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Proline, Glycine, Betaine and Dry Matter Accumulation in Rabi Sorghum Under Moisture Stress

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In order to evaluate physiological traits related to biochemical basis of drought tolerance under moisture stress, a field experiment with ten sorghum genotypes was carried out in split plot design with three replications. Seeds were grown separately under three moisture 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. The accumulation of proline and glycine betaine was higher under moisture stress than terminal stress and non-stress condition. Accumulation of proline and glycine betaine content was recorded at the time of 50% flowering and at dough stage to estimate the efficiency of drought tolerance. Among the genotypes under study, RSV 1237 accumulated more leaf proline, whereas, RSV 1572 accumulated more glycine betaine at 50% flowering stage and dough stage under moisture stress. Genotypes differed significantly with respect to leaf, stem, panicle and total dry matter per plant. RSV 1237 and RSV 1572 had better partitioning of dry matter into reproductive parts under moisture and terminal stress conditions. It was concluded that these genotypes could be useful in sorghum breeding for drought tolerance.

Key words: Osmolytes, Drought tolerance, Leaf proline, Glycine betaine, Dry matter partitioning.

Sorghum (*Sorghum bicolor*) is grown in many parts of the world. 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 is 963 kg ha^{-1} which is much less than the world average of 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 M.T. During the year 2013, sorghum was cultivated on 8.04 and 22.44 lakh ha area in *kharif* and *rabi* season with an average productivity of 1152 and 693 kg per ha, respectively (FAO Report, 2013). Sorghum is a C_4 crop with a high photo synthetic efficiency, drought tolerant and heat tolerant, well adapted to grow in hot, arid or semiarid areas. As compared to *kharif* season, the productivity of *rabi* season is very less. Moisture stress is one of the important drought factor. Nearly 70% of sorghum area depends on rain not assured in most of the sorghum growing areas, where it is grown under stored and receding soil moisture conditions with increasing temperature after flowering. These are faces the problem of drought. As such the crop productivity in such area is low.

It is recognized that resistant plants under water stress conditions develop various physiological and biochemical responses of adaptive nature. These include changes of water use efficiency, pigment content, osmotic adjustment and photosynthetic activity . Water stress in a cell profoundly alters the chemical composition of plant *viz*; accumulation.of proline, polyamines, glycine betaines, increases nitrate reductase activity, increases storage of carbohydrates, sugar content *etc*. (Salimath and Biradar, 2002). Accumulation of solutes during moisture stress, save the plant cell from dehydration and the addition accumulation of several other solutes, particularly sugar and potassium contributes a greater extent in osmotic adjustment. As mechanisms of responses to drought stress varies with genotypes and growth stages of individual plants (Ashraf and Harris 2004), it would be much more valuable if biochemical indicators could be specified for individual crop species. Knowledge on interrelationships among various physiological responses to dehydration can offer insight for developing useful strategies to improve drought stress tolerance in sorghum.

Materials and Methods

Eight promising genotypes and two released varieties of sorghum were evaluated in split plot design with three replication under moisture stress (irrigation given at the time of sowing), terminal stress (irrigation given at the time of sowing and panicle initiation stage) and non stress (irrigation given at

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the time of sowing and at proper stages of growth) condition separately at Pulses Improvement Project, MPKV, Rahuri during *rabi* 2013-14 and 2014-15. The plant samples used for estimation of leaf area was also subsequently used for estimation of dry matter per plant. The plant parts *viz.,* stem, leaves and panicles were separated and dried in hot air oven at 80ºC for first one hour and then at 60ºC till the samples was dried completely and constant weight was obtained. The dry weight of individual plant parts were recorded separately. Then total dry matter per plant was computed.Third fully expanded leaf from the top was used at 50% flowering stage and at dough stage for estimation of biochemical parameters. Proline content in leaf tissues of stress and unstress seedlings were determined by using the acid ninhydrin reagent as per the method described by Bates *et al.* (1973). Glycine betaine content in leaves of stress and non-stress seedlings was determined by using the Dragendorff reagent as per the method described by Stumpf (1984). The data were analyzed statistically by using standard method of "Analysis of Variance" suggested by Panse and Sukhatme (1964).

Due to drought there is reduction in yield. Thus stress index is very useful and reliable to identify the drought resistant varieties. 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 will be calculated as per the formula suggested by Fisher and Wood (1981).

