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Original article

## Kaolin and Jasmonic acid improved cotton productivity under water stress conditions



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## ABSTRACT

Drought is one of the most emerging threat that causes a severe reduction in cotton plant growth and development. Being cotton is a major cash crop has great threat to prevailing drought events in Pakistan. A field experiment was conducted in Kharif season 2018 at Research Area of MNS-University of Agriculture, Multan, Pakistan to assess the role of foliar applied kaolin and jasmonic acid on vegetative growth, gas exchange and reproductive traits of cotton under normal irrigated and artificial water deficit conditions. The experiment was laid -out in a factorial randomized complete block design with split – split plot arrangement. Main plots were allocated for irrigation levels, sub-plots for two –cotton genotypes viz. NIAB – 878 and SLH – 19 while sub – sub plots for treatments of kaolin and Jasmonic acid. Water deficit stress was created by skipping irrigation at flowering for 21 days. Foliar sprays of Kaolin (5%, w/v) and Jasmonic acid (100 μM) were applied alone or in combination at 60 days after planntinon both to normal irrigated and water-stresse skip irrigation while irrigation water alone was sprayed in control plots. Both cotton genotypes responded variably to normal irrigated and skip conditions. Skipping irrigation for up to 21 days at flowering caused a significant decrease in leaf relative water content, SPAD values, net photosynthetic rate and seed cotton yield in both the genotypes. Seed cotton yield showed an overall decline of 24.7% in skip over Normal irrigated crop. The genotype NIAB – 878 produced maximum seed cotton yield of 3.304 Mg ha<sup>-1</sup> in normal that dropped to 2.579 Mg ha<sup>-1</sup> in skip, thus showing an average decline of 21.9%. Similarly, SLH – 19 produced 2.537 Mg ha<sup>-1</sup> seed cotton under normal that dropped to 1.822 Mg ha<sup>-1</sup> in skip, showing an average decline of 28.2%. The Application of Kaolin and JA Jasmonic acid, either applied individually or in combination, improved vegetative and

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reproductive development of both cotton varieties in normal and skip regimes. However, combined kaolin and Jasmonic Acid application proved to be more beneficial in terms of seed cotton production and other parameters studied.

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## 1. Introductions

Irrigation water plays an important role in crop growth and development. Globally water and energy demand are increasing (Shabbir et al., 2015) and are expected to rise 6.9 trillion cubic meters by 2030, the demand exceeding 40 % than the available water supplies (Gilbert, 2010). Rising temperatures due to climate change have caused lesser rainfall and created water shortage which has led to lower crop production (Muhammad et al., 2017). Cotton crop is commercially grown in tropical and subtropical regions of the world (Riaz et al., 2013). In Pakistan, it was cultivated on an area of 2.69 million ha with the total production of 11.93 million bales (GOP, 2018). Although, Pakistan ranks fifth in world cotton production, yet the cotton yield per unit area is lower due to a number of factors including high cost of agricultural inputs (fertilizers, seed, pesticides), water scarcity, small land holdings, lack of quality seed and lack of farmer's interest to adopted innovative technology.

Water deficiency is one of the major threats to vegetative and reproductive development of cotton plants. Water deficit stress decreases the stomatal conductance (Danish et al., 2020a), modifies plant-water-nutrient relations and water use efficiency (Danish et al., 2020; Zafar-ul-Hye et al., 2019; Jaleel et al., 2009; Zafar-ul-Hye et al., 2020). Water stress in cotton may have drastic impact during seed germination, early growth season, flowering and during the boll formation stages.

Generally, water shortage is a critical abiotic stress restricted to crop growth and consequently reduces crop yield. It encourages the losses in crop growth and their yield. It also impacts on the growth, phenology parameters, photosynthesis rate, assimilate partitioning, nutrient and water relations, reduced respiration in plants (Abid et al., 2016). Water stress is a complex phenomenon that affects wide range of morpho-physiological traits. Cotton yield decline up to 50%, when the plant experienced water stress during the period of flowering and boll development (Patil et al., 2012). Levi et al. (2009) revealed that water stress reduced seed cotton yield by 48.2%, lint yield by 41.2%, boll weight by 40.0% and GOT by 21.0%. Morpho-Physiological, biochemical and molecular adaptation naturally or by genetic engineering intervention have led to the evolution of drought tolerant varieties.

Kaolin is used as an anti-transparent. Film particle technology positively impacts on plant during water stress, It can reduce the harmful effects of water stress through improved physiological processes leading to efficient yield (Rosati et al., 2006). The kaolin developed an anti-transparent layer on leaf surface that enhanced the grapevines' enhanced phenolic content and antioxidant capacity (Dinis et al., 2016). The kaolin-based particle film technology is multifunctional and environment friendly, which mitigates water and heat stress and leads to the production of high-quality crops. Kaolin used to reduce the transpiration rate could positively affect drought stress.

Jasmonic Acid plays a significant role in various plant processes such as cell cycle (Świątek et al., 2004), seed germination (Dave and Graham, 2012), lateral root formation (Stenzel et al., 2003) and flower development (Wasternack, 2007). Jasmonic acid is also responsible for activating the defense mechanism against water stress (Cheong and Choi, 2003).

