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Evaluation the productivity of Egyptian cotton under climatic conditions and growth stimulates

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ABSTRACT

Cotton is grown in different locations in Egypt, which different climatic conditions (temperature and relative humidity) from location to another and from year to year in the same area. Climatic conditions affected significantly on growth, productivity and quality of cotton. The experiments were carried out at three Research Station farms, Giza, Sids and Mallawi, Cotton Research Institute, Agricultural Research Center, Egypt, during 2020 and 2021 seasons to evaluate the productivity of Giza 95 cotton variety under climatic conditions and growth stimulates (potassium silicate, proline and gibberellins) in three different locations and study their effects on leaves chemical constituents, growth and yield. Each experiment was planted under randomized complete block design with four replications for growth stimulates sprayed at 400 ppm concentration at squaring, beginning and top flowering stages and untreated plants. The combined analyses were used for all collected data (seasons, locations and growth stimulates). The results showed that years significantly affected by the variation in total amount of heat units, which 2021 growing season was lower than 2020 season, this led to season 2021 significantly increased all characters under study. Sids location gave the highest significantly value in all study characters, then Giza and Mallawi locations. Spraying proline recorded the maximum values of all study characters, then sprayed potassium silicate and gibberellins. The highest yield for Giza 95 cotton variety were obtained in season 2021 when plants sprayed by proline in Sids location.

Keywords: Cotton, Temperature, Growth stimulators, Growth, Yield and Chemical constituents

1. Introduction

Cotton is very sensitive to environmental conditions and grown in a wide range of ecological zones and thus, a number of factors such as humidity and temperature are the base climatic factors that ruling cotton flower, boll production and yield. Climate change increase in local and global temperatures, which temperature is the first important environmental factor affecting on all stages of plant growth from germination to production of crops (Hussain *et al.,* 2019). The increasing in temperature is 1.8-4°C by the turn of 21st century causing to grand in stability in cotton crop growth, development and fiber production, which the increasing in temperature than the optimum (30/20°C) due to increase the evaportranspiration, closed stomal and modification for water stress conditions (Sankaranarayanan *et al.,* 2010). Cotton is grown in hot and semi-arid regions, where the daily temperatures may be over than 48-50°C.High temperatures reduce the growth and boll production in cotton (Rahman *et al.,* 2004). The cotton fiber yield reduced at the average of 110 kilo gram/hectare by increasing in daily maximum temperatures up to 1 ˚C. Extreme temperature event has short-term duration of a few days in summer, which temperature increased over than 5 °C above the normal temperatures, that led to very harmful effects on plant growth and productivity by reducing daily photosynthesis, and increasing respiration at night expend stored capacities that led to increase in square and boll shedding and decreasing seed numbers/boll (Loka and Oosterhuis, 2010 and Sawan, 2017). Hemantaranjan *et al.* (2014); Ghaffari *et al.* (2015) and Saleem *et al.* (2018) found that high night temperature is a negative environmental factor, which that led to increase respiration, decrease leaves adenosine tri-phosphate (ATP) levels, carbohydrate accumulation and cotton yield. Hamed *et al.* (2017)

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found that the correlations between number of open bolls/plant, boll weight and seed cotton yield/f, were significant with air temperature and heat units. Cotton cultivars have a wide range of adoptability, requires different total number of accumulation heat units (AHU) and growing degree days (GDD) for their growth, development, yield and maturity. The AHU or GDD is the most important index used to determinate cotton development. This heat unit's accumulation determines the crop maturity along with the end product quality (Ullah *et al.,* 2015). As, the rate of plant growth is mainly temperature driven thus the gap between the actual and potential yield needs to be closed via modeling of the impact of temperature variation on yield and quality of genotypes.

The second important climatic factor is relative humidity % (RH %) in the air that might influence on cotton plant growth, which air temperature affected both directly and indirectly on relative humidity around plant. Cotton plant growth showed many reactions to changes in relative humidity. Mergeai and Demol (1991)stated that reduces of humidity at both leaf surfaces decreased photosynthetic rate of the whole leaf for plants grown under a mild temperature and medium light level in plant. Also, Sawan (2017) observed that maximum temperature and maximum humidity led to negative significant effect with fruiting branches and productivity, which means that these climatic parameters have determinable effects upon Egyptian cotton productivity.

Potassium silicate ($K_2Si_2O_5$) is a source of soluble potassium and silicon. Silicon (Si) concentration ranges from 1% to 10% or higher in plant dry matter, which is an essential element and enhances growth and development by improving many useful physiological processes in plant and alleviative the effect of abiotic stresses (Moustafa *et al.,* 2018). Potassium (K) plays an important role in the translocation of photosynthesis, which potassium fertilization increased yield and cotton productivity as reported by Ibrahim *et al.* (2015) and Emara *et al.* (2018). Foliar spraying of potassium silicate resulted in a significant effect on all growth parameters and improved photosynthetic pigments, amino acids and protein content as well as uptake of macro and micronutrients by plants which translated finally to an increment in yield (Shedeed, 2018).

Proline has a protective role in plant under stress conditions, which it acted as an osmolyte, a metal chelator, an antioxidant compound, a signal molecule and accumulated during stress (Ibrahim *et al.,* 2019). Under stress conditions, proline constitutes about 80% of free amino acids in plants, which it share in the synthesis of primary metabolites, transports metabolites during growth and development stages (Kahlaoui *et al.,* 2018). Proline helps in oxidative phosphorylation in mitochondria, activator ATP synthesis as plant resistant mechanism and ameliorates stress effects in crops (Rady and Mohamed, 2018 and Yaqoob *et al.,* 2019).

Gibberellin (GA_3) is a plant hormone shared in plant stress responses, which foliar applications gibberellins activated many physiological processes like growth, flowering, earliness, ion transport, fruit set, osmoregulation, internode elongation, biomass production, fruit weight and increasing endogenous levels of salicylic acid (Miceli*et al.,* 2019). Foliar application of gibberellin regulates growth processes like seed germination, stem elongation uniform flowering and increase number of flowering (Sadoei and Shandadneghad, 2014 and Ülger *et al.,* 2018).