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

Results and Discussion

Osmolytes accumulation

Plants accumulate different types of organic and inorganic solutes in the cytosol to lower osmotic potential thereby maintaining cell turgor (Rhodes and Samaras, 1994). Under drought, the maintenance of leaf turgor may also be achieved by the way of osmotic adjustment in response to the accumulation of proline, sucrose, soluble carbohydrates, glycinebetaine, and other solutes in

Table 1. Mean proline content (mmoles gram^{-1} fr. wt.) 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	0.695	0.586	0.246	0.509	0.554	0.441	0.261	0.419	0.625	0.514	0.254	0.464
RSV 1199	1.382	0.997	0.301	0.893	1.052	0.897	0.264	0.738	1.217	0.947	0.283	0.816
RSV 1209	1.356	0.981	0.354	0.897	1.070	0.885	0.280	0.745	1.213	0.933	0.317	0.821
RSV 1237	2.669	1.358	0.377	1.468	2.330	1.344	0.347	1.340	2.500	1.351	0.362	1.404
RSV 1454	0.833	0.956	0.263	0.684	0.870	0.688	0.274	0.611	0.852	0.822	0.269	0.647
RSV 1458	1.560	1.008	0.330	0.966	1.313	0.996	0.284	0.864	1.437	1.002	0.307	0.915
RSV 1572	2.521	1.274	0.374	*1.390*	*2.203*	1.216	0.333	1.251	*2.362*	1.245	0.354	*1.320*
RSV 1620	1.391	1.000	0.332	0.908	1.288	0.984	0.297	0.856	1.340	0.992	0.315	0.882
P.Anuradha	2.408	1.308	0.393	1.370	2.196	1.214	0.346	1.252	2.302	1.261	0.370	*1.311*
P.Yashoda	0.925	0.703	0.249	0.626	0.836	0.616	0.268	0.573	0.881	0.660	0.259	0.600
Mean	1.574	1.017	0.322		1.371	0.928	0.295		1.473	0.973	0.309	
	M	**G**	**M x G**		**M**	**G**	**M x G**		**M**	**G**	**M x G**	
S.E.±	0.020	0.030	0.052		0.019	0.026	0.045		0.024	0.034	0.059	
C.D. at 5%	0.080	0.085	0.147		0.073	0.073	0.127		0.078	0.096	0.167	
At dough stage												
RSV 1188	0.807	0.703	0.263	0.591	0.647	0.593	0.277	0.506	0.727	0.648	0.270	0.548
RSV 1199	1.583	1.143	0.320	1.016	1.423	1.013	0.287	0.908	1.503	1.078	0.303	0.962
RSV 1209	1.837	1.273	0.367	1.159	1.484	0.990	0.307	0.927	1.661	1.132	0.337	1.043
RSV 1237	2.790	1.857	0.413	1.687	2.817	1.730	0.377	1.641	2.803	1.793	0.395	1.664
RSV 1454	1.307	1.103	0.287	0.899	1.033	0.783	0.303	0.707	1.170	0.943	0.295	0.803
RSV 1458	1.917	1.543	0.353	1.271	1.697	1.153	0.353	1.068	1.807	1.348	0.353	1.169
RSV 1572	*2.687*	1.587	0.390	1.554	2.617	1.677	0.363	1.552	2.652	1.632	0.377	1.553
RSV 1620	1.560	1.370	0.363	1.098	1.623	1.143	0.323	1.030	1.592	1.257	0.343	1.064
P.Anuradha	*2.667*	1.470	0.417	1.518	2.493	1.617	0.393	1.501	2.580	1.543	0.405	1.509
P.Yashoda	1.207	0.930	0.297	0.811	0.957	0.703	0.297	0.652	1.082	0.817	0.297	0.732
Mean	1.836	1.298	0.347		1.679	1.140	0.328		1.758	1.219	0.338	
	M	**G**	**M x G**		**M**	**G**	**M x G**		**M**	**G**	**M x G**	
S.E.±	0.010	0.025	0.044		0.011	0.022	0.038		0.013	0.029	0.050	