The Jasmonates regulate numerous plant physiological functions and protects from the abiotic stresses (Walia et al., 2007). JA applied at the vegetative-reproductive stages appropriately mitigated the negative effects of water deficit by enhancing the morphological and physiological attributes of cotton (Yosefi et al., 2018). Many recent studies have demonstrated that Jasmonates are essential components of the signaling pathway, which activate plant defense genes' expression in response to various environmental stresses (Harms et al., 1995). However, an increase in Jasmonate level can promote the biosynthesis of some substances such as proline contents related to tolerance of environmental stresses (Chen and Zhang, 2016). Jasmonates are connected with the butaine enhanced plant growth under environmental stresses such as water stress. The Jasmonate regulates numerous plant physiological functions and protects from abiotic stresses (Walia et al., 2007). Kaolin and Jasmonic acid are rarely study in combination especially in cotton crop under climatic condition of Pakistan. Therefore present investigation was undertaken to explore the role of Kaolin and Jasmonic acid in improving the Cotton (*Gossypium hirsutum* L.) productivity, quantification of morpho-physiological alterations in cotton genotypes under water deficit conditions and to evaluate the potential efficacy of kaolin and Jasmonic acid in improving drought tolerance in cotton.

## 2. Materials and methods

A field experiment was conducted during Kharif-2018 at Agromonic Research Area (30.130 °N, 71.45°E and 129 m above sea level), MNS-University of Agriculture, Multan, Pakistan. The experiment was conducted in randomized complete block design (RCBD) under split-split plot arrangements (irrigation levels were kept in the main plot; genotypes were kept in subplot; Jasmonic acid and Kaolin were kept in sub-sub plot) to investigate cotton performance under normal and skipped water conditions

Seed of two cotton cultivars: NIAB-878(drought tolerant) and SLH-19 (drought sensitive) were collected from Nuclear Institute of Agriculture and Biology, Faisalabad (NIAB) and Cotton Research Station, Sahiwal.

Irrigation was suspended for the plants in the water deficit treatment groups when first flowering will appear (41 days). Kaolin (White fine powder, K08180-31) and Jasmonic acid (100 mg in 1 ml ethanol) were used.

### 2.1. Crop husbandry

Seedbeds were prepared by tractor driven bed-maker. Cotton seeds were treated with fungicides (Argyl super 5 gm Kg<sup>-1</sup>) prior to sowing on May 2018. Sowing was done manually by dibbling seed 23 cm apart along the edges of the beds by maintaining 75 cm apart row-to-row distance. The net plot size was 15 m<sup>2</sup> (5 m × 3 m) and the gross plot size was retained 18 m<sup>2</sup> (6 m × 3 m). The NPK fertilizer was applied @ 25–35–69 kg per acre, respectively. All P and K was applied at the time of sowing and N was applied in 3 splits; One-third N was applied at the time of sowing and remaining N was applied at 55 and 85 days after planting. All the agronomic practices were kept uniform for all

**Table 1**  
Chemical analysis of soil (Pre-experiment).

Soil characteristics	Unit	Value	
<b>A) Depth of sample</b>	cm	0–15	15–30
Textural class	Loamy Soil		
<b>B) Chemical Analysis</b>			
Saturation	%	36	36
EC	dS m <sup>-1</sup>	3.89	4.59
pH	–	8.2	8.3
Organic matter	%	0.71	0.70
Total nitrogen	%	0.035	0.03
Available phosphorous	mg kg <sup>-1</sup>	8.22	8.20
Available potassium	mg kg <sup>-1</sup>	232	230

the treatments. The soil was characterised for physiochemichemical properties (Table 1). The crop was kept free of weeds by integrated weed management i.e. by chemical application (Dual gold @ 400 ml acre<sup>-1</sup>) and by manual hoeing 2 times during the crop season.

## 2.2. Irrigation treatments

First irrigation was applied at sowing while the remaining twelve irrigations were given according to the crop requirement in normal irrigated plots. To create water deficit stress, three irrigations were skipped at 45, 65- and 75-days old crop. The quantity of irrigation water applied was measured through “Cut through Flume” (20.32 cm × 45.72 cm) fixed at the center of the inlet water channel of the field (Skogerboe and Hyatt, 1967). The total quantity of irrigation water applied was (3238 m<sup>3</sup>) in normal irrigated plot and (2665 m<sup>3</sup>) in skipped irrigated plots. The time to apply a required depth of water was determined by the following formula (Isrealson et al., 1980):

$$T = \frac{A \times D}{Q}$$

Where is, T; application time in hours, Q; discharge, A; irrigated area, d; irrigation depth.

## 2.3. Exogenous applications of Kaolin and Jasmonic acid

Kaolin (White fine powder, K08180-31) and jasmonic acid (100 mg in 1 ml ethanol) were applied at flowering stage (45 days after sowing of crop). The above condition was followed for one week there after applying the supplemental foliar jasmonic acid (100 μM) and kaolin 5% (w/v) at flowering stage under both conditions.

## 2.4. Data recording

Data on various morphological and physiological parameters were recorded using standard methods. Gas exchange characteristics were measured using portable photosynthesis system (Ci-340, CID-USA).

