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ANTIOXIDATIVE RESPONSE IN *RABI* SORGHUM UNDER MOISTURE STRESS

R. S. Shaikh[1], R. W. Bharud[2], A. A. Kale[3] and D.V.Deshmukh[4]

[1.]Ph D Scholar, [2]Prof. & Head, Department of Botany, [3]Associate Professor, Biochemistry, [4]Sr. Res. Asstt.
Department of Agricultural Botany, Mahatma Phule Krishi Vidyapeeth,
Rahuri-413722, Dist.: Ahmednagar (M.S.), India

ABSTRACT

Drought stress is one of the major abiotic stresses in agriculture worldwide. This study was carried out to investigate the effect of moisture stress on antioxidative response in *rabi* sorghum, in ten genotypes of *rabi* sorghum. A field experiment with three irrigation regimes *viz;* moisture stress condition with irrigation applied at the time of sowing, terminal stress condition with irrigation applied at the time of sowing and panicle initiation stage and non stress condition with irrigation applied at various critical growth stages was carried out in a split plot design with three replications. Seeds were grown separately under three moisture regimes Antioxidant enzymes such as superoxide dismutase, guiacol peroxidase and catalase were significantly increased under moisture stress condition at 50% flowering as well as at dough stage. Among the genotypes, RSV 1572 and variety Phule Anuradha recorded highest SOD, CAT and GPX activity under moisture stress condition at both stages. Increased activity of antioxidant enzymes will be helpful to detoxify reactive oxygen species generated due to moisture stress. Therefore, RSV 1572 and Phule Anuradha may be used for boosting up further breeding programme.

Key words: antioxidative enzymes, moisture stress, irrigation regimes, drought tolerance.

I. INTRODUCTION

Moisture stress has a significant effect on plant growth and development, physiological and biochemical parameters, yield and yield contributing parameters in *rabi* sorghum crop. However plants have different adaptive mechanisms for coping with moisture stress. Out of which one or more than one mechanism exist for adaptation to moisture stress conditions. Sorghum genotypes are known to be better adapted to drought condition with little or no injury. Sorghum is the fifth most important cereal crop next only to rice, wheat, maize and barley. It is the staple food of poor and the most food insecure people, living mainly in the semi-arid and tropics (Ali *et al*. 2009, Bibi *et al*. 2010). It is grown in 98 countries of Africa, Asia, Oceania and the Americas, Nigeria, India, USA, Mexica, Sudan, China and Argentina, which are the major sorghum producers. In India, it is cultivated on an area of about 5.90 million ha with the production of 5.39 million tonnes. The productivity of sorghum in India (963 kg ha^{-1}) is much less than the world average (1395 kg ha^{-1}) (Rakshit *et. al*., 2014). Maharashtra, Karnataka, Andhra Pradesh, Gujarat, Tamilnadu and Madhya Pradesh are the major sorghum growing states. Maharashtra ranks first in sorghum production in India, where it is cultivated on an area of about 30.48 lakh ha with the production of 24.82 lakh MT. During the year 2013, sorghum is cultivated on 8.04 and 22.44 lakh ha area in *kharif* and *rabi* season with an average per ha productivity of 1152 and 693 kg respectively (Anonymous, 2013). As compare to *kharif* season the productivity of *rabi* season is very less. The low yields of sorghum might be due to various biotic and abiotic stresses. Moisture stress is one of the important drought factors.

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The generation of reactive oxygen species (ROS) is one of the earliest biochemical responses of eukaryotic cells to biotic and abiotic stresses. ROS, which include oxygen ions, free radicals and peroxides, form as a natural byproduct of the normal metabolism of oxygen and have important role in cell signaling. However, during environmental stress such as drought, ROS levels increase dramatically resulting in oxidative damage to proteins, DNA and lipids (Apel and Hirt, 2004). When ROS level enhanced the lipid peroxidation takes place in both cellular and organelle membranes. Lipid peroxidation aggravates the oxidative stress through the production of lipid derived radicals that themselves can react with and damage proteins and DNA. To minimize the affections of oxidative stress, plants have evolved a complex enzymatic and non-enzymatic antioxidant system, such as low-molecular mass antioxidants (glutathione, ascorbate, carotenoids) and ROS scavenging enzymes (superoxide dismutase (SOD), peroxidase (POD), catalase (CAT), ascorbate peroxidase (APX) (Apel and Hirt, 2004). Non-enzymatic antioxidants cooperate to maintain the integrity of the photosynthetic membranes under oxidative stress. The enzymatic components may directly scavenge ROS or may act by producing a non-enzymatic antioxidant.

II. MATERIALS AND METHODS

Eight promising genotypes and two released varieties of sorghum were grown under three moisture regimes *viz;* moisture stress, terminal stress and non stress at Pulses Improvement Project, MPKV, Rahuri during the year 2013-14 and 2014-15. The experiment was laid out in split plot design. Under moisture stress condition, irrigation was applied at the time of sowing. Under terminal stress condition irrigations applied at the time of sowing and panicle initiation stage, while, under non stress condition irrigation were applied at the time of sowing and at critical growth stages. Observations on biochemical parameters were recorded at 50% flowering stage and at dough stage. Third fully expanded leaf from the top used for estimation of biochemical parameters.

Extraction of enzyme extract

Anti-oxidative enzymes such as catalase (CAT), guaiacol peroxidase (GPX), and superoxide dismutase (SOD) were extracted from leaf tissue by using the method of Coasta *et al.* (2002).

150 mg of leaf sample were homogenized with a pestle in a chilled mortar with 2 ml of an ice-cold 50 mM sodium phosphate buffer (pH 7.2) containing 1% (w/v) polyvinylpyrrolidone. The homogenates were filtered through four layers of cheesecloth and then centrifuged at 4°C for 20 min at 15,000 xg. The supernatant fraction was used as crude extract for enzyme activity assays.

