https://doi.org/10.56093/ijas.v90i3.101458

*Indian Journal of Agricultural Sciences* **90** (3): 507–12, March 2020/Article

# Soil moisture deficit induced changes in antioxidative defense mechanism of sugarcane (*Saccharum officinarum*) varieties differing in maturity

POOJA*, A S NANDWAL, MEHAR CHAND, AJAY PAL, ANITA KUMARI, BABITA RANI, VISHAL GOEL and NEERAJ KULSHRESHTHA

*CCS Haryana Agricultural University, Hisar, Haryana 125 004, India*

Received: 25 June 2018; Accepted: 15 July 2019

## ABSTRACT

A split plot experiment was conducted at Regional Research Station, CCS HAU, Uchani, Karnal during 2014–15 and 2015–16 to investigate the effect of different soil moisture regimes on antioxidative defense mechanism of sugarcane (*Saccharum officinarum* L.) varieties. The experiment consisted of three moisture regimes based on available soil moisture i.e. irrigation at 50% ASM, 40% ASM and 30% ASM in main plot and four commercial sugarcane varieties, i.e. CoS 767, CoH 128, CoJ 64 and Co 0238 in sub plot with three replications. The observations recorded on antioxidative defense system have suggested possible key characteristics of drought tolerance. Low ASM levels induced the antioxidative defense system by increasing ROS and the specific activities of antioxidative enzymes, viz. peroxidase, catalase and ascorbate peroxidase. Specific activity of these enzymes increased in varieties Co 0238 and CoS 767 at 60 and 90 DAP. Severe stress of 30% ASM levels also resulted in a sharp rise in total ascorbic acid content (9.36 to 13.14 mg/g), total soluble proteins (from 9.6 to 13.77 mg/g), and the increase was more in varieties Co 0238 and CoS 767. A gradual decrease was observed in all the parameters after stress revival (120 DAP). ASM levels 30% and 40% significantly reduced $K^+$ content in leaves (2.93 to 1.83%) as compared to 50% ASM level. So, it might be concluded from this study that biochemical traits had a significant varietal variation, indicating that these parameters could be used as screening criteria for selecting the tolerant and sensitive cultivars exposed to water limiting stress.

**Key words**: Antioxidants, Antioxidative enzymes, Available soil moisture, ROS, Sugarcane

Sugarcane (*Saccharum officinarum* L.), a crop of worldwide economic importance, accounts for approximately 75% of the global sugar production. Being a high water demanding crop, sugarcane has necessitated the need to evolve drought tolerant varieties to sustain sugarcane production (Pooja *et al.* 2019a, b). Water is the major constituent of cane and approximately 2.97 lakh ha of cane area is prone to drought, affecting the crop at one or other stage of growth in every state of India (Vision SBI 2030).

Water stress like other abiotic stresses elicits a complex of responses, which is associated with increased oxidative stress due to the enhanced production of ROS, particularly $O_2^{\bullet-}$ and $H_2O_2$ (Rani *et al.* 2018). Increased ROS cause damage to various cellular mechanisms, such as enzyme inhibition, protein degradation, DNA/RNA damage, and membrane lipid peroxidation, thus, inhibiting growth and yield which ultimately culminate in cell death (Ishikawa *et al.* 2010). The equilibrium between the production and scavenging of ROS is commonly known as redox homeostasis. However, when ROS production overwhelms the cellular scavenging capacity, plants initiated their antioxidant mechanisms for scavenging the excess ROS and prevent damages to cells (Mann *et al.* 2015, 2019).

Plants have developed ROS scavenging mechanism, which is categorized as enzymatic and non-enzymatic defense system. Enzymatic system includes superoxide dismutase (SOD), a metalloenzyme catalyzes the dismutation of $O_2^-$ radical to molecular $O_2$ and $H_2O_2$. The $H_2O_2$ is then detoxified either by catalase (CAT)/peroxidase (POX) or in ascorbate glutathione cycle which involves oxidation and reduction of ascorbate and glutathione through ascorbate peroxidase (APX) and glutathione reductase (GR) action (Noctor and Foyer 1998), and correlate with enhanced cellular protection (Asada 2006, Duan *et al.* 2012). Keeping in view the burning problem of global warming which may result into yield loss, the present investigation was proposed to understand how plants tolerate water deficit and identifying mechanisms of tolerance in terms of antioxidant potential (Nepomuceno *et al.* 2001). It is therefore important to understand the response of sugarcane varieties differing in their maturity to water stress and its revival with main emphasis on the role of antioxidants and antioxidative enzymes in imparting tolerance to sugarcane crop.

