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Regulation of Growth and Metabolism by Paclobutrazol and ABA in *Sesamum indicum* L. Under Drought Condition

[1]Sindhu. S. Abraham, [1,2]Cheruth Abdul Jaleel, [3]Zhao Chang-Xing, [1]R. Somasundaram, [4,5]M.M. Azooz, [1]P. Manivannan and [1]Rajaram Panneerselvam

[1]Stress Physiology Lab, Department of Botany, Annamalai University, Annamalainagar 608 002, Tamilnadu, India
[2]DMJM International (AECOM Middle East Ltd.), Consultant of Gardens Sector Projects, Alain Municipality and Eastern Emirates, P.O. Box 1419, Al-Ain, Abu Dhabi, United Arab Emirates
[3]College of Plant Science and Technology, Qingdao Agricultural University, Chunyang Road, Chengyang District, Qingdao 266109, China
[4]Department of Botany, Faculty of Science, South Valley University, 83523 Qena, Egypt
[5]Department of Biology, Faculty of Science, King Faisal University, P.O. Box: 380, Al-Hassa 31982, Saudi Arabia

Abstract: The plants under pot culture were subjected to 2, 4 and 6 days interval drought (DID) stress and drought stress with Drought + PBZ, Drought + ABA, PBZ, ABA from 30 days after sowing (DAS) and regular irrigation was kept as control. The plants were uprooted on 50DAS. Drought stress decreased the protein and proline oxidase and increased the amino acid, praline and glycine betaine content. But the treatment with PBZ enhanced this parameters under drought stress and partially ameliorated the drought induced growth inhibition by increasing osmoregulation significantly. The osmoregulation content was again increased due to ABA treatment to the drought stressed plants.

Key words: Drought, ABA, Osmoregulation, Glycine betaine, Proline oxidase

INTRODUCTION

Modern agriculture is affected by environmental factors such as water, drought, temperature, light and salt stress. Sustainable agriculture in harsh environments requires an understanding of the ways that plant genes respond to both biotic and abiotic factors [1]. Water deficit is one of the major abiotic stresses, which adversely affect the crop growth and yield. Drought is a meteorological term and is commonly defined as a period without significant rainfall. Drought stress occurs when the available water in the soil is reduced and atmospheric conditions cause continuous loss of water by transpiration or evaporation [2].

Water stress tolerance is seen in almost all plant species but its extent varies from species to species. Water deficit stress is a global issue to ensure survival of agricultural crops and sustainable food production [3]. Conventional plant breeding attempts have changed over to use physiological selection criteria since they are time consuming and rely on present genetic variability [4]. Currently, protection of plants from abiotic stresses through application of plant growth regulators (PGR) attracts more attention [5, 6]. Tolerance to abiotic stresses is very complex, due to the complexity of interactions between stress factor and various molecular, biochemical and physiological phenomena affecting plant growth and development [7]. High yield potential is the target of most crop breeding, not superior drought resistance and in many cases high yield potential can contribute to yield in moderate stress environment [8].

The plant growth regulating properties of triazoles are mediated by their ability to alter the balance of important plant hormones including gibberellic acid, ABA and cytokinins [9]. Triazoles induce a variety of morphological and biochemical responses in plants, including inhibited shoot elongation, stimulated root growth, increased cytokinin synthesis and a transient rise in ABA, as well as conferring protection from various environmental stresses [6, 10, 11]. Protection of plants

Corresponding Author: Dr. Zhao Chang-Xing, College of Plant Science and Technology, Qingdao Agricultural University, Chunyang Road, Chengyang District, China

from apparently unrelated stress by triazole is also mediated by a reduction in free radical damage and increase in the antioxidant potential and have an efficient free-radical scavenging system that enables them to detoxify active oxygen [12].

Paclobutrazol (2RS, 3RS)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1H-1,2,4-trizol-1-yl)-pentan-3-ol] is a triazolic group of fungicide which have plant growth regulating properties. The growth regulating properties of paclobutrazol are mediated by changes in the balance of important plant hormones including the Gibberellins, ABA and cytokinins [13]. Paclobutrazol has been proved as an agent in stress amelioration in medicinal plants [6]. Paclobutrazol increased the diameter and length of fibrous roots and enhanced the lateral root formation in apple seedlings [14] and tomato plants [15].

The phytohormone abscisic acid (ABA) plays a regulatory role in many physiological processes in plants. Different stress conditions such as water, drought, cold, light and temperature result in increased amounts of ABA. The action of ABA involves modification of gene expression and analysis of responsive promoters revealed several potential cis-and trans-acting regulatory elements. The nature of ABA receptors is unknown [1]. Exogenous application of ABA was able to increase plant adaptive response to various environmental conditions. The precise role of ABA under both abiotic and biotic stress conditions, while unclear, is of current interest in many laboratories in the world.

Gingelly (*Sesamum indicum* L.) is a member of the Pedaliaceae family. Gingelly is one of the ancient oil seed crop cultivated for its superior quality oil and seed, hence it is regarded as "Queen of the oil seeds". The species is native to Africa. It is cultivated extensively in USA, India, Burma, Indo-china and Japan [16]. India is the largest producer of sesame in the world. Tamilnadu is one of the major sesame growing state in India. At present it occupies an area of 2 million hectares with a total production of 0.7 million tones, contributing 32 percent of the total production in the country [17]. Sesame is used as a traditional medicine for curing many diseases. It has a good composition of amino acids, protein, niacin, folic acid, vitamin E, calcium and phosphorus [18].