The purpose of this study to evaluation the productivity of Giza 95 Egyptian cotton variety under climatic conditions and growth stimulates (potassium silicate, proline and gibberellins) in three different locations (Giza, Sids and Mallawi) and study their effect of this on growth, yield and leaves chemical constituents.

2. Materials and Method

2.1. Experiment design

The experiments were carried out at three Research Station farms, Giza (29°59′13″N: 31°12′42″E), Sids (29°04′N: 31°05′E) and Mallawi (27.7317°N: 30.8395°E), Cotton Research Institute, Agricultural Research Center, Egypt, during 2020 and 2021 seasons to evaluation the productivity of Giza 95 Egyptian cotton variety under climatic conditions and growth stimulates (potassium silicate, proline and gibberellins) in three different locations (Giza, Sids and Mallawi) and study their effect of this on growth, yield and leaves chemical constituents. Characterized Giza 95 cotton cultivar showed in (Table 1). Each experiment was planted under randomized complete block design with four replications for growth stimulates (potassium Silicate, proline and gibberellins) which sprayed at (400 ppm) concentration at three times (squaring, beginning and top flowering stages)and the

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untreated plants (control). The combined analyses were used for all collected data (seasons, locations and growth stimulates).

Table 1: Characterized Giza 95 cotton variety

Variety name	Giza 95
Species	Barbadense.
Category	Long staple
Pedigree	Crossing between [Giza 83 (Giza 75 x 5844)] and Giza 80
Characteristics	Long staple characterized by high yielding, early maturity, high lint percentage about 39 - 40 %, light Creamy color, resistance to Fusarium wilt and tolerant to high temperature.
Botanical distinguishing characters	The stem has a medium length and the main stem has strong growth with round shape of stem cross section. The leaves are medium size, green color, five deep lobes and it have one gland in lower midrib. The first fruiting branch is located at 6^{th}-7^{th} node and compact internodes. The flower is tubular shape with yellow petals and a dark purple spot on the petals base and yellow pollen grains. The boll is conically shape with three loculi and sometimes four, Pitted. The bracts are large and have one gland under bract. Seed is medium size with little brown fuzz.
Variety bred by	Cotton Breeding Research Section, Cotton Research Institute**,** Agricultural Research Center, Giza, Egypt.

In each experiment, the plot consisted of 7 rows, 3.5 m long and 0.60 m width (plot area = 14.70 m^2). Seeds of Giza 95 cotton variety were sown on 24^{th} of April in all seasons for all locations (Giza, Sids and Mallawi). Hills were spaced at 25 cm within rows and seedlings were thinned at 2 plants/hill after 35 day from planting. Phosphorus fertilizer as ordinary superphosphate (15.5% P_2O_5) at the rate of 22.5 kg P_2O_5/f was incorporated during seed bed preparation. Nitrogen fertilizer in the form of ammonium nitrate (33.5% N) at the rate 60 kg N/f was applied in two equal doses, immediately before the first and the second irrigations. Potassium fertilizers in the form of potassium sulfate (48% K_2O) at the rate of 24 kg K_2O/f was side-dressed in a single dose before the second irrigation. Standard agricultural practices were followed throughout the growing seasons in all locations. Representative soil samples were taken from the experimental sites before sowing in the two seasons and three locations were prepared for analysis, according to Chapman and Pratt (1978).Chemical properties of soil in the three locations Giza, Sids and Mallawi in 2020 and 2021 seasons are shown in Table (2).

Table 2: Chemical properties of soil in the three locations Giza, Sids and Mallawi stations in 2020 and 2021 seasons

Properties	**Giza station**		**Sids station**		**Mallawi station**	
	2020	**2021**	**2020**	**2021**	**2020**	**2021**
pH	7.75	7.84	7.30	7.55	8.34	8.05
E.C. (dsm^{-1})	1.64	1.50	0.98	1.18	0.58	0.36
Saturation percentage (g/cm^3)	54.16	52.7	50.3	52.31	52.24	51.56
N (mg/Kg soil)	44.23	43.93	39.08	40.19	41.31	40.24
Soluble cations (meq/l)						
Ca^{++}	6.32	5.93	7.14	7.24	1.68	1.53
Mg^{++}	3.04	2.98	3.83	3.95	0.69	0.62
Na^{+}	6.21	5.95	4.52	4.82	1.45	1.21
K^{+}	0.42	0.36	0.89	0.97	0.34	0.26
P	9.33	9.20	8.15	8.43	8.74	8.65
Soluble anions (meq/l)						
CO_3^{-}	--	--	--	--	--	--
HCO_3^{-}	3.62	3.54	3.20	3.46	1.24	1.00
Cl^{-}	5.62	5.29	2.90	3.17	2.27	2.00
SO_4^{--}	6.48	6.32	3.45	3.62	0.73	0.60

All samples were taken at random from each plot in order to study growth and yield traits. At harvest, 6 guarded plants were randomly taken from the central ridge to determine plant height (cm), number of fruiting branches/plant, number of open bolls/plant, boll weight (gm), lint % and seed index (gm). Seed cotton yield (k/f.) was estimated as the weight of seed cotton yield (kilogram) picked from the three central ridges collected from two picks, then converted to yield per feddan in kentar (Kentar = 157.5 kg.).

Climatic conditions and heat unit accumulations were monitored using in Department of Meteorology, Agricultural Research Center. Maximum and minimum, mean air temperature (°C) and relative humidity % in the three locations Giza, Sids and Mallawi stations during 2020 and 2021 seasons are shown in Table (3). The data covered the period from the start of planting to harvesting stage. Average of air temperatures (°C) through the growing seasons recorded in order to calculate heat units (HU). Heat units (HU) were calculated according to Sutherland (2012) equation as follows:

Heat unit (HU) = mean daily temperature – Base Temp. (Base Temp. = zero growth =15.6 °C).