## MATERIALS AND METHODS

Present study was carried out on four commercial

---

*Corresponding author e-mail: poojadhansu@gmail.com sugarcane varieties of different maturity group in split plot design with 3 replications. Two budded setts of four sugarcane varieties, two under mid late group, viz. CoH 128, CoS 767 and two under early group, viz. Co 0238 and CoJ 64 were planted by half ridge irrigation method in spring season of the year 2014–15 and 2015–16 in the field conditions at Regional Research Station, Chaudhary Charan Singh Haryana Agricultural University, Uchani, Karnal, Haryana, India. After complete germination (45 days after planting), three levels of available soil moisture (ASM) regimes were created, i.e. irrigation at 50% ASM level (control), irrigation at 40% ASM level (mild stress) and irrigation at 30% ASM level (severe stress). These ASM levels were created only during pre-monsoon (in the month of April, May and June) period by withholding irrigation and later on, i.e. post monsoon period (in the month of July), the crop was irrigated for stress revival as per requirement. Average rainfall is 600 mm and 70-80% of it is received from July to September.

ROS production was measured by monitoring the reduction of XTT [2, 3- bis-(2-methoxy-4-nitro-5-sulphophenyl)-2 H-tetrazolium-5-caboxanilide)] with some modifications. Data was expressed in µmoles XTT FORMAZAN/g FW. Ascorbic acid content was estimated as per method of Mukherjee and Choudhari (1983). Ascorbate peroxidase was assayed by the procedure of Nakano and Asada (1981). The activity of catalase was estimated according to the procedure described by Aebi (1984). The procedure at Siegel and Siegel (1969) was followed for estimating peroxidase activity. Potassium content was determined using Flame photometer (Elico, India) and expressed in ppm values. Total soluble proteins were determined by Bradford (1976). All the data were subjected to variance analysis using the SAS (Version 9.3, SAS Institute Inc., Cary, NC, USA). Least significant difference test was applied at 5% probability level to compare the mean differences.

## RESULTS AND DISCUSSION

In the present investigation, attempts were made to establish a correlation between ROS defense mechanism and drought induced changes in different varieties of sugarcane and results showed enhanced activities of POX, CAT and APX in leaves of sugarcane.

*Reactive oxygen species (ROS) content:* Significant enhancement of ROS content in leaves was recorded in all the sugarcane varieties under different moisture regimes (Fig 1A). A significant elevation in ROS content occurred both at 30% (40.09 and 49.57%) and 40% ASM levels (31.24 and 41.25%) as compared to 50% ASM level at 60 and 90 DAP. The higher concentration of ROS content has been observed in varieties CoJ 64 (1051.1 and 1191.6 µmoles XTT FORMAZAN/g FW) followed by CoH 128 (1031.3 and 1117.1 µmoles XTT FORMAZAN/g FW) as compared to varieties Co 0238 (972.1 and 1022.8 µmoles XTT FORMAZAN/g FW) and CoS 767 (902.8 and 983.3 µmoles XTT FORMAZAN/g FW) at 60 and 90 DAP, respectively (Fig 1A). An increase in ROS content might

