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RESEARCH ARTICLE

Alleviation of Drought Stress in Maize by Exogenous Application of Gibberellic Acid and Cytokinin

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Abstract

The study was conducted to investigate the ameliorative roles of GA_3 and CK on adverse effects of drought in maize. Drought stressed maize plants were applied with GA_3 and CK at 50, 100, and 150 mg L^{-1} as foliar spray at the vegetative and the reproductive stages. Plant height, internode length, stem diameter, leaf chlorophyll index, and dry matter production were significantly affected by drought. In most cases, GA_3 and CK significantly improved the depressed plant traits, but in varying degrees depending on the growth stage encountering hormones, and their types and concentrations. Both GA_3 and CK were found to be very effective in alleviating drought-imposed adverse effects on maize at the vegetative phase. Such alleviating effects varied depending on the concentration of the hormones. Application of CK at 150 mg L^{-1} was excellent resulting in a 106% yield advantage compared to drought stress and 79.9% increase relative to well-watered controls. Conversely, GA_3 at 50 mg L^{-1} performed well showing 78.8% increase in grain yield. However, both GA_3 and CK had very little effect on improving the depressed growth and yield attributes in maize at the reproductive phase. The relative yield advantages for the hormones were mainly attributed to improving the cob and seed-bearing capacity of drought-stressed maize plants.

Key words: cytokinin (CK), drought alleviation, gibberellic acid (GA_3), growth and yield, maize

Introduction

Maize (*Zea mays* L.) is an important food and feed crop contributing greatly to global food security (Campos et al. 2004). In 2030, the demand for maize will be almost double that in 2000 for south Asia, China, and India and will exceed demand for rice and wheat by 2020. Besides, maize demand for feed in the developing world will lead all other cereal crops with a rate of increase of 2.9% annually (Timsina et al. 2011). For this, development of various crop improvement and management technologies are underway for intensive cultivation and sustainability of maize. Among many constraints of maize intensification, drought is considered as the major one in many countries of the world (Bruce et al. 2002; Netting 2000). In Africa, maize production has been reported to be reduced up to 70% due to drought and the failure of total crop is not uncommon (Ashraf 2010; Muoma et al. 2010). The problem is also widespread in Asia including the southwest and northwest regions of Bangladesh.

Agronomic manipulations including exogenous application of growth hormones have been found to be effective as drought management techniques. The sustainability of maize production under drought-stressed environments applying plant breeding techniques is thought to be difficult (Tinker 2002). Conversely, the role of plant growth regulators under drought stress is important in modulating physiological responses that eventually lead to adaptation to an unfavorable environment. Generally, drought quickly affects the processes related to cell turgidity, particularly the growth of the meristems (Figueiredo et al. 1999). The decrease in cytokinin (CK) and gibberellic acid (GA_3), and increase in abscisic acid (ABA) under drought conditions suggested that the growth reduction could be the result of the drought-induced changes

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in membrane permeability and water uptake due to altered hormonal balance. Therefore, the exogenous application of hormones could be an attractive approach to cope with drought stress (Saeidi-Sar et al. 2007).

Although much attention has been paid to the possible involvement of GA_3 and CK for the management of drought environment in various field crops (Achard et al. 2006; Gadallah 1995; Li et al. 2010; Maggio et al. 2010; Magome et al. 2008; Rodriguez et al. 2006), very little attention has been given to their role in alleviating the adverse effects of drought in maize. High concentrations of GA_3 and CK may have inhibitory effects on the growth or deleterious effects on the cellular metabolism (Nanjo et al. 2003). Since the drought stress tolerance of maize varies with the developmental stages (Westgate 1994), it is also necessary to determine the appropriate growth stage at which GA_3 and CK could be most effective. Therefore, this study aimed at optimizing the level of GA_3 and CK and determining the appropriate growth stage at which exogenous application of GA_3 and CK could effectively alleviate the adverse effects of drought stress and eventually provide maximum growth and yield in maize.

