Defoliant	Water	Defoliant	Water	Defoliant	Water	Defoliant	Water
2019												
Cultivars												
LMY21 (A1)	43.01 ± 0.42 b	43.34 ± 1.18 b	43 ± 0.41 c	42.98 ± 0.68 b	41.17 ± 2.53 ab	41.59 ± 0.86 a	5.86 ± 0.41 b	5.49 ± 0.51 b	6.06 ± 0.42 b	6.07 ± 0.48 b	4.62 ± 0.7 b	5.43 ± 0.36 b
LMY36 (A2)	44.96 ± 0.67 a	46.03 ± 2.64 a	44.66 ± 0.48 a	44.5 ± 0.67 a	42.53 ± 2.17 a	41.9 ± 1.28 a	5.38 ± 0.41 c	5.51 ± 0.28 b	5.64 ± 0.5 b	5.9 ± 0.17 b	4.85 ± 0.52 b	5.62 ± 0.6 b
K836 (A3)	42.16 ± 1.02 c	42.16 ± 0.98 b	41.68 ± 0.5 d	41.74 ± 0.73 c	39.78 ± 1.23 b	39.41 ± 0.94 b	6.66 ± 0.57 a	6.84 ± 0.42 a	7.22 ± 0.32 a	7.45 ± 0.36 a	5.8 ± 0.72 a	6.47 ± 0.64 a
L7619 (A4)	44.23 ± 1.22 a	43.73 ± 1.13 b	43.45 ± 0.57 b	43.1 ± 0.46 b	41.66 ± 1.37 ab	39.83 ± 1.42 b	5.02 ± 0.34 c	5.19 ± 0.41 b	5.82 ± 0.32 b	6.08 ± 0.5 b	4.68 ± 0.43 b	5.5 ± 0.57 b
Spraying time												
26 Aug (B1)	43.88 ± 1.22 a	43.36 ± 1.46 a	43.26 ± 1.32 a	43.01 ± 1.35 a	41.68 ± 2.04 a	40.45 ± 1.71 a	5.73 ± 0.71 a	5.92 ± 0.89 a	6.23 ± 0.69 a	6.2 ± 0.7 a	4.66 ± 0.83 b	5.72 ± 0.7 a
6 Sep (B2)	43.58 ± 1.79 a	43.6 ± 1.78 a	43.22 ± 1.28 a	43.12 ± 1.16 a	41.15 ± 2.84 a	41.17 ± 1.34 a	5.7 ± 1 a	5.74 ± 0.7 a	6.08 ± 0.84 a	6.47 ± 0.83 a	4.88 ± 0.57 b	5.79 ± 0.56 a
17 Sep (B3)	43.31 ± 1.12 a	44.49 ± 2.84 a	43.11 ± 1.02 a	43.11 ± 1.07 a	41.03 ± 1.15 a	40.42 ± 1.6 a	5.75 ± 0.54 a	5.62 ± 0.7 a	6.24 ± 0.72 a	6.46 ± 0.72 a	5.42 ± 0.68 a	5.76 ± 0.81 a
Source of variance												
Cultivars (A)	0.0013	0.0053	0.0001	0.0003	0.0128	0.0162	0.0009	0.0002	0.0001	0.0001	0.0080	0.0610
Spraying time (B)	0.1971	0.2690	0.7454	0.9138	0.7256	0.1882	0.9550	0.1668	0.6565	0.1718	0.0104	0.9440
AxB	0.0448	0.6456	0.3081	0.2384	0.6025	0.3600	0.2137	0.2329	0.7893	0.1594	0.4377	0.5400
2020												
Cultivars												
LMY21 (A1)	40.92 ± 1.35 b	40.49 ± 1.14 bc	39.58 ± 1.14 b	39.17 ± 0.87 b	38.87 ± 1.31 b	39.3 ± 0.91 b	5.46 ± 0.2 b	5.86 ± 0.26 b	5.75 ± 0.55 b	6.23 ± 0.29 b	4.98 ± 1.28 b	6.31 ± 0.36 b
LMY36 (A2)	43.33 ± 0.88 a	42.91 ± 1.4 a	42.24 ± 1.3 a	40.96 ± 1.08 a	40.08 ± 0.73 a	40.62 ± 1.01 a	5.51 ± 0.15 b	5.6 ± 0.24 b	5.44 ± 1.62 b	6.19 ± 0.2 b	4.66 ± 1 bc	5.94 ± 0.35 b
K836 (A3)	39.77 ± 1.06 c	39.6 ± 0.72 c	38.87 ± 0.93 b	38.24 ± 1.11 b	35.52 ± 2.16 c	36.64 ± 1.74 c	6.56 ± 0.35 a	6.75 ± 0.43 a	6.89 ± 0.44 a	7.29 ± 0.52 a	5.95 ± 1.05 a	6.96 ± 0.57 a
L7619 (A4)	41.751.49 b	41.36 ± 1.51 b	39.49 ± 1.47 b	38.53 ± 0.87 b	38.79 ± 0.97 b	38.4 ± 0.9 b	5.1 ± 0.24 c	5.14 ± 0.23 c	5.33 ± 0.61 b	5.8 ± 0.35 c	4.53 ± 1.03 c	6.01 ± 0.27 b
Spraying time												
26 Aug (B1)	42.27 ± 1.48 a	41.18 ± 1.61 a	40.78 ± 2.02 a	38.7 ± 1.16 b	37.33 ± 2.9 c	38.57 ± 1.57 a	5.51 ± 0.6 b	5.8 ± 0.5 a	5.37 ± 0.72 b	6.38 ± 0.61 a	3.75 ± 0.63 c	6.22 ± 0.5 a
6 Sep (B2)	41.35 ± 1.66 b	41.44 ± 1.92 a	39.97 ± 1.32 ab	39.75 ± 1.65 a	39.17 ± 1.22 a	38.61 ± 2.36 a	5.71 ± 0.58 a	5.85 ± 0.71 a	6.21 ± 0.57 a	6.36 ± 0.79 a	5.23 ± 0.72 b	6.42 ± 0.72 a
17 Sep (B3)	40.7 ± 1.88 b	40.65 ± 1.61 a	39.39 ± 1.73 b	39.23 ± 1.35 ab	38.45 ± 1.82 b	39.05 ± 1.67 a	5.75 ± 0.65 a	5.86 ± 0.79 a	5.97 ± 1.6 ab	6.39 ± 0.61 a	6.11 ± 0.7 a	6.27 ± 0.47 a
Source of variance												
Cultivars (A)	0.0011	0.0308	0.0107	0.0059	0.0001	0.0098	0.0001	0.0001	0.0447	0.0001	0.0001	0.0211
Spraying time (B)	0.0062	0.2469	0.0101	0.0498	0.0001	0.5202	0.0495	0.8500	0.0665	0.9857	0.0001	0.3450
AxB	0.3157	0.7000	0.2805	0.9123	0.0001	0.6623	0.7617	0.1553	0.3155	0.7080	0.2367	0.2766