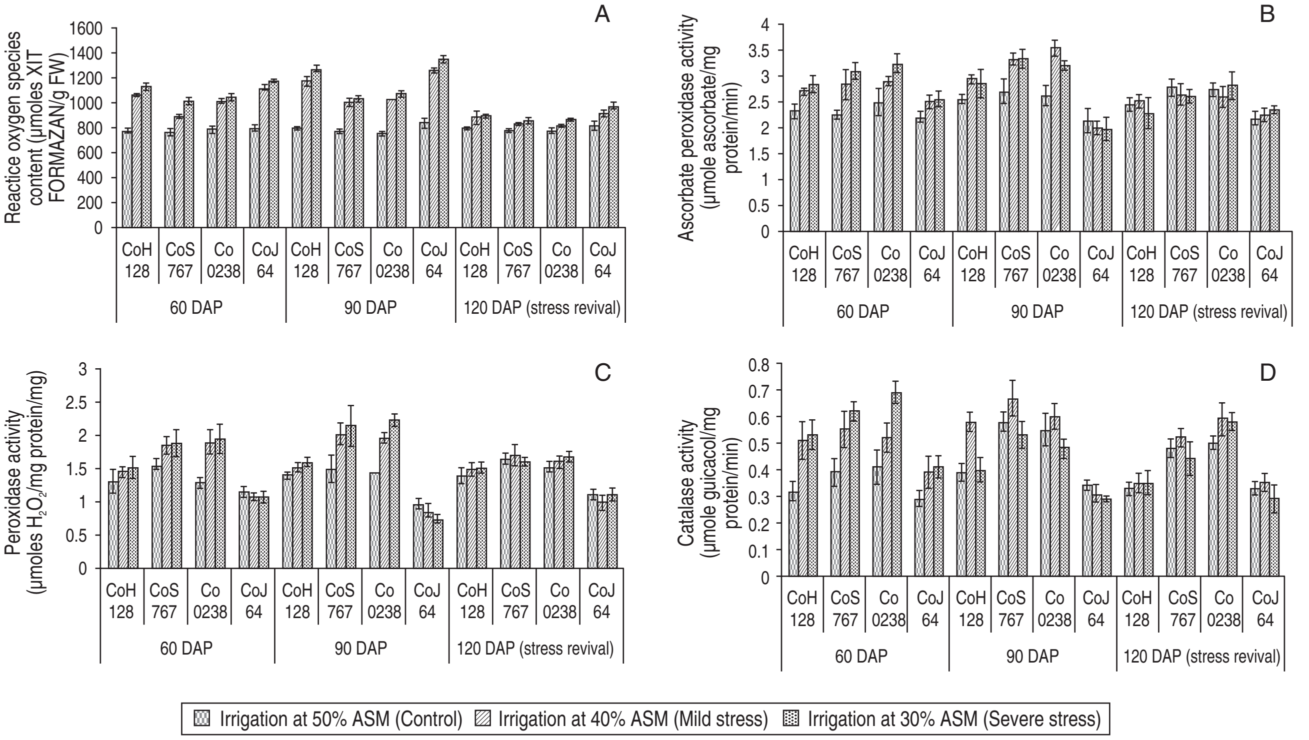

Fig 1 Effect of different soil moisture regimes and sugarcane varieties on reactive oxygen species content (Fig 1A), specific activity of ascorbate peroxidase (Fig 1B), peroxidase (Fig 1C) and catalase (Fig 1D) in leaves at different time intervals (Bar represent SE of the mean of 3 replicates).

be due to a decline in photosynthetic capacity leads to condition of excess light energy and increased generation of ROS content (Asada 2006). After stress revival (at 120 DAP), a significant decrease in ROS content was recorded at both 30% (23.95%) and 40% ASM levels (23.23%) as compared to respective values at 90 DAP. Increased ROS can cause lipid peroxidation and consequently membrane injury which leads to leakage of cellular content, peroxidation of membrane lipids, protein degrading, enzyme inactivation, pigment bleaching and disruption of DNA strands and ultimately leads to cell death (Sairam and Tyagi 2004, Ngamhui *et al.* 2015).

*Antioxidative enzymes activities:* Sugarcane varieties exposed to low ASM levels (30% and 40%) showed an appreciable increase in specific activity of antioxidative enzymes, viz. ascorbate peroxidase (Fig 1B), peroxidase (Fig 1C) and catalase (Fig 1D) as compared to 50% ASM level (control) in all varieties.