Materials and Methods

Experimental site and plant materials

The experiment was conducted under semi-controlled environmental conditions in the Stress Research Site of the Department of Agronomy, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur-1706, Bangladesh during the period from December 2009 to May 2010. The location lies 24.09° N latitude and 90.26° E longitude. A widely used variety BARI maize-5 developed by Bangladesh Agricultural Research Institute (BARI) was used in the experiment.

Plant establishment

A total of 192 plants were grown in Waggoner pots having 12 kg sandy clay loam soil. Organic compost was added in pots for maintaining a soil compost ratio of 4 : 1. Chemical fertilizers, i.e. urea, triple super phosphate, muriate of potash and gypsum were applied as per recommendation (BARC 2005). Two sets of pots of which one containing 96 plants were kept for vegetative stage treatment and another set containing 96 plants were retained for reproductive stage treatment. Soil moisture was maintained at full capacity up to the imposition of drought treatments.

Imposition of drought and hormonal treatments

In the experiment, the well-watered pots designated as control were maintained at full pot capacity. Drought treatment was maintained by keeping soil moisture at 25% pot capacity by regular monitoring. Drought stress (DS) treatment was imposed at the vegetative (45 - 69 DAE) and the reproductive (70 - 94 DAE) stages. The hormonal treatments GA_3 and CK at 50, 100, and 150 mg L^{-1} were applied to drought-stressed plants two times at 11-day intervals, i.e. at 49 and 60 DAE at the vegetative stage and at 74 and 85 DAE at the reproductive stage. Different concentrations of GA_3 and CK were prepared and applied as a foliar spray. Drought-stressed and hormone-treated plants were given optimum moisture at 69 DAE onwards for the vegetative stage treatment and at 94 DAE onwards for the reproductive stage treatment. Half of the plants were harvested at the end of both drought and hormonal treatments at every growth stage. The remaining plants were allowed to grow until final harvest at 123 DAE. At the same time, a separate set of plants were kept under drought conditions at both the growth stages without imposing a hormonal treatment for comparison.

Measurement of plant traits and grain yield

Data were recorded on plant height, internode length, stem diameter, leaf chlorophyll index (SPAD values), leaf area, plant components dry weight, yield attributes, and grain yield. Plant height was measured at 49 and 69 DAE corresponding to the vegetative stage and at 74 and 94 DAE corresponding to the reproductive stage. Internode length, stem diameter, and SPAD values were measured at 6-day intervals starting from 49 DAE at the vegetative stage and 74 DAE at the reproductive stage. Total plant dry weight was recorded at 69 DAE for the vegetative stage treatment and at 94 DAE for the reproductive stage treatment. The final harvest was done at the maturity stage (123 DAE) and data were recorded on cob length, cob diameter, number of cobs per plant, number of seeds per cob, 100-grain weight, and grain yield.

Experimental design and Statistical analysis

The experiment was laid out in a randomized complete block design with six replications. Analysis of variance was conducted using MSTAT-C software (Russel and Eisensmith 1983) and significance of differences among means was compared employing DMRT. Necessary correlations were determined with the program SPSS version 16.

Results

Response of plant height to GA_3 and CK applications

Plant height showed a significant reduction under drought stress at both the growth stages in maize, but the reduction was greater at the vegetative stage compared to the reproductive stage (Fig. 1). Drought stress reduced plant height by 20.5% relative to the control at 49 DAE during the vegetative stage. At 69 DAE, GA_3- and CK-treated plants resulted in increased plant height ranging from 11.1 to 36.8% relative to the drought-stressed plants. In general, GA_3 was more responsive in increasing plant height compared to CK. The highest plant height attained for GA_3 at 150 mg L^{-1} was 94.7% relative to well-watered control plants. At 74 DAE, drought stress at