Monthly heat units (HU) during a six month cotton growth period in the three locations Giza, Sids and Mallawi stations during 2020 and 2021 seasons are showed in Table (4).

Table 3: Monthly maximum, minimum, mean temperature and relative humidity % in three locations Giza, Sids and Mallawi stations during 2020 and 2021 seasons

Seasons	Months	Giza				Sids				Mallawi			
		Temperature °C			RH%	Temperature °C			RH%	Temperature °C			RH%
		Max	Min	Mean		Max	Min	Mean		Max	Min	Mean	
2020	April	25.38	17.25	21.31	74.82	27.49	19.51	23.20	77.23	29.21	20.00	24.60	78.85
	May	28.74	19.68	24.21	75.44	30.07	21.48	25.77	77.81	32.64	22.32	27.48	78.92
	June	33.57	23.08	28.32	78.75	34.84	25.76	30.30	79.46	37.83	27.14	32.48	82.34
	July	36.72	27.62	32.17	79.69	38.81	29.65	34.23	81.35	39.95	31.09	35.52	82.73
	August	37.13	28.35	32.74	80.31	39.36	30.83	35.09	82.07	41.82	32.64	37.23	84.28
	September	32.22	24.90	28.56	68.28	33.10	25.59	29.34	69.64	35.31	26.85	31.07	70.46
	October	29.01	18.87	23.94	64.35	29.75	20.42	25.08	65.28	30.74	23.63	27.19	66.71
Mean		**31.82**	**22.82**	**27.32**	**74.52**	**33.34**	**24.74**	**29.00**	**76.12**	**35.35**	**26.23**	**30.79**	**77.75**
2021	April	24.43	16.08	20.25	73.62	25.82	18.39	22.10	76.94	28.46	18.67	23.56	78.05
	May	28.07	18.69	23.38	75.19	29.91	20.84	25.37	77.23	31.28	21.75	26.51	78.64
	June	32.95	21.82	27.38	77.54	34.57	24.62	29.59	78.56	36.99	26.82	31.90	81.77
	July	36.05	26.61	31.33	78.75	37.74	28.43	33.08	80.75	39.14	30.91	35.02	82.18
	August	36.68	27.34	32.01	79.83	38.00	29.59	33.79	81.18	40.76	31.64	36.20	82.96
	September	31.26	23.75	27.50	65.13	31.85	24.67	28.26	67.26	34.63	25.75	30.19	69.63
	October	27.54	17.16	22.35	61.28	28.16	18.84	23.50	62.74	29.85	21.68	25.76	63.25
Mean		**30.99**	**21.63**	**26.31**	**73.04**	**32.29**	**23.62**	**27.95**	**74.95**	**34.44**	**25.31**	**29.87**	**76.64**

Table 4: Monthly heat units (HU) during a six month cotton growth period in the three locations Giza, Sids and Mallawi stations during 2020 and 2021 seasons.

Months	2020			2021		
	Monthly heat units at			Monthly heat units at		
	Giza	Sids	Mallawi	Giza	Sids	Mallawi
April	171.30	228.00	270.00	139.50	195.00	238.80
May	258.30	305.10	356.40	233.40	293.10	327.30
June	381.60	441.00	506.40	353.40	419.70	489.00
July	497.10	558.90	597.60	471.90	524.40	582.60
August	514.20	584.70	648.90	492.30	545.70	618.00
September	388.80	412.20	464.10	357.00	379.80	437.70
October	250.20	284.40	347.70	202.50	237.00	304.80
Total heat units	**2461.5**	**2814.3**	**3191.1**	**2250.0**	**2594.7**	**2998.2**

2.2. Chemical analysis

Cotton samples of 4th upper leaf/plant were taken randomly after 10 days from the last sprayed time (at top flowering stage) with growth stimulates (potassium Silicate, proline and gibberellins) to determine the chemical analysis as follows:

2.2.1. Total chlorophyll and carotenoids contents

Total chlorophyll (mg/g, FW) estimated by the spectrophotometric method recommended by Arnon (1949) and carotenoids of Robbelen (1957). Leaf samples (0.3 g from each replicate were homogenized in 50 ml 80 % (v/v) acetone and centrifuged at 10,000 × g for 10 min. The absorbance of each acetone extract was measured at 665, 649, and 440 nm using a UV-visible spectrophotometer.

2.2.2. Total soluble sugars content

Total soluble sugars were determined in ethanol extract of leaves by the phenol-sulfuric acid method according to Cerning (1975). A stranded curve was prepared using different concentration (10 to 100mg/ml) of pure glucose.

2.2.3. Total free amino acids content

Total free amino acids were determined in ethanol extract of cotton leaves by ninhydrin method according to Rosen (1957).

2.2.4. Total phenols content

Total phenols were determined in ethanol of leaves using Folin-Ciocalteau method according to Simons and Ross (1971). One milliliter of sample was mixed with 1ml of Folin and Ciocalten's phenol reagent, after 3min, 1ml of saturated Na_2CO_3 (14%) was added to the mixture and completed to 10ml by adding distilled water. The reaction was kept in the dark for 90min, after which its absorbance was read at 725nm. A calibration curve was constructed with different concentrations of gallic acid (0.01–1mM) as standard.

2.2.5. Total antioxidant capacity

Total antioxidant capacity was determined in ethanol extract of cotton leaves using the phosphomolybdenum method of Prieto *et al.* (1999) as described by Kumaran and Krunakaran (2007). The results are expressed as the increase in absorbance ($O.D_{695nm}$).

2.3. Yield and its components

At first pick, random sample of ten guarded plants was taken and labeled from each plot to determine the following characters; Growth characters of plant height (cm) and number of fruiting branches. Yield and its components, including, number of open bolls/plant, boll weight (g), lint percentage, seed index (g) and seed cotton yield (k/f).

2.4. Statistical analysis

All collected data were subjected to statistical analysis as proposed by Gomez and Gomez (1984) and means were compared by LSD and T test at 5% level of probability.