*Ascorbate peroxidase (APX, EC 1.11.1.11):* The specific activity of ascorbate peroxidase (APX) in leaves significantly increased by 26.7 and 18.53% at 30% and 40% ASM levels, respectively, as compared to 50% ASM level at 60 DAP. However, at 90 DAP the maximum activity of APX was recorded at 40% ASM level (17.86%) followed by 30% ASM level (13.1%) as compared to 50% ASM level. Among the varieties, Co 0238 showed significantly higher APX activity (2.89 and 3.13 µmol/mg protein/min) closely followed by CoS 767 (2.74 and 3.13 µmol/mg protein/min) and CoH 128 (2.63 and 2.79 µmol/mg protein/min), whereas the lowest in CoJ 64 (2.43 and 2.04 µmol/mg protein/min) at 60 and 90 DAP, respectively (Fig 1B). After stress revival (at 120 DAP), APX activity decreased by 11.93% at 30% ASM level and 15.83% at 40% ASM level over their values at 90 DAP.

*Peroxidase (POX, EC 1.11.1.7):* Data presented in Fig 1C show that specific activity of peroxidase (POX) significantly increased in leaves at both 30% (1.61 and 1.68 µmol/mg protein/min) and 40% ASM levels (1.57 and 1.59 µmol/mg protein/min) as compared to 50% ASM level (1.32 and 1.32 µmol/mg protein/min) at 60 and 90 DAP, respectively. Among the varieties, CoS 767 showed the highest POX activity followed by Co 0238 and CoH 128, whereas the lowest POX activity was noted in CoJ 64 at 60 DAP as well as 90 DAP, respectively. After stress revival (at 120 DAP), there was no significant difference in POX activity at both 30% and 40% ASM levels as compared to 50% ASM level.

*Catalase (CAT, EC 1.11.1.6):* Specific activity of catalase (CAT) in leaves significantly increased by 1.6 and 1.14 fold at 30% and 40% ASM levels, respectively, as compared to 50% ASM level at 60 DAP. However, at 90 DAP, CAT activity increased by 1.15 fold at 40% ASM level while it decreased at 30% ASM level as compared to 50% ASM level. Among the varieties, CoS 767 (0.52 and 0.59 µmol/mg protein/min) showed the highest activity followed by Co 0238 (0.54 and 0.54 µmol/mg protein/min) and CoH 128 (0.45 and 0.46 µmol/mg protein/min) and the lowest in CoJ 64 (0.36 and 0.31 µmol/mg protein/min) at 60 and 90 DAP, respectively (Fig 1D).

In the present study, APX had the highest activity in among three $H_2O_2$ scavenging enzymes and activity increased under water stress. It might be due to that in $C_4$ photosynthesis, photorespiration could be negligible and the major site of $H_2O_2$ production is chloroplast and mitochondria. As sugarcane is a $C_4$ plant, photorespiration is minimized by $CO_2$ concentration mechanism within bundle sheath cell. Thereby minimizing the requirement of CAT activity under water stress could be accounted for an increase the activity of APX (Edwards and Walker 1983, Ngamhui *et al.* 2015). Higher APX, POX and SOD activity have also been correlated with the relative tolerance of many crop plants (Allen 1995, Wang *et al.* 2000, Sairam and Saxena 2000).

*Total ascorbic acid content:* A significant elevation in TAA content was recorded at 30% and 40% ASM levels as compared to 50% ASM level. Among the varieties, significantly higher TAA content was recorded in variety Co 0238, CoS 767 and CoJ 64 than CoH 128 at 60 and 90 DAP (Table 1). Our findings are in confirmatory with earlier findings of Chugh *et al.* (2011) who reported that TAA content was higher in the tolerant maize genotypes (104% increase) and Krishnappa and Sudhakar (2014) in two cultivar of groundnut under drought. This increase in TAA content under water stress might be due to the fact that the TAA provides protection to membrane by directly scavenging super oxide radical, and hydroxyl radical and by regenerating α- tocopherol from tocopheroxy radical (Wang *et al.* 2010).