Table 2. Mean glycine betaine content (mmoles g^{-1} fr. wt.) 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 stage												
RSV 1188	5.061	3.568	2.014	3.548	4.862	3.339	1.826	3.342	4.962	3.454	1.920	3.445
RSV 1199	5.394	4.090	2.452	3.979	5.238	3.850	2.222	3.770	5.316	3.970	2.337	3.874
RSV 1209	4.528	2.890	1.826	3.081	4.476	2.702	1.576	2.918	4.502	2.796	1.701	3.000
RSV 1237	5.697	4.685	2.974	4.452	5.436	4.455	2.702	4.198	5.567	4.570	2.838	4.325
RSV 1454	4.748	3.099	1.899	3.249	4.601	2.838	1.659	3.033	4.675	2.969	1.779	3.141
RSV 1458	5.916	4.163	2.421	4.167	5.687	3.923	2.233	3.948	5.802	4.043	2.327	4.057
RSV 1572	6.386	4.758	2.796	4.647	6.156	4.414	2.546	4.372	6.271	4.586	2.671	4.509
RSV 1620	4.988	3.955	2.713	3.885	4.789	3.756	2.483	3.676	4.889	3.856	2.598	3.781
P.Anuradha	5.624	4.539	2.890	4.351	5.384	4.278	2.650	4.104	5.504	4.409	2.770	4.228
P.Yashoda	5.342	3.798	2.129	3.756	5.186	3.579	1.962	3.576	5.264	3.689	2.046	3.666
Mean	5.368	3.955	2.411		5.182	3.713	2.186		5.275	3.834	2.299	
	M	**G**	**M x G**		**M**	**G**	**M x G**		**M**	**G**	**M x G**	
S.E.±	0.050	0.050	0.087		0.029	0.045	0.078		0.050	0.058	0.101	
C.D. at 5%	0.197	0.142	0.246		0.115	0.128	0.222		0.164	0.164	0.284	
At dough stage												
RSV 1188	4.435	2.661	1.784	2.960	4.236	2.473	1.669	2.793	4.336	2.567	1.727	2.876
RSV 1199	4.581	3.182	2.045	3.269	4.508	2.995	1.920	3.141	4.545	3.089	1.983	3.205
RSV 1209	3.996	2.515	1.555	2.689	3.767	2.285	1.419	2.490	3.882	2.400	1.487	2.590
RSV 1237	4.883	3.704	2.327	*3.638*	4.654	3.433	2.181	*3.423*	4.769	3.569	2.254	*3.530*
RSV 1454	4.195	2.619	1.628	2.814	4.007	2.379	1.534	2.640	4.101	2.499	1.581	2.727
RSV 1458	*5.165*	3.506	2.087	3.586	*4.988*	3.224	1.962	*3.391*	*5.077*	3.365	2.025	*3.489*
RSV 1572	5.384	3.568	2.243	3.732	5.196	3.308	2.108	3.537	5.290	3.438	2.176	3.635
RSV 1620	4.351	2.974	2.181	3.169	4.184	2.775	2.097	3.019	4.268	2.875	2.139	3.094
P.Anuradha	4.810	3.558	2.264	3.544	4.581	3.266	2.129	3.325	4.696	3.412	2.197	3.435
P.Yashoda	4.539	2.807	1.847	3.064	4.309	2.629	1.722	2.887	4.424	2.718	1.785	2.976
Mean	4.634	3.109	1.996		4.443	2.877	1.874		4.538	2.993	1.935	
	M	**G**	**M x G**		**M**	**G**	**M x G**		**M**	**G**	**M x G**	
S.E.±	0.039	0.047	0.081		0.024	0.052	0.091		0.039	0.061	0.105	
C.D. at 5%	0.152	0.132	0.229		0.093	0.148	0.257		0.128	0.170	0.295	

cytoplasm improving water uptake from drying soil. The process of accumulation of such solutes under drought stress is known as osmotic adjustment which strongly depends on the rate of plant water stress. Wheat is marked by low level of these compatible solutes and the accumulation and

Table 3. Leaf dry matter $plant^{-1}$ as influenced by moisture regimes, genotypes and their interactions in sorghum

Genotypes	2013-14				2014-15				Pooled Data			
	MS	TS	NS	Mean	MS	TS	NS	Mean	MS	TS	NS	Mean
50 % flowering stage												
RSV 1188	17.4	21.2	35.6	24.7	18.1	20.8	33.9	24.3	17.8	21.0	34.8	24.5
RSV 1199	16.3	20.1	33.1	23.2	16.9	19.3	30.1	22.1	16.6	19.7	31.6	22.6
RSV 1209	15.4	19.8	30.8	22.0	16.6	18.7	26.7	20.7	16.0	19.3	28.8	21.3
RSV 1237	21.3	24.9	33.4	26.5	20.2	23.5	30.5	24.7	20.8	24.2	32.0	25.6
RSV 1454	15.0	18.3	27.3	20.2	15.5	16.8	26.4	19.6	15.3	17.6	26.9	19.9
RSV 1458	20.4	23.2	28.9	24.2	19.1	22.7	24.9	22.2	19.8	23.0	26.9	23.2
RSV 1572	19.6	21.9	25.1	22.2	18.7	21.8	22.3	20.9	19.2	21.9	23.7	21.6
RSV 1620	11.4	14.1	23.9	16.5	10.7	13.9	19.5	14.7	11.1	14.0	21.7	15.6
P.Anuradha	13.1	15.7	24.8	17.9	12.6	14.2	21.8	16.2	12.9	15.0	23.3	17.0
P.Yashoda	17.2	20.6	39.5	25.8	17.5	19.9	36.5	24.6	17.4	20.3	38.0	25.2
Mean	16.7	20.0	30.2		16.6	19.2	27.3		16.7	19.6	28.8	
	(44.70)	(33.77)			(39.19)	(29.67)			(42.01)	(31.94)		
	M	G	M x G		M	G	M x G		M	G	M x G	
S.E.±	0.233	0.415	0.718		0.132	0.339	0.587		0.232	0.463	0.803	
C.D. at 5%	0.916	1.176	2.036		0.520	0.961	1.664		0.758	1.300	2.252	
Physiological maturity												
RSV 1188	15.6	19.0	32.7	22.4	16.9	18.3	30.8	22.0	16.2	18.6	31.8	22.2
RSV 1199	15.5	18.9	28.9	21.1	15.8	16.6	25.6	19.3	15.7	17.8	27.3	20.2
RSV 1209	14.2	17.7	25.8	19.2	15.4	16.1	22.1	17.8	14.8	16.9	24.0	18.5
RSV 1237	19.3	21.8	28.9	23.3	18.3	21.1	26.9	22.1	18.8	21.5	27.9	22.7
RSV 1454	13.5	16.4	23.9	17.9	14.0	15.2	22.4	17.2	13.8	15.8	23.2	17.6
RSV 1458	17.4	21.5	25.1	21.3	17.9	20.4	22.2	20.2	17.7	21.0	23.7	20.8
RSV 1572	16.9	19.9	21.7	19.5	17.6	19.7	20.8	19.4	17.3	19.8	21.3	19.4
RSV 1620	9.6	12.1	20.6	14.1	9.8	11.1	17.6	12.8	9.7	11.6	19.1	13.5
P.Anuradha	11.8	13.6	21.9	15.8	10.8	12.0	18.9	13.9	11.3	12.8	20.4	14.8
P.Yashoda	16.0	19.2	33.7	23.0	15.7	17.4	30.2	21.1	15.9	18.3	32.0	22.0
Mean	15.0	18.0	26.3		15.2	16.8	23.8		15.1	17.4	25.0	
	(42.97)	(31.56)			(36.13)	(29.41			(39.60)	(30.40)		
M	G	M x G		M	G	M x G		M	G	M x G		
S.E.±	0.341	0.447	0.775		0.188	0.298	0.516		0.337	0.465	0.806	
C.D. at 5%	1.340	1.269	2.197		0.737	0.844	1.462		1.099	1.305	2.260	