3. Results

Crop growth and yield are controlled by environmental factors (light, CO_2, temperature, water, nutrients, etc.). Crop production is directly influenced by climatic conditions. Through the different growing seasons, the cotton plants were exposed to different air temperatures and relative humidity %. Data in Table (3 and 4) cleared that average mean air temperature and total heat units which were received by cotton plants in 2020 planting season were higher than that in 2021 season and Mallawi location was higher on mean air temperature and relative humidity % total heat units compared with the other locations.

Data in Tables (5 to 9) showed that the effect of the main factors seasons, locations, growth stimulators and their interactions on leave chemical constituents (total chlorophyll, carotenoids, total soluble sugars, total phenols, total amino acids and total antioxidant capacity), growth traits (plant height and no. of fruiting branches/plant) and yield and yield components (no. of bolls/plant, boll weight, seed index, lint% and seed cotton yield/f).

3.1. Seasonal effect on chemical constituents, growth, yield and its components on cotton

Data in Table (5) cleared those seasons had a significant effect on leave chemical constituents, growth traits, yield and its components. Season 2021 recorded the highest values in the cotton leaves chemical constitute of total chlorophyll, carotenoids, total soluble sugars, total phenols, total amino acids and total antioxidant capacity (8.39, 1.206. 28.09, 15.03, 26.48 mg/g and 0.947 O.D), respectively. As well as, season 2021 recorded the highest values in plant height (130.5 cm), number of fruiting branches/plant (12.6), number of bolls/plant (14.89), boll weight (2.86 g), seed index (10.67 g) and seed cotton yield (9.23 k/f).

3.2. Effect of locations on chemical constituents, growth, yield and its components on cotton

Data also in Table (5) showed that locations had a significant effect on leaves chemical constituents, growth traits and yield characters The best values in Table (5) registered in Sids location on cotton leaves chemical constituents of total chlorophyll, carotenoids, total soluble sugars, total phenols, total amino acids and total antioxidant capacity (9.98, 1.307, 29.15, 16.92, 30.07 mg/g and 1.294 O.D), respectively. Also, Sids location recorded the highest values of plant height (128.88 cm), no. of fruiting branches/plant (14.32), no. of bolls/plant (16.53), boll weight (2.93 g), seed index (11.24 g), seed cotton yield (10.57 k/f). Sids location recorded the maximum results then followed by Giza location while Mallawi location came the last in this respect.

3.3. Effect of growth stimulators on chemical constituents, growth, yield and its components on cotton

The results in Table (5) stated that the foliar application of growth stimulators (potassium silicate, proline and gibberellins) affected significantly on leave chemical constituents, growth and yield characters of cotton plant. It is clear from results in Table (5) that foliar applications of proline gave the best results on cotton leaves chemical constituents of total chlorophyll by 27.97%, carotenoids by 46.26%, total soluble sugars by 19.1%, total phenols by 25.95%, total amino acids by 35.34% and total antioxidant capacity by 74.08%. Likewise, exogenous proline gave the best results on growth traits (plant height by 9.87%, number of fruiting branches/plant by 17.21%) and yield characters (number of bolls/plant by 14.35%, boll weight by 7.4%, seed index by 7.24% and seed cotton yield by 19.92%) compared with control cotton plants. Exogenous cotton plants with proline achieved the maximum results then spraying with potassium silicate and gibberellins comparing with untreated plants in the three different locations.

3.4. Effect of the interactions among seasons, locations and Growth stimulators on chemical constituents, growth, yield and its components on cotton.

The interactions effect among factors of seasons (2020 and 2021), locations (Giza, Sids and Mallawi locations) and spraying growth stimulators (potassium silicate, proline and gibberellin) on leaves chemical constituents, growth, yield and its components of cotton plant showed in Tables (6, 7, 8 and 9).

It is clear from data in Table (6) that the interaction between seasons and locations affected significantly on leaves chemical constituents (total chlorophyll, total soluble sugars and total antioxidant capacity), growth (plant height and no. of fruiting branches/plant) and yield characters (number of bolls/plant, boll weight, seed index, lint% and seed cotton yield). While it affected insignificantly on carotenoids, total phenols and total free amino acids contents on cotton leaves. Sids location in 2021 season recorded the best results on leaves chemical constituents of total chlorophyll, total soluble sugars and total antioxidant capacity (10.45, 30.24 mg/g and 1.35 O.D), respectively. Moreover, this interaction gave the best values of plant height (138.51 cm) and number of fruiting branches/plant (14.74), number of bolls/plant (17.17), boll weight (2.97 g), seed index (11.3 g) and seed cotton yield (10.96 k/f).

Data in Table (7) revealed that the interaction between seasons and growth stimulators affected significantly on leaves chemical contents (total chlorophyll, carotenoids, total soluble sugars, total phenols and total antioxidant capacity), growth (plant height and number of fruiting branches/plant) and

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Table 5: Effect of the main factors on leaves chemical constituents, growth and yield characters on cotton

Treatments		Chemical constituents						Growth traits		Yield and yield components				
		Total Chl. (mg/g FW)	Carotenoids (mg/g FW)	Total soluble sugars (mg/g FW)	Total Phenols (mg/g FW)	Total amino acids (mg/g FW)	Total antioxidant capacity ($O.D_{695\ nm}$)	Plant height	No. of fruiting branches/p	No. of bolls/p	Boll weight	Seed index	Lint %	Seed cotton yield (k/f)
Seasons	2020	7.44	1.099	26.09	12.88	24.40	0.844	116.74	11.95	13.86	2.75	10.19	40.66	8.54
	2021	8.39	1.206	28.09	15.03	26.48	0.947	130.50	12.60	14.89	2.86	10.67	40.11	9.23
T_{tes}		**	**	**	**	**	**	**	**	**	**	**	**	**
Locations	Giza	8.11	1.115	28.10	15.25	28.00	0.675	124.71	11.70	13.64	2.81	10.27	40.34	8.41
	Sids	9.98	1.307	29.15	16.92	30.07	1.294	128.88	14.32	16.53	2.93	11.24	40.15	10.57
	Mallawi	5.67	1.035	24.03	9.69	18.25	0.718	117.26	10.81	12.95	2.68	9.78	40.67	7.68
LSD at 0.05		**0.051**	**0.010**	**0.112**	**0.068**	**0.125**	**0.004**	**0.433**	**0.021**	**0.183**	**0.027**	**0.195**	**0.024**	**0.139**
Growth stimulators	Control	6.90	0.923	24.65	12.52	21.19	0.714	117.37	11.21	13.31	2.70	10.07	41.03	8.03
	Silicate	8.46	1.267	28.09	14.49	27.22	0.846	126.13	12.65	14.82	2.84	10.57	40.22	9.22
	Proline	8.83	1.350	29.36	15.77	28.68	1.243	128.96	13.14	15.22	2.90	10.80	39.71	9.63
	Gibberellin	7.49	1.069	26.27	13.04	24.67	0.780	122.01	12.10	14.09	2.77	10.28	40.58	8.67
LSD at 0.05		**0.059**	**0.012**	**0.129**	**0.079**	**0.144**	**0.006**	**0.500**	**0.025**	**0.211**	**0.031**	**0.225**	**0.028**	**0.161**