*Potassium (K) content:* Potassium is a major cation in cell organization and it was reported to be a major contributor to osmotic adjustment in several plant species. Potassium content decreased by 18.35 and 27.67% at 30% ASM level and 13.61 and 22.53% at 40% ASM level as compared to 50% ASM level at 60 and 90 DAP, respectively (Table 2). Among the varieties, maximum reduction in potassium content was recorded in Co 0238 (22.62 and 35.14%) and CoS 767 (20.23 and 32.67%) than CoH 128 (16.1 and 21.51%) and CoJ 64 (13.3 and 17.5%) at 30% ASM level as compared to 50% ASM level at 60 and 90 DAP, respectively. After stress revival, values of potassium content were at par at all the ASM levels (Table 2). Effect of different ASM levels and interactive effect of varieties and ASM levels were found non-significant. Present results are in confirmatory with Patil (2008) who reported that potassium content decreased significantly (from 1.58 to 1.28%) under drought stress in sugarcane.

*Total soluble protein content:* Total soluble proteins content in leaves significantly increased at both 30% (27.15 and 43.44%) and 40% ASM levels (21.05 and 27.19%) as compared to 50% ASM level at 60 and 90 DAP, respectively (Table 3). It might be because with other osmoregulators, proteins were the major contributors to the osmoregulation. At 30% ASM level, significantly higher proteins content was recorded in variety Co 0238 (13.7 mg/g DW) followed

Table 1 Effect of different soil moisture regimes on ascorbic acid content (mg/g DW) in sugarcane varieties differing in their maturity group

| Variety/ Treatment | CoH 128 | CoS 767 | Co 0238 | CoJ 64 | Mean | CoH 128 | CoS 767 | Co 0238 | CoJ 64 | Mean | CoH 128 | CoS 767 | Co 0238 | CoJ 64 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | After 60 DAP |  |  |  |  | After 90 DAP |  |  |  |  | After 120 DAP (stress revival) |  |  |  |  |
| 50 % ASM (Control) | 8.80 | 9.47 | 9.23 | 9.53 | $9.26^{B}$ | 8.95 | 9.67 | 9.15 | 9.68 | $9.36^{B}$ | 9.33 | 9.85 | 10.09 | 9.88 | 9.79 |
| 40 % ASM (Mild stress) | 10.66 | 11.76 | 11.99 | 11.53 | $11.49^{A}$ | 11.25 | 12.59 | 12.41 | 12.10 | $12.09^{A}$ | 9.53 | 9.91 | 10.20 | 9.99 | 9.91 |
| 30 % ASM (Severe stress) | 11.19 | 12.93 | 13.09 | 12.12 | $12.33^{A}$ | 11.72 | 13.86 | 14.10 | 12.87 | $13.14^{A}$ | 9.50 | 9.93 | 10.11 | 9.84 | 9.85 |
| Mean | $10.22^{B}$ | $11.39^{A}$ | $11.44^{A}$ | $11.06^{A}$ |  | $10.64^{B}$ | $12.04^{A}$ | $11.89^{A}$ | $11.55^{A}$ |  | $9.45^{B}$ | $9.9^{A}$ | $10.13^{A}$ | $9.91^{A}$ |  |
| CV | Varieties (V) – 5.494; Treatments (T) – 10.136 |  |  |  |  | Varieties – 7.385; Treatments – 12.787 |  |  |  |  | Varieties – 2.854; Treatments – 1.489 |  |  |  |  |
| LSD | V– 0.60 | T – 1.27 |  | T×V– NS | V×T –NS | V – 0.84 |  | T – 1.67 | T×V –NS | V×T – NS | V – 0.28 | T – NS | T×V – NS |  | V×T – NS |

Table 3 Effect of different soil moisture regimes on total protein content (mg $g^{-1}$ DW) in sugarcane varieties differing in their maturity group