Superoxide dismutase activity was determined by measuring its ability to inhibit the photochemical reduction of Nitroblue tetrazolium using the method described by Dhindsa *et al.* (1981). For GPX, the rate of decomposition of hydrogen peroxide by peroxidase with guaiacol as a hydrogen donor was measured by the increase in absorbance at 436 nm per min as per the method described by Sterjiades (1992). Catalase activity was measured immediately in fresh extract and the assay employed was the one described by Aebi (1984). The hydrogen peroxide dependent oxidation was estimated by the decrease in absorbance at 240 nm. The data were analyzed statistically by using standard method of “Analysis of Variance” suggested by Panse and Sukhatme (1964).

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The drought susceptibility index was calculated by using formula suggested by Fischer and Maurer (1978) as below

$$DSI = \frac{1 - (Y_S / Y_P)}{DI}$$

Where, DSI = Drought susceptibility index
DI = Drought index
Y_S = Yield in water stress condition
Y_P = Yield in irrigated condition
While, DI = $1 - (X_S / X_P)$
Where, Xs = Mean yield of all genotypes in water stress condition
Xp = Mean yield of all genotypes in irrigated condition.

Drought tolerance efficiency was calculated as per the formula suggested by Fisher and Wood (1981).

$$DTE\ \% = \frac{\text{Grain yield under water stress condition}}{\text{Grain yield under irrigated condition}} \times 100$$

III. RESULTS AND DISCUSSION

There is a defensive system in plants, that is to say, plants have an internal protective enzyme-catalyzed clean up system, which is fine and elaborate enough to avoid injuries of active oxygen, thus guaranteeing normal cellular function (Horváth *et al.,* 2007). The balance between ROS production and activities of antioxidative enzyme determines whether oxidative signaling and/or damage will occur (Moller *et al*., 2007). Yang *et al*. (2009) exhibited that as compared with 100% field capacity, at 25% field capacity the increased activities of CAT, SOD, POD, APX and GR were 4.3, 103, 172, 208 and 56% in *P. cathayana*, respectively, whereas they were 8.1, 125, 326, 276 and 78% in *P. kangdingensis*. Efficient destruction of O_2^- and H_2O_2 in plant cells requires the concerted action of antioxidants. O_2^- can be dismutated into H_2O_2 by SOD in the chloroplast, mitochondrion, cytoplasm and peroxisome. POD plays a key role in scavenging H_2O_2 which was produces through dismutation of O_2^- catalyzed by SOD. CAT is a main enzyme to eliminate H_2O_2 in the mitochondrion and microbody (Shigeoka *et al*., 2002) and thus help in ameliorating the detrimental effects of oxidative stress. It is found in peroxisomes, but considered indispensable for decomposing H_2O_2 during stress. Maintaining a higher level of antioxidative enzyme activities may contribute to drought induction by increasing the capacity against oxidative damage (Sharma and Dubey, 2005). The capability of antioxidant enzymes to scavenge ROS and reduce the damaging effects may correlate with the drought resistance of plants.

Superoxide dismutase (SOD): The activities of several enzymes have been shown to be affected by stress in different plants (Mali and Mehta, 1977). Activities of SOD and catalase can determine the abundance of $O_2^{\cdot -}$, H_2O_2, $^{\cdot}OH$ and O_2 which control lipid peroxidation (Dhindsa *et al*., 1981). Cadenas (1989) reported that closure of stomata decreases CO_2 concentration in leaf mesophyll tissue and results in an accumulation of NADPH. Under such conditions, where

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NADP is a limiting factor oxygen acts as an alternate acceptor of electrons from the thylakoid electron transport chain resulting in formation of superoxide radical (O_2^-). In the present investigation**,** superoxide dismutase was influenced significantly due to various moisture regimes, genotypes and their interaction effects at both the stages (Table 1). On an average of 2013-2014 and 2014-2015, SOD activity was increased by 99.13 and 140.99 per cent of non stress under terminal and moisture stress, respectively at 50% flowering, whereas, at dough stage it was increased by 107.30 and 156.69 per cent, respectively. Among the genotypes, RSV 1572 recorded significantly maximum SOD activity (151.25 units mg^{-1} soluble protein) at 50% flowering and (169.55 units mg^{-1} soluble protein) at dough stage (Fig. 1 & 2). Under all stress conditions, RSV 1572 had maximum SOD activity at both stages. Thus the results are in agreement with the findings of ; Moussa and Abdel Aziz 2008; Kumar *et al.* 2011 and Singh and Sharma 2013. Rahman *et al*. (1999) recorded increased activity of SOD during water stress and suggested the possibility of using this as a criterion for drought tolerance.

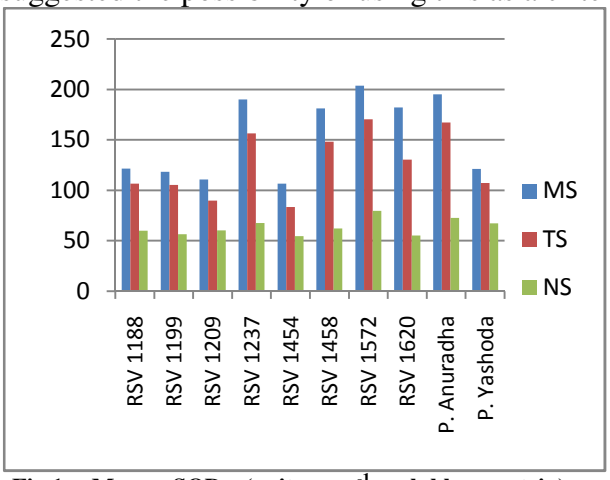

Fig.1. Mean SOD (units mg^{-1} soluble protein) as influenced by moisture regimes, genotypes at 50% flowering stage.