MATERIALS AND METHODS

Seeds and Growth Regulators: The seeds of Sesamum indicum L. were obtained from Department of Agronomy, Faculty of Agriculture, Annamalai University. The triazole compound paclobutrazol was obtained from Syngenta, India Ltd., Mumbai. ABA was purchased from Himedia India Ltd., Mumbai.

During the study, average temperature was 32/26°C (maximum/minimum) and relative humidity (RH) varied between 60-75 per cent. The experimental part of this work was carried out in Botanical Garden and stress Physiology Lab, Department of Botany, Annamalai University, Tamil Nadu. The methodologies adopted are described below.

Cultivation Methods: The plants were raised in Botanical Garden, during the months of February-May, 2006. The seeds were surface sterilized with 0.2% Mercuric chloride solution for five minutes with frequent shaking and thoroughly washed with tap water. The experiments were carried out in polythene bags (27x16 cm). The pots were filled with 3 kg uniform soil mixture containing red soil: sand: farm yard manure (FYM) in 1:1:1 ratio. The experiment was laid out in a Completely Randomized Block Design (CRBD).

The treatment schedule was as shown below.

Sl. No.	Treatments
1	Control
2	Drought
3	Drought + PBZ
4	Drought + ABA
5	PBZ
6	ABA

Drought Stress Induction, Paclobutrazol and ABA Treatments: In the preliminary experiments, 2, 5, 10, 15 and 20 mg L^{-1} paclobutrazol and 5, 10 and 15 µM ABA were used for treatment to determine the optimum concentration. Among the treatments, 5 mgL^{-1} paclobutrazol and 10µM ABA concentration increased the growth and dry weight significantly and higher concentration slightly decreased the growth and dry weight when compared to drought stressed plants. In the lower concentrations, there was no change in weight and growth. Hence 5mgL^{-1} paclobutrazol concentration was used to study the effect of paclobutrazol and 10 µM ABA on the drought stress amelioration of Sesamum indicum.

Drought Treatment intervals were from 30th to 50th DAS 2, 4 and 6 days interval drought (DID). The treatments were given as foliar spray for ABA and soil drenching for PBZ on 30, 40 and 50 days after sowing (DAS).The plants were taken randomly on 50 DAS and separated into roots, stems and leaves and used for determining growth, biochemical and antioxidant potentials. After 50 DAS the remaining plants were kept as such in the pots with regular irrigation for estimation of yield parameters.

Height of the Plant: The plant height was measured from the soil level to the tip of the shoot and expressed in cm.

Root Length: The plant root length was measured from the point of first cotyledonary node to the tip of longest root and expressed in cm.

Number of Leaves: The total number of leaves, which were fully developed, were counted and expressed as number of leaves per plant.

Leaf Area: The total leaf area of the plants was measured using LICOR Photo Electric Area Meter (Model LI-3100, Lincoln, USA) and expressed in cm^2 per plant.

Fresh Weight and Dry Weight: After washing the plants in the tap water, fresh weight was determined by using an electronic balance (Model-XK3190-A7M) and the values were expressed in grams. After taking fresh weight, the plants were dried at 60 °C in hot air oven for 24 hours. After drying, the weight was measured and the values were expressed in grams.

Pigment Analysis

Chlorophyll and Carotenoid: Chlorophyll and carotenoid were extracted from the leaves and estimated by the method of Arnon [19].

Carotenoid content was estimated using the formula of Kirk and Allen [20] and expressed in milligrams per gram fresh weight.

Statistics: Statistical analysis was performed using one way analysis of variance (ANOVA) followed by Duncan's Multiple Range Test (DMRT). The values are mean ± SD for seven samples in each group. *P* values $\leq$ 0.05 were considered as significant.

RESULTS AND DISCUSSION

Morphological Parameters (Table 1-3):

Root Length: The root length was increased by drought stressed *Sesamum indicum* when compared to control. It was nearly 126.01 per cent over control on 6 DID. The root length again increased under paclobutrazol and ABA treatments under drought stress. The extent of increase was more in paclobutrazol treated plants (147.66 per cent over control) when compared to ABA treated plants (139.73 per cent over control). Paclobutrazol treatment alone increased (114.94 per cent over control) the root length significantly when compared to ABA treated plants. The root length was increased by drought stressed *Sesamum indicum* when compared to control. The root length again increased under paclobutrazol and ABA treatments under drought stress. But the development of root system increases the water uptake and maintains right osmotic pressure through higher proline levels [21]. An increased root growth was reported by [22] in mango tree under water stress. Water stress greatly suppresses cell expansion and cell growth due to the low turgor pressure [3].

Paclobutrazol increased the diameter and length of fibrous roots and enhanced the lateral root formation in tomato plants [15]. The root growth was increased initially, but in later stage it was reduced because of severe drought stress. The reduction in plant height might be associated with declined cell enlargement and cell growth due to the low turgour pressure and also more leaf senescence under drought stress [23]. Past studies report that root to shoot ratio increases under water stress conditions to facilitate water absorption [24] and is related to ABA content of roots and shoots [25]. The morphological and physiological responses to exogenous ABA application showed that ABA could play an important role to control drought tolerance in two *Populus* species [26].

Shoot Length: A decrease in shoot length was noted in *Sesamum indicum* plants under drought stress and growth regulator treatments. It was nearly 61.53 per cent over control on 6 DID. But the drought stress in combination with growth regulators paclobutrazol and ABA caused an enhancement in stem length when compared to drought stressed plants at all sampling days. Paclobutrazol treatment alone decreased (76.20 per cent over control) the plant height significantly when compared to ABA treatments. Under drought stress the shoot length got decreased in larger extent when compared to control on all sampling days in *Sesamum indicum*. Paclobutrazol treatment alone decreased the plant height significantly when compared to all other treatments. The plant height was reduced under drought stress in *Populus* species [26]. Reduced plant height was reported in *Albizzia* seedlings due to reduced stem length under drought stress [27]. Barley seedlings showed reduced growth under treatment with paclobutrazol [28]. ABA induced growth inhibition was resulted from signal transduction at the single-cell level and thereby induces closure of stomata [29].