The data were the mean and standard error of three replications. The same letter indicated no significant difference at 0.05 level.

lint percentage of the middle part within two years. For the B1 treatment, the lint percentage of lower part increased by 0.52 and 1.09 respectively in two years after spraying defoliant. Among the four varieties, the boll weight of the upper, middle and lower parts of K836 (A3) was the highest, which was stable in two years. The boll weight of all three parts was highest for the B3 treatment. In general, spraying defoliant for the B1 treatment increased the lint percentage of the middle and lower parts, and reduced the boll weight of the upper and middle parts. The negative effect for B1 treatment on lint percentage and boll weight was greater than for the B2 and B3 treatments.

The interactive effect of cotton cultivars and spraying time on fibre quality of different parts of cotton fruiting branches

The results of the multiple comparison analysis for all treatments on fibre quality of different parts of cotton fruiting branches are shown in Table 4, S1 and S2.<TE: Please check Supplementary material with xml.> Comparing the results of the two years, it was found that the fibre length and elongation of the upper, middle and lower parts decreased in 2020, and the fibre uniformity and strength increased. The fibre micronaire did not differ significantly between the two years ($P = 0.187$, 0.019 and 0.624 for fibre micronaire of the upper, middle and lower parts, respectively). The change trend of each treatment was consistent in two years. The cultivar was the main source of variation for the fibre length and strength of the upper, middle and lower parts. Among the four cultivars, the fibre length and strength of L7619 (A4) was the lowest, and the value of K836 (A3) was the highest. The fibre length and strength of the upper part were most negatively affected by spraying defoliant for the B1 treatment. Although there were no significant differences in fibre length and strength, the fibre length of all cultivars was reduced by the effect of defoliant, while the fibre strength was slightly increased after spraying defoliant for the B3 treatment.

The fibre uniformity of the upper, middle and lower parts had little difference among cultivars. In all treatments, the earlier the spraying time, the greater the impact on the fibre uniformity. Spraying defoliant for the B1 treatment had the greatest negative impact on the fibre uniformity. The micronaire of the upper, middle and lower parts was reduced after spraying defoliant for the B1 and B2 treatments, and the influence on the upper part was the greatest. Among all the observed traits in the current study, the variation of fibre elongation was the smallest. Spraying defoliant for the B1 treatment reduced the fibre elongation of the upper part, while spraying defoliant for the B2 and B3 treatments had little effect on the fibre elongation of all the observed parts.

Discussion

The results of the current study showed that defoliation, boll opening, seed cotton yield, fibre strength and uniformity differed greatly across two years. The main reason might be that the amount of rain in the middle of cotton growth in 2020 was higher than that in 2019, and the plant grew vigorously. The dense crop canopy caused by the excessive vegetative growth of cotton hindered the opening of mature bolls, delayed crop maturity, and affected a series of subsequent related traits (Bange and Milroy, 2000; Mo *et al*., 2018; Mrunalini *et al*., 2019; Raghavendra and Reddy, 2020). Some traits had the same change trend in the two years after spraying the defoliant, while some traits had opposite, which indicated that the effect of defoliant spraying on these traits might be also affected by environmental changes.

Previous studies have found that applying defoliants at the time of 20–40% boll opening would reduce the cotton lint yield (Snipes and Baskin, 1994; Gwathmey *et al*., 2004; Bange *et al*., 2010; Çopur *et al*., 2010; Chen *et al*., 2017; Gormus *et al*., 2017), while the application of defoliants at 60% boll opening could increase the cotton lint yield (Bynum and Cothren, 2008; Gormus *et al*., 2017; Chandrasekaran *et al*., 2020, 2021; Haliloglu *et al*., 2020; Jajoria *et al*., 2020; Raghavendra and Reddy, 2020). In the current study, the opened bolls accounted for about 20% when spraying defoliant on 26 August (B1), about 40% on 6 September (B2) and 60% on 17 September (B3). The current results showed that defoliant caused significant yield loss at the time of 20–60% boll opening across two years, and the loss was the largest under 20% boll opening. In terms of field performance, early spraying of defoliant resulted in smaller bolls and poor boll formation, which in turn affected yield. Nevertheless, spraying defoliant at 20–40% boll opening had little effect on the lint percentage, and spraying defoliant at 60% boll opening even slightly increased the lint percentage. For quality traits, most studies suggest that spraying defoliants at proper time might shed immature cotton bolls without affecting cotton fibre quality (Malik and Makhdum, 2002; Faircloth *et al*., 2004; Bange *et al*., 2010; Çopur *et al*., 2010; Singh and Rathore, 2015; Ashraf *et al*., 2020; Meng *et al*., 2021). Other studies have shown that spraying defoliants at later stage may promote the fibre micronaire and maturity ratio (Long *et al*., 2021). As shown in Table 2, spraying defoliant at 20–60% boll opening only affected the fibre length in 2020 and the fibre micronaire in 2019. And compared with the blank control (water), the application of defoliant at 60% boll opening had the least impact on fibre quality traits.