## 2.5. Weather data

The weather data like daily maximum and minimum temperatures (°C), relative humidity (%) and rainfall (mm) during crop growth period was collected from the meteorological station installed at Central Cotton Research Institute, Multan which is located about 500 m away from the experimental site (Fig. 1).

## 2.6. Statistical analysis

R software version 4.0.0 (linear model) was used to analyze the recorded/ collected data. The treatment means were compared using Tukey's multiple comparison at 5% probability level (P < 0.005) (Steel et al., 1997).

## 3. Results

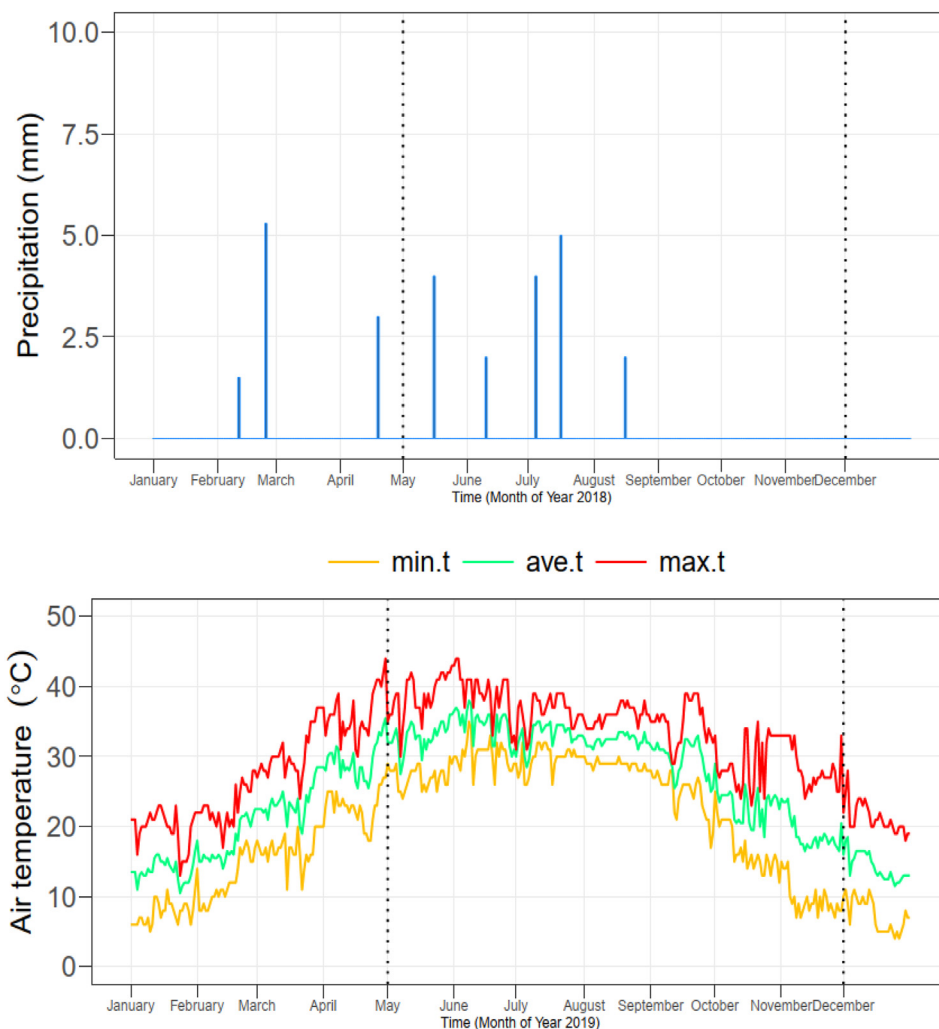
### 3.1. Plant height and boll weight

The main and interaction effects of treatments, irrigation, and variety were found significant at p < 0.05 on the cotton plant height (Table 2). The plant height was found higher in normal irrigation in both NIAB-878 and SLH-19 varieties than skipped irrigation. In normal and skipped irrigation conditions, the NIAB-878 performed better as compared to SLH-19. The effect of combined application of Jasmonic acid + Kaolin was higher over control and individual application of Jasmonic acid and Kaolin. In NIAB-878 under normal irrigation, Jasmonic acid + Kaolin showed 12.8%, 5.4%, and 10.2% as compared to control, Jasmonic acid, and Kaolin, respectively. Kaolin application showed better result on plant height in both varieties NIAB-878 and SLH-19 under both normal and skip irrigation over Jasmonic acid application except in SLH-19 under skipped irrigation where Jasmonic acid showed 9.07% higher plant height as compared to Kaolin (Table 3).

The same main and interaction effects of treatments, irrigation, and variety were found significant at p < 0.05 on the cotton boll weight (Table 2). The boll weight was found higher in normal irrigation in both SLH-19 and NIAB-878 varieties than skipped irrigation conditions. The normal irrigation showed higher boll weight in variety SLH-19. The effect of combined application of Jasmonic acid + Kaolin was higher over control and individual application of Jasmonic acid and Kaolin. SLH-19 under normal irrigation, Jasmonic acid + Kaolin showed 3%, 0.3%, and 1.5% compared to control, Jasmonic acid, and Kaolin, respectively. Jasmonic Acid application showed better results on boll weight in both varieties SLH-19 and NIAB-878 under both water regimes (Table 3).

