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Performance of physiological parameters in response to photothermal sensitivity of *rabi* sorghum parental lines and hybrids

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Abstract
The experiment was laid out in split plot design with three replications during *rabi* 2013-14 at All India Co-Ordinated Sorghum Improvement Project, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar (M.S.). Seven sowing dates (E1-15th August, E2-15 September, E3-15 October, E4-15 November, E5-15 December, E6- 15 January and E7- 15 February) were assigned to main plot and 16 parental lines with four male sterile and their maintainers *viz*., 104A and B, 185A and B, RMS2010-24A and B, RMS20120-10A and B. and four restorer *viz*., SPV1830, RSV1130, RSV1098 and BJV116 and their four respective hybrids 104A x SPV1830, 185A x RSV1130, RMS2010-24A x RSV1098 and RMS2010-10A x BJV116 were assigned to sub plot treatment. The observations on physiology were recorded during 50% flowering. The data on grain yield and yield contributing characters were recorded at harvest. The physiological parameters *viz*., photosynthetic rate, Canopy temperature depression CTD, leaf thickness, SPAD chlorophyll value, transpiration rate, PAR and stomatal conductance were higher in the month of October sowing date. The hybrid RMS2010-10AXBJV116 recorded highest leaf thickness and hybrid 104AXSPV1830 recorded the highest photosynthetic rate, CTD, SPAD value, transpiration rate, PAR and stomatal conductance. The results of various physiological parameters indicated their positive correlation with grain yield and other yield contributing characters.

Keywords: Physiological parameters, yield and yield contributing characters

Introduction
Sorghum (*Sorghum bicolor* L. Moench) is one of the worlds most important nutritional cereal crops and also the major staple food crop of millions of people in semi arid tropics (SAT). In India, sorghum is grown between 9^0 N and 21^0 N, on plant and plateau below 1000 m elevation receiving 500 mm to 750 mm annual rainfall with temperature ranging between 25 °C to 37 °C. Sorghum is one of the main staple food for the world's poorest and most food insecure people across the semi-arid tropics. According to FAO report (Anonymous, 2013) [1] in the world, sorghum cultivated over 38.16 million hectares producing 57.01 million tons of grain. India contribute about 16% of the worlds sorghum production. Sorghum is used for food, fodder and the production of alcoholic beverages. The sorghum growth and development is sensitive to temperature and photoperiod. Panicle initiation and flowering growth stages are delayed under long day photoperiod. Planting date is probably the most important as the growth cycle depend on the intensity of the growth cycle depend on the region and its climate. The yield with advance date of planting is always high due to favourable soil moisture and temperature. Sowing date is one of the most important factor that influences the growth and development of crop species which is related to photoperiod and temperature. However the information on photo-periodism (light) and thermo-periodism (temperature) and their influence on growth and development of sorghum are limited. Therefore, to generate physiological information on these aspects for practical utility, the present investigation was undertaken to study the photo-thermo-sensitivity in parental lines and their hybrids of *rabi* sorghum.

Materials and Methods
The experiment was laid out in a split plot design and replicated three times with total 16 parental lines and their hybrids and seven sowing dates. Seven sowing dates (E1-15th August, E2-15 September, E3-15 October, E4-15 November, E5-15 December, E6- 15 January and E7- 15 February) were assigned to main plot treatment and 16 parental lines with four male sterile and their maintainers *viz*., 104 A and B, 185 A and B, RMS 2010-24 A and RMS 2010-24 B,

RMS 2010-10 A and RMS 2010-10 B and four restorer *viz*., SPV 1830, RSV 1130, RSV 1098 and BJV 116 and their four respective hybrids 104 A x SPV 1830, 185 A x RSV 1130, RMS 2010-24 A x RSV 1098 and RMS 2010-10 A x BJV 116 were assigned to sub plot treatment. The spacing adopted was 45 x 15 cm^2. Each parental or hybrid line comprised of two rows. The fertilizers were applied to the soil as per recommended dose 100:50:50, NPK kg ha^{-1}. The half dose of nitrogen and full dose of P_2O_5 and K_2O was given at the time of sowing. The remaining half dose of nitrogen was applied at 30 days after sowing. Five plants from each plot were selected randomly and tagged at 25 DAS for recording the various growth traits, yield and other physiological parameters. The observations on morpho-physiological traits and yield parameters were recorded at 50% flowering and at harvest, respectively. Measurement of various biophysical Parameters *viz*., Photosynthetic rate, transpiration rate and stomatal conductance were recorded on the adaxial surface of third fully expanded leaf from the top at 50 per cent flowering by using IRGA (CID – 301, USA). These measurements were made between 10.00 am to 12.00 noon at all the sampling dates. Canopy temperature depression is the calculating difference of a canopy temperature from air true temperature. Infrared thermometer was used to measure canopy temperature. If value is negative then canopy temperature was lower than air temperature. This indicates sufficient water in plant. Resistance genotypes had low leaf temperature. If values positive this indicates the higher canopy temperature than air temperature. Leaf thickness measured by using 'Guage meter'. Measure the thickness at the top of leaves then middle of leaves and last end of leaves of top, middle and bottom leaves of selected sorghum plant. Calculated the average of these three values. The various components of PAR *viz.*, incident radiation, transmitted radiation, reflected radiation were measured at flowering stage with the help of line quantum sensor. The line quantum sensor was connected to data logger and the value was recorded from the data logger. Two values were recorded from each spot for accuracy and their average was considered. Absorbed radiation was worked out by adopting the equation suggested by Gallo and Daughtry (1986) [9].