mobilization of proline was observed to enhance tolerance to water stress (Nayyar and Walia, 2003). Of these solutes, proline is the most widely studied because of its considerable importance in the stress tolerance. Proline accumulation is the first response of plants exposed to water-deficit stress in order to reduce injury to cells. Progressive drought stress induced a considerable accumulation of proline in water stressed maize plants.

Table 4. Stem dry matter plant^{-1} (g) as influenced by moisture regimes, genotypes and their interactions in sorghum

Genotypes	2013-14				2014-15				Pooled Data			
	MS	TS	NS	Mean	MS	TS	NS	Mean	MS	TS	NS	Mean
50 % flowering stage												
RSV1188	44.3	64.4	127.6	78.8	46.5	56.2	112.8	71.8	45.4	60.3	120.2	75.3
RSV1199	42.8	61.6	117.4	73.9	43.2	55.4	107.4	68.7	43.0	58.5	112.4	71.3
RSV 1209	41.1	60.8	107.3	69.7	42.8	54.3	101.8	66.3	42.0	57.6	104.6	68.0
RSV 1237	52.2	78.5	112.5	81.1	49.6	62.1	110.5	74.1	50.9	70.3	111.5	77.6
RSV 1454	40.9	59.4	100.1	66.8	42.4	53.8	98.7	65.0	41.7	56.6	99.4	65.9
RSV 1458	48.4	68.2	100.4	72.3	46.2	57.4	89.7	64.4	47.3	62.8	95.1	68.4
RSV 1572	49.5	71.3	101.7	74.2	47.6	59.7	99.2	68.8	48.6	65.5	100.5	71.5
RSV 1620	39.5	59.9	83.4	60.9	40.1	48.6	77.7	55.5	39.8	54.3	80.6	58.2
P.Anuradha	41.6	61.5	89.3	64.1	41.6	49.3	79.8	56.9	41.6	55.4	84.6	60.5
P.Yashoda	46.7	63.9	123.8	78.1	45.6	55.90	133.5	78.3	46.2	59.9	128.7	78.2
Mean	44.7	65.0	106.4		44.6	55.3	101.1		44.6	60.1	103.7	
	M	G	M x G		M	G	M x G		M	G	M x G	
S.E.±	0.176	0.729	1.262		0.314	0.713	1.235		0.312	0.883	1.529	
C.D. at 5%	0.693	2.066	3.578		1.234	2.022	3.501		1.018	2.475	4.287	
Physiological maturity												
RSV1188	42.0	61.5	121.6	75.0	45.1	53.3	103.5	67.3	43.5	57.4	112.5	71.1
RSV1199	40.3	58.1	109.1	69.2	42.1	53.4	97.4	64.3	41.2	55.7	103.2	66.7
RSV 1209	39.9	57.6	103.0	66.8	41.1	52.3	92.3	61.9	40.5	54.9	97.7	64.4
RSV 1237	49.8	73.6	105.0	76.1	47.6	58.8	101.8	69.4	48.7	66.2	103.4	72.8
RSV 1454	38.6	56.7	91.4	62.2	40.9	52.2	87.4	60.2	39.8	54.4	89.4	61.2
RSV 1458	45.4	63.4	94.3	67.7	44.5	53.9	81.4	59.9	45.0	58.6	87.9	63.8
RSV 1572	46.2	66.2	95.4	69.3	44.3	56.1	87.9	62.8	45.3	61.2	91.7	66.0
RSV 1620	35.3	52.8	75.7	54.6	36.9	45.1	68.6	50.2	36.1	49.0	72.1	52.4
P.Anuradha	37.8	57.9	80.7	58.8	38.3	45.6	70.7	51.5	38.1	51.7	75.7	55.2
P.Yashoda	45.2	60.4	115.4	73.7	44.1	54.3	124.7	74.4	44.6	57.4	120.0	74.0
Mean	42.1	60.8	99.2		42.5	52.5	91.6		42.3	56.7	95.4	
	M	G	M x G		M	G	M x G		M	G	M x G	
S.E.±	0.319	0.771	1.336		0.327	0.793	1.374		0.396	0.958	1.659	
C.D. at 5%	1.254	2.187	3.788		1.283	2.249	3.896		1.290	2.686	4.653	