### 3.2. Monopodial and sympodial branches plant<sup>-1</sup>

The number of monopodial branches were found higher where applied combined application of Jasmonic acid + Kaolin in normal irrigation was applied. Jasmonic acid also showed the same results in skipped irrigation where applied individual application of Jasmonic acid showed higher monopodial branches. The main and interaction effects of treatments, irrigation, and variety were significant at p < 0.05 on the cotton sympodial branches (Table 2). The sympodial branches were found higher in normal irrigation in both NIAB-878 and SLH-19 varieties than skipped irrigation conditions. In normal and skipped irrigation conditions, the NIAB-878 performed better as compared to SLH-19. The effect of combined application of Jasmonic acid + Kaolin was higher over control and individual application of Jasmonic acid and Kaolin. In NIAB-878 under normal irrigation, Jasmonic acid + Kaolin showed 40.4%, 9.5%, and 26.3% as compared to control, Jasmonic acid, and Kaolin, respectively. Kaolin application showed better sympodial branches in both varieties NIAB-878 and SLH-19 under normal and skip irrigation over Jasmonic acid application except in SLH-19 under skipped irrigation Jasmonic acid showed 21.05% higher sympodial branches as compared to Kaolin (Table 4).



**Fig. 1.** Climate data of experimental site (Multan, Pakistan) for the year 2018. Figures show total precipitation (a) and daily minimum, average and maximum air temperature (b). The black dotted lines depict the experiment/ research duration.

**Table 2**

P values of main and interactions effects of Variety, treatments, and irrigation regimes on cotton productivity.

Effect	Plant height	Boll weight	Mono podial branches	Sympodial Branches	Yield	Transpiration rate	SPAD Value	Relative water contents	Stomatal conductance
Variety (V)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Treatment (T)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Irrigation (I)	<0.001	<0.001	0.66	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
V × T	<0.001	<0.001	<0.001	0.16	<0.001	0.01	0.25	<0.001	<0.001
V × I	<0.001	<0.001	0.66	<0.001	0.08	0.02	<0.001	0.11	0.39
T × I	<0.001	<0.001	0.1	0.03	0.01	0.44	0.16	0.01	<0.001
V × T × I	<0.001	<0.001	<0.001	0.16	0.11	0.09	0.04	0.09	<0.001

**Table 3**

Impact of Jasmonic acid and Kaolin on plant height and boll weight under normal and skip irrigation conditions.

Treatment	Plant height (cm)				Boll weight (g)			
	Normal Irrigation		Skip Irrigation		Normal Irrigation		Skip Irrigation	
	NIAB-878	SLH-19	NIAB-878	SLH-19	NIAB-878	SLH-19	NIAB-878	SLH-19
Control	139.10 ± 5.20a	111.4 ± 4.00a	94.27 ± 3.00a	88.73 ± 4.62a	2.21 ± 0.05a	2.59 ± 0.05a	1.92 ± 0.04a	2.41 ± 0.05a
JA	148.93 ± 5.42c	121.83 ± 4.51c	120.00 ± 5.88c	105.4 ± 4.3c	2.39 ± 0.05c	2.63 ± 0.05b	2.21 ± 0.05c	2.59 ± 0.05c
K	142.43 ± 5.85b	117.50 ± 4.00b	114.70 ± 4.51b	96.63 ± 4.5b	2.31 ± 0.05b	2.6 ± 0.04a	2.14 ± 0.05b	2.53 ± 0.05b
JA + K	157.00 ± 5.66d	127.50 ± 4.00d	123.27 ± 4.9c	110.8 ± 5.1d	2.47 ± 0.05 d	2.67 ± 0.05c	2.28 ± 0.05d	2.62 ± 0.04 d

**Table 4**

Impact of Jasmonic acid and Kaolin on monopodial and sympodial branches per plant under normal and skip irrigation conditions.

Treatment	Monopodial branches per plant				Sympodial Branches per plant			
	Normal Irrigation		Skip Irrigation		Normal Irrigation		Skip Irrigation	
	NIAB-878	SLH-19	NIAB-878	SLH-19	NIAB-878	SLH-19	NIAB-878	SLH-19
Control	1.00 ± 0.00a	1.00 ± 0.0a	1.33 ± 0.5ab	0 ± 0.0a	19 ± 1.00a	17 ± 0.58a	18 ± 1.00a	18 ± 1.53a
JA	2.33 ± 0.58b	1.00 ± 0.0a	2.00 ± 0.0b	1 ± 0.0b	24 ± 1.53c	23 ± 1.00c	23 ± 1.00c	22 ± 1.15bc
K	1.00 ± 0.00a	0.33 ± 0.5a	1.00 ± 0.0a	1 ± 0.0b	21 ± 1.00b	20 ± 0.50b	20 ± 1.15b	20 ± 1.53ab
JA + K	2.33 ± 0.58b	1.00 ± 0.0a	2.33 ± 0.5c	1 ± 0.0b	27 ± 0.58d	25 ± 1.00d	25 ± .001d	24 ± 1.00c