Absorbed PAR = (Total Incident Radiation + Reflected Radiation)

(Total Reflected Radiation + Transmitted Radiation)

The greenness or relative chlorophyll content of the leaves was measured by SPAD (soil plant Analytical development) Chlorophyll meter (SPAD 502; Minolta company ltd). The mean data analyzed for analysis of variance by 'split plot' method suggested by Panse and Sukhatme (1967) [24].

Results and Discussion

Sorghum is a C_4 plant and efficiently converts solar energy into chemical energy. High level of photosynthesis and accumulation of photosynthates during grain filling stage determine the yield. Since photosynthesis is the corner stone of crop production, it is important to be aware of the energy available to drive photosynthesis process. The rate of photosynthesis is an important physiological parameter and consequently the yield. Biological yield is a function of photosynthetic efficiency (Kulkarni *et al.*, 1981) [19]. From the results, the highest photosynthetic rate (μmol CO_2 $m^{-2}S^{-1}$) was recorded in the month of October sowing date (38.70) due to high leaf area and favourable temperature (Max temp. 29.1 °C, Min temp. 12.4 °C), sunshine hours (8.2 h) and photoperiod (10.68 h) at critical growth stage similar results were observed by Baviskar (2012) [3]. While, lowest (20.21) mean photosynthetic rate (μmol CO_2 $m^{-2}S^{-1}$) was recorded at February sowing date as Kamatar (2004) [16] also observed that photosynthesis shows a decline with an increase in temperature and is inactivated at excessively high temperature. The physiological parameters in *rabi* sorghum varieties and hybrids exhibited significant differences for photosynthetic rate at flowering. He also stated that hybrids showed higher photosynthetic rate when compared to varieties. Similar to the results as the hybrid 104 A x SPV 1830 recorded significantly the highest mean photosynthetic rate (30.01 μmol CO_2 $m^{-2}S^{-1}$). Also, the G x E interaction effect revealed that the hybrid RMS2010-10A x BJV 116 recorded significantly the highest mean photosynthetic rate (41.77 μmol CO_2 $m^{-2}S^{-1}$) in the month of October sowing date (Table 1).

Jackson *et al.* (1981) [13] reported that the plant canopy temperature provides a measure of the plant response to its environment and has been recognized as a sensitive indicator of plant water status. From the results, the highest mean canopy temperature depression (°C) was recorded in the month of October sowing date (-6.06). While, lowest (-3.78) mean canopy temperature depression (°C) was recorded at February sowing followed by January and December sowing dates. As, CTD declined significantly under high temperature (>30 °C) condition. Bhaskar (2013) [4] also reported that with the increase in days to exposure the CTD decreased from -4.7 to -2.9 and showed that CTD can be used to determine tolerant genotypes under high temperature conditions. The hybrid 104 A x SPV 1830 recorded significantly the highest mean canopy temperature depression (°C) (-5.59) followed by RMS 2010-24 A x RSV 1098, 185A x RSV 1130 and RMS 2010-10 A x BJV 116. G x E interaction effect revealed that the hybrid 185A x RSV 1130 recorded significantly the highest mean canopy temperature depression (°C) (-6.93) in the month of October sowing date (Table 2). Hybrid 104 A x SPV 1830 also gives the highest 1000 grain weight and harvest index showed that positive correlation of CTD with grain yield, as hybrids showed more CTD than parents. Similar results shown by Ravikiran (2008) [27], Bilge Bahar (2008) [6], Khan (2012) [17], Guendouz (2012) [12] and Malviya (2013) [23].

From the results highest mean leaf thickness (mm) was recorded in the month of October sowing date (0.233). The hybrid RMS 2010-10 A x BJV 116 recorded the highest mean leaf thickness (0.209 mm) followed by with 104 A x SPV1830, RSV1130, 185A x RSV1130 and RMS2010-24A x RSV1098 which are the high yielding genotypes. While, G x E interaction effect revealed that the hybrid104 A x SPV 1830 recorded significantly the highest mean leaf thickness (0.293 mm) in the month of October sowing date (Table 3). The higher leaf thickness of leaves contained more photosynthetic active cells resulting in higher photosynthetic rate (30.01 μmol CO_2 m^{-2} s^{-1}) in 104 A x SPV1830. The changes in leaf structure correlated with major climatic factors. Leaf thickness was increase with increasing mean temperatures at October sowing date (Max temp. 29.1 °C, Min temp. 12.4 °C), sunshine hours (8.2h) and photoperiod (10.68 h). Similar results found by Voronin *et al.* (2003) [36] and Baviskar (2012) [3].