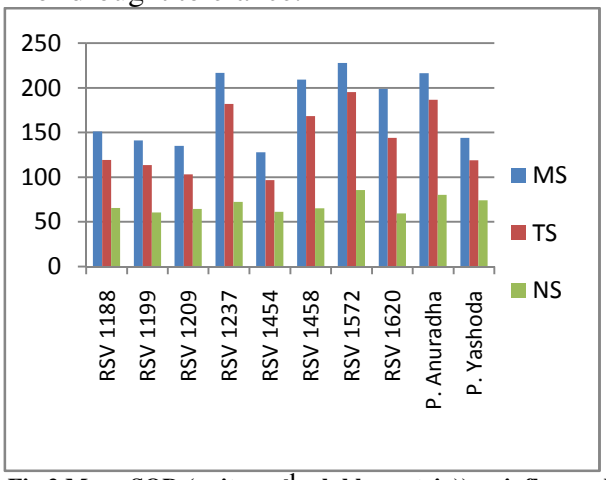

Fig.2 Mean SOD (units mg^{-1} soluble protein)) as influenced by moisture regimes, genotypes at dough stage.

Table 1. Mean SOD activity (units mg^{-1} soluble protein) as influenced by moisture regimes, genotypes and their interactions in sorghum.

Genotypes	2013-2014				2014-2015				Pooled			
	MS	TS	NS	Mean	MS	TS	NS	Mean	MS	TS	NS	Mean
At 50% flowering												
RSV 1188	124.30	108.52	62.31	98.38	118.85	104.39	57.51	93.58	121.58	106.46	59.91	95.98
RSV 1199	120.54	108.37	56.90	95.27	115.89	102.44	55.75	91.36	118.22	105.41	56.33	93.32
RSV 1209	117.46	82.65	64.93	88.35	103.97	97.20	55.49	85.55	110.72	89.93	60.21	86.95
RSV 1237	187.44	155.47	72.28	138.40	192.76	157.60	62.86	137.74	190.10	156.54	67.57	138.07
RSV 1454	107.98	80.28	54.92	81.06	105.31	86.30	54.07	81.89	106.65	83.29	54.50	81.48
RSV 1458	179.84	144.70	62.80	129.11	182.26	151.57	61.60	131.81	181.05	148.13	62.20	130.46
RSV 1572	202.74	168.70	83.54	151.66	204.82	172.24	75.43	150.83	203.78	170.47	79.49	151.25
RSV 1620	181.39	136.98	54.26	124.21	183.13	123.81	55.89	120.94	182.26	130.40	55.08	122.58

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P. Anuradha	196.98	165.78	75.66	146.14	193.32	168.39	69.90	143.87	195.15	167.09	72.78	145.01
P. Yashoda	124.22	109.70	65.54	99.82	118.31	104.64	68.84	97.26	121.27	107.17	67.19	98.54
Mean	154.29	126.12	65.31		151.86	126.86	61.73		153.08	126.49	63.52	
	M	G	M x G		M	G	M x G		M	G	M x G	
S.E.±	0.805	1.658	2.871		0.519	0.654	1.133		0.830	1.543	2.673	
C.D. at 5%	3.161	4.700	8.141		2.038	1.855	3.212		2.706	4.326	7.493	
At dough stage												
RSV 1188	152.37	117.79	66.74	112.30	149.64	120.45	63.99	111.36	151.01	119.12	65.37	111.83
RSV 1199	145.02	110.91	58.81	104.91	137.26	116.13	62.45	105.28	141.14	113.52	60.63	105.10
RSV 1209	142.36	96.36	67.85	102.19	127.61	109.98	60.90	99.50	134.99	103.17	64.38	100.84
RSV 1237	209.36	171.45	75.22	152.01	224.16	192.32	69.70	162.06	216.76	181.89	72.46	157.04
RSV 1454	127.21	94.00	62.31	94.51	128.29	99.44	60.25	95.99	127.75	96.72	61.28	95.25
RSV 1458	207.60	151.66	66.68	141.98	210.85	184.76	63.38	153.00	209.23	168.21	65.03	147.49
RSV 1572	218.54	180.52	87.14	162.07	236.84	210.09	84.15	177.03	227.69	195.31	85.65	169.55
RSV 1620	200.53	140.06	57.00	132.53	197.18	147.89	62.06	135.71	198.86	143.98	59.53	134.12
P. Anuradha	220.02	173.69	82.61	158.77	212.29	199.74	78.08	163.37	216.16	186.72	80.35	161.07
P. Yashoda	151.31	120.42	71.59	114.44	136.66	117.25	76.35	110.09	143.99	118.84	73.97	112.26
Mean	177.43	135.69	69.60		176.08	149.81	68.13		176.76	142.75	68.86	
	M	G	M x G		M	G	M x G		M	G	M x G	
S.E.±	0.354	0.561	0.972		0.367	0.752	1.303		0.441	0.812	1.407	
C.D. at 5%	1.390	1.590	2.756		1.440	2.133	3.695		1.440	2.279	3.947	

Catalase (CAT): Scavenging of reactive oxygen species by enzymatic and non-enzymatic systems, cell membrane stability, expression of aquaporns and stress proteins are vital mechanisms of drought tolerance (Anjum *et al*., 2011). The data on mean catalase activity was influenced significantly due to various moisture regimes, genotypes and their interaction effects at both the stages (Table 2). On an average of 2013-2014 and 2014-2015, CAT activity was increased by 51.54 and 75.44 per cent of non stress under terminal and moisture stress, respectively at 50% flowering, whereas, at dough stage it was increased by 64.85 and 81.62 per cent, respectively. Mean values indicated that, RSV 1572 (7.72 µmoles H_2O_2 decomposed mg^{-1} soluble protein min^{-1}) recorded significantly maximum CAT activity followed by Phule Anuradha (7.60 µmoles H_2O_2 decomposed mg^{-1} soluble protein min^{-1}) which was at par with each other at 50% flowering. At dough stage, RSV 1572 (8.81 µmoles H_2O_2 decomposed mg^{-1} soluble protein min^{-1}) recorded significantly maximum CAT activity. Among the genotypes, RSV 1572 under moisture stress (9.68 µmoles H_2O_2 decomposed mg^{-1} soluble protein min^{-1}) and non stress (5.21 µmoles H_2O_2 decomposed mg^{-1} soluble protein min^{-1}), whereas, Phule Anuradha under terminal stress (8.69 µmoles H_2O_2 decomposed mg^{-1} soluble protein min^{-1}) recorded maximum CAT activity at 50% flowering. At dough stage, RSV 1572 under moisture stress (10.89 µmoles H_2O_2 decomposed mg^{-1} soluble protein min^{-1}), Phule Anuradha under terminal