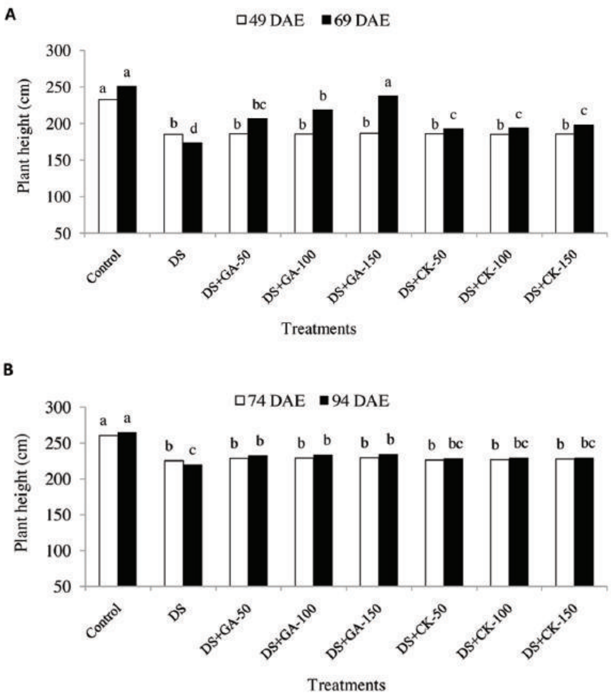

Fig. 1. Plant height of maize as influenced by exogenous application of GA_3 at 50, 100, and 150 mg L^{-1} and CK at 50, 100, and 150 mg L^{-1} at (A) the vegetative and (B) the reproductive growth stages. Means followed by the same letter (s) are not significantly different at $P < 0.01$ by DMRT. DAE-days after emergence and DS-drought stress.

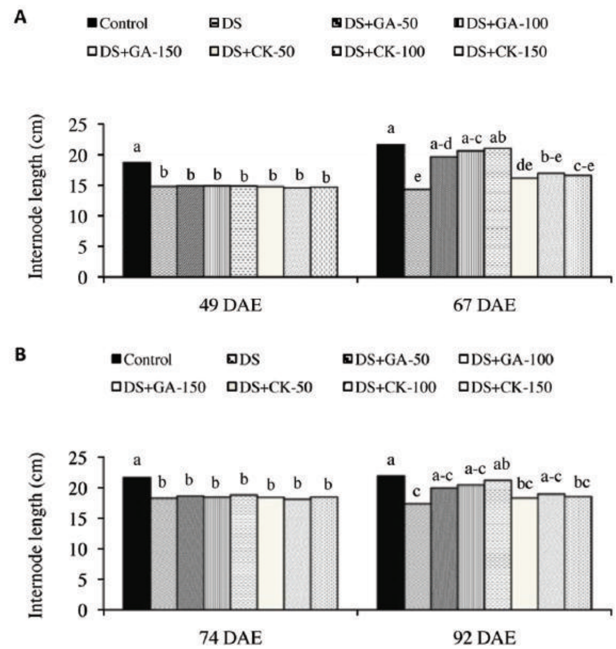

Fig. 2. Effect of different concentrations of GA_3 at 50, 100, and 150 mg L^{-1} and CK at 50, 100, and 150 mg L^{-1} on internode length of drought-stressed maize plants at (A) the vegetative and (B) the reproductive growth stages. Means followed by the same letter (s) are not significantly different at $P < 0.01$ by DMRT. DAE-days after emergence and DS-drought stress.

the reproductive stage reduced plant height by 13.7% relative to the control treatment, but at 94 DAE the hormonal treatments did not show any remarkable increase in plant height.

Response of internode length to GA_3 and CK applications

At 49 DAE following days of drought, internode length was reduced by 20.9% relative to the control during the vegetative phase (Fig. 2). At 67 DAE following application of the treatments, internode length was reduced 33.9% in the untreated but only 2.9 - 25.2% in the GA_3 and CK treatments. However, GA_3 responded greatly compared to CK in increasing internode length at 67 DAE. The internode length of GA_3 at 150 mg L^{-1}-treated plants increased by 46.9% relative to the drought-stressed plants. At 74 DAE corresponding to the reproductive stage, drought stress reduced the internode length by 15.8% relative to the control. At 92 DAE, the internode length was reduced 20.9% relative to the control in drought-stressed plants, but only 3.3 - 16.5% in GA_3- and CK-treated plants. At this stage, also GA_3 at 150 mg L^{-1} performed better compared to CK in increasing internode length.