Besides, the growth period of cotton generally extends 4 months. In the North China Plain, cotton is usually harvested in mid-October. The current study showed that 25 days after defoliant spraying in all treatments, the leaf abscission rate exceeded 90%. However, if the time between the defoliant spraying and the harvest was too long, it might increase the possibility of a decline in fibre yield and quality due to the adverse weather (Bange and Milroy, 2000; Wright *et al*., 2015; Mo *et al*., 2018; Raghavendra and Reddy, 2020). On the other side, after spraying defoliant at an early stage, cotton was prone to secondary growth before harvest, resulting in redundant vegetative shoots and thus increased the trash content at harvest. In 2019, the defoliation exceeded 90% at 20 days after spraying for the B1 treatment, 15 days after defoliant spraying for the B2 and B3 treatments, respectively. While in 2020, 25 days after defoliant spraying for the B1 and B2 treatments, and 15 days after defoliant spraying for the B3 treatment, the defoliation exceeded 90%. Therefore, despite the large difference in weather between the two years, the effect of spraying defoliant at a late stage was the most stable, and it could promote leaf defoliation in a short time and achieved the effect of assisting harvest.

In addition to environmental factors, cotton deciduous leaves were also affected by genetic factors (Singh and Rathore, 2015; Raghavendra and Reddy, 2020; Long *et al*., 2021). In the current experiment, four different cotton cultivars that had been approved by the Shandong Province were selected. The four cultivars had relatively large variations in the yield, lint percentage, fibre length and strength. Comparing the four cultivars, it was found that the quality (fibre length and strength) of LMY21 (A1) and K836 (A3)

Table 4. Effects of cotton cultivars and spraying time on fibre quality in three parts of fruiting branches