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stress (10.13 µmoles H_2O_2 decomposed mg^{-1} soluble protein min^{-1}) and RSV 1237 under non stress (5.60 µmoles H_2O_2 decomposed mg^{-1} soluble protein min^{-1}) recorded maximum CAT activity (Fig. 3 and 4). Apel and Hirt (2004) reported that, to minimize the affections of oxidative stress, plants have evolved a complex enzymatic and non-enzymatic antioxidant system such as low molecular mass antioxidants (glutathione, ascorbate, carotenoids) and ROS scavenging enzymes (superoxide dismutase (SOD), Perioxidase (POD) catalaze (CAT), ascorbate peroxidase (APX).

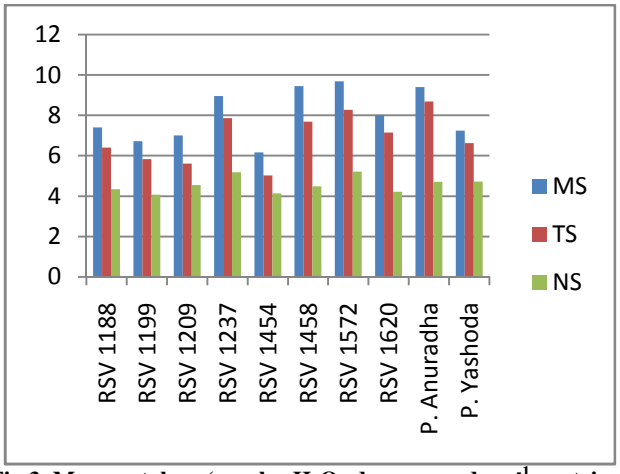

Fig.3. Mean catalase (µmoles H_2O_2 decomposed mg^{-1} protein min^{-1}) as influenced by moisture regimes, genotypes at 50% flowering stage

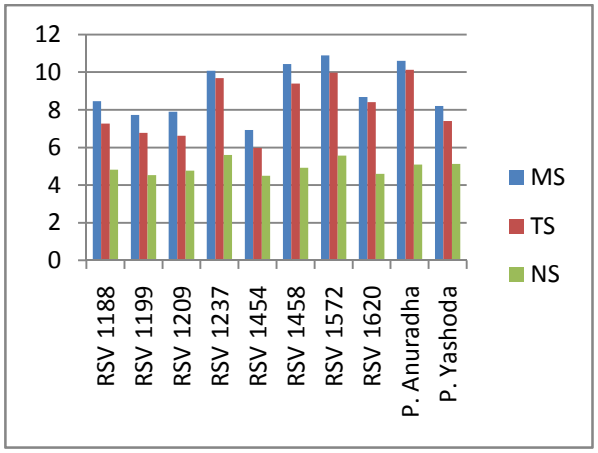

Fig.4. Mean catalase (µmoles H_2O_2 decomposed mg^{-1} protein min^{-1}) as influenced by moisture regimes, genotypes at dough stage.

Table 2. Mean catalase activity (µmoles H_2O_2 decomposed mg^{-1} protein min^{-1}) as influenced by moisture regimes, genotypes and their interactions in sorghum

Genotypes	2013-2014				2014-2015				Pooled Data			
	MS	TS	NS	Mean	MS	TS	NS	Mean	MS	TS	NS	Mean
At 50% flowering												
RSV 1188	7.14	6.42	4.36	5.97	7.68	6.37	4.33	6.13	7.41	6.40	4.35	6.05
RSV 1199	6.38	5.88	4.05	5.44	7.06	5.77	4.10	5.64	6.72	5.83	4.08	5.54
RSV 1209	6.74	5.54	4.57	5.62	7.25	5.67	4.52	5.81	7.00	5.61	4.55	5.72
RSV 1237	9.08	7.59	4.73	7.13	8.84	8.15	5.63	7.54	8.96	7.87	5.18	7.34
RSV 1454	5.48	5.02	3.99	4.83	6.86	5.01	4.26	5.38	6.17	5.02	4.13	5.10
RSV 1458	9.63	8.01	4.35	7.33	9.24	7.36	4.62	7.07	9.44	7.69	4.49	7.20
RSV 1572	9.72	8.17	4.84	7.58	9.64	8.36	5.57	7.86	9.68	8.27	5.21	7.72
RSV 1620	8.93	7.34	4.00	6.76	7.10	6.96	4.44	6.17	8.02	7.15	4.22	6.46
P. Anuradha	9.41	8.33	4.69	7.48	9.38	9.05	4.72	7.72	9.40	8.69	4.71	7.60
P. Yashoda	6.98	6.44	4.67	6.03	7.52	6.81	4.78	6.37	7.25	6.63	4.73	6.20
Mean	7.95	6.87	4.43		8.06	6.95	4.70		8.00	6.91	4.56	
	M	G	M x G		M	G	M x G		M	G	M x G	