### 3.3. Seed cotton yield and transpiration rate

The main and interaction effects of treatments, irrigation, and variety were significant at  $p < 0.05$  on the seed cotton yield and transpiration rate (Table 2). The lowest seed cotton yield was found in skipped irrigation in both NIAB-878 and SLH-19 varieties than normal irrigation conditions. In normal and skipped irrigation conditions, the NIAB-878 performed better as compared to SLH-19. The combined application of Jasmonic acid + Kaolin was higher over control and individual application of Jasmonic acid and Kaolin. In NIAB-878 under normal irrigation, Jasmonic acid + Kaolin showed 35.8%, 22.7%, and 9.6% compared to control, Jasmonic acid, and Kaolin, respectively. The Kaolin application showed better results on seed cotton yield in both varieties NIAB-878 and SLH-19 under normal and skip irrigation over Jasmonic acid application except in SLH-19 under skipped irrigation where Jasmonic acid showed 14.6% higher seed cotton yield as compared to Kaolin (Table 5).

The transpiration rate was found higher in normal irrigation in both NIAB-878 and SLH-19 varieties than skipped irrigation conditions. In normal and skipped irrigation conditions, the NIAB-878 performed better as compared to SLH-19. The combined application of Jasmonic acid + Kaolin was higher over control and individual application of Jasmonic acid and Kaolin. In NIAB-878 under normal irrigation, Jasmonic acid + Kaolin showed 78.8%, 42.26%, and 20.3% compared to control, Jasmonic acid, and Kaolin, respectively. Kaolin application showed better results on transpiration rate in both varieties NIAB-878 and SLH-19 under normal and skip irrigation over Jasmonic acid application except in SLH-19 under skipped irrigation where Jasmonic acid showed 40.3% higher transpiration rate as compared to Kaolin (Table 5).

### 3.4. SPAD value, relative water contents, stomatal conductance and photosynthetic rate

The main and interaction effects of treatments, irrigation, and variety were found significant at  $p < 0.05$  on the SPAD value, relative water contents, stomatal conductance and photosynthetic rate (Table 2). The lowest SPAD value, relative water contents, stomatal conductance and photosynthetic rate were found in skipped irrigation in both NIAB-878 and SLH-19 varieties as compared to normal irrigation conditions. In normal and skipped irrigation conditions, the NIAB-878 performed better as compared to SLH-19. The effect of combined application of Jasmonic acid + Kaolin was higher over

control and individual application of Jasmonic acid and Kaolin. In NIAB-878, under normal irrigation, Jasmonic acid + Kaolin showed 28.3%, 18.9%, and 15% compared to control, Jasmonic acid, and Kaolin, respectively. Kaolin application showed better SPAD value in both varieties NIAB-878 and SLH-19 under normal and skipped irrigation over Jasmonic acid application except in SLH-19 under skipped irrigation where Jasmonic acid showed 6% higher SPAD value as compared to Kaolin (Fig. 2). In NIAB-878, under normal irrigation, Jasmonic acid + Kaolin showed higher RWC 18.2%, 11.6%, and 8% as compared to control, Jasmonic acid, and Kaolin, respectively. Kaolin application showed better results on RWC in both varieties NIAB-878 and SLH-19 under normal and skipped irrigation over Jasmonic acid application except in SLH-19 under skipped irrigation where Jasmonic acid showed 7.8% higher RWC as compared to Kaolin (Fig. 2).

In NIAB-878 under normal irrigation, Jasmonic acid + Kaolin showed higher stomatal conductance 47.4%, 59%, and 38.7% compared to control, Jasmonic acid, and Kaolin, respectively. Kaolin application showed better results on RWC in both varieties NIAB-878 and SLH-19 under normal and skip irrigation over Jasmonic acid application except in SLH-19 under skipped irrigation where Jasmonic acid showed 59.1% higher stomatal conductance as compared to Kaolin (Fig. 3).

In NIAB-878 under normal irrigation, Jasmonic acid + Kaolin showed higher photosynthetic rate 55.8%, 53.2%, and 19% compared to control, Jasmonic acid, and Kaolin, respectively. Kaolin application showed better results on RWC in both varieties NIAB-878 and SLH-19 under normal and skipped irrigation over Jasmonic acid application except in SLH-19 under skipped irrigation where Jasmonic acid showed 44.21% higher photosynthetic rate as compared to Kaolin (Fig. 3).