Treatments	Fibre length-Lower part (mm)		Fibre length-Middle part (mm)		Fibre length-Upper part (mm)		Fibre strength-Lower part (CN/tex)		Fibre strength-Middle part (CN/tex)		Fibre strength-Upper part (CN/tex)	
	Defoliant	Water	Defoliant	Water	Defoliant	Water	Defoliant	Water	Defoliant	Water	Defoliant	Water
2019												
Cultivars												
LMY21 (A1)	29.89 ± 0.63 a	30.08 ± 0.72 a	29.48 ± 0.7 ab	29.73 ± 0.63 a	29.8 ± 0.89 a	30.36 ± 0.76 a	28.91 ± 0.97 a	28.87 ± 1.01 a	28.32 ± 1.28 b	28.73 ± 1.36 b	29.68 ± 1.38 ab	30.53 ± 1.08 a
LMY36 (A2)	29.41 ± 0.9 a	29.48 ± 0.92 a	29.02 ± 0.89 b	29 ± 0.79 b	29.13 ± 0.92 a	29.69 ± 0.85 a	28.91 ± 1.98 a	28.51 ± 1.15 a	28.72 ± 0.58 b	28.43 ± 1.43 b	30.36 ± 1.69 a	30.48 ± 1.59 a
K836 (A3)	30.09 ± 0.61 a	29.49 ± 0.88 a	29.92 ± 0.85 a	29.94 ± 0.99 a	29.48 ± 0.74 a	30 ± 0.77 a	30.63 ± 1.6 a	29.91 ± 1.89 a	30.47 ± 1.08 a	31.07 ± 1.29 a	30.91 ± 1.89 a	31.33 ± 0.97 a
L7619 (A4)	28.02 ± 0.75 b	27.93 ± 0.71 b	27.42 ± 0.75 c	27.66 ± 0.77 c	28.23 ± 0.93 b	28.79 ± 0.73 b	27.12 ± 1.39 b	27.04 ± 1.42 b	27.08 ± 1.39 c	26.94 ± 1.08 c	28.44 ± 1.48 b	28.6 ± 1.03 b
Spraying time												
26 Aug (B1)	29.37 ± 1.19 a	29.64 ± 1.27 a	28.85 ± 1.43 a	29.18 ± 1.45 a	28.55 ± 1.04 b	29.99 ± 1.01 a	28.98 ± 2.14 a	28.54 ± 1.48 a	28.54 ± 1.65 a	29.12 ± 2.34 a	28.79 ± 2.18 b	30.72 ± 1.56 a
6 Sep (B2)	29.33 ± 1.04 a	28.97 ± 1.12 a	28.84 ± 1.33 a	29.05 ± 1.03 a	29.14 ± 0.74 b	29.34 ± 0.79 a	29.13 ± 1.46 a	28.86 ± 2.1 a	28.71 ± 1.91 a	28.94 ± 1.55 a	29.98 ± 1.1 a	29.83 ± 1.73 a
17 Sep (B3)	29.36 ± 1.08 a	29.12 ± 0.91 a	29.19 ± 0.92 a	29.02 ± 1.16 a	29.79 ± 0.93 a	29.79 ± 0.99 a	28.57 ± 2.23 a	28.35 ± 1.57 a	28.69 ± 1.45 a	28.32 ± 1.94 a	30.77 ± 1.52 a	30.16 ± 1.26 a
Source of variance												
Cultivars (A)	0.0045	0.0232	0.0002	0.0024	0.0548	0.0258	0.0455	0.0331	0.0170	0.0002	0.0351	0.0164