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S.E.±	0.036	0.085	0.147		0.017	0.029	0.049		0.035	0.077	0.134	
C.D. at 5%	0.142	0.240	0.416		0.068	0.081	0.140		0.113	0.217	0.376	
At dough stage												
RSV 1188	7.86	7.17	4.82	6.62	9.06	7.35	4.82	7.08	8.46	7.26	4.82	6.85
RSV 1199	7.81	7.02	4.47	6.43	7.65	6.54	4.56	6.25	7.73	6.78	4.52	6.34
RSV 1209	7.70	6.81	4.58	6.36	8.07	6.42	4.96	6.48	7.89	6.62	4.77	6.42
RSV 1237	10.32	9.42	4.95	8.23	9.82	9.94	6.25	8.67	10.07	9.68	5.60	8.45
RSV 1454	6.32	6.17	4.23	5.57	7.52	5.78	4.75	6.02	6.92	5.98	4.49	5.80
RSV 1458	10.72	9.79	4.71	8.41	10.16	8.98	5.12	8.09	10.44	9.39	4.92	8.25
RSV 1572	11.16	9.73	4.96	8.62	10.62	10.20	6.18	9.00	10.89	9.97	5.57	8.81
RSV 1620	9.49	8.51	4.25	7.42	7.86	8.31	4.93	7.03	8.68	8.41	4.59	7.23
P. Anuradha	10.91	9.53	4.89	8.44	10.30	10.73	5.28	8.77	10.61	10.13	5.09	8.61
P. Yashoda	7.74	7.17	4.91	6.61	8.68	7.63	5.32	7.21	8.21	7.40	5.12	6.91
Mean	9.00	8.13	4.68		8.97	8.19	5.22		8.99	8.16	4.95	
	M	G	M x G		M	G	M x G		M	G	M x G	
S.E.±	0.009	0.030	0.052		0.005	0.038	0.066		0.009	0.041	0.072	
C.D. at 5%	0.037	0.084	0..146		0.021	0.108	0.186		0.030	0.117	0.203	

Guiacol peroxidase (GPX): The data on mean guiacol peroxidase activity was influenced significantly due to various moisture regimes**,** genotypes and their interaction effects at both the stages (Table 3). On an average of 2013-2014 and 2014-2015, GPX activity was increased by 70.31 and 93.25 per cent of non stress under terminal and moisture stress, respectively at 50% flowering, whereas, at dough stage it was increased by 72.86 and 94.56 per cent, respectively. RSV 1572 (84.66 and 96.42 ηmoles of tetra-guaiacol formed mg^{-1} soluble protein min^{-1}) recorded significantly maximum GPX activity followed by Phule Anuradha (84.12 and 95.93 ηmoles of tetra-guaiacol formed mg^{-1} soluble protein min^{-1}) at 50% flowering and dought stage which was at par with each other. Among the genotypes, RSV 1572 under moisture stress (105.80 ηmoles of tetra-guaiacol formed mg^{-1} soluble protein min^{-1}), terminal stress (93.06 ηmoles of tetra-guaiacol formed mg^{-1} soluble protein min^{-1}) and non stress (55.11 ηmoles of tetra-guaiacol formed mg^{-1} soluble protein min^{-1}) recorded maximum GPX activity at 50% flowering. At dough stage, RSV 1572 under moisture stress (119.56 ηmoles of tetra-guaiacol formed mg^{-1} soluble protein min^{-1}) and non stress (62.13 ηmoles of tetra-guaiacol formed mg^{-1} soluble protein min^{-1}), whereas, Phule Anuradha under terminal stress (107.66 η moles of tetra-guaiacol formed mg^{-1} soluble protein min^{-1}) recorded maximum GPX activity (Fig. 5 and 6). The GPX activity decreased in control and increased in moisture stress, though the degree of increase was variable. Guaiacol peroxidase (GPX) a heme containing protein. These enzymes have four conserved disulfide bridges and contain two structural Ca^{2+} ions. GPX is associated with degradation of IAA, lignifications of cellwall, biosynthesis of ethylene, wound healing and

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defense against biotic and abiotic stresses. GPX can function as effective quencher of reactive intermediary forms of O_2 and peroxy radicals under stressed conditions. *(Sharma et al. 2012).*

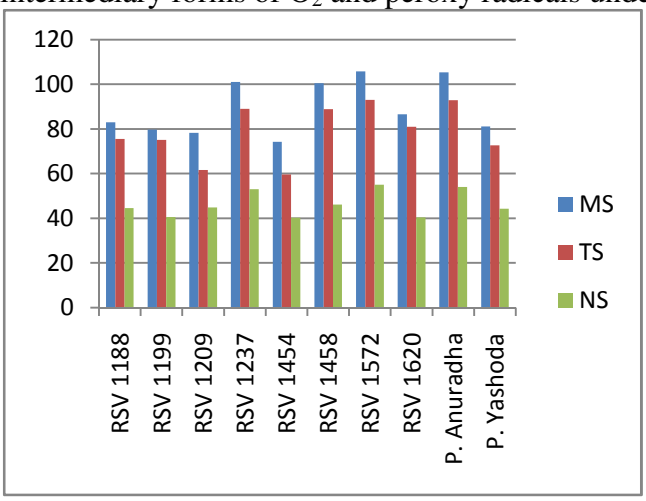

Fig. 5. Mean GPX (ηanomoles of tetra-guaiacol formed mg^{-1} protein min^{-1}) as influenced by moisture regimes and genotypes in sorghum at 50% flowering stage.

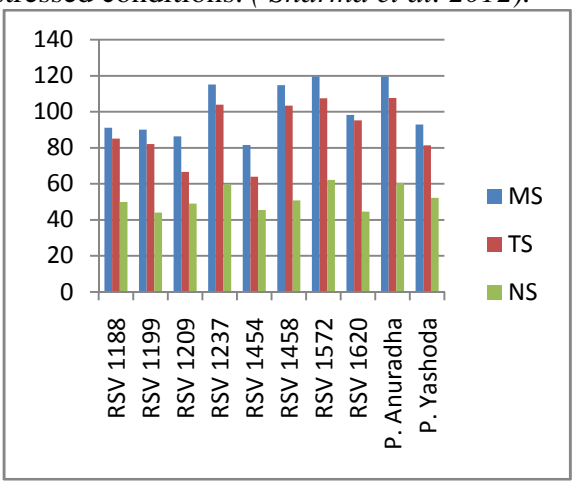

Fig. 6. Mean GPX (ηanomoles of tetra-guaiacol formed mg^{-1} protein min^{-1}) as influenced by moisture regimes and genotypes in sorghum at dough stage.