Table 6: Effect of the interaction between seasons and locations on leaves chemical constituents, growth and yield characters on cotton

Treatments		Chemical constituents						Growth traits		Yield and yield components				
Seasons	**Locations**	**Total Chl. (mg/g FW)**	**Carotenoids (mg/g FW)**	**Total soluble sugars (mg/g FW)**	**Total Phenols (mg/g FW)**	**Total amino acids (mg/g FW)**	**Total antioxidant capacity (O.D$_{695\ nm}$)**	**Plant height**	**No. of fruiting branches/p**	**No. of bolls/p**	**Boll weight**	**Seed index**	**Lint %**	**Seed cotton yield (k/f)**
2020	**Giza**	7.73	1.062	27.11	14.18	26.97	0.631	117.25	11.29	13.32	2.73	9.95	40.57	8.08
	Sids	9.50	1.253	28.06	15.86	29.01	1.238	119.26	13.89	15.90	2.89	11.18	40.38	10.17
	Mallawi	5.10	0.981	23.11	8.61	17.24	0.663	113.70	10.65	12.38	2.63	9.44	41.02	7.38
2021	**Giza**	8.48	1.168	29.08	16.32	29.04	0.719	132.18	12.11	13.97	2.88	10.60	40.10	8.74
	Sids	10.45	1.361	30.24	17.99	31.14	1.350	138.51	14.74	17.17	2.97	11.30	39.92	10.96
	Mallawi	6.25	1.089	24.96	10.77	19.25	0.773	120.81	10.97	13.53	2.73	10.11	40.31	7.98
LSD at 0.05		**0.072**	**N.S**	**0.158**	**N.S**	**N.S**	**0.008**	**0.612**	**0.031**	**0.259**	**0.039**	**0.276**	**0.035**	**0.101**

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Table 7: Effect of the interaction between seasons and growth stimulators on leaves chemical constituents, growth and yield characters on cotton

Treatments		Chemical constituents						Growth traits		Yield and yield components				
Seasons	**Growth stimulators**	**Total Chl. (mg/g FW)**	**Carotenoids (mg/g FW)**	**Total soluble sugars (mg/g FW)**	**Total Phenols (mg/g FW)**	**Total amino acids (mg/g FW)**	**Total antioxidant capacity (O.D$_{695\ nm}$)**	**Plant height**	**No. of fruiting branches/p**	**No. of bolls/p**	**Boll weight**	**Seed index**	**Lint %**	**Seed cotton yield (k/f)**
2020	**Control**	6.66	0.875	23.80	11.55	20.18	0.662	110.84	10.94	12.05	2.65	9.84	41.29	7.74
	Potassium silicate	7.89	1.211	27.04	13.33	26.12	0.785	119.10	12.30	15.88	2.79	10.30	40.54	8.82
	Proline	8.17	1.282	28.27	14.62	27.61	1.188	121.25	12.73	17.05	2.83	10.56	39.81	9.01
	Gibberellin	7.06	1.027	25.26	12.03	23.71	0.742	115.76	11.82	14.03	2.72	10.06	40.99	8.41
2021	**Control**	7.15	0.972	25.50	13.49	22.21	0.766	123.91	11.48	13.77	2.76	10.29	40.77	8.26
	Potassium silicate	9.03	1.323	29.13	15.65	28.32	0.907	133.16	13.00	15.34	2.89	10.85	39.90	9.55
	Proline	9.48	1.418	30.45	16.92	29.76	1.297	136.66	13.56	15.86	2.97	11.05	39.61	10.23
	Gibberellin	7.93	1.111	27.29	14.05	25.63	0.818	128.26	12.38	14.58	2.83	10.50	40.16	8.87
LSD 0.05		**0.083**	**0.017**	**0.182**	**0.112**	**N.S**	**0.009**	**0.707**	**0.035**	**0.510**	**N.S**	**N.S**	**0.040**	**0.209**

Table 8: Effect of the interaction between locations and growth stimulators on leaves chemical constituents, growth and yield characters on cotton