| Variety/Treatment | CoH 128 | CoS 767 | Co 0238 | CoJ 64 | Mean | CoH 128 | CoS 767 | Co 0238 | CoJ 64 | Mean | CoH 128 | CoS 767 | Co 0238 | CoJ 64 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | After 60 DAP |  |  |  |  | After 90 DAP |  |  |  |  | After 120 DAP (stress revival) |  |  |  |  |
| 50 % ASM (Control) | 7.64 | 8.85 | 8.83 | 8.13 | $8.36^{B}$ | 11.65 | 8.26 | 10.24 | 8.23 | $9.6^{C}$ | 9.50 | 8.90 | 10.61 | 9.43 | 9.61 |
| 40% ASM (Mild stress) | 8.52 | 10.48 | 13.18 | 8.32 | $10.12^{A}$ | 13.18 | 13.16 | 13.95 | 8.57 | $12.21^{B}$ | 8.26 | 9.09 | 9.48 | 9.30 | 9.03 |
| 30 % ASM (Severe stress) | 9.07 | 10.80 | 13.97 | 8.70 | $10.63^{A}$ | 15.25 | 13.73 | 16.89 | 9.21 | $13.77^{A}$ | 8.37 | 8.98 | 9.93 | 9.75 | 9.26 |
| Mean | $8.41^{C}$ | $10.04^{B}$ | $11.99^{A}$ | $8.38^{C}$ |  | $13.36^{A}$ | $11.71^{B}$ | $13.7^{A}$ | $8.67^{C}$ |  | $8.71^{C}$ | $8.99^{BC}$ | $10^{A}$ | $9.49^{AB}$ |  |
| CV | Varieties – 7.92; Treatments – 6.06 |  |  |  |  | Varieties – 3.857; Treatments – 2.352 |  |  |  |  | Varieties – 5.67; Treatments – 5.572 |  |  |  |  |
| LSD | V – 0.76 |  | T – 0.67 | T×V – 1.31 | V×T – 1.32 | V – 0.45 |  | T – 0.32 | T×V – 0.75 | V×T – 0.78 | V – 0.52 |  | T – NS | T×V – NS | V×T – NS |

Least significant difference test was applied at 5 % probability level to compare the mean differences.

Table 2 Effect of different soil moisture regimes on potassium content (%) in sugarcane varieties differing in their maturity group

| Variety/Treatment | CoH 128 | CoS 767 | Co 0238 | CoJ 64 | Mean | CoH 128 | CoS 767 | Co 0238 | CoJ 64 | Mean | CoH 128 | CoS 767 | Co 0238 | CoJ 64 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | After 60 DAP |  |  |  |  | After 90 DAP |  |  |  |  | After 120 DAP (stress revival) |  |  |  |  |
| 50 % ASM (Control) | 2.92 | 3.51 | 3.36 | 2.85 | $3.16^{A}$ | 2.65 | 2.51 | 2.96 | 2.00 | $2.53^{A}$ | 2.80 | 2.94 | 3.12 | 2.57 | 2.86 |
| 40% ASM (Mild stress) | 2.59 | 3.00 | 2.77 | 2.55 | $2.73^{B}$ | 2.19 | 1.83 | 2.11 | 1.70 | $1.96^{B}$ | 2.54 | 2.87 | 3.05 | 2.38 | 2.71 |
| 30 % ASM (Severe stress) | 2.45 | 2.80 | 2.60 | 2.47 | $2.58^{C}$ | 2.08 | 1.69 | 1.92 | 1.65 | $1.83^{B}$ | 2.50 | 2.83 | 3.06 | 2.37 | 2.69 |
| Mean | $2.65^{B}$ | $3.1^{A}$ | $2.91^{A}$ | $2.62^{B}$ |  | $2.31^{A}$ | $2.01^{B}$ | $2.33^{A}$ | $1.78^{C}$ |  | $2.61^{BC}$ | $2.88^{AB}$ | $3.08^{A}$ | $2.44^{C}$ |  |
| CV | Varieties – 8.755; Treatments – 4.385 |  |  |  |  | Varieties – 6.58; Treatments – 6.639 |  |  |  |  | Varieties – 12.16; Treatments – 8.525 |  |  |  |  |
| LSD | V – 0.24 |  | T – 0.14 | T×V– NS | V×T – NS | V – 0.14 |  | T – 0.16 | T×V –0.26 | V×T – 0.24 | V – 0.28 |  | T – NS | T×V – NS | V×T – NS |