Table 3. Mean GPX activity (ηmoles of tetra-guaiacol formed mg^{-1} soluble protein min^{-1}) as influenced by Moisture regimes, genotypes and their interactions in sorghum.

Genotypes	2013-2014				2014-2015				Pooled Data			
	MS	TS	NS	Mean	MS	TS	NS	Mean	MS	TS	NS	Mean
At 50% flowering												
RSV 1188	78.62	71.35	40.13	63.37	87.40	79.70	48.95	72.02	83.01	75.53	44.54	67.69
RSV 1199	72.85	73.33	38.86	61.68	86.49	76.89	42.18	68.52	79.67	75.11	40.52	65.10
RSV 1209	78.13	59.25	43.22	60.20	78.57	63.95	46.56	63.03	78.35	61.60	44.89	61.61
RSV 1237	95.13	85.48	48.91	76.51	106.89	92.56	57.29	85.58	101.01	89.02	53.10	81.04
RSV 1454	67.70	57.76	37.53	54.33	80.83	61.55	43.08	61.82	74.27	59.66	40.31	58.08
RSV 1458	96.77	89.06	42.54	76.12	104.13	88.68	49.79	80.87	100.45	88.87	46.17	78.50
RSV 1572	101.73	93.92	53.72	83.12	109.86	92.20	56.50	86.19	105.80	93.06	55.11	84.66
RSV 1620	84.31	78.84	36.36	66.50	88.92	83.08	44.51	72.17	86.62	80.96	40.44	69.34
P. Anuradha	99.83	92.24	51.20	81.09	110.89	93.57	56.97	87.14	105.36	92.91	54.09	84.12
P. Yashoda	78.10	71.10	41.66	63.62	84.32	74.24	46.94	68.50	81.21	72.67	44.30	66.06
Mean	85.32	77.23	43.41		93.83	80.64	49.28		89.57	78.94	46.35	
	M	G	M x G		M	G	M x G		M	G	M x G	
S.E.±	0.207	0.495	0.858		0.188	0.707	1.224		0.243	0.748	1.295	
C.D. at 5%	0.816	1.405	2.433		0.738	2.004	3.471		0.791	2.096	3.629	
At dough stage												

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RSV 1188	87.03	78.31	45.50	70.28	95.42	91.92	54.46	80.60	91.23	85.12	49.98	75.44
RSV 1199	86.62	76.93	40.73	68.09	93.66	87.16	47.25	76.02	90.14	82.05	43.99	72.06
RSV 1209	85.45	60.86	46.98	64.43	87.36	72.35	51.11	70.27	86.40	66.61	49.05	67.35
RSV 1237	114.28	94.78	56.04	88.37	115.97	112.95	63.49	97.47	115.13	103.87	59.77	92.92
RSV 1454	74.51	56.94	43.04	58.16	88.62	71.07	48.00	69.23	81.57	64.01	45.52	63.70
RSV 1458	114.99	98.75	46.28	86.67	114.44	108.12	55.27	92.61	114.72	103.44	50.78	89.64
RSV 1572	118.05	102.66	61.24	93.98	121.06	112.46	63.02	98.85	119.56	107.56	62.13	96.42
RSV 1620	98.06	91.10	39.91	76.36	98.35	99.24	49.42	82.34	98.20	95.17	44.67	79.35
P. Anuradha	117.28	104.33	57.57	93.06	121.77	110.99	63.65	98.80	119.53	107.66	60.61	95.93
P. Yashoda	88.49	79.43	49.35	72.42	97.40	83.19	55.19	78.59	92.95	81.31	52.27	75.51
Mean	98.48	84.41	48.66		103.40	94.95	55.09		100.94	89.68	51.88	
	M	G	M x G		M	G	M x G		M	G	M x G	
S.E.±	0.219	0.692	1.199		0.382	0.678	1.174		0.381	0.839	1.453	
C.D. at 5%	0.860	1.962	3.398		1.498	1.921	3.328		1.243	2.352	4.073	

Yield and drought indices: Differences in Osmotic adjustment capacity contribute to maintain plant productivity under water stress (Morgan, 1980; Blum *et al.,* 1999). At anthesis, pollen mother cells during meisosis are more sensitive to water stress, and water deficit during these stages significantly reduces grain set as a result of male sterility (Saini and Aspinall, 1982). The capacity to adjust osmotically may enhance spikelet fertility due to pollen development. Under severe drought stress, plants with the ability to adjust osmotically can maintain turgor when leaf water potential is reduced (Morgan, 1980). Morgan and Codon (1986) found a positive relationship between seed set and turgor maintenance and concluded that genotypes with low turgor maintenance produced less seed. Osmotic adjustment appears to be associated with extended root growth (Sharp *et al*, 2004), sustained leaf gas exchange, sustained cellular membrane and protein function, as well as chloroplast volume and function (Blum, 1988; Zhang, *et al,* 1999). Osmotic adjustment, in addition to maintaining turgor and sustaining cellular function for a longer time under drought conditions, might allow plants to recover faster from water stress. Moisture stress has a significant effect on plant growth and development, physiological and biochemical parameters, yield and yield contributing parameters in *rabi* sorghum crop. However, plants have different adaptive mechanisms for coping with moisture stress. Out of which one or more than one mechanism exist for adaptation to moisture stress conditions. Scavenging of reactive oxygen species by enzymatic and non-enzymatic systems is one of the vital mechanisms of drought tolerance. In the present study, RSV 1572 recorded maximum grain yield (1003 kg/ha) under moisture stress and (1426 kg/ha) under terminal stress (Table 4). This genotype had least DSI value (0.762) and high DTE value (40.05) under moisture stress (Table 5). Under terminal stress, this genotype had least DSI values (0.636) and high DTE value (56.90).