Treatments		**Chemical constituents**						**Growth traits**		**Yield and yield components**				
Location	**Growth stimulators**	**Total Chl. (mg/g FW)**	**Carotenoids (mg/g FW)**	**Total soluble sugars (mg/g FW)**	**Total Phenols (mg/g FW)**	**Total amino acids (mg/g FW)**	**Total antioxidant capacity ($O.D_{695\ nm}$)**	**Plant height**	**No. of fruiting branches/p**	**No. of bolls/p**	**Boll weight**	**Seed index**	**Lint %**	**Seed cotton yield (k/f)**
Giza	**Control**	7.32	0.913	25.85	14.10	20.86	0.547	118.10	11.27	12.96	2.71	9.99	40.94	7.75
	Potassium silicate	8.54	1.205	29.12	14.98	31.10	0.561	127.41	11.78	13.87	2.84	10.38	40.19	8.66
	Proline	8.80	1.312	30.69	17.73	32.36	1.086	130.12	12.20	14.29	2.90	10.57	39.71	8.91
	Gibberellin	7.78	1.029	26.73	14.20	27.70	0.505	123.22	11.55	13.47	2.78	10.16	40.51	8.30
Sids	**Control**	8.11	1.050	26.59	15.89	26.02	1.202	122.89	12.48	14.98	2.81	10.79	40.72	9.23
	Potassium silicate	11.18	1.447	30.45	17.08	32.22	1.298	131.00	14.99	17.21	2.98	11.45	40.03	11.06
	Proline	11.40	1.532	31.25	17.97	33.28	1.422	133.86	15.65	17.87	3.04	11.66	39.58	11.66
	Gibberellin	9.22	1.201	28.32	16.77	28.78	1.255	127.78	14.15	16.07	2.90	11.06	40.28	10.31
Mallawi	**Control**	5.28	0.808	21.51	7.57	16.71	0.393	111.13	9.89	12.01	2.60	9.41	41.44	7.09
	Potassium silicate	5.66	1.150	24.70	11.41	18.35	0.679	119.97	11.18	13.37	2.71	9.89	40.45	7.92
	Proline	6.29	1.205	26.15	11.62	20.41	1.220	122.89	11.58	13.70	2.76	10.18	39.84	8.31
	Gibberellin	5.48	0.977	23.78	8.15	17.53	0.579	115.04	10.60	12.74	2.65	9.63	40.94	7.40
LSD 0.05		**0.102**	**0.021**	**0.223**	**0.36**	**0.250**	**0.012**	**0.866**	**0.043**	**0.366**	**N.S**	**N.S**	**0.049**	**0.279**

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Table 9: Effect of the interaction among seasons, locations and growth stimulators on leaves chemical constituents, growth and yield characters on cotton

Treatments			Chemical constituents						Growth traits		Yield and yield components				
Seasons	**Location**	**Growth stimulator**	**Total Chl. (mg/g FW)**	**Carotenoids (mg/g FW)**	**Total soluble sugars (mg/g FW)**	**Total Phenols (mg/g FW)**	**Total amino acids (mg/g FW)**	**Total antioxidant capacity (O.D$_{695\ nm}$)**	**Plant height**	**No. of fruiting branches/p**	**No. of bolls/p**	**Boll weight**	**Seed index**	**Lint %**	**Seed cotton yield (k/f)**
2020	**Giza**	**Control**	7.07	0.872	24.87	13.08	19.80	0.490	110.90	10.83	12.60	2.65	9.71	41.13	7.41
		Potassium silicate	8.12	1.147	28.09	13.79	30.03	0.504	119.90	11.42	13.60	2.77	10.00	40.44	8.18
		Proline	8.33	1.243	29.65	16.72	31.27	1.031	121.40	11.78	13.90	2.79	10.20	39.82	8.32
		Gibberellin	7.43	0.985	25.84	13.16	26.78	0.499	116.80	11.16	13.20	2.17	9.90	40.90	8.02
	Sids	**Control**	8.16	0.999	25.55	14.85	24.97	1.161	112.83	12.26	14.50	2.75	10.73	40.82	8.91
		Potassium silicate	10.48	1.389	29.32	16.02	31.15	1.234	121.30	14.53	16.50	2.96	11.40	40.33	10.68
		Proline	10.57	1.476	30.14	16.88	32.21	1.358	124.20	15.08	17.20	3.00	11.60	39.75	11.03
		Gibberellin	8.80	1.150	27.23	15.70	27.72	1.201	118.73	13.72	15.40	2.85	11.00	40.65	10.06
	Mallawi	**Control**	4.75	0.754	20.98	6.73	15.74	0.334	108.80	9.75	11.50	2.56	9.08	41.93	6.90
		Potassium silicate	5.09	1.097	23.72	10.20	17.20	0.618	116.10	10.96	12.80	2.66	9.50	40.87	7.60
		Proline	5.63	1.126	25.03	10.28	19.35	1.174	118.16	11.34	13.03	2.70	9.89	39.88	7.70
		Gibberellin	4.95	0.945	22.71	7.23	16.64	0.525	111.76	10.58	12.02	2.62	9.30	41.43	7.15
2021	**Giza**	**Control**	7.58	0.954	26.84	15.13	21.93	0.604	125.31	11.72	13.32	2.77	10.28	40.75	8.09
		Potassium silicate	8.96	1.263	30.15	16.18	32.18	0.618	134.92	12.14	14.15	2.92	10.76	39.94	8.95
		Proline	9.27	1.381	31.73	18.75	33.45	1.142	138.85	12.63	14.68	3.01	10.95	39.61	9.51
		Gibberellin	8.14	1.072	27.62	15.24	28.62	0.511	129.64	11.95	13.74	2.85	10.42	40.13	8.42
	Sids	**Control**	8.06	1.100	27.63	16.93	27.07	1.243	132.96	12.71	15.46	2.87	10.86	40.62	9.56
		Potassium silicate	11.89	1.504	31.58	18.14	33.29	1.362	140.71	15.46	17.93	3.00	11.51	39.73	11.45
		Proline	12.23	1.588	32.37	19.06	34.36	1.485	143.53	16.23	18.55	3.08	11.72	39.42	12.29
		Gibberellin	9.65	1.252	29.41	17.85	29.85	1.310	136.84	14.58	16.74	2.95	11.13	39.91	10.57
	Mallawi	**Control**	5.81	0.861	22.04	8.42	17.63	0.452	113.47	10.03	12.53	2.64	9.75	40.95	7.15
		Potassium silicate	6.24	1.203	25.68	12.63	19.51	0.741	123.85	11.41	13.95	2.76	10.29	40.03	8.25
		Proline	6.95	1.285	27.27	12.97	21.47	1.265	127.62	11.82	14.37	2.83	10.48	39.81	8.90
		Gibberellin	6.01	1.009	24.85	9.08	18.42	0.634	118.32	10.63	13.28	2.69	9.95	40.46	7.63
LSD 0.05			**0.144**	**N.S**	**0.316**	**0.193**	**N.S**	**0.017**	**1.226**	**0.061**	**0.284**	**N.S**	**N.S**	**0.07**	**0.362**

yield characters (number of bolls/plant, lint% and seed cotton yield/f). Whereas it did not affect significantly on leaves total amino acids content, boll weight and seed index of cotton plant. Spraying proline in season 2021 gave the best values on leaves chemical constituents of total chlorophyll, carotenoids, total soluble sugars, total phenols, total antioxidant capacity (9.48, 1.418, 30.45, 16.92 mg/g and 1.297 O.D), respectively. Besides that, this interaction recorded the best results of plant height (136.66 cm) and number of fruiting branches/plant (13.56), boll weight (2.97 g), seed index (11.05 g) and seed cotton yield (10.23 k/f).