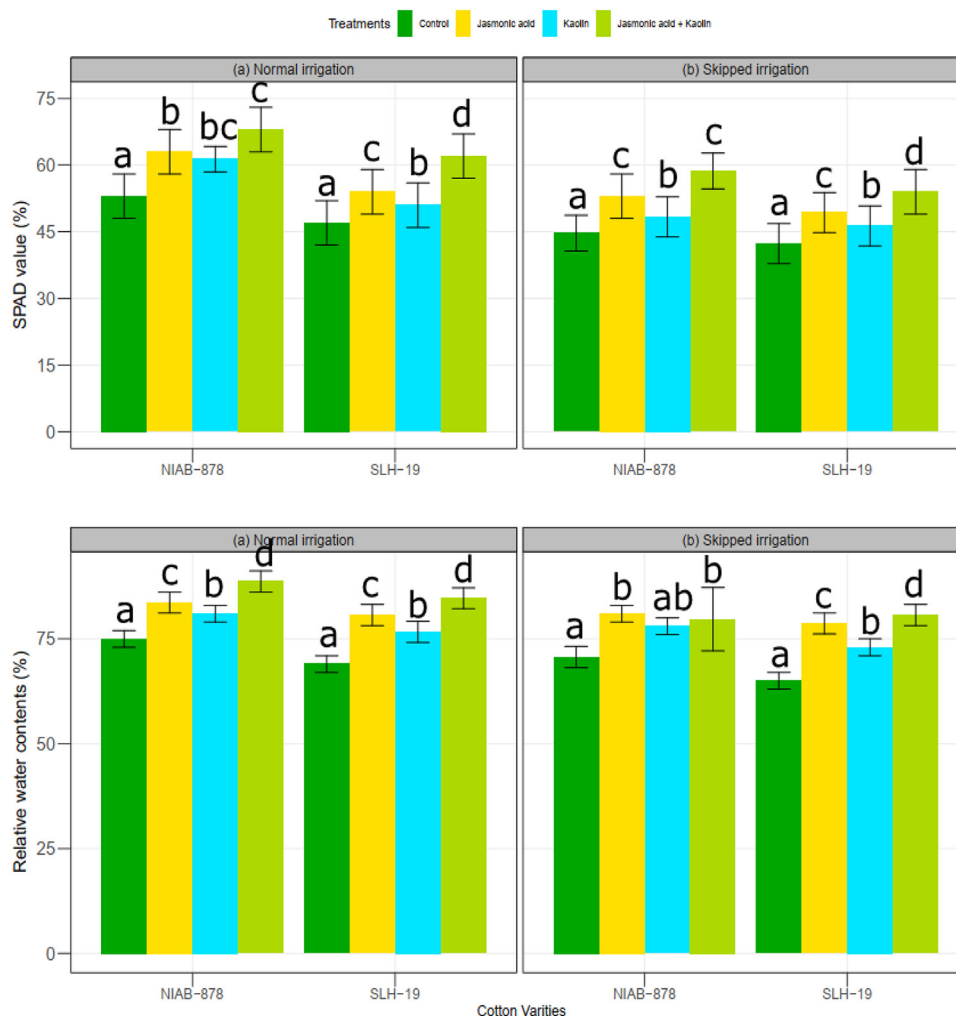
## 4. Discussion

Cotton is an essential cash and fiber crop in Pakistan. It is the most important oilseed crop after soybean in Pakistan. Cotton provides fiber which is utilized as raw material in the textile sector. Cotton has a deep root system and is considered as moderate-resistant crop under water shortage (Rosenow et al., 1983). Moreover, water shortage in semiarid regions is a major yield reduction factor. Water shortage could result in the decline of cotton yield and quality (Reddy et al., 2004). Water stress can affect cotton crop by altering their morphology, anatomy, physiology and yield (Raza

**Table 5**

Impact of Jasmonic acid and Kaolin on seed cotton yield and transpiration rate under normal and skip irrigation conditions.

Treatment	Seed cotton yield (Mg ha <sup>-1</sup> )				Transpiration rate (mm H <sub>2</sub> O m <sup>-2</sup> s <sup>-1</sup> )			
	Normal Irrigation		Skip Irrigation		Normal Irrigation		Skip Irrigation	
	NIAB-878	SLH-19	NIAB-878	SLH-19	NIAB-878	SLH-19	NIAB-878	SLH-19
Control	2.82 ± 0.20a	2.194 ± 0.26a	2.08 ± 0.152a	1.34 ± 0.10a	4.33 ± 0.6a	2.88 ± 0.37a	3.44 ± 0.28a	2.41 ± 0.39a
JA	3.46 ± 0.20b	2.49 ± 0.34b	2.81 ± 0.356c	2.04 ± 0.31bc	6.16 ± 0.42b	6.63 ± 0.3c	5.99 ± 0.33c	5.22 ± 0.49c
K	3.09 ± 0.31a	2.36 ± 0.27 ab	2.46 ± 0.028b	1.78 ± 0.29b	5.21 ± 0.37ab	5.24 ± 0.5b	4.34 ± 0.4b	3.72 ± 0.26b
JA + K	3.83 ± 0.38c	2.75 ± 0.20c	2.95 ± 0.20c	2.11 ± 0.14c	7.74 ± 0.7c	7.26 ± 0.25c	7.37 ± 0.41d	6.02 ± 0.26c



**Fig. 2.** Jasmonic acid and kaolin impact the SPAD value and relative water contents of cotton crop under normal and skip irrigation conditions. Within the variety, same letter (s) indicates the treatments were statistically not significant at  $p < 0.05$ . Error bars represent the standard deviation of the mean ( $n = 3$ ), three replications.

et al., 2012). It may create negative effects on growth stages and yield components like number of bolls plant<sup>-1</sup>, boll weight and flower buds plant<sup>-1</sup> (Jaleel et al., 2008). Similarly, maximum plant height was recorded in normal irrigation, while lowest plant height was observed in skip. irrigation regime (Yagmur et al., 2014). So, it's a dire need to use different irrigation strategies for attaining higher water use efficiency under low water environment (Aliakbari et al., 2013). During the current study study, water deficit conditions reduced plant height in both cotton varieties. Under skipped irrigation, both genotypes (NIAB-878 and SLH-19) reduction in plant height was higher as compared to normal irrigation.