Proline can act as a signaling molecule to modulate mitochondrial functions, influence cell proliferation or cell death and trigger specific gene

Table 5. Panicle dry matter plant^{-1} (g) as influenced by moisture regimes, genotypes and their interactions in sorghum

Genotypes	2013-14				2014-15				Pooled Data			
	MS	TS	NS	Mean	MS	TS	NS	Mean	MS	TS	NS	Mean
50 % flowering stage												
RSV1188	5.8	7.5	15.4	9.6	6.0	7.0	12.6	8.5	5.9	7.3	14.0	9.1
RSV1199	4.1	6.1	14.6	8.3	3.8	6.0	12.0	7.3	4.0	6.1	13.3	7.8
RSV 1209	3.8	5.9	13.5	7.7	3.1	5.1	11.9	6.7	3.5	5.5	12.7	7.2
RSV 1237	8.9	10.5	13.9	11.1	7.2	8.6	12.4	9.4	8.0	9.5	13.2	10.2
RSV 1454	3.7	5.6	12.0	7.1	3.3	5.7	11.2	6.8	3.5	5.7	11.6	6.9
RSV 1458	8.4	9.4	12.8	10.2	6.8	7.8	11.1	8.6	7.6	8.6	12.0	9.4
RSV 1572	7.8	8.9	12.3	9.7	7.0	8.1	11.4	8.8	7.4	8.5	11.9	9.3
RSV 1620	7.3	7.8	11.4	8.8	6.0	6.6	10.2	7.6	6.7	7.2	10.8	8.2
P.Anuradha	7.6	8.3	11.8	9.2	6.2	6.9	11.1	8.1	6.9	7.6	11.4	8.7
P.Yashoda	4.6	6.6	17.0	9.4	3.7	6.2	14.3	8.1	4.2	6.4	15.6	8.7
Mean	6.2	7.7	13.5		5.3	6.8	11.8		5.8	7.2	12.6	
	M	G	M x G		M	G	M x G		M	G	M x G	
S.E.±	0.084	0.245	0.424		0.060	0.076	0.132		0.089	0.222	0.385	
C.D. at 5%	0.329	0.694	1.203		0.237	0.216	0.374		0.292	0.623	1.079	
Physiological maturity												
RSV1188	13.9	17.3	41.9	24.4	13.3	15.2	41.6	23.4	13.6	16.3	41.8	23.9
RSV1199	9.1	12.3	42.6	21.3	7.7	11.3	43.1	20.7	8.4	11.8	42.9	21.0
RSV 1209	8.8	12.0	41.2	20.7	7.3	10.7	40.7	19.6	8.1	11.4	41.0	20.1
RSV 1237	19.1	22.6	40.3	27.3	18.6	21.9	39.6	26.7	18.9	22.3	40.0	27.0
RSV 1454	8.5	11.6	35.9	18.7	7.1	10.4	33.1	16.9	7.8	11.0	34.5	17.8
RSV 1458	20.3	21.6	37.3	26.4	19.8	20.7	35.8	25.4	20.1	21.2	36.6	25.9
RSV 1572	20.0	22.3	38.8	27.0	19.2	21.2	37.6	26.0	19.6	21.8	38.2	26.5
RSV 1620	17.2	19.3	35.0	23.8	16.9	18.8	32.3	22.7	17.1	19.1	33.7	23.3
P.Anuradha	18.1	20.1	36.1	24.8	17.4	20.2	33.3	23.6	17.8	20.2	34.7	24.2
P.Yashoda	9.4	14.3	45.3	23.0	8.1	13.7	45.8	22.5	8.8	14.0	45.6	22.8
Mean	14.4	17.3	39.4		13.5	16.4	38.3		14.0	16.9	38.9	
	M	G	M x G		M	G	M x G		M	G	M x G	
S.E.±	0.062	0.372	0.644		0.164	0.273	0.472		0.152	0.399	0.692	
C.D. at 5%	0.244	1.054	1.826		0.643	0.773	1.339		0.495	1.119	1.939	

expression, which can be essential for plant recovery from stress (Szabados and Savoure´, 2009). Accumulation of proline under stress in many plant species has been correlated with stress tolerance, and its concentration has been shown to be generally higher in stress-tolerant than in stress-sensitive plants. It influences protein solvation and preserves the quarternary structure of complex proteins, maintains membrane integrity under dehydration stress and reduces oxidation of lipid membranes or photoinhibition (Demiral and Turkan, 2004). In the present investigation, the differences amongst the genotypes, moisture regimes and interaction effects were statistically significant for proline content during both the years (Table 1). On an average of 2013-2014 and 2014-2015, the leaf proline content was increased by 214.89 and 376.69 per cent of non stress under terminal and moisture stress, respectively at 50% flowering, whereas, at dough stage it was increased by 260.65 and 420.12 per cent, respectively. Among the genotypes, RSV 1237 under moisture stress (2.500 mmoles g^{-1} fr.