Total Leaf Area: Total leaf area reduced under drought stress when compared to control. It was nearly 30.83 per cent over control on 6 DID. Individual paclobutrazol and ABA treatments resulted in decreased of leaf area in *Sesamum indicum* plants when compared to other treatments. But the drought stress in combination with paclobutrazol and ABA caused a slight increase in leaf area when compared to drought stressed plants at all sampling days. The extent of increase was more in paclobutrazol treated plants (64.46 per cent over control) when compared to ABA treated plants (54.12 per cent over control). Drought condition reduced the leaf area when compared to control in *Sesamum indicum*. Individual paclobutrazol and ABA treatments resulted in decreased of leaf area in *Sesamum indicum* plants when compared to other treatments. Similar results were observed under drought stress in in *Abelmoschus esculentum* [30]. The leaf growth was more sensitive to water stress in wheat, but it was not so in the case of maize [31]. Paclobutrazol reduced the leaf area in wheat [32], tomato [15] and barley [28].

The involvement of ABA in mediating drought stress has been extensively researched. ABA plays a critical role in regulating plant water status through guard cells and growth as well as by induction of genes that encode enzymes and other proteins involved in cellular dehydration tolerance [4, 33]. The increased leaf area under drought stress by ABA is a part of drought stress mitigation mechanisms.

Number of Leaves: The number of leaves increased with age in control and treated plants. However the number of leaves was reduced with the induction of drought stress in *Sesamum indicum*. Paclobutrazol treatment reduced the number of leaves to a greater extent and it was 82.92 per cent and 40.93 per cent over control in control and drought respectively on 6 DID. ABA in combination with drought increased the number of leaves slightly and it was 57.85 per cent over control on 6 DID. The number of leaves was reduced with the induction of drought stress in *Sesamum indicum*. The paclobutrazol treatment reduced the number of leaves to a greater extent in control and drought respectively on 37 DAS. ABA in combination with drought increased the number of leaves slightly on 37 DAS. Water deficit stress mostly reduced leaf growth and in turn the leaf area in many species of plants like *Ziziphus* sp [34]. The leaf growth was more sensitive to water stress in wheat, but it was not so in the case of maize [31].

The leaf production is reduced in *Catharanthus* plants under paclobutrazol treatment [6]. Uniconazole reduced the leaf number in *pyrecantha* species [52]. The exogenous application of ABA will initiate stomatal closure and protect the plants from stress. Application of ABA at room temperature results in reduced leaf production in many plants [1].

Number of Flowers: The number of flowers increased with age in control and treated plants. However the number of flowers was reduced with the induction of drought stress in *Sesamum indicum*. But the treatment with paclobutrazol and ABA increased number of flowers to a large extent and it was 79 per cent and 69 per cent over control respectively on 6 DID. The number of flowers increased with age in control and treated plants. However the number of flowers was reduced with the induction of drought stress in *Sesamum indicum*. Alonso *et al*. [35] subjected *Pinis halpensis* to water stress by skipping irrigation at flowering and at seed filling stages. Water stress at flowering also gave the lowest seed oil content. The flower number is increased in *Catharanthus* plants under paclobutrazol treatment [36]. In many plants, ABA induced flowering with enhanced pigment accumulation [37].

Number of Branches: The number of branches increased with age in control and treated plants. However the number of branches was reduced under drought stress in *Sesamum indicum*. But the treatment with paclobutrazol and ABA increased number of branches to a large extent and it was 70 per cent and 74 per cent over control respectively on 6 DID.

Whole Plant Fresh Weight: The whole plant fresh weight decreased with drought stress in *Sesamum indicum*. The fresh weight increased under paclobutrazol and ABA treatments under drought stress. The extent of increase was more in paclobutrazol treated plants (71.09 per cent over control) when compared to ABA treated plants (66.38 per cent over control). Paclobutrazol treatment alone increased the fresh weight significantly (95.08 per cent over control) when compared to ABA treatments. Water deficit condition decreased the whole plant fresh weight to a larger extent in *Sesamum indicum* plants. Similar results were observed in higher plants like Pearl millet [38] and *Abelmoschus esculentum* [30]. The fresh weight decreased under drought condition might be the reason for suppression of cell expansion and cell growth due to the low turgor pressure. Regulated deficit irrigation and partial root drying caused a significant reduction in shoot biomass when compared to control in wheat plants [39]. Paclobutrazol treatment increased the fresh weight under drought stress. Similar case of enhancement in fresh weight was reported in *Catharanthus* plants under salt stress [6].

Whole Plant Dry Weight: Drought stress caused decreased dry weight accumulation in *Sesamum indicum*. The dry weight increased under paclobutrazol and ABA treatments under drought stress. The extent of increase was more in paclobutrazol treated plants (68.74 per cent over control) when compared to ABA treated plants (48.98 per cent over control). Paclobutrazol treatment alone increased the dry weight significantly when compared to ABA treatments (86.95 per cent over control). Drought stress decreased the dry weight in *Sesamum indicum*. Paclobutrazol and ABA treatments increased the dry weight considerably under drought stress. A decrease in plant biomass was reported in drought stressed wheat [2] and in *Asteriscus maritimus* [40]. Severe water stress may result in arrest of photosynthesis, disturbance of metabolism and finally dying [23]. Water stress inhibits cell enlargement more than cell division. It reduces plant growth inhibition of various physiological and biochemical processes, such as photosynthesis, respiration translocation, ion uptake, carbohydrates, nutrient metabolism and hormones [2].