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Table 4. Mean grain yield (kg/ha) as influenced by moisture regimes, genotypes and their interactions in sorghum.

Genotypes	2013-2014				2014-2015				Pooled Data			
	MS	TS	NS	Mean	MS	TS	NS	Mean	MS	TS	NS	Mean
RSV1188	490	737	3547	1591	407	774	3473	1551	449	756	3510	1571
RAV1199	304	504	3120	1309	272	491	2970	1244	288	498	3045	1277
RSV1209	207	352	2785	1115	170	373	2832	1125	189	363	2809	1120
RSV1237	802	1240	3398	1813	890	1340	3287	1839	846	1290	3343	1826
RSV1454	196	313	2235	915	165	302	2031	833	181	308	2133	874
RSV1458	933	1312	2496	1580	1037	1372	2517	1642	985	1342	2506	1611
RSV1572	944	1402	2561	1636	1062	1449	2450	1654	1003	1426	2506	1645
RSV1620	775	1162	2483	1473	807	1227	2241	1425	791	1194	2362	1449
P. Anuradha	901	1293	2669	1621	933	1357	2754	1681	917	1325	2711	1651
P. Yashoda	467	720	3733	1640	424	698	3553	1558	445	709	3643	1599
Mean	602	903	2903		617	939	2811		609	921	2857	
	M	G	M x G		M	G	M x G		M	G	M x G	
S.E.±	19.86	20.78	35.99		13.82	37.44	64.86		20.96	37.09	64.24	
C.D. at 5%	77.99	58.92	102.06		54.28	106.17	183.89		68.34	103.97	180.07	

Table 5. Drought susceptibility index (DSI) (%) and Drought tolerance efficiency (DTE) (%) under moisture stress in sorghum.

Genotypes	2013-2014				2014-2015				Pooled			
	DSI		DTE		DSI		DTE		DSI		DTE	
	MS	TS	MS	TS	MS	TS	MS	TS	MS	TS	MS	TS
RSV 1188	1.087	1.150	13.82	20.78	1.131	1.167	11.73	22.29	1.109	1.158	12.79	21.53
RSV 1199	1.139	1.217	9.73	16.14	1.164	1.253	9.14	16.54	1.151	1.235	9.45	16.34
RSV 1209	1.168	1.268	7.45	12.63	1.204	1.303	6.02	13.19	1.186	1.285	6.73	12.91
RSV 1237	0.964	0.922	23.60	36.49	0.934	0.889	27.06	40.77	0.950	0.906	25.30	38.60
RSV 1454	1.151	1.249	8.78	14.00	1.177	1.278	8.14	14.89	1.163	1.263	8.48	14.42
RSV 1458	0.790	0.689	37.39	52.55	0.753	0.683	41.21	54.50	0.772	0.686	39.31	53.53
RSV 1572	0.796	0.657	36.88	54.74	0.726	0.613	43.36	59.16	0.762	0.636	40.05	56.90
RSV 1620	0.868	0.773	31.22	46.78	0.819	0.679	36.03	54.77	0.845	0.729	33.50	50.57
P. Anuradha	0.836	0.749	33.77	48.44	0.847	0.761	33.87	49.29	0.841	0.754	33.82	48.87
P. Yashoda	1.104	1.172	12.50	19.30	1.128	1.206	11.94	19.65	1.116	1.188	12.22	19.47

IV. CONCLUSION

These results concluded that biochemical indices such as the increased activity of SOD, CAT and GPX under moisture stress condition play an important role in scavenging ROS species and improving yield. The promising genotype, RSV 1572, and released variety Phule Anuradha found superior in accumulation higher concentration of SOD, CAT and GPX under stress condition. These genotypes maintained higher grain yield under moisture stress as well as terminal stress condition having least DSI and high DTE due to moisture stress condition. Therefore, these cultures may be considered in further breeding programme for the development of drought tolerant varieties

BIBLIOGRAPHY

[1] Aebi, H. 1984. Catalase in vitro. Meth. *Enzymol*. **105**:121-126

[2] Ali, M. A. Abbas, A. Niaz, S. Zulkiffal, M., Ali, S. 2009. Morpho-physiological criteria for drought tolerance in sorghum (Sorghum bicolor) at seedling and post anthesis stages. *Int. J. Agric. Biol*. **11**: 674-680.