Spraying time (B)	0.9936	0.0377	0.4174	0.8182	0.0007	0.1112	0.6986	0.7001	0.9070	0.2757	0.0094	0.1598
AxB	0.7186	0.0949	0.4476	0.1134	0.4853	0.4090	0.8937	0.4203	0.2166	0.0878	0.8144	0.1920
2020												
Cultivars												
LMY21 (A1)	29.59 ± 0.94 a	29 ± 0.6 ab	30.19 ± 0.76 a	30.4 ± 0.5 a	30.04 ± 0.43 a	29.82 ± 0.49 a	29.53 ± 1.42 b	28.74 ± 0.92 b	30.58 ± 1.57 a	30.33 ± 0.86 ab	29.24 ± 1.51 b	30.37 ± 0.75 b
LMY36 (A2)	28.11 ± 0.64 b	28.36 ± 1.18 bc	28.76 ± 0.64 bc	28.97 ± 0.45 c	28.7 ± 0.61 b	28.6 ± 0.54 b	28.37 ± 0.96 c	28.56 ± 0.9 b	29.01 ± 1.05 b	29.33 ± 1.07 bc	29.1 ± 1.87 b	29.78 ± 1.33 b
K836 (A3)	29.49 ± 0.55 a	29.38 ± 0.71 a	29.46 ± 0.71 ab	29.81 ± 0.68 b	29.4 ± 0.8 a	29.57 ± 0.66 a	31.01 ± 0.83 a	31.4 ± 1.49 a	31.16 ± 0.87 a	30.99 ± 1.31 a	31.07 ± 1.59 a	31.66 ± 1.45 a
L7619 (A4)	27.48 ± 0.68 b	27.86 ± 0.8 c	28.33 ± 0.74 c	28.2 ± 0.45 d	27.8 ± 0.68 c	28.28 ± 0.58 b	27.8 ± 0.9 c	28.7 ± 0.61 b	29.02 ± 0.84 b	28.88 ± 0.83 c	27.74 ± 1.23 c	29.4 ± 0.71 b
Spraying time												
26 Aug (B1)	28.47 ± 1.02 a	28.48 ± 0.81 a	29.13 ± 1.09 a	29.47 ± 1.01 a	28.83 ± 0.98 a	28.93 ± 0.7 a	28.96 ± 1.42 a	29.2 ± 1.16 a	30.1 ± 1.92 a	29.49 ± 1.28 a	27.63 ± 1.26 b	30.31 ± 1.35 a
6 Sep (B2)	28.85 ± 1.31 a	28.82 ± 1.19 a	29.34 ± 1.09 a	29.47 ± 1.09 a	29.12 ± 1.14 a	29.32 ± 0.73 a	29.29 ± 1.58 a	29.42 ± 2.02 a	29.89 ± 1.34 a	30.39 ± 1.29 a	30.18 ± 1.81 a	30 ± 0.92 a
17 Sep (B3)	28.68 ± 1.14 a	28.64 ± 1.05 a	29.08 ± 0.83 a	29.1 ± 0.89 a	29.02 ± 1.09 a	28.95 ± 1.09 a	29.28 ± 1.89 a	29.43 ± 1.49 a	29.83 ± 1.03 a	29.77 ± 1.27 a	30.06 ± 1.54 a	30.59 ± 1.77 a
Source of variance												
Cultivars (A)	0.0108	0.1976	0.0037	0.0037	0.0028	0.0011	0.0057	0.0055	0.0071	0.0421	0.0007	0.0083
Spraying time (B)	0.3884	0.3954	0.7180	0.0367	0.5551	0.2657	0.5426	0.7522	0.8201	0.0776	0.0001	0.4706
AxB	0.7141	0.0861	0.7287	0.7194	0.4935	0.6461	0.0212	0.0295	0.3244	0.7479	0.8603	0.3469