by CoH 128 (13.36 mg/g DW) and CoS 767 (11.71 mg/g DW), whereas the lowest value was recorded in CoJ 64 (8.67 mg/g DW). After stress revival (at 120 DAP), non-significant difference was recorded at 30% and 40% ASM levels as compared to 50% ASM level. An apparent increase in total soluble protein content under drought stress conditions in sugarcane were also reported by Medeiros *et al.* (2013) and Pooja *et al.* (2017). The earlier finding of Gomathi *et al.* (2013) in sugarcane under salt stress also found that the stress induced higher accumulation of protein under salinity condition. An increase in protein content was due to reductions in proteolysis caused by salinity leading to slower depletion of reserve protein rather than enhancement in protein synthesis (Lata *et al.* 2017).

The results confirm that the antioxidative defence system is dependent on plant genotype during stress intensification as well as stress duration. Varieties differing in their maturity clearly responded differently to different soil moisture regimes in terms of ROS content, the activities of APX, CAT and POX, ascorbic acid content, $K^+$ content. It might be concluded from this study that biochemical traits particularly antioxidative defense system had a significant varietal variation and might play an important role in conferring drought tolerance, indicating that these parameters could be used as screening criteria for selecting the tolerant and sensitive cultivars exposed to water limiting stress.

## ACKNOWLEDGEMENTS

The authors are thankful to Regional Director, CCS HAU, Uchani, Karnal for providing the required research facilities and Director, ICAR-SBI, Coimbatore is duly acknowledged.

## REFERENCES

Aebi H. 1984. Catalase *in vitro*. *Methods in Enzymology* **105**: 121–6.

Allen R D. 1995. Dissection of oxidative stress tolerance using transgenic plants. *Plant Physiology* **107**: 1049–54.

Asada K. 2006. Production and scavenging of reactive oxygen species in chloroplasts and their functions. *Plant Physiology* **141**: 391–6.

Bradford M M. 1976. A rapid and sensitive method for the quantization of microgram quantities of protein utilizing the principle of protein dye binding. *Analytical Biochemistry* **72**: 248–54.

Chugh V, Kaur N and Gupta A K. 2011. Evaluation of oxidative stress tolerance in maize (*Zea mays* L.) seedlings in response to drought. *Indian Journal of Biochemistry and Biophysics* **48**: 47–53.

Duan M, Feng H L, Wang LY, Li D and Meng Q W. 2012. Overexpression of thylakoidal ascorbate peroxidase shows enhanced resistance to chilling stress in tomato. *Journal of Plant Physiology* **169**: 867–77.

Edwards G and Walker D A. 1983. *$C_3$, $C_4$: Mechanisms, and Cellular and Environmental Regulation of Photosynthesis*, pp. 542. Blackwell Scientific, Oxford, UK.

Gomathi R, Vasantha S, Hemaprabha S, Shiyamala S and Rakkiyappan P. 2013. Differential accumulation of salt induced protein in contrasting sugarcane genotypes. *European Journal of Biological Science* **1**: 7–11.

Ishikawa T, Takahara K, Hirabayashi T, Matsumura H, Fujisawa S, Terauchi R, Uchimiya H and Kawai-Yamada M. 2010. Metabolome analysis of response to oxidative stress in rice suspension cells overexpressing cell death suppressor *Bax inhibitor-1*. *Plant Cell Physiology* **51**: 9–20.

Krishnappa B V and Sudhakar C. 2014. Physiological and biochemical responses of two high yielding groundnuts cultivars (*Arachis hypogaea* L.cv. KCG-6 and GPBD-4) of Karnataka with contrasting drought tolerance. *Journal of Applied Science and Research* **2**(5): 18–25.

Lata C, Kumar A, Sharma S K, Singh J, Sheokand S, Pooja, Mann A and Rani B. 2017. Tolerance to combined boron and salt stress in wheat varieties: biochemical and molecular characterization. *Indian Journal of Experimental Biology* **55**: 321–8.

Mann A, Bishi S K, Mahatma M K and Kumar A. 2015. Metabolomics and salt stress tolerance in plants. *Managing Salt Tolerance in Plants: Molecular and Genomic Perspectives,* pp 251–66. Taylor and Francis Group, LLC.