ABA plays a critical role in regulating plant water status through guard cells and growth as well as by induction of genes that encode enzymes and other proteins involved in cellular dehydration tolerance [4, 33] which might be the reason for increased dry weight under drought stress. Triadimefon and paclobutrazol altered the shoot dry weight in peanut [41] and tomato [42]. The alteration of hormonal status in *Sesamum* induced by paclobutrazol might be the cause for the increased dry weight under drought stress.

Yield and Yield Components (Table 4):

Number of Pods: The number of pods increased with age in control and treated plants. However the number of pods was reduced under drought stress in *Sesamum indicum*. But the treatment with paclobutrazol and ABA increased number of pods to a large extent and it was 84 per cent and 90 per cent over control respectively on 6 DID.

Number of Seeds/Pod: The number of seeds/pod weight of seeds/pod decreased with drought stress in *Sesamum indicum*. The number of seeds/pod increased under paclobutrazol and ABA treatments under drought stress. The extent of increase was more in paclobutrazol treated plants (64 per cent over control) when compared to ABA treated plants (58 per cent over control). Paclobutrazol treatment alone increased the number of seeds/pod significantly (93 per cent over control) when compared to all other treatments.

Weight of Seeds/Pod: The decreased with drought stress in *Sesamum indicum*. The weight of seeds/pod increased under paclobutrazol and ABA treatments under drought stress. The extent of increase was more in paclobutrazol treated plants (63 per cent over control) when compared to ABA treated plants (67 per cent over control). Paclobutrazol treatment alone increased the weight of seeds/pod significantly (94 per cent over control) when compared to all other treatments. The yield and yield components like number of pods, number of seeds/pod, weight of 100 seeds and weight of seeds/pod increased with age in control and treated plants. However these parameters reduced under drought stress in *Sesamum indicum*. But the treatment with paclobutrazol and ABA increased these parameters to a large extent. The yield components like grain yield, grain number, grain size and floret number were found decreased under pre-anthesis drought stress treatment in sunflower [43]. Water stress greatly reduced the yield of *Eragrostis curvula* plants [44] and this reduction in grain yield was dependent up on the level of defoliation water stress during early reproductive growth reduces yield in soybean usually as a result of fewer pods and seeds per unit area [45]. Under non-compact soil conditions, salinity, water logging and saline-watered logged treatments significantly reduced grain yield in wheat genotypes [39].

Photosynthetic Pigments (Table 5,6):

Chlorophyll Content: The chlorophyll ‘a’ ‘b’ total chlorophyll and carotenoid content of the *Sesamum indicum* leaves increased with age in control and treated plants. Treatment with paclobutrazol and ABA increased the chlorophyll ‘a’‘b’ total chlorophyll and carotenoid content and it was 120.22 per cent and 114.64 per cent over control respectively on 6 DID. Paclobutrazol and ABA in combination with drought increased the chlorophyll ‘a’‘b’ total chlorophyll and carotenoid content and reduced the drought induced pigment

Table 1: Individual and combined effects of drought, PBZ, ABA on growth parameters of *Sesamum indicum* (Values are mean ± S.D. of 3 samples)

Treatments	2 DID	4 DID	6 DID
Root length (cm plant^{-1})			
Control	25.324 ± 0.820	28.074 ± 1.062	31.471 ± 1.111
Drought	29.267 ± 1.150	32.537 ± 1.300	35.623 ± 1.250
Drought +PBZ	35.623 ± 1.260	37.654 ± 1.380	41.437 ± 1.460
Drought +ABA	33.543 ± 1.120	35.623 ± 1.262	38.627 ± 1.311
PBZ	28.197 ± 0.950	31.356 ± 1.080	35.972 ± 1.150
ABA	26.543 ± 0.960	28.364 ± 1.080	33.514 ± 1.160
Shoot length (cm plant^{-1})			
Control	35.423 ± 1.080	36.722 ± 1.045	39.041 ± 1.358
Drought	17.976 ± 0.688	18.762 ± 0.651	24.062 ± 0.861
Drought +PBZ	23.434 ± 0.890	25.254 ± 0.983	28.446 ± 1.180
Drought +ABA	29.423 ± 1.080	32.623 ± 1.145	35.086 ± 1.358
PBZ	20.052 ± 0.088	23.563 ± 0.081	29.751 ± 1.061
ABA	27.351 ± 0.990	30.278 ± 1.083	33.031 ± 1.080
Total leaf area (cm^2 plant^{-1})			
Control	29.926 ± 1.360	30.624 ± 1.220	33.543 ± 1.240
Drought	15.754 ± 0.411	13.236 ± 0.440	10.343 ± 0.264
Drought +PBZ	19.264 ± 0.621	18.354 ± 0.667	18.823 ± 0.520
Drought +ABA	17.341 ± 0.560	16.821 ± 0.520	13.762 ± 0.440
PBZ	24.755 ± 0.811	23.754 ± 0.840	21.624 ± 0.764
ABA	21.932 ± 0.721	20.624 ± 0.767	18.154 ± 0.620

Table 2: Individual and combined effects of drought, PBZ, ABA on growth parameters of *Sesamum indicum* (Values are mean ± S.D. of 3 samples)