Response of stem diameter to GA_3 and CK applications

At 49 and 74 DAE following days of drought stress stem diameter of maize showed a significant reduction during the vegetative and the reproductive stages (Table 1). Drought stress affected the stem diameter more adversely when the drought was prolonged. However, drought had a greater effect on stem diameter at the vegetative stage compared to the reproductive stage. At 67 DAE following days of drought, stem diameter was reduced by 61.8% relative to the control and application of GA_3 and CK reduced stem diameter ranged from 15.1 to 53.2%, whereas at 96 DAE such reduction in stem diameter was 54.4% relative to the control and the range of reduction was only 17.4 to 28.4% for the GA_3 and CK treatments. At 67 DAE, the stem diameter of CK-treated plants at 150 mg L^{-1} increased 122.6% relative to untreated plants. At the reproductive stage, drought-stressed plants treated with CK at 150 mg L^{-1} exhibited 80.9% increase in stem diameter. The differences of increase in stem diameter for different concentrations of GA_3 and CK were not significant.

Table 1. Effect of different concentrations of GA_3 and CK on stem diameter of drought-stressed maize plants at the vegetative and the reproductive growth stages

Treatments	Stem diameter (mm)			
	Vegetative stage		Reproductive stage	
	49 DAE	67 DAE	74 DAE	92 DAE
Control	3.13 a	4.98 a	3.95 a	4.82 a
Drought stress(DS)	2.03 b	1.90 e	3.08 b	2.20 e
DS+GA_3-50	2.38 b	2.63 d	3.32 b	3.47 cd
DS+GA_3-100	2.23 b	2.55 d	3.15 b	3.52 cd
DS+GA_3-150	2.08 b	2.33 de	3.13 b	3.45 d
DS+CK-50	2.07 b	3.63 c	3.23 b	3.78 b-d
DS+CK-100	2.15 b	4.08 bc	3.25 b	3.87 bc
DS+CK-150	2.25 b	4.23 b	3.30 b	3.98 b

Means in a column followed by the common letter (s) are not significantly different $P < 0.01$ by DMRT. DAE-days after emergence and DS-drought stress.

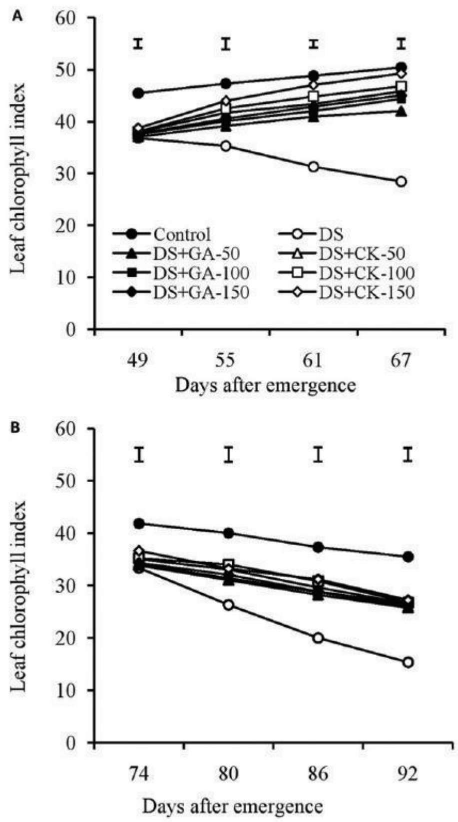

Fig. 3. Changes in leaf chlorophyll index (SPAD values) of drought-stressed maize plants as influenced by exogenous application of GA_3 at 50, 100, and 150 mg L^{-1} and CK at 50, 100, and 150 mg L^{-1} at the vegetative (A) and the reproductive (B) growth stages. Vertical bars indicate the mean difference values according to LSD at $P < 0.01$. DS means drought stress.