The data were the mean and standard error of three replications. The same letter indicated no significant difference at 0.05 level.

was better, and the yield and lint percentage were medium. LMY36 (A2) had the highest lint percentage, but the yield and quality were lower than medium. L7619 (A4) grew vigorously and had the highest yield, while the lint percentage, fibre length and strength were the worst. The comprehensive results showed that the degree of adverse effects of defoliant on fibre quality-related traits was less than that of fibre yield-related traits. Among them, L7619 (A4) had the strongest boll opening, and the cotton squares were easy to fall off after spraying defoliant, resulting in the largest loss in yield.

Spraying defoliant at an early stage affected the bolls in the middle and upper fruiting branches of cotton, and had the greatest impact on all traits. Spraying in the middle stage affected the boll in the upper fruiting branches, while spraying defoliant at late stage had little or even no effect on traits. Taken together, the spraying time of defoliant should be best determined according to the field conditions, cultivar characteristics, upcoming weather as well as the target harvest time.

Conclusion

In the current study, the effects of different spraying time of defoliant and cotton cultivars treatments were investigated, and the main factors affecting fibre yield and quality related traits were discussed. In terms of defoliant spraying time, compared with the blank control (water), the application of defoliant at 60% boll opening (B3, 17 September) resulted in the highest defoliation rate and boll opening rate, the minimal loss of seed cotton yield and had the least negative impact on fibre quality traits. The current results showed that the differences in fibre yield and quality were mainly due to cultivars. In addition, the cultivar and spraying time did not interact for almost all of the investigated traits.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0021859623000151.

Author contributions. ZW and XS conceived and designed the study. BD, MX and XW conducted data gathering. LG, GS, JW and ZH collected and cultivated all the plant materials. LW, YD and FK performed statistical analyses. LW, MS and XS wrote and revised the article.

Financial support. The study was funded by Demonstration and Promotion Project of Lumianyan No. 30 and No. 36 (08214224444014), Agricultural Seed Projects of Shandong Province (2020LZGC002) and Modern Agro-industry Technology Research System of Shandong Province (SDAIT-03-02/03/05).

Conflict of interest. None.

Ethical standards. Not applicable.

References

Ashraf AM, Ragavan T and Begam SN (2020) Standardize the dose and timing of defoliant application to facilitate synchronized maturity for mechanical harvesting of rainfed cotton (*Gossypium hirsutum*). *Indian Journal of Agronomy* **65**, 444–450.

Ashraf AM, Begam SN and Ragavan T (2021) Defoliants harvest-aid chemicals: cost effective technology to facilitate synchronized maturity for mechanical harvesting in cotton: a review. *Agricultural Reviews*, 1–8.

Awg-Adeni DS, Abd-Aziz S, Bujang K and Hassan MA (2010) Bioconversion of sago residue into value added products. *African Journal of Biotechnology* **9**, 2016–2021.

Bange MP and Milroy SP (2000) Timing of crop maturity in cotton. Impact of dry matter production and partitioning. *Field Crops Research* **68**, 143–155.

Bange MP, Long RL, Constable GA and Gordon SG (2010) Minimizing immature fibre and Neps in upland cotton. *Agronomy Journal* **102**, 781–789.

Bednarz CW, Shurley WD and Anthony WS (2002) Losses in yield, quality, and profitability of cotton from improper harvest timing. *Agronomy Journal* **94**, 1004–1011.

Bynum JB and Cothren JT (2008) Indicators of last effective boll population and harvest aid timing in cotton. *Agronomy Journal* **100**, 1106–1111.