Treatments	2 DID	4 DID	6 DID
Number of leaves (Number plant^{-1})			
Control	50.00 ± 1.720	53.00 ± 1.862	57.00 ± 2.111
Drought	23.00 ± 0.850	23.00 ± 0.800	23.50 ± 0.850
Drought +PBZ	26.00 ± 0.960	26.10 ± 0.980	26.20 ± 0.960
Drought +ABA	33.00 ± 1.120	33.00 ± 1.162	33.00 ± 1.111
PBZ	40.00 ± 1.550	43.00 ± 1.700	47.00 ± 1.150
ABA	51.00 ± 1.960	56.00 ± 2.080	59.00 ± 2.160
Number of Flowers (Number plant^{-1})			
Control	21.00 ± 0.080	16.00 ± 0.045	15.00 ± 0.058
Drought	22.00 ± 0.088	17.00 ± 0.051	19.00 ± 0.061
Drought +PBZ	26.10 ± 0.090	23.80 ± 0.083	24.50 ± 0.080
Drought +ABA	21.00 ± 0.080	16.00 ± 0.045	15.00 ± 0.058
PBZ	22.00 ± 0.088	17.00 ± 0.051	19.00 ± 0.061
ABA	26.10 ± 0.090	23.80 ± 0.083	24.50 ± 0.080
Number of Branches (Number plant^{-1})			
Control	9.00 ± 0.360	9.40 ± 0.220	10.00 ± 0.240
Drought	8.00 ± 0.411	9.30 ± 0.240	10.80 ± 0.264
Drought +PBZ	10.50 ± 0.421	10.80 ± 0.267	11.00 ± 0.320
Drought +ABA	10.00 ± 0.360	10.40 ± 0.220	11.20 ± 0.240
PBZ	11.00 ± 0.411	11.30 ± 0.240	12.00 ± 0.264
ABA	10.50 ± 0.421	10.90 ± 0.267	11.90 ± 0.320

Table 3: Individual and combined effects of drought, PBZ, ABA on fresh and dry weights of *Sesamum indicum* (Values are mean ± S.D. of 3 samples)

Treatments	2 DID	4 DID	6 DID
Whole plant fresh weight (gms)			
Control	39.629 ± 1.520	41.724 ± 1.662	44.786 ± 1.711
Drought	22.362 ± 0.750	20.541 ± 0.700	19.126 ± 0.650
Drought +PBZ	26.567 ± 0.960	29.754 ± 0.980	31.892 ± 0.940
Drought +ABA	25.623 ± 0.920	28.791 ± 0.962	29.254 ± 0.911
PBZ	36.862 ± 1.350	39.542 ± 1.400	41.754 ± 1.550
ABA	31.654 ± 1.160	34.956 ± 1.280	36.279 ± 1.360
Whole plant dry weight (gms)			
Control	7.192 ± 0.258	10.962 ± 0.345	12.279 ± 0.480
Drought	2.836 ± 0.101	3.862 ± 0.151	5.266 ± 0.288
Drought +PBZ	4.914 ± 0.170	7.730 ± 0.283	8.923 ± 0.330
Drought +ABA	3.523 ± 0.128	6.489 ± 0.245	7.827 ± 0.260
PBZ	6.254 ± 0.261	9.544 ± 0.351	10.412 ± 0.378
ABA	5.722 ± 0.200	8.295 ± 0.383	9.615 ± 0.350

Table 4: Individual and combined effects of drought, PBZ, ABA on yield parameters of *Sesamum indicum* (Values are mean ± S.D. of 3 samples)

Treatments	2 DID	4 DID	6 DID
	Number of pods (Number plant^{-1})		
Control	44.00 ± 1.720	46.00 ± 1.662	48.00 ± 1.711
Drought	15.00 ± 0.650	16.00 ± 0.500	16.00 ± 0.550
Drought +PBZ	29.00 ± 1.160	30.00 ± 1.080	32.00 ± 1.160
Drought +ABA	36.00 ± 1.320	39.00 ± 1.462	40.00 ± 1.411
PBZ	39.00 ± 1.550	40.00 ± 1.500	40.00 ± 1.450
ABA	41.00 ± 1.560	43.00 ± 1.580	43.00 ± 1.460
Number of seeds (Number pod^{-1})			
Control	59.00 ± 2.080	61.00 ± 2.245	62.00 ± 2.258
Drought	22.00 ± 0.888	23.00 ± 0.081	24.00 ± 0.861
Drought +PBZ	39.00 ± 1.490	40.00 ± 1.483	40.00 ± 1.480
Drought +ABA	35.00 ± 1.280	36.00 ± 1.445	36.00 ± 1.458
PBZ	55.00 ± 1.888	56.00 ± 2.051	58.00 ± 2.061
ABA	51.00 ± 1.790	52.00 ± 1.883	52.00 ± 1.880
Weight of seeds pod^{-1} (gms)			
Control	0.681 ± 0.020	0.684 ± 0.020	0.690 ± 0.020
Drought	0.374 ± 0.011	0.393 ± 0.020	0.399 ± 0.014
Drought +PBZ	0.415 ± 0.011	0.427 ± 0.067	0.439 ± 0.0120
Drought +ABA	0.445 ± 0.0150	0.461 ± 0.017	0.465 ± 0.0180
PBZ	0.627 ± 0.021	0.635 ± 0.020	0.622 ± 0.024
ABA	0.567 ± 0.021	0.569 ± 0.027	0.574 ± 0.020

Table 5: Individual and combined effects of drought, PBZ, ABA on chlorophyll contents of *Sesamum indicum* (Values are mean ± S.D. of 3 samples)