Response of leaf chlorophyll index to GA_3 and CK applications

In general, during the vegetative period, leaf chlorophyll index (SPAD values) declined with advancing growth stage in the drought stress treatment, but increased in the control. SPAD values also increased with all of the GA_3 and CK treatments (Fig. 3). During the reproductive period, SPAD values were in decreasing trends but had increasing trends for drought-stressed plants compared to well-watered plants and moderately increasing trends for plants treated with GA_3 and CK. At 49 DAE following days of drought, leaf chlorophyll indices were reduced by 19.2 and 34.2% at the vegetative and the reproductive stages, respectively. Such reductions were more pronounced when drought continued, and showed 42.2 and 56.7% at 67 and 92 DAE corresponding to the vegetative and the reproductive stages. However, the application of GA_3 and CK in drought-stressed plants increased leaf chlorophyll index at both the stages, but to a greater extent at the vegetative stage compared to the reproductive stage. Between two hormones, CK responded much better in increasing leaf chlorophyll index particularly at the vegetative stage. CK at 150 mg L^{-1} showed almost full recovery with high increment rate and reached 95% relative to the control. At the reproductive stage, GA_3 and CK improved leaf chlorophyll index, but the differences were insignificant irrespective of types and concentrations of the hormones.

Response of total plant dry weight to GA_3 and CK applications

The total plant dry weight (DW) was recorded after the end of drought and hormonal treatments at both the growth stages. Drought stress reduced total DW by 40.7 and 31.4% relative to the control at the vegetative and the reproductive phases, respectively. However, application of GA_3 and CK increased total DW by 35.9 - 67.5% at the vegetative stage and 15.0 - 28.0% at the reproductive stage relative to the drought-stressed treatment. In general, the total DW decreased with the increase of GA_3 concentration but increased with the increase of CK concentration at the vegetative stage (Table 2). CK at 150 mg L^{-1} followed by GA_3 at 50 mg L^{-1} were found to be most effective in producing total dry matter at this stage. However, the different concentrations of the hormones had very little effect on total dry matter production at the reproductive stage.

Table 2. Total dry weight production of maize as influenced by drought and exogenous application of GA_3 and CK

Treatments	Total plant dry weight (g $plant^{-1}$)	
	Vegetative stage (69 DAE)	Reproductive stage (94 DAE)
Control	60.28 a	67.19 a
Drought stress(DS)	35.76 d	46.09 e
DS+GA_3-50	52.20 b	59.00 b
DS+GA_3-100	48.91 c	55.65 cd
DS+GA_3-150	48.58 c	54.08 d
DS+CK-50	49.91 c	54.50 d
DS+CK-100	50.10 c	58.04 bc
DS+CK-150	59.88 b	53.00 b
$LSD_{0.01}$	1.47	2.86

Means in a column followed by the common letter (s) are not significantly different at $P < 0.01$ by DMRT. DAE-days after emergence and DS-drought stress.

Response of yield attributes and grain yield to GA_3 and CK applications

Drought stress significantly reduced yield attributes of maize at the vegetative stage. The number of cobs per plant and the number of seeds per cob were highly affected showing 62.4 and 61.4% reduction, respectively. Drought also caused significant reduction in cob length, seed weight, and cob diameter. However, exogenous application of GA_3 and CK improved all the depressed yield attributes, but in varying degrees depending on the type and concentration of the hormones (Table 3). Generally, yield attributes were found to improve when CK concentration increased and GA_3 concentration decreased. For instance, cob diameter and seed weight were increased by 48.8 and 33.8% relative to the drought-stressed treatment, respectively, for GA_3 at 50 mg L^{-1} against 6.2 and 10.5% at 150 mg L^{-1}. In contrast, these two plant characteristics responded better for CK at 150 mg L^{-1} compared to 50 or 100 mg L^{-1}. Drought severely affected the grain yield, but to a lesser extent in the straw yield corresponding

Table 3. Grain yield and yield attributes of maize plants under drought-stressed conditions as influenced by exogenously applied GA_3 and CK at the vegetative and the reproductive growth stages