Chandrasekaran P, Ravichandran V, Senthil A, Mahalingam L and Sakthivel N (2020) Effect of different defoliants and time of application on defoliation percentage and boll opening percentage in high density cotton (*Gossypium hirsutum* L.). *International Journal of Plant & Soil Science* **32**, 37–45.

Chandrasekaran P, Ravichandran V, Senthil A, Mahalingam L and Sakthivel N (2021) Impact of chemical defoliants on chlorophyll fluorescence, biochemical parameters, yield and fibre quality of high density cotton. *Indian Journal of Agricultural Research*, 1–7.

Chen ZJ, Scheffler BE, Dennis E, Triplett BA, Zhang TZ, Guo WZ, Chen XY, Stelly DM, Rabinowicz PD, Town CD, Arioli T, Brubaker C, Cantrell RG, Lacape JM, Ulloa M, Chee P, Gingle AR, Haigler CH, Percy R, Saha S, Wilkins T, Wright RJ, Van Deynze A, Zhu YX, Yu SX, Abdurakhmonov I, Katageri I, Kumar PA, Mehboob-Ur-Rahman ZY, Yu JZ, Kohel RJ, Wendel JF and Paterson AH (2007) Toward sequencing cotton (*Gossypium*) genomes. *Plant Physiology* **145**, 1303–1310.

Chen B, Han H, Zhang G, Wang F, Yu Y and Lin H (2017) Effect of four defoliants and ripeners on cotton. *China Cotton* **44**, 26–28.

Çopur O, Demirel U, Polat R and Gür MA (2010) Effect of different defoliants and application times on the yield and quality components of cotton in semi-arid conditions. *African Journal of Biotechnology* **9**, 2095–2100.

Du MW, Ren XM, Tian XL, Duan LS, Zhang MC, Tan WM and Li ZH (2013) Evaluation of harvest aid chemicals for the cotton-winter wheat double cropping system. *Journal of Integrative Agriculture* **12**, 273–282.

Faircloth JC, Edmisten KL, Wells R and Stewart AM (2004) The influence of defoliation timing on yields and quality of two cotton cultivars. *Crop Science* **44**, 165–172.

Gormus O, Kurt F and Sabagh AE (2017) Impact of defoliation timings and leaf pubescence on yield and fibre quality of cotton. *Journal of Agricultural Science and Technology* **19**, 903–915.

Gwathmey CO, Bednarz CW, Fromme DD, Holman EM and Miller DK (2004) Agronomy and soils: response to defoliation timing based on heat-unit accumulation in diverse field environments. *Journal of Cotton Science* **8**, 142–153.

Haliloglu H, Cevheri Cİ and Beyyavas V (2020) The effect of defoliant application on yield and yield components of some cotton (*Gossypium hirsutum* L.) cultivars at timely and late sowing. *International Journal of Agriculture, Environment and Food Sciences* **4**, 157–164.

Jajoria DK, Sharma SS, Sharma SK and Narolia G (2020) Effect of chemical defoliation on boll opening and yield of cotton. *International Journal of Chemical Studies* **8**, 1980–1983.

Jin DS, Wang XR, Xu YC, Gui HP, Zhang HH, Dong Q, Sikder RK, Yang GZ and Song MZ (2020) Chemical defoliant promotes leaf abscission by altering ROS metabolism and photosynthetic efficiency in *Gossypium hirsutum*. *International Journal of Molecular Sciences* **21**, 2738.

Jin DS, Xu YC, Gui HP, Zhang HH, Dong Q, Sikder RK, Wang XR, Yang GZ and Song MZ (2021) Evaluation of cotton (*Gossypium hirsutum* L.) leaf abscission sensitivity triggered by thidiazuron through membership function value. *Plants* **10**, 1–14.

Kaur S, Singh K, Deol JS, Malik S and Kaur N (2021) Effect of plant growth regulators and defoliants on growth and productivity of American cotton (*Gossypium hirsutum* L.). *Agricultural Research Journal* **58**, 650–656.