The results in Table (8) mentioned that the interaction between locations and spraying cotton plants with growth stimulators affected significantly on leaves chemical constituents (total chlorophyll, carotenoids, total soluble sugars, total phenols, total free amino acids ant total antioxidant capacity), growth (plant height, number of fruiting branches/plant) and yield characters (number of bolls/plant, lint% and seed cotton yield/f). While it affected insignificantly on boll weight and seed index of cotton plants. The highest values recorded by the interaction between Sids location and spraying proline on leaves chemical constituents of total chlorophyll, carotenoids, total soluble sugars, total phenols, total free amino acids and total antioxidant capacity (11.4, 1.532, 31.25, 17.97, 33.28 mg/g and 1.422 O.D), respectively. Similarly, this interaction gave the best values of growth traits of plant height (133.86 cm), number of fruiting branches/plant (15.65), number of bolls/plant (17.87), boll weight (3.04 g),seed index (11.66 g) and seed cotton yield (11.66 k/f).

Data in Table (9) showed that the interaction among seasons, locations and growth stimulators affected significantly on leaves chemical constituents (total chlorophyll, total soluble sugars, total phenols and total antioxidant capacity), growth (plant height, number of fruiting branches/plant) and yield characters (number of bolls/plant, lint% and seed cotton yield/f). Whereas it affected insignificantly on carotenoids, total free amino acids contents of cotton leaves, boll weight, seed index of cotton plant. Sprayed cotton plants with proline in Sids location during 2021 season gave the maximum values on chemical constituents of total chlorophyll, carotenoids, total soluble sugars, total phenols, total free amino acids and total antioxidant capacity (12.23, 1.588, 32.37, 19.06, 34.36 mg/g and 1.485 O.D), respectively. Also, it gave the maximum values on growth traits of plant height (143.53 cm) and number of fruiting branches/plant (16.23) and yield characters of number of bolls/plant (18.55), boll weight (3.08 g), seed index (11.72 g) and seed cotton yield (12.29 k/f).

4. Discussion

High temperature during season 2020 then season 2021 led to decreased significantly cotton leaves of chemical constituents (Table 5). That might be related to exposure cotton plants to high temperature for long time, which reduce the photosynthesis rate and pigments content, causing a reduction in carbohydrates content, phenols and amino acids biosynthesis. Cotton plants grown in hot conditions that the ideal temperature range is 20-30˚C for its growth and biomass accumulation and the optimum temperature range for biochemical and metabolic activities determinate to be between 23.5 and 32˚C (Reddy *et al.*, 1992 and Loka and Oosterhuis, 2010). Under higher temperature than the optimum (i.e., >32˚C) affected negatively on cotton plants thought flowering, boll development and inhibition of photosynthesis (Bibi *et al.,* 2008), increased respiration and photorespiration, decreased metabolism, decreased pollination and fertilization and decreased crop growth rate (Reddy *et al.,* 1996 and Snider *et al.,* 2009). Temperature increased in 2021 season than 2020 season in growth traits, yield and yield components might be attributed to the temperature which affected significantly on physiological, biochemistry metabolism and productivity of cotton plants. Cotton plants need warm days and comparatively cool nights for the optimum growth and development. Cotton seedling had insensitive response for increasing the temperature up to 40/32˚C during the first two weeks of emergence, after that they had sensitive to high temperature, which the increasing of temperature to 40/30˚C due to decrease plants biomass by 50% as comparing to optimum temperature at 30/20˚C for the ideal growth rate and fruiting branches (number of squares and bolls retained). Sankaranaryanan *et al.* (2010) and Aggarwal (2008) documented that cotton grown under high temperature at 40/32˚C had not fruiting branches, fewer branches at 35/27˚C and more branches at 30/22˚C. High temperature stress had significantly negative effects on cotton plant, especially during late reproductive stages of flowering and boll formation, so that there are many agronomic practices reduced the harmful effects of high temperature on cotton such as spraying osmotic adjustment and antioxidant compounds (Prasad and Jagadish, 2015). Albers (1993) mentioned that cotton plants need about 2800 total heat units for normal crop production through average 180-190 days from sown. Over heat units lead to increasing vegetative growth. Increasing temperature rate and its subsequent increase in vegetative growth don't necessarily lead to higher cotton characters particularly yield but, however, it insteadly could reduce it. With increasing heat units, cotton yield always reaches a plateau then it declines.