Table 6. Total dry matter plant^{-1} (g) as influenced by moisture regimes, genotypes and their interactions in sorghum

Genotypes	2013-14				2014-15				Pooled Data			
	MS	TS	NS	Mean	MS	TS	NS	Mean	MS	TS	NS	Mean
50 % flowering stage												
RSV 1188	67.5	93.1	178.6	113.1	70.6	84.0	159.3	104.6	69.0	88.6	169.0	108.9
RSV 1199	63.2	87.8	165.1	105.4	63.9	80.7	149.5	98.1	63.6	84.3	157.3	101.7
RSV 1209	60.3	86.5	151.6	99.5	62.5	78.1	140.4	93.7	61.4	82.3	146.0	96.6
RSV 1237	82.4	113.9	159.8	118.7	77.0	94.2	153.4	108.2	79.7	104.1	156.6	113.4
RSV 1454	59.6	83.3	139.4	94.1	61.2	76.3	136.3	91.3	60.4	79.8	137.9	92.7
RSV 1458	77.2	100.8	142.1	106.7	72.1	87.9	125.7	95.3	74.7	94.4	133.9	101.0
RSV 1572	76.9	102.1	139.1	106.0	73.3	89.6	132.9	98.6	75.1	95.8	136.0	102.3
RSV 1620	58.2	81.8	118.7	86.2	56.8	69.1	107.4	77.8	57.5	75.4	113.0	82.0
P.Anuradha	62.3	85.5	125.9	91.2	60.4	70.4	112.7	81.2	61.4	78.0	119.3	86.2
P.Yashoda	68.5	91.1	180.3	113.3	66.8	82.0	184.3	111.0	67.7	86.5	182.3	112.2
Mean	67.6	92.6	150.1		66.5	81.2	140.2		67.0	86.9	145.1	
	M	**G**	**M x G**		**M**	**G**	**M x G**		**M**	**G**	**M x G**	
S.E.±	0.226	0.922	1.596		0.287	0.835	1.446		0.316	1.077	1.865	
C.D. at 5%	0.889	2.613	4.526		1.125	2.367	4.099		1.031	3.019	5.228	
Physiological maturity												
RSV 1188	71.5	97.8	196.2	121.8	75.2	86.8	175.9	112.6	73.4	92.3	186.0	117.2
RSV 1199	64.9	89.3	180.6	111.6	65.6	81.3	166.1	104.3	65.3	85.3	173.3	108.0
RSV 1209	62.8	87.3	170.0	106.7	63.8	79.1	155.1	99.3	63.3	83.2	162.6	103.0
RSV 1237	88.2	118.0	174.2	126.8	84.5	101.8	168.3	118.2	86.4	109.9	171.2	122.5
RSV 1454	60.6	84.7	151.2	98.8	62.0	77.8	142.9	94.2	61.3	81.2	147.0	96.5
RSV 1458	83.1	106.5	156.7	115.4	82.2	95.0	139.4	105.5	82.7	100.7	148.1	110.5
RSV 1572	83.1	108.4	155.9	115.8	81.1	97.0	146.3	108.1	82.1	102.7	151.1	112.0
RSV 1620	62.1	84.2	131.3	92.5	63.6	75.0	118.5	85.7	62.9	79.6	124.9	89.1
P.Anuradha	67.7	91.6	138.7	99.3	66.5	77.8	122.9	89.1	67.1	84.7	130.8	94.2
P.Yashoda	70.6	93.9	194.4	119.6	67.9	85.4	200.6	118.0	69.2	89.6	197.5	118.8
Mean	71.5	96.2	164.9		71.2	85.7	153.6		71.4	90.9	159.3	
	M	**G**	**M x G**		**M**	**G**	**M x G**		**M**	**G**	**M x G**	
S.E.±	0.605	1.030	1.783		0.388	0.895	1.550		0.623	1.181	2.046	
C.D. at 5%	2.377	2.920	5.078		1.526	2.537	4.395		2.031	3.312	5.737	

Table 7. 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 8. Drought susceptibility index (DSI) (%) and Drought tolerance efficiency (DTE) (%) in sorghum under stress conditions.