Treatments	Yield attributes and grain yield							Harvest Index (HI)
	Cobs plant^{-1}	No. of seeds cob^{-1} plant^{-1}	Cob length (cm plant^{-1})	Cob diameter (mm plant^{-1})	100-seed weight (g)	Straw yield (g plant^{-1})	Grain yield (g plant^{-1})	
Vegetative stage[a]								
Control	1.33	297.7	14.90	36.81	18.64	72.04	54.31	75.52
Drought stress (DS)	0.83	115.0	7.33	22.44	12.98	46.64	20.97	44.14
DS + GA_3 - 50	1.00	242.8	9.78	33.40	17.37	66.73	37.50	61.15
DS + GA_3 - 100	1.00	187.0	10.42	30.30	16.45	54.65	29.47	55.04
DS + GA_3 - 150	0.83	142.7	6.48	23.83	14.34	57.97	25.30	43.09
DS + CK - 50	1.00	216.3	11.55	31.30	17.40	56.31	37.13	67.90
DS + CK - 100	1.00	228.2	12.35	34.24	15.34	58.65	41.58	72.81
DS + CK - 150	1.00	247.3	12.92	33.50	18.08	62.81	43.38	70.10
Reproductive stage[b]								
Control	1.33	233.2	14.35	35.65	18.43	70.25	52.85	75.33
Drought stress (DS)	0.33	45.3	3.03	8.62	3.76	57.64	5.03	8.68
DS + GA_3 - 50	0.83	50.0	4.33	12.74	6.22	63.48	9.33	14.24
DS + GA_3 - 100	0.33	11.0	2.85	7.21	3.41	60.42	2.25	3.23
DS + GA_3 - 150	0.17	0	0.73	2.43	0	55.06	0	0
DS + CK - 50	0.83	52.5	6.88	18.41	10.52	58.38	6.74	11.32
DS + CK - 100	0.33	25.5	5.98	15.40	4.19	61.72	3.20	5.81
DS + CK - 150	0.17	0	1.43	2.46	0	46.51	0	0
$LSD_{0.05}$	0.49	71.3	4.35	12.49	7.15	8.02	14.69	27.73

[a]Plants were treated with GA_3 at 50, 100, and 150 mg L^{-1} and CK at 50, 100, and 150 mg L^{-1} under drought stress conditions from 49 - 69 DAE and then allowed to grow at optimum soil moisture up to final harvest.

[b]Plants were treated with GA_3 and CK under drought stress conditions from 74 - 94 DAE and then allowed to grow at optimum soil moisture up to final harvest. DAE-days after emergence and DS-drought stress.

to 61.4 and 35.3% reductions relative to the control. Such yield reduction was found to be compensated due to hormonal treatment. It is also evident that hormone-induced yield improvement was much higher for CK compared to GA_3 application. The most remarkable increase in grain yield was 106.9% followed by 98.3% relative to drought stress for CK at 150 mg L^{-1} and 100 mg L^{-1}, and attained 79.9 and 76.6% relative to the control, respectively. The application of GA_3 at 50 mg L^{-1} increased grain yield by 78.8% relative to drought stress, although 50 mg L^{-1} GA_3 increased only 20.6%. Harvest index decreased 41.6% due to drought and CK was more responsive compared to GA_3 in increasing harvest index, showing only 7.2 - 10.1% reduction relative to the control depending on concentrations.

The reproductive stage drought has a more deleterious effect on yield attributes and grain yield of maize compared to the vegetative stage drought (Table 3). The application of GA_3 or CK at low concentration had very little effect on improving the depressed yield attributes. Evidently, high concentration of the hormones had much a more adverse effect on yield attributes. Imposition of drought at the reproductive stage reduced grain yield by 90.5%. The application of GA_3 or CK at 100 and 150 mg L^{-1} to drought-stressed plants did not have any yield advantage and might even have negative impacts on grain yield. However, GA_3 and CK at 50 mg L^{-1} gave 85.5 and 34.0% more grain yield over drought-stressed plants which were 17.7 and 12.8% relative to the control. These relative yield advantages at low concentrations of hormones were mainly attributed to improving the cob-bearing capacity of the plants.