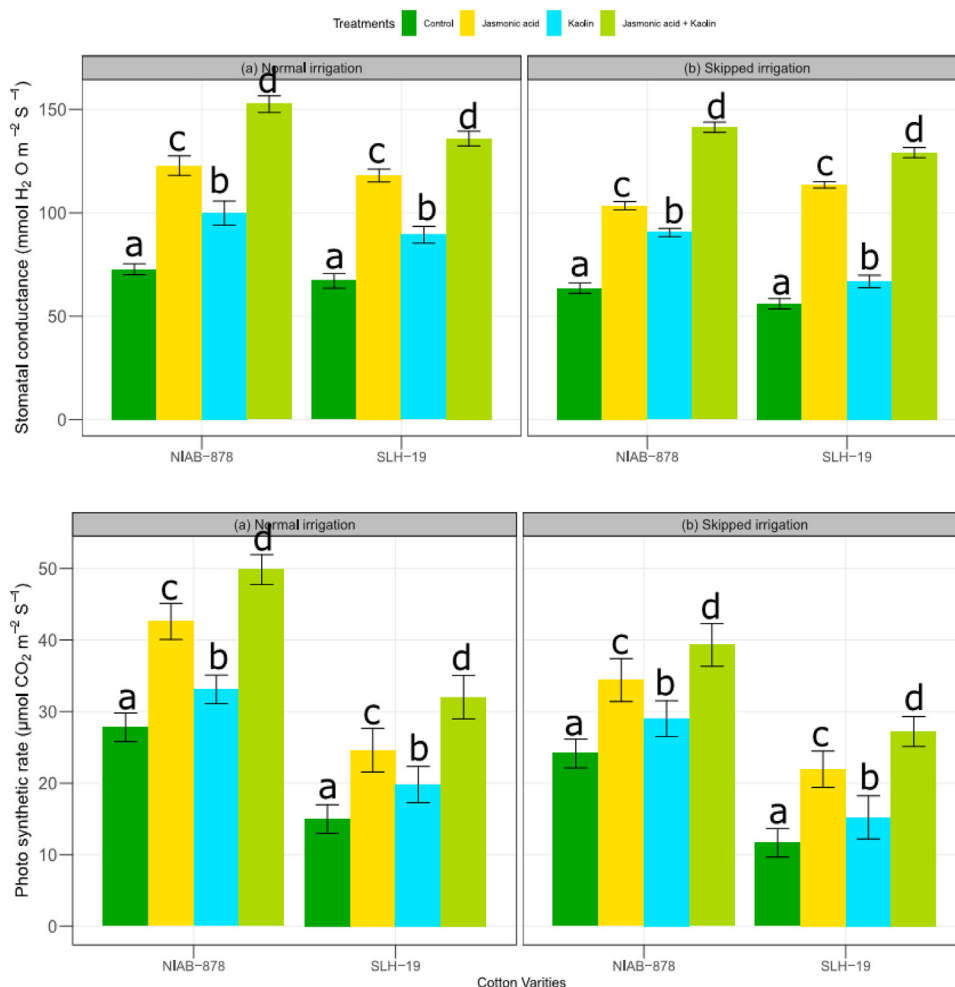
However, Jasmonic acid application increased plant height in normal and skipped irrigation. Kaolin application increased plant height of NIAB-878 and SLH-19 under normal and skipped irrigation. Plant height decreased under skip irrigation, which might be due to varietal characteristics and less water availability. Ferreira et al. (2013) found reduction in root and shoot length of matured cotton crops under water deficit conditions. Shoot length and dry matter contents of stressed cotton plants decreased which might be due to less growth in water scarcity conditions.

Kaolin improved plant height and total dry matter water deficit conditions in current study (Segura-Monroy et al., 2015). Yosefi et al. (2018) found that the application of Jasmonic acid @ 50 mg L<sup>-1</sup> could enable the cotton plant to survive under the adverse

effects of water deficit conditions. The Jasmonic acid and kaolin application might help the cotton plant to maintain relative water contents, water potential, and water use efficiency by increasing the plant turgor pressure which ultimately led to the higher yield in current study. During water stress, enhancement of active solutes such as Chlorophyll, RLWC and biochemical activities are actual mechanism to prevent damage plants. Seed cotton and fiber yield were decreased due to the imposition of water stress. Water stress adversely affects cotton growth and productivity by reducing leaf area index, sympodial. branches, average. boll. weight, yield and fiber quality (Loka et al., 2011).

Foliar application of kaolin @ 4% and 6% improved leaf area, plant height and plant dry weight. Increase in leaf area, plant height and dry weight by kaolin application was also reported by Desoky et al. (2013). Similar results found in the current study, where Jasmonic acid and kaolin application helped to maintain leaf area, transpiration rate, and photosynthetic rate. Similarly, highest chlorophyll contents were observed in combined application of kaolin and Jasmonic acid as compared to control. The higher SPAD value might be resulted in better assimilation and translocation of photosynthates (Iqbal et al., 2012).