Treatments	2 DID	4 DID	6 DID
	Chlorophyll ‘a’ (mg g^{-1} FW)		
Control	0.620 ± 0.024	0.655 ± 0.022	0.717 ± 0.025
Drought	0.125 ± 0.004	0.095 ± 0.003	0.068 ± 0.0025
Drought +PBZ	1.415 ± 0.054	1.420 ± 0.018	1.364 ± 0.048
Drought +ABA	1.379 ± 0.058	1.354 ± 0.045	1.318 ± 0.058
PBZ	0.764 ± 0.027	0.795 ± 0.025	0.862 ± 0.036
ABA	0.654 ± 0.027	0.727 ± 0.026	0.822 ± 0.028
	Chlorophyll ‘b’ (mg g^{-1} FW)		
Control	0.595 ± 0.021	0.625 ± 0.020	0.703 ± 0.024
Drought	0.084 ± 0.004	0.072 ± 0.002	0.063 ± 0.002
Drought +PBZ	1.405 ± 0.041	1.396 ± 0.047	1.321 ± 0.430
Drought +ABA	1.324 ± 0.060	1.337 ± 0.040	1.309 ± 0.040
PBZ	0.697 ± 0.021	0.753 ± 0.027	0.792 ± 0.026
ABA	0.694 ± 0.024	0.715 ± 0.027	0.785 ± 0.030
	Total chlorophyll (mg g^{-1} FW)		
Control	1.215 ± 0.040	1.28 ± 0.0450	1.42 ± 0.051
Drought	0.209 ± 0.003	0.167 ± 0.005	0.131 ± 0.004
Drought +PBZ	2.820 ± 0.014	2.796 ± 0.096	2.685 ± 0.090
Drought +ABA	2.703 ± 0.012	2.691 ± 0.096	2.627 ± 0.091
PBZ	1.461 ± 0.050	1.548 ± 0.050	1.654 ± 0.057
ABA	1.348 ± 0.047	1.428 ± 0.050	1.601 ± 0.056

Table 6: Individual and combined effects of drought, PBZ, ABA on carotenoid contents of *Sesamum indicum* (Values are mean ± S.D. of 3 samples)

Treatments	2 DID	4 DID	6 DID
	Carotenoid (mg g^{-1} FW)		
Control	0.725 ± 0.022	0.817 ± 0.026	0.897 ± 0.011
Drought	0.654 ± 0.021	0.507 ± 0.017	0.325 ± 0.015
Drought +PBZ	0.790 ± 0.031	0.649 ± 0.024	0.534 ± 0.021
Drought +ABA	0.657 ± 0.020	0.594 ± 0.026	0.513 ± 0.021
PBZ	0.849 ± 0.031	0.889 ± 0.032	0.919 ± 0.030
ABA	0.816 ± 0.031	0.835 ± 0.030	0.895 ± 0.031

inhibition in *Sesamum indicum* plants. The chlorophyll ‘a’ content of the *Sesamum indicum* leaves increased with age in control and treated plants. There was decrease in pigment content under drought stress but treatment with paclobutrazol and ABA increased the chlorophyll ‘a’ content. Paclobutrazol treated barley seedlings [46] and tomato [42], retained two times more chlorophyll than control. Paclobutrazol treated leaves were dark green due to high chlorophyll a and b in potato [47]. Sebastian *et al.* [48] reported enhanced chlorophyll synthesis in *Dianthus caryophyllus* treated with paclobutrazol. The chlorophyll ‘b’ content of Sesamum indicum leaves also increased with age in the control and treated plants. Drought induced a reduction in chlorophyll ‘b’ content in the leaves of Sesamum indicum when compared to well-watered control plants. Treatment with paclobutrazol and ABA increased the chlorophyll ‘b’ content. The higher chlorophyll content in triazole treated radish may be related to the influence of triazole on endogenous cytokinin levels. It has been proposed that triazoles stimulate cytokinin synthesis that enhances chloroplast differentiation, chlorophyll biosynthesis and prevents chlorophyll degradation [10]. The total chlorophyll content of the leaves of Sesamum indicum increased with age of plant in control, paclobutrazol and ABA treatments. But drought stress caused a reduction in total chlorophyll content in Sesamum indicum plants. The chlorophyll content in the wheat leaf decreased due to chemical desiccation treatments [3]. A reduction in chlorophyll content has reported in drought stressed soybean plants by Zhang *et al*. [37]. The chlorophyll content decreased to a significant level at higher water deficits in maize and wheat plants [31].

Paclobutrazol treatment increased the chlorophyll a, b and carotenoid pigments in the leaf of tomato [15, 42], wheat [42] and barley seedling [28].

The carotenoid content of the *Sesamum indicum* leaves increased with age in control and treated plants. Treatment with paclobutrazol and ABA increased the carotenoid content. Paclobutrazol and ABA in combination with drought increased the carotenoid content and reduced the drought induced pigment inhibition in *Sesamum indicum* plants.

Paclobutrazol treatment increased the carotenoid content in *Catharanthus* plants [49]. Triadimefon treatment increased the carotenoid content to a higher level in cucumber [50]. Paclobutrazol treatment increased the carotenoid content in *Raphanus sativus* plants [51].