Genotypes	2013-2014				2014-2015				Pooled			
	DSI		DTE		DSI		DTE		DSI		DTE	
	MS	TS	MS	TS	MS	TS	MS	TS	MS	TS	MS	TS
RSV1188	1.087	1.150	13.82	20.78	1.131	1.167	11.73	22.29	1.109	1.158	12.79	21.53
RSV1199	1.139	1.217	9.73	16.14	1.164	1.253	9.14	16.54	1.151	1.235	9.45	16.34
RSV1209	1.168	1.268	7.45	12.63	1.204	1.303	6.02	13.19	1.186	1.285	6.73	12.91
RSV1237	0.964	0.922	23.60	36.49	0.934	0.889	27.06	40.77	0.950	0.906	25.30	38.60
RSV1454	1.151	1.249	8.78	14.00	1.177	1.278	8.14	14.89	1.163	1.263	8.48	14.42
RSV1458	0.790	0.689	37.39	52.55	0.753	0.683	41.21	54.50	0.772	0.686	39.31	53.53
RSV1572	0.796	0.657	36.88	54.74	0.726	0.613	43.36	59.16	0.762	0.636	40.05	56.90
RSV1620	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

wt.) and terminal stress (1.351 mmoles g^{-1} fr. wt.) accumulated more leaf proline at 50% flowering stage. RSV 1572 found second best genotype had

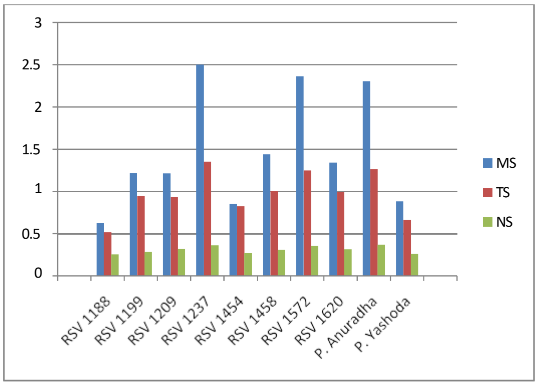

Fig. 1. Leaf proline content influenced due to moisture regimes and genotypes at 50% flowering stage

higher proline (2.362 mmoles g^{-1} fr. wt.) under moisture stress. Similar trend was observed at dough stage (Figure 1 and 2.). It was observed that

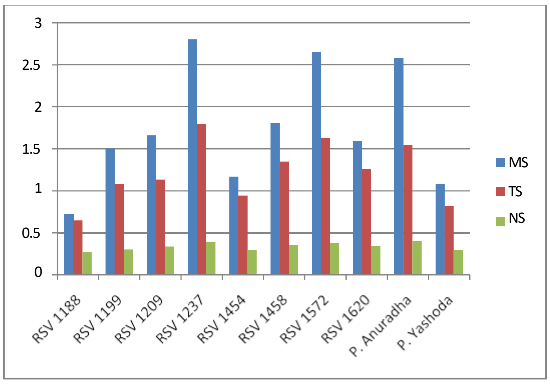

Fig. 2. Leaf proline content influenced due to moisture regimes and genotypes at dough stage.

the level of proline increased at dough stage. Many researchers reported that proline accumulated in higher level under water stress condition in drought tolerant genotypes (Sairam *et al*., 2002; Demiral and Turkan, 2004 and Deshmukh and Dhumal, 2005). In contrast, Ibrahim and Aldesuquy (2003), Ibarra-Caballero *et al*. (1988), Lutts *et al.* (1996) reported that that increased level of proline is a indicator of

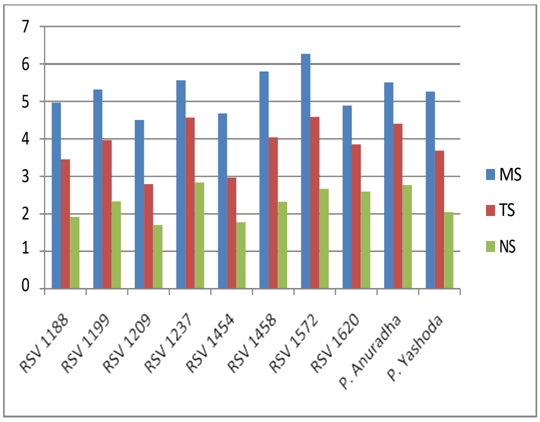

Fig. 3. Glycine betaine influenced due to moisture regimes and genotypes at 50% flowering stage.

stress not a indicator of tolerance. Premchandra *et al*. (1995) reported that the proline concentration was higher in stressed plants in contrast to all other solutes and higher proline was noticed in drought tolerant sorghum (CS 3541) than in susceptible line (K886). Jadhav *et al*. (2001) noticed in sorghum cultivar Sel-3 that content of leaf proline was increased 63% with increased water stress.

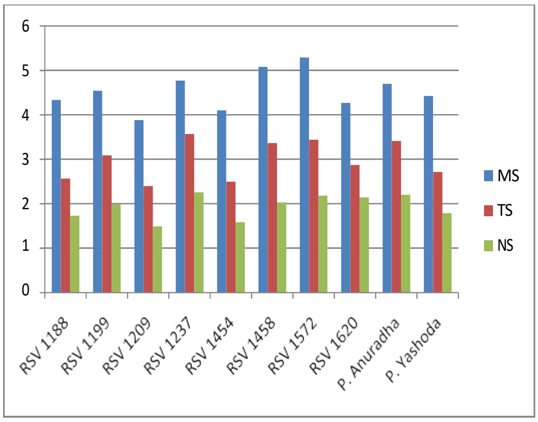

Fig. 4. Glycine betaine influenced due to moisture regimes and genotypes at dough stage.