Mann A, Kumar A, Saha M, Lata C and Kumar A. 2019. Stress induced changes in osmoprotectants, ionic relations, antioxidants activities and protein profilling characterize *Sporobolus marginatus* Hochst. Ex A. Rich. Salt tolerance mechanism. *Indian Journal of Experimental Biology* **57**: 672–9.

Medeiros D B, da Silva E C, Nogueira R J M C, Teixeira M M and Buckeridge M S. 2013. Physiological limitations in two sugarcane varieties under water suppression and after recovering. *Theoretical and Experimental Plant Physiology* **25**(3): 213–22.

Mukherjee S P and Choudhuri M A. 1983. Implications of water stress-induced changes in the levels of endogenous ascorbic acid and hydrogen peroxide in *Vigna* seedlings. *Physiologia Plantarum* **58**(2): 166–70.

Nakano Y and Asada K. 1981. Hydrogen peroxide is scavenged by ascorbate-specific peroxidase in spinach chloroplasts. *Plant Cell Physiology* **22**(5): 867–88.

Nepomuceno A L, Neumaier N, Farias J R B and Oyax T. 2001. Tolerancia a secaem plantas. Biotecnologia, *Ciencia e Desenvolvimento* **4**: 12–18.

Ngamhui N, Tantisuwichwong, Roytrakul S, Zhu Y J, Li X Q and Akkasaeng C. 2015. Relationship between drought tolerance with activities of antioxidant enzyme in sugarcane. *Indian Journal of Plant Physiology* **20**: 145–50

Noctor G and Foyer C H. 1998. Ascorbate and glutathione: Keeping active oxygen under control. *Annual Review of Plant Physiology and Plant Molecular Biology* **49**: 249–79.

Patil R P. 2008. 'Physiological approaches for drought tolerance in sugarcane (*Saccharum officinarum* L.)'. Ph d thesis, UAS, Dharwad.

Pooja, Nandwal A S, Chand M, Kumar A, Rani B, Kumari A and Kulshreshtha N. 2017. Comparative evaluation of changes in protein profile of sugarcane under different soil moisture regimes. *International Journal of Current Microbiology and Applied Sciences* **6**: 1203–10.

Pooja, Nandwal A S, Chand M, Kumari A, Rani B, Goel V and Singh S. 2019a. Genotypic differences in growth behavior and quality parameters of sugarcane varieties under moisture stress conditions. *Indian Journal of Agricultural Sciences* **89** (1): 65–72.

Pooja, Nandwal A S, Chand M, Singh K, Mishra A K, Kumar A, Kumari A and Rani B. 2019b. Varietal variation in physiological and biochemical attributes of sugarcane varieties under different soil moisture regimes. *Indian Journal of Experimental Biology* **57**(10): 721–32.

Rani B, Madan S, Sharma K D, Pooja and Kumar A. 2018. Influence of arbuscular mycorrhiza on antioxidative system of wheat under drought stress. *Indian Journal of Agricultural Sciences* **88** (2): 289–95.

Sairam R K and Saxena D C. 2000. Oxidative stress and antioxidants in wheat genotypes: Possible mechanism of water stress tolerance. *Journal of Agronomy and Crop Science* **184**: 55–61.

Sairam R K and Tyagi A. 2004. Physiology and molecular biology of salinity stress tolerance in plants. *Current Science* **86**: 407–21.

Siegel B S and Siegel S M. 1969. Anomalous substrate specificities among the algal peroxidases. *American Journal of botany* **57**: 285–7.

Vision S B I. 2030. *Vision 2030*. Sugarcane Breeding Institute, Coimbatore.

Wang H L, Lee P D, Chen W L, Huang D J and Su J C. 2000. Osmotic stress-induced changes of sucrose metabolism in cultured sweet potato cells. *Journal of Experimental Botany* **51**: 1991–9.

Wang Z, Xiao Y, Chen W, Tang K and Zhang L. 2010 Increased vitamin C content accompanied by an enhanced recycling pathway confers oxidative stress tolerance in *Arabidopsis*. *Journal of Integrative Plant Biology* **52**: 400-9.