REFERENCES

1. Swamy, P.M. and N. Bruce Smith, 2001. Role of abscisic acid in plant stress tolerance. Department of Botany and Range Science, Brigham Young University, Provo, Utah, 84602, USA.
2. Shao, H.B., L.Y. Chuc, G. Wu, J.H. Zhang, Z.H. Lua and Y.C. Hug, 2007. Changes of some anti-oxidative physiological indices under soil water deficits among 10 wheat (*Triticum aestivum* L.) genotypes at tillering stage. Colloids Surf. B: Biointerfaces, 54: 143-149.
3. Shao, H.B., M.A. Shao and Z.S. Liang, 2006. Osmotic adjustment comparison of 10 wheat (*Triticum aestivum* L) genotypes at soil water deficits. Colloids Surf. B: Biointerfaces, 47: 132-139.
4. Zhu, J.K., 2002. Salt and drought stress signal transduction in plants. Ann. Rev. Plant Biol., 53: 247-273.
5. Manivannan, P., C.A. Jaleel, A. Kishorekumar, B. Sankar, R. Somasundaram, R. Sridharan and R. Panneerselvam, 2007a. Propiconazole induced changes in antioxidant metabolism and drought stress amelioration in *Vigna unguiculata* (L.) Walp. Colloids and Surf. B: Biointerfaces, 57: 69-74.
6. Jaleel, C.A., R. Gopi, P. Manivannan and R. Panneerselvam, 2007a. Responses of antioxidant defense system of *Catharanthus roseus* (L.) G. Don. to paclobutrazol treatment under salinity. Acta Physiol. Plantarum, 29: 205-209.
7. Ashraf, M. And P.J. Harris, 2004. Potential biochemical indicators of salinity tolerance in plants. Plant Sci., 166: 3-16.
8. Blum, A., 1996. Crop response to drought and the interpretation of adaptation. Plant Growth Regul., 20: 135-148.
9. Kamountsis, A.P. and A.G. Chronopoulon-Sereli, 1999. Paclobutrazol affects growth and flower bud production in gardenia under different light regimes. Hort. Sci., 34: 674-675.
10. Fletcher, R.A., A. Gilley, N. Sankhla and T.M. Davis, 2000. Triazoles as plant growth regulators and stress protectants. Hort. Rev., 24: 56-138.
11. Jaleel, C.A., R. Gopi, P. Manivannan, A. Kishorekumar, M. Gomathinayagam and R. Panneerselvam, 2007b. Changes in biochemical constituents and induction of early sprouting by triadimefon treatment in white yam (*Dioscorea rotundata* Poir.) tubers during storage. J. Zhejiang Univ. Sci. B., 8(4): 283-288.
12. Kopyra, M. and E.A. Gwozdz, 2003. Antioxidant enzymes in paraquat and cadmium resistant cell lines of horseradish. Biol. Lett., 40: 61-69.
13. Fletcher, R.A. and G. Hofstra, 1990. Improvement of uniconazole induced protection in wheat seedlings. J. Plant Growth Regul., 9: 207-212.
14. Steffens, G.L., S.Y. Wang, C.L. Steffens and T. Brennan, 1983. Influence of paclobutrazol (PP 333) on apple seedling growth and physiology. Proc. Plant Growth Regul. Soc. Amer., 10: 195-205.

15. Berova, M., Z. Zlatev and N. Stoeva, 2002. Effect of paclobutrazol on wheat seedlings under low temperature stress. Bulg. J. Plant Physiol., 28: 75-84.
16. Ucan, K., F. Killi, C. Gencoglan and H. Merdun, 2007. Effect of irrigation frequency and amount on water use efficiency andyield of sesame (*Sesamum indicum* L.) under field conditions. Field Crops Res., 101: 249-258.
17. FAO, 2000. Production year book. 54: 93-94.
18. Orruno, E.M.R.A., 2007. Morgan Purification and characterisation of the 7S globulin storage protein from sesame (*Sesamum indicum* L.). Food Chem., 100: 926-934.
19. Arnon, D.I., 1949. Copper enzymes in isolated chloroplasts, ployphenol oxidase in *Beta vulgaris* L. Plant Physiol., 24 : 1-15.
20. Kirk, J.T.O. and R.L. Allen, 1965. Dependence of chloroplast pigment synthesis on protein synthesis: Effect of acsidione. Biochem. Biophys. Res. Commun., 21: 530-532.
21. Jaleel, C.A., P. Manivannan, B. Sankar, A. Kishorekumar and R. Panneerselvam, 2007. Calcium chloride effects on salinity induced oxidative stress, proline metabolism and indole alkaloid accumulation in *Catharanthus roseus*. Comptes Rendus Biologies, 330(9): 674-683.
22. Tahir, F.M., M. Ibrahim, K. Hamid, 2003. Effect of drought stress on vegetative and reproductive growth behaviour of mango (*Mangifera indica* L.). Asian. J. Plant Sci., 2: 116-118.
23. Liang, Z.S., J.W. Yang, H.B. Shao and R.L. Han, 2006. Investigation on water consumption characteristics and water use efficiency of poplar under soil water deficits on the Loess Plateau. Colloids Surf. B: Biointerfaces, 53: 23-28.
24. Lambers, H., F.S. Chapin and T. Pones, 1998. Plant Physiological Ecology. Springer-Verlag, Newyork.
25. Sharp, R.E. and M.E. LeNoble, 2002. ABA, ethylene and the control of shootand root rowth under water stress. J. Exp. Bot., 53: 33-37.
26. Yin, C., X. Wang, B. Duan, J. Luo and C. Li, 2005. Early growth, dry matter allocation and water use efficiency of two Sympatric *populus* species as affected by water stress. Environ. Exp. Bot., 53: 315-322.
27. Sundaravalli, M.V., K. Paliwal and A. Ruckmani, 2005. Effect of water stress on photosynthesis, protein content and nitrate reductase activity of *Albizzia* seedlings. J. Plant. Biol., 32: 13-17.
28. Sunitha, S., M.R. Perras, D.E. Falk, R. Ruichuon Zhang, P. Pharis and R.A. Fletcher, 2004. Relationship between gibberellins, height and stress tolerance on barley seedlings. Plant Growth Regul., 42: 125-135.
29. Trejo, C.L., A. Clephan and W.J. Davies, 1995. How do stomata read abscisicacid signal? Plant Physiol., 109: 803-811.
30. Bhatt, R.M. and N.K. Srinivasa Rao, 2005. Influence of pod load on response of okra to water stress. Indian J. Plant Physiol., 10: 54-59.
31. Nayyar, H. And D. Gupta, 2006. Differential sensitivity of C3 and C4 plants to water deficit stress: Association with oxidative stress and antioxidants. Environ. Exp. Bot., 58: 106-113.
32. Tonkinson, C.L., R.L. Lyndon, G.M. Arnold and J.R. Lenton, 1995. Effect of Rht3 dwarfing gene on dynamics of cell extension in wheat leaves and its modification by gibberellic acid and paclobutrazol. J. Exp. Bot., 46: 1085-1092.
33. Luan, S., 2002. Signalling drought in guard cells. Plant Cell Environ., 25: 229-237.
34. Zhang, X., R Zang and C. Li, 2004. Population differences in physiological and morphological adaptations of *Populus davidiana* seedlings in response to progressive drought stress. Plant Sci., 166: 791-797.
35. Alonso, R., S. Elvira, F.J. Castillo and B.S. Gimeno, 2001. Interactive effect of ozone and drought stress on pigments and activities of antioxidative enzymes in Pinis halpensis. Plant Cell Environ., 24: 905-916.
36. Jaleel, C.A., R. Gopi, P. Manivannan, A. Kishorekumar, B. Sankar and R. Panneerselvam, 2006b. Paclobutrazol influences vegetative growth and floral characteristics of *Catharanthus roseus* (L.) G. Don. Indian J. App. Pure Biol., 21: 369-372.
37. Zhang, J., W. Jia, J. Yang and A.M. Ismail, 2006. Role of ABA in integrating plant responses to drought and salt stresses. Field Crops Res., 97: 111-119.
38. Kusaka, M., A.G. Lalusin and T. Fujimura, 2005. The maintenance of growth and turgor in pearl millet (*Pennisetum glaucum* (L.) Leeke) cultivars with different root structures and osmo-regulation under drought stress. Plant Sci., 168: 1-14.
39. Shao, H.B., Z.S. Liang, M.A. Shao and A. Sun, 2005. Dynamic changes of antioxidative enzymes of ten wheat genotypes at soil water deficits. Colloids Surf. B: Biointerfaces, 42: 187-195.