The all chemical constituents of cotton leaves reduced significantly with the increasing or decreasing in heat units in different locations, which they decreased significantly in Giza location (the lowest location in heat units) and then in Mallawi location (the highest location in heat units), while Sids location had the best heat units for cotton plants growth during all seasons, so that it have the highest contents of leaves chemical constituents (Table 5). The reduction in total phenols contents, pigments and soluble sugars might be attributed to increase oxidative stress because of high temperature, which decrement in pigments and cell membrane stability by the increasing in temperature and humidity in the air led to reduction in photosynthesis rate. The negative effects of increasing heat and humidity enhanced chlorophyll degradation and reduced photosynthetic activity. Additionally, the reducing in total free amino acids contents might have aggravated damage to soluble proteins. Lower availability of carbohydrates for development might have reduced phenols biosynthesis and total antioxidant compounds. These results are agreement with Hemantaranjan *et al.* (2014) and Saleem *et al.* (2018), who stated that high heat conditions due to damage photosynthesis and decrease pigments, carbohydrate, total phenols, free amino acids and antioxidant compounds, then finally reduce number of fruiting branches, open bolls and yield. As shown in Table (5), the yield characters improved significantly in the three different locations. That explained the increasing or decreasing in temperature and humidity than the optimum conditions due to the reduction in growth and yield characters, which cotton plants need about 450 heat units for appearing squaring parts through average 45 days from planting (Reddy *et al.,* 1991 and Albers, 1993). Data in Table (4) inducted that Giza location have (429.6 and 372.9) heat units, Sids location have (533.1 and 498) heat units and Millawi location have (635.4 and 566.1) heat units through average first 45 days from planting in 2020 and 2021 seasons respectively. The reduction in heat units in Giza location and increasing in heat units in Millawi location in total heat units than the ideal heat units during growth season affected significantly on the number of squaring parts, thus led to increase absent of fruiting branches, boll shedding and then reducing the yield of Giza location 25.68% and Millawi location 37.63% compared with Sids location. Sids location have almost the ideal heat units (533.1 and 498) in both seasons for appearing squaring parts and suitable weather parameters (temperature and relative humidity) during all seasons, so that Sids location had the highest growth and yield, which there are many biochemical reactions involved in the growth and development of cotton plant that are very sensitive to high temperature and humidity of air. Reduction in number of opened bolls/plant and boll weight in the three different locations during two seasons might be due to high temperature and humidity % of air, which that at flowering stage might be caused boll shedding then reduced boll setting and increased cell membrane thermostability (CMT) then enhanced lipid peroxidation leading to decreased number of opened bolls. Similar results obtained by Hasanuzzaman *et al.* (2013) and Ghaffari *et al.* (2015) deduced that high temperature stress damaged membrane stability, aggravated oxidative stress, reduced total soluble proteins, phenols and finally damaged reproductive tissues and boll weight that might be due to increasing the damage of photosynthesis under heat stress. Likewise, Sawan (2017) and Saleem *et al.* (2018) found that boll weight depended on CMT, so that high temperature caused to decrease boll weight and yield (k/f).

The increasing in leaves chemical constituents by spraying proline might be a result of increasing photosynthesis pigment, carbohydrates, phenols and amino acids contents. Proline as a source of ATP and nitrogen in leaves enhances the photosynthesis rate. These results are in harmony with Rady and Mohamed (2018) and Yaqoob *et al.* (2019), who tended that proline at the lower concentration improved plants chlorophyll a fluorescence parameters as compared with control under stress conditions. Also, Ibrahim *et al.* (2019) reported that proline foliar application led to increased photosynthetic pigments and proline contents in plant. Similarly, potassium silicate application significantly increased the total chlorophyll contents. Silicon increased the photosynthesis by enhancing carboxylase activities that acted as "windows" to help the light transmission to mesophyll area. Likewise, potassium increased the total soluble protein content by improving the activities of amino acids biosynthesis enzymes, which potassium equalized different organic anions and other compounds within the plant to stabilize the optimum pH (between 7 and 8) for most enzyme reactions (Ibrahim *et al.,* 2015). In this observation, Moustafa *et al.* (2018) and Shedeed (2018) found that potassium silicate foliar applications significantly increased chlorophylls, carbohydrates and protein contents in the leaves of plants. This improvement may be due to the role of silicon in enhancing plant growth via promoting desirable physiological processes in plant. As well as, foliar application of gibberellin increased the contents of chlorophyll a, b, total chlorophyll and carotene (Sardoei and Shahdadneghad, 2014). That may be attributed to the role of growth regulators in increasing leaf area that due to their influence on cell division and cell elongation. Also, Lakshmipathi *et al.* (2017) reported that gibberellin acted as a growth promoting compound that significantly regulates leaf expansion. The significantly increasing in growth, yield and its components related to the positive effects of potassium silicate, proline and gibberellin foliar applications, which proline gave the best results in the three different locations then potassium silicate and finally gebberellin. Proline applications significantly increased of cotton yield, which acts as an important nutrient that could be beneficial roles for plant like enhancing the activities of enzymatic and non-enzymatic antioxidants compounds, increasing growth, physiological parameters and yield characteristics. These results are in line with Rady and Mohamed (2018), Ibrahim *et al.* (2019) and Yaqoob *et al.* (2019). Likewise, the useful effects of potassium silicate spraying to cotton yield and its components might be attributed to the enhancement in nutrient availability and to the increase in nutrients uptake. Potassium silicate increase leaves K and Si contents and increase photosynthesis, assimilates accumulation and yield components of cotton. The boll weight increases related to the high K level mainly caused by the increasing in photosynthesis rate of cotton plants and the increasing in the accumulation of metabolites with direct enhances boll weight. These results are in accordance with those outlined by Emara *et al.* (2018), Moustafa *et al.* (2018) and Shedeed (2018). As well as, gebberellin application significantly enhanced the cotton yield, which gibberellin enhanced plant leave area and thus increased pigments contents and growth characteristics. These results are agreement with Ülger *et al.* (2018) and Miceli *et al.* (2019).

Conclusion

Cotton productivity for Giza 95 variety changed with different seasons and locations (Giza, Sids and Mallawi) that due to the different mean temperatures and heat units between season and different locations. Cotton plants need warm temperature (30/20˚C) and total heat units (2800) for ideal growth rate, fruiting branches and metabolic activities. High temperature had significantly negative effects on cotton plants include, decreasing plants biomass, increasing photorespiration, closed stomal, reducing photosynthesis rate and carbohydrate content. Spraying cotton plants with growth stimulators such as potassium silicate, proline and gibberellin amelioration the adverse effects of high temperature by improving the biochemical contents, growth and yield characters, which they are acted as osmolytes enhancing the photosynthesis rate and increasing cotton plant tolerance at heat stress.

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