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[3] Anjum, S. A. Xiao-yu-xie, Wang, L. C., Sleem, M. F. Chen man and Wang Lei. 2011. Morphological, physiological and biochemical responses of plants to drought stress. *Afric. J. Agric. Res*., **6(9)**: 2026-2032.
[4] Anonymous 2013. Production yearbook, Rome, Italy, http:// www.Faostat.fao.org/567.
[5] Apel, K. and Hirt, H. 2004. Rective oxygen species: metabolism oxidative stress and signal transduction. *Annu. Rev. Plant Biol.* **55**:373-399.
[6] Bibi, A. Sadaqut, H. A., Akram, H. M., Mohammed, M. I. 2010. Physiological markers for screening sorghum (sorghum bicolor) germplasm under water stress condition. *Int. J. Agric. Biol.* **12**: 451-455.
[7] Blum, A. 1988. Plant breeding for stress environments. Boca Raton, Florida: CRC Press.
[8] Blum, A., Zhang, J. and Nguyen, H. T. 1999. Consistent differences among wheat cultivars in osmotic adjustment and their relationship to plant production. *Field Crops Res.*, **64**:287–291.
[9] Cadenas, S. E., 1989. Biochemistry of oxygen toxicity. *Annu. Rev. Biochem.* **58**: 79-110.
[10] Coasta , H., Gallego, S.M. and Tomaro, M. L. 2002. Effect of UV-B radiations on ntioxidant defense system in Sunflower cotyledons. *Plant Sci.* **162**: 939-945.
[11] Dhindsa, R. A., Dhinda, P.P. and Thorpe, T.A. 1981. Senescence: correlated with increased permeability and lipid peroxidation and decreases levels of superoxide dismutase and catalase. *J.Expt. Bot.***126**:93-101.
[12] Fischer, R.A. and Maurer, R. 1978. Drought resistance in spring wheat cultivars, I. Grain yield responses in spring wheat. *Aust. J. Agril. Sci.* **29** : 892-912.
[13] Fischer, K.S. and Wood. G. 1981. Breeding and selection for drought tolerance in tropical maize. Proc. In: *Proc. Symp. on Principles and Methods in crop improvement for drought resistance with emphasis on rice.* IRRI, Philippines.23-25th May, 1981.
[14] Hussain, M., Malik, M.A., Farooq, M., Ashraf, M.Y. and Cheema, M.A. 2008. Improving drought tolerance by exogenous application of glycinebetaine and salicylic acid in sunflower. *J. Agron. Crop Sci.,* **194**: 193-199.
[15] Kumar, R. R., Karajol, K. and Naik, G. R. 2011. Effect of polyethelene glycol induced water
[16] stress on physiological and biochemical responses in pigeonpea (*Cajanus cajan* L.
[17] Millsp) *Rec. Res. Sci. Tech.* **3(1)** : 148-152.
[18] Mali, P.C. and Mehta, S. L. 1977. Effect of drought on enzymes and free proline in rice varieties. *Phytochem.* **16** : 11-16.
[19] Moller, I.M., Jensen, P.E. and Hansson, A. 2007. Oxidative modifications to cellular components in plants. *Annu. Rev. Plant Biol.,* **58**: 459-481.
[20] Morgan, J. M. 1980. Osmotic adjustment in the spikelets and leaves of wheat. *J.Exptl. Bot.* **31:**655–665.
[21] Morgan, J.M. and Condon, A.G. 1986. Water use, grain yield, and osmoregulation in wheat. *Aust. J. Plant Physiol.,* **13**:523–532.
[22] Moussa, H. R. and Abdel-Aziz, S. M. 2008. Comparative response of drought tolerant and
[23] drought sensitive maize genotypes to water stress. *Aus. J. Crop Sci.* **1(1)** : 31-36.
[24] Panase, V. G. and Sukhatme, P. V. 1964. Statistical methods for agricultural workers. 2nd ed. P. S. Hariharan, ICAR, New Delhi, Chap. **9a1**, 166-174.
[25] Peltzer, D., Dreyer, E. and Polle, A. 2002. Differential temperature dependencies of antioxidative enzymes in two contrasting species *Fagus sylvatica* and *Coleus blumei. Plant Physiol. Biochem.* **40** : 141-150.
[26] Rahman, S. M. L., Nawata, E. and Sakuratani, T. 1999. Effect of water stress on superoxide dismutase and water content of tomato cultivars at different plant ages. *Hortic. Sci.* **34** : 490.
[27] Rakshit, S., Hariprasanna, K., Gomashe, S., Ganapathy, K. N., Das, I. K., Ramana, O. V., Dhandapani, A. and Patil, J. V. 2014. Changes in area, yield grains and yield stability of sorghum in major sorghum producing countries. *Crop Sci.* **54**: 1571-1584.
[28] Saini, H.S. and Aspinall, D. 1982. Sterility in wheat (*Triticum aestivum* L.) induced by water deficit or high temperature: possible mediation by abscisic acid. *Aust. J. Plant Physiol.,* **9**:529–537.
[29] Sairam, R. K., Deshmukh, P. S. and Shukla, D. S. 1997. Tolerance of drought and temperature stress in relation to increased antioxidant enzyme activity in wheat. *J. Agron. Crop Sci.* **178 :** 171-178.
[30] Sharma, P., Dubey, R.S. 2005. Drought induces oxidative stress and enhances the activities of antioxidant enzyme in growing rice seedling. *Plant Growth Regul.,* **46**: 209-221.
[31] Sharma, P., Jha, A. B., Dubey, R. S. and Pessarakli, M. 2012. Reactive oxygen species, oxidative damage and antioxidative mechanism in plants under stressful conditions. *J. Bot.* ID 217037 :26 http://dx.doi.org/10-1155/2012/217037.

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[32] Sharp, R. E., Poroyko, V., Hejlek, L.G., Spollen, W.G., Springer, G.K., Bohnert, H.J. and Nguyen, H. T. 2004. Root growth maintenance during water deficits: physiology to functional genomics. *J. Exptl. Bot.*, **55**:2343–2351.

[33] Shigeoka, S., Ishikawa, T., Tamoi, M., Miyagawa, Y., Takeda, T., Yabuta, Y. and Yoshimura, K. 2002. Regulation and function of ascorbate peroxidase isoenzymes. *J. Exp. Bot.*, **53**: 1305-1319.

[34] Singh, G. and Sharma, N. 2013. Antioxidative response of various cultivars of sorghum (*sorghum bicolor* (L.) to drought stress. *J. Stress Physiol. & Biochem.,* **9(3)**: 139-151.

[35] Sterjiades, R., Dean, F.P. and Eriksson, K. L. 1992. Laccase from sycamore maple (Acer pseudoplatanus) polymerizes monoolignols. *Plant Physiol.* **99**: 1162-1168. (1992).

[36] Yang, F., Xu, X., Xiao, X., Li, C. 2009. Responses to drought stress in two poplar species originating from different altitudes. *Biol. Plant.,* **53**: 511-516.

[37] Zhang, J., Nguyen, H.T. and Blum, A. 1999. Genetic analysis of osmotic adjustment in crop plants. *J. Exptl. Bot.*, **50**:291–302.

[38] Ziatko Zlatev and Lindon, F. C. 2012. An overview on drought induced changes in plant growth, water relations and photosynthesis. *Emir. J. Food Agric.* **24(1)**: 57-72.

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