Correlation coefficient

A significant positive correlation was observed between leaf chlorophyll index and grain yield of maize at the vegetative stage (Table 4). The relationship was very strong (r = 0.62) at 49 DAE and became weak when drought stress prevailed. After applying GA_3 and CK to drought-stressed plants, the relationship remained and became strong (r = 0.50) at 67 DAE. At the reproductive stage, the relationship between leaf chlorophyll index and grain yield under drought-stress conditions was insignificant, but there were significant negative correlations between chlorophyll index and grain yield when drought-stressed plants were treated with GA_3 and CK. This relationship became more negative (r

Table 4. Functional relationship of leaf chlorophyll index with final grain yield in drought stress and drought stress experiencing exogenous application of GA_3 and CK at the vegetative and the reproductive growth stages

Growth stages	Days after emergence (DAE)	Correlation coefficient (r) with grain yield under	
		Drought stress (DS)	DS + hormone
Vegetative	49	0.62**	0.57**
	55	0.49**	0.65**
	61	0.37*	0.60**
	67	0.38*	0.50**
Reproductive	74	- 0.20^{ns}	- 0.37*
	80	0.19^{ns}	- 0.31*
	86	- 0.05^{ns}	- 0.44*
	92	- 0.06^{ns}	- 0.63**

*Significant at $P < 0.05$,
**Significant at $P < 0.01$ and ^{ns}Non-significant. DS-drought stress

= -0.63) at 92 DAE. Except for the reproductive stage, there were no significant correlations between leaf area and total DW with grain yield under drought stress conditions and the relationships became significant with the application of GA_3 and CK (Table 5). At the reproductive stage, leaf area had a strong negative relationship with grain yield for drought, but hormone application improved the relationship a bit.

Table 5. Functional relationship between final grain yield and other phenotypic traits in drought stress and drought stress experiencing exogenous application of GA_3 and CK at the vegetative and the reproductive growth stages

Traits	Growth stages	Correlation coefficient (r) with grain yield under	
		Drought stress (DS)	DS + hormone
Leaf area	Vegetative	0.01^{ns}	0.62**
	Reproductive	- 0.57**	$- 0.20^{ns}$
Total DW	Vegetative	0.18^{ns}	0.69**
	Reproductive	0.07^{ns}	0.48*

*Significant at $P < 0.05$,
**Significant at $P < 0.01$ and ^{ns}Non-significant. DS-drought stress

Discussion

Drought stress imposed at the vegetative and the reproductive stages caused significant reduction in the growth and yield of maize. These adverse effects of drought were significantly alleviated with the exogenous application of GA_3 and CK to drought-stressed plants. The improvement of drought-stressed plants for hormonal treatment was found to be much better at the vegetative stage compared to the reproductive stage. In this regard, CK was found to be more effective compared to GA_3. The concentration of the hormones also had a greater impact on improving drought-induced ill effects. However, plant attributes responded differently under differential hormonal treatments. The study revealed that drought stress reduced plant height and internode length of maize plants. Such adverse effects due to drought stress were also evident in other crops (Manivannan et al. 2007; Zhang et al. 2004). However, application of GA_3 was found to alleviate deleterious effects of drought by increasing plant height and internode length. The increase of plant height and internode length of drought-stressed maize was very evident for GA_3 at 150 mg L^{-1} at the vegetative stage. GA_3 has previously been reported to be helpful in enhancing growth of wheat, maize, and tomato under water stress conditions (Ashraf et al. 2002; Kaya et al. 2006; Maggio et al. 2010). This was explained by the fact that drought stress affected both elongation and expansion of plant growth, but exogenously applied GA_3 increased impaired cell division and cell elongation by enhancing endogenous gibberellic acid content under drought stress (Rodriguez et al. 2006; Shao et al. 2008). The beneficial effects of CK were the enhancement of stem diameter and leaf chlorophyll index, and delay of leaf senescence (data not presented), higher dry matter production, and more assimilate translocation to the grain. Similar observations were also reported in sorghum by Gadallah (1994). Between two hormones, CK was found to be more effective in enhancing stem diameter compared to GA_3, and the higher the CK dose, the greater the diameter. This is probably because CK was found to enhance stem girth through the promotion of cell division (Hoque et al. 2007).