Larson JA, Gwathmey CO and Hayes RM (2002) Cotton defoliation and harvest timing effects on yields, quality, and net revenues. *Journal of Cotton Science* **6**, 13–27.

Liu Q, Wei K, Yang LY, Xu WM and Xue W (2021) Preparation and application of a thidiazuron·diuron ultra-low-volume spray suitable for plant protection unmanned aerial vehicles. *Scientific Reports* **11**, 1–12.

Long RL, Delhom CD and Bange MP (2021) Effects of cotton genotype, defoliation timing and season on fibre cross-sectional properties and yarn performance. *Textile Research Journal* **91**, 1943–1956.

Malik MN and Makhdum MI (2002) Use of thidiazuron as harvest-aid in early and late planted cotton. *International Journal of Agriculture and Biology* **4**, 71–73.

Meng L, Zhang LZ, Qi HK, Du MW, Zuo YL, Zhang MC, Tian XL and Li ZH (2021) Optimizing the application of a novel harvest aid to improve the quality of mechanically harvested cotton in the North China Plain. *Journal of Integrative Agriculture* **20**, 2892–2899.

Mo J, McDougall S, Beaumont S, Munro S and Stevens MM (2018) Effects of simulated seedling defoliation on growth and yield of cotton in southern New South Wales. *Crop and Pasture Science* **69**, 915–925.

Mrunalini K and Rekha MS (2018) Dose dependent response of different defoliants on per cent defoliation in high density cotton. *International Journal of Current Microbiology and Applied Sciences* **32**, 116–121.

Mrunalini K, Rekha MS and Murthy VRK (2018) Effectiveness of harvest – aid defoliants and environmental conditions in high density cotton. *International Journal of Current Microbiology and Applied Sciences* **7**, 2312–2316.

Mrunalini K, Rekha MS, Murthy VRK and Jayalalitha K (2019) Impact of harvest-aid defoliants on yield and economics of high density cotton. *Indian Journal of Agricultural Research* **53**, 116–119.

Raghavendra T and Reddy YR (2020) Efficacy of defoliants on yield and fibre quality of American cotton in semi-arid conditions. *Indian Journal of Agricultural Research* **54**, 404–407.

Siebert JD and Stewart AM (2006) Correlation of defoliation timing methods to optimize cotton yield, quality and revenue. *Journal of Cotton Science* **10**, 146–154.

Singh K and Rathore P (2015) Effect of different defoliants and their rate and time of application on American cotton cultivars under semi-arid conditions of north-western India. *Research on Crops* **16**, 258–263.

Singh K, Rathore P and Gumber RK (2014) Growth, seed cotton yield and picking percentage of Bt cotton hybrids as altered by defoliants application under semi-arid conditions. *International Journal of Agricultural and Statistical Sciences* **10**, 91–97.

Snipes CE and Baskin CC (1994) Influence of early defoliation on cotton yield, seed quality, and fibre properties. *Field Crops Research* **37**, 137–143.

Sravanthi S, Rekha MS, Venkateswarlu B, Rao CS and Jayalalitha K (2022) Crop diversification of cotton (*Gossypium hirsutum*) based cropping system for high resource use efficiency. *Indian Journal of Agricultural Research* **56**, 429–434.

Wang FY, Han HY, Lin H, Chen B, Kong XH, Ning XZ, Wang XW, Yu Y and Liu JD (2019) Effects of planting patterns on yield, quality, and defoliation in machine-harvested cotton. *Journal of Integrative Agriculture* **18**, 2019–2028.

Wright SD, Hutmacher RB, Shrestha A, Banuelos G, Rios S, Hutmacher K, Munk DS and Keeley MP (2015) Impact of early defoliation on California Pima cotton boll opening, lint yield, and quality. *Journal of Crop Improvement* **29**, 528–541.

Xu J, Chen L, Sun H, Wusiman N, Sun WN, Li BQ, Gao Y, Kong J, Zhang DW, Zhang XL, Xu HJ and Yang XY (2019) Crosstalk between cytokinin and ethylene signaling pathways regulates leaf abscission in cotton in response to chemical defoliants. *Journal of Experimental Botany* **70**, 1525–1538.