40. Rodriguez, P., A. Torrecillas, M.A. Morales, M.F. Ortuno and M.J.S. Blanco, 2005. Effects of NaCl salinity and water stress on growth and leaf water relations of *Asteriscus maritimus* plants. Environ. Exp. Bot., 53: 113-123.
41. Muthukumarasamy, M. and R. Panneerselvam, 1997a. Triazole induced protein metabolism in the salt stressed *Raphanus sativus* seedlings. J. Indian Bot. Soc., 76: 39-42.
42. Still, J.R. and W.G. Pill, 2004. Growth and stress tolerance of tomato seedlings (*Lycopersicon esculentum* Mill.) in response to seed treatment with paclobutrazol. Hort. Sci., 79: 197-203.
43. Chimneti, C.A., J. Pearson and A.J. Hall, 2002. Osmotic adjustment and yield maintenance under drought in sunflower. Field Crop Res., 75: 235-246.
44. Colom, M.R. and C. Vazzana, 2001. Drought stress effects on three cultivars of *Eragrostis curvula*: Photosynthesis and water relations. Plant Growth Regulation, 34: 195-202.
45. Reddy, A.R., K.V. Chiatanya and M. Vivekanandan, 2004. Draught induced responses of photosynthesis and antioxidant metabolism in higher plants. J. Plant Physiol., 161: 1189-1202.
46. Sarkar, S., Michel, R. Perras, Duane, E. Falk, Ruichuan Zhang, P. Richard Pharis and R. Austin Fletcher, 2004. Relationship between gibberellins, height and stress tolerance in barley (*Hordeum vulgare* L.) seedlings. Plant Growth Regul., 42: 125-135.
47. Tekalign, T., S. Hammes and J. Robbertse, 2005. Paclobutrazol induced leaf stem and root anatomical modifications in potato. Hort. Sci., 40(5): 1343-1346.
48. Sebastian, B., G. Alberto, A.C. Emilio, A.F. Jose and A.F. Juan, 2002. Growth development and color response of potted Dianthus caryophyllus to paclobutrazol treatment. Sci. Hort., 1767: 1-7.
49. Jaleel, C.A., R. Gopi, G.M. Alagulakshmanan and R. Panneerselvam, 2006a. Triadimefon induced changes in the antioxidant metabolism and ajmalicine production in *Catharanthus roseus* (L.) G. Don. Plant Sci., 171: 271-276.
50. Feng, Z., Guo and Feng, 2003. Amelioraton of chilling stress by Triadimefon in cucumber seedlings. Plant Growth Regul., 30: 277-283.
51. Sankari, S., R. Gopi, M. Gomathinayagam, R. Sridharan, R. Somasundaram and R. Panneerselvam, 2006. Responses of triazoles on growth and antioxidant levels in white radish. Indian. J. Applied Pure Bio., 21(1): 77-80.
52. Norcini, J.G. and G.w. Knox, 1989. Response of *Ligustrum xibolium, Photiniaze frasedri* and *Pyracantha koidzumi* ‘Wonder berry’ to XE-1019 and pruning. J. Environ. Hort., 7: 126-128.