The most detrimental effect of drought was the reduction in leaf chlorophyll index in maize. In many studies, drought has been found to reduce leaf chlorophyll content and the cause of chlorophyll degradation may result from the formation of chlorophyllase enzyme (Ashraf et al. 2007; Kauser et al. 2006). The study reveals that leaf chlorophyll indices were significantly alleviated in drought stress plants, but application of hormones remarkably improved this depressed character. The response of the hormone was not so striking at the reproductive stage probably because of maturity and senescence of leaves. Synkova et al. (1997) also reported similar results where no improvement in leaf chlorophyll content was found at the reproductive stage.

Total dry matter production indicates assimilates accumulated in plants resulting from photosynthesis. Drought has been found to depress total dry matter production in maize. Such adverse effect was significantly alleviated by the GA_3 and CK treatments. The plants treated with GA_3 at 50 mg L^{-1} and CK at 150 mg L^{-1} showed higher dry matter production than the other concentrations at both growth stages. However, alleviating drought-induced reduction in dry matter production was more pronounced at the vegetative stage compared to the reproductive stage. Exogenously applied GA_3 and CK during the early growth stage might have caused enhanced endogenous phytohormone accumulation under drought conditions which not only protects enzymes but also supplies energy for growth and survival thereby helping the plant to tolerate stress (Hoque et al. 2007; Hussain et al. 2008).

The exposure of maize plants to drought stress at the reproductive stage was more detrimental to yield attributes and grain yield compared to the vegetative stage. The drought stress decreased grain yield up to 90.5% at the reproductive stage. Application of hormones at 50 mg L^{-1} showed slight increase in grain yield, but beyond this dose the number of seeds and seed size decreased or plants failed to produce any seed. In general, the grain yield reduction was attributed to a decrease in number of cobs per plant, the number of seeds per cob, and seed size. Many investigations have pointed out that drought stress increased the embryo abortion and loss of seed weight which resulted in the reduction of yield and harvest index (Cakir 2004; Kamara et al. 2003; Monneveux et al. 2006). Imbalance in the endogenous hormone under drought-stress conditions is known to aid embryo abortion and low fruit set (Nunez-Elisea and Davenport 1983). Therefore, exogenous application of hormones might in a way enhance the balance of endogenous hormones. Here exogenous application of CK at 150 mg L^{-1} at the vegetative stage produced the maximum grain yield per plant. Similar results have been reported in many previous studies on maize (Bassetti and Westgate 1993; Laffitte and Edmeades 1995; Schussler and Westgate 1995).

From this study, we tried to understand the relationships between different plant traits as affected by drought or improved by hormonal application with final grain yield. A greater contribution of leaf chlorophyll content in plants treated with GA_3 and CK was observed to produce higher grain yield. As biomass is the product of photosynthesis, the maintenance of better chlorophyll index during the vegetative stage contributed to higher grain yield by accumulating a greater amount of biomass in plants. This is also an agreement supported by other studies (Kauser et al. 2006; Raza et al. 2006). The ameliorating effects of GA_3 and CK on total biomass production indicating an adaptive strategy of maize plants under drought conditions by allocating more dry matter through photosynthesis that ultimately is re-invested in accelerating foliage development at the vegetative stage. A strong relationship between leaf area and grain yield ($r = 0.62$) supported this view. The investigation also enumerated that grain yield was highly correlated with the total plant DW. A closer association between grain yield and total plant DW of drought-stressed maize plants treated with hormones ($r = 0.69$) suggests a greater contribution of hormones to increase plant biomass and eventually to increase grain yield.

The combined results of the experiment indicated that using GA_3 and CK in drought-stressed plants at the vegetative growth stage improved the growth attributes and produced stable yield as compared to without using these elements. The vegetative stage was the appropriate growth stage at which exogenously applied GA_3 and CK effectively alleviated the adverse effects of drought in maize. In point of fact, low concentration of GA_3 and high concentration of CK improved drought tolerance of maize plants by maintaining higher biomass production and its greater contribution to grain size and grain yield.

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