Gas exchange and water relations were negatively affected by drought stress due to osmotic and oxidative damage at cellular levels (Chutipajit et al., 2012). Drought stress limits cell division



**Fig. 3.** The impact of Jasmonic acid and kaolin on the stomatal conductance and photosynthetic rate of cotton crop under normal and skip irrigation conditions. Within the variety, same letter (s) indicates the treatments were statistically not significant at  $p < 0.05$ . Error bars represent the standard deviation of the mean ( $n = 3$ ), three replications.

capability. Because of low cell turgor pressure, loss of cell volume makes the contents of cell dense due to solute accumulation that might be harmful to photosynthetic apparatus (Farooq et al., 2009; Hoekstra et al., 2001). Consequently, water deficiency reduced the productivity of cotton crops without affecting the growth stage (Sikuku et al., 2012).

The use of kaolin based particle film technology may be an effective tool to control stomatal conductance and transpiration rate, thus mitigating the detrimental effect of abiotic stress (Boari et al., 2014). However, higher concentration of Jasmonic acid can promote the biosynthesis of substances (such as putrescine and proline) related to environmental stresses (Chen and Zhang, 2016). Hence, it has shown that exogenous application of Jasmonic acid and methyl ester (JA-Me) can improve plants' tolerance against drought stress (Wang and Buta, 1994).

Jasmonic acid could mitigate the damaging impacts of several abiotic stresses on plants (Kaya and Doganlar, 2016; Per et al., 2018). Studies reported that Jasmonic acid control the plant defense system by moderating the physiological and biochemical responses under stress environment (Kaya and Doganlar, 2016). Jasmonic acid's exogenous use can develop the tolerance in plants against drought and temperature stress (Ghasempour et al., 1998; Wang and Buta, 1994). Jasmonic acid applied at the vegetative and reproductive stages could mitigate the negative impacts of water shortage thus enhanced the morpho-physiological traits of cotton (Yosefi et al., 2018).

Stomatal conductance under skipped irrigation decreased in both genotypes but Ja application increased stomatal conductance as compared to normal irrigation. Water stress decline stomatal conductivity in barley genotypes. The decline in stomatal conductance under water stress may be due to a reduction in cells' turgor pressure. Application of methyl Jasmonate (100 mg kg<sup>-1</sup>) increased 73% to 81% stomatal conductance in barley genotypes; Yousef and Morocco under water deficit conditions (Pazirandeh et al., 2015).

The relative water contents were found higher in normal irrigation as compared to skipped irrigation. The NIAB-878 showed higher relative water content in all normal and skipped irrigation treatments compared to SLH-19. However, in skipped irrigation NIAB-878 and SLH-19 showed decreased in relative water in control. The Jasmonic acid increased RLWC in both cotton genotypes under skipped irrigation. These results are in line with Anjum et al. (2011) that found a decrease in RLWC due to increased water stress in soybean. However, the methyl Jasmonate application in soybean increased the percentage of relative leaf water contents and leaf water potential, ultimately improving biophysical characteristics like net photosynthetic rate. Maximum leaf temperature was recorded under skipped irrigation. However, the leaf temperature was higher in SLH-19 in both normal and skipped irrigation than NIAB-878. There was reduction in cotton yield due to highest leaf temperature in NIAB-878 and SLH-19 under skipped irrigation. Kaolin application proved a beneficial anti-transparent layer for cotton genotypes. A decrease in leaf temperature due to kaolin

was also found by (Rosati et al., 2006). Decrease of growth and yield contributing attributes in stressed plants was found by Shallan et al. (2012), but the combine application of kaolin and Jasmonic acid resulted in photosynthetically active radiation (PAR) which led to higher water use efficiency, total biomass, dry matter and cotton seed yield. Exogenous application of kaolin and Jasmonic acid has been proved helpful in the management of stress plant for brassica (Alam et al., 2014), wheat (Qiu et al., 2014) and tomato (Muñoz-Espinoza et al., 2015). Furthermore, Ollas et al. (2013) reported that Jasmonic acid application could mitigate water stress in cotton.

## 5. Conclusions

It can be concluded from the recent study; skipped irrigation has a significant effect on the growth and physiological attributes of cotton. Cotton genotypes showed variable response under normal irrigated and water deficit (skip irrigation) conditions. Cotton genotype (NIAB-878) executed a better response under both irrigation regimes. Combined kaolin and Jasmonic acid applications significantly improved the vegetative and reproductive development of both cotton varieties in normal and water shortage to mitigate the drastic effects of drought stress. It was also noticed that exogenous application of (Jasmonic acid @ 100  $\mu$ M and kaolin @ 5% w/v) performed better both under normal and skipped irrigation among all the treatments. It showed the best response in ameliorating a superior defense mechanism in water deficit conditions for the cotton genotypes. The foliar application of Jasmonic acid may minimize the negative effects of water stress.

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## Institutional Review Board Statement

Not applicable.

## Data Availability Statement

Not applicable.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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