Wahid *et al*., 2007 reported that glycine betaine (N,N,N-trimethyl glycine) is one of the most extensively studied quaternary ammonium compounds and compatible solutes in plants, animals and bacteria. Yang (1990) reported that almost all the cereal crops including sorghum accumulate glycine betaine under stress except rice but its levels vary among and within the species. On an average of 2013-2014 and 2014-2015, the glycine betaine increased by 66.77 and 129.45 per cent of non stress under terminal and moisture stress, respectively at 50% flowering, whereas, at dough stage it was increased by 54.68 and 134.52 per cent due, respectively. Among the genotypes, RSV 1572 under moisture stress (6.271 mmoles g^{-1} fr. wt.) and terminal stress (4.586 mmoles g^{-1} fr. wt.) accumulated more glycine betaine at 50% flowering stage. At dough stage, RSV 1572 under moisture stress (5.290 mmoles g^{-1} fr. wt.) and RSV 1237 under terminal stress (3.569 moles g^{-1} fr. Wt) recorded higher glycine betaine content. Jun *et al*. (2000) reported that glycine betaine accumulated more in drought tolerant than drought susceptible plants. Moussa and Abdel Aziz (2008) suggested that free proline and glycine betaine accumulation in the leaves can be used as the possible indicator for drought tolerance in maize genotypes because these osmolytes greatly accumulated in maize tolerant genotype Giza-2 at PEG stress -20 bar. Garg and Noor (2009) reported that salt tolerant genotypes accumulated more glycine betaine than salt sensitive pigeonpea genotypes.

Dry matter accumulation

The total dry matter is the result of net photosynthesis in leaves and stem during vegetative phase and mainly leaves, earheads and stem during reproductive phase. The total dry matter per unit area includes dry matter of leaves, stem and reproductive parts. The dry matter production is the net accumulation of photosynthates after meeting requirement of respiration. The manner in which the dry matter is produced by the plant and partitioned among different parts is important for obtaining high yield. Several researchers reported that drought stress reduced plant total dry weight which adversely affect grain yield. Reduction in dry matter was mainly due to reduced leaf area, reduced assimilation of photosynthetic materials.

In the present study, leaves dry matter and stem dry matter per plant were high at 50% flowering and declined at physiological maturity whereas panicle dry weight and total dry weight progressively increase up to physiological maturity. The total dry mater and dry matter of plant parts significantly reduced under moisture stress. These results are in conformity with the findings of Ravindra *et al.* (1990) and Dhopate *et al.* (1991). In the present investigation, RSV 1237 recorded maximum leaf dry weight and stem dry weight at both stages under both stress conditions (Table 3 and 4). RSV 1458 (20.1 g $plant^{-1}$) under moisture stress and RSV 1237 (22.3 g $plant^{-1}$) under terminal stress recorded maximum panicle dry weight at physiological maturity (Table 5). In case of total dry weight, RSV 1237 under moisture stress (79.7 g $plant^{-1}$) and terminal stress (104.1 g $plant^{-1}$) recorded maximum total dry weight at 50% flowering. At physiological maturity, RSV 1237 under moisture stress (86.4 g $plant^{-1}$) and terminal stress (109.9 g $plant^{-1}$) recorded maximum total dry weight (Table 6). Hiremath and Parvatikar (1985) reported that there were positive correlations between total dry matter produced by the plant and yield in sorghum.

Yield and drought indices

The yield of sorghum affected by various biotic and abiotic stresses. Moisture stress is one of the important drought factor. 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. Morgan (1984) reported that accumulation of solutes during moisture stress, save the plant cell from dehydration. Similarly reported correlation of proline accumulation with grain yield in water limited environment. In the present study RSV 1572 recorded maximum grain yield (1003 kg/ha) under moisture stress and (1426 kg ha^{-1}) under terminal stress (Table 7). This genotype had least DSI value (0.762) and high DTE value (40.05) under moisture stress (Table 4). Under terminal stress, this genotype had least DSI values (0.636) and high DTE value (56.90). RSV 1572, which gave a maximum grain yield under moisture stress and terminal stress was attributed to moderate accumulation of total dry matter with maximum harvest index and grain productivity per day. Blum (1990) reported that increase in grain yield under limited moisture not only due to high biomass production but also due to high harvest index, high biological yield. Abede *et al.* (2003) reported that cultivars with higher osmotic adjustment produces higher yield than those with lower osmotic adjustment capacity.

Conclusion

The concentration of proline and glycine betaine was increased as water stress increased. The increased concentration of proline noticed in RSV 1237 and RSV 1572 Similarly, the increased concentration of glycine betaine noticed in RSV 1572 under moisture stress condition. These two genotypes produced higher biomass and grain yield under moisture stress condition and found drought tolerant genotypes might be used in further breeding programme for the development of drought tolerant cultivars.

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