The relevant data on mean SPAD Chlorophyll meter indicate that the highest mean SPAD Chlorophyll meter readings were recorded in the month of October sowing date (47.45). While, lowest (37.33) readings were recorded at February sowing date. The present findings matches with Kumar (2009) and Bhasker (2013) [4] as chlorophyll content decreases with increase in temperature. The hybrid 104 A x SPV 1830 recorded significantly the highest mean SPAD Chlorophyll meter readings (44.15) shows direct positive correlation with photosynthetic rate and grain yield. Similar results recorded by Malviya (2013) [23] and Devkumar (2014). The G x E interaction effect revealed that the restorer BJV116 recorded significantly the highest mean SPAD Chlorophyll meter readings (48.20) in the month of October sowing date (Table 4).

Transpiration is an important bio-physical trait which helps gas exchange. From the Table 5 it is observed that significantly the highest mean transpiration rate (mmol $H_2Om^{-2}s^{-1}$) was recorded in the month of October sowing date (3.57mmol $H_2Om^{-2}s^{-1}$c). The hybrid 104 A x SPV1830 recorded significantly the highest mean transpiration rate (2.80 mmol $H_2Om^{-2}s^{-1}$). Show that high yielding genotype possess high transpiration rate similar to Ashwathama *et al*. (1997) [2]. and the interaction (G x E) effect revealed that the hybrid 104 A x SPV 1830 recorded the highest mean transpiration rate (mmol $H_2Om^{-2}s^{-1}$) (4.20) in the month of October sowing date shows that positive association with photosynthetic rate. Similar findings proposed by Channappagoudar *et al*. (2007) [7].

The productivity of plant communities is governed in part by their ability to absorb and utilize photosynthetically active radiation (PAR) in sorghum. From the results, the highest mean photosynthetically active radiation (PAR) (nm) was recorded in the month of October sowing date (787). The hybrid 104 A x SPV1830 recorded significantly the highest mean photosynthetically active radiation (PAR) (nm) (708) which was at par with RMS2010-10A x BJV116 shows the positive relation with LAI. Similar to the findings of Samba *et al*. (2003) [29]. From the G x E interaction effect the restorer RSV1130 recorded significantly the highest mean photosynthetically active radiation (PAR) (nm) (799) in the month of October sowing date (Table 6).

The relevant data on mean stomatal conductance (moles $m^{-2}s^{-1}$) are presented in Table 7 show that the highest mean stomatal conductance (moles $m^{-2}s^{-1}$) was recorded in the month of October sowing date (0.47). While, lowest (0.19) recorded at February sowing. Means stomatal conductance decreases with increase in temperature similar to photosynthesis. Gives the relationship of these two parameters. Similar report presented by Girma and Krieg (1992) [11]. The hybrid104 A x SPV 1830 recorded significantly the highest mean stomatal conductance (moles $m^{-2}s^{-1}$) (0.34) and from G x E interaction effect the both restorer line BJV 116 and hybrid RMS 2010-10 A x BJV 116 recorded significantly the highest mean stomatal conductance (moles $m^{-2}s^{-1}$) (0.51) in the month of October sowing date.

A crop yield is an end product of various closely linked metabolic process of the plant. The highest grain yield (28.87 $qha^{-1}$was recorded in October sowing date due to favourable environmental temperature (max temp. 30.1, min. temp. 14.0 °C) photoperiod (10.09 hours), sunshine (8.5 hours), Singh and Kumar (2005) [33] Saha (2008) [28], Bhuiyan (2008) [5] and Waghmare *et al*. (2010) [37] and Vijay (2012) [35] and also the leaf area (28.69 dm^2).Similar results found by Baviskar (2012) [3]. Significantly, the highest number of grains per earhead (2098) in the month of October sowing. While, lowest mean number of grains per earhead (657) was recorded at February sowing date. As number of grains/earhead is greatly affected due to climatic conditions. Similar to report of Siddique (2002) [32]. The hybrid RMS2010-10B x BJV 116 recorded significantly the highest (1760). The G x E interaction effect revealed that the restorer SPV 1830 recorded significantly the highest mean number of grains per earhead (3028) in the month of October sowing date (Table 8). The highest thousand grain weight (42.52 g) was recorded in the month of October sowing. The hybrid 104 A x SPV 1830 recorded significantly the highest thousand grain weight (36.03 g) and from G x E interaction effect the ms line RMS 2010-24 A recorded significantly the highest mean thousand grain yield (47.77 g) in the month of October sowing date (Table 9). Significantly the highest grain yield (28.87 qha^{-1}) was recorded in the month of October sowing and hybrid RMS 2010-10 A x BJV 116 recorded significantly the highest grain yield (25.03 qha^{-1}) which was at par with 104 A x SPV 1830, 185A x RSV 1130 and RSV 1098. The G x E interaction effect revealed that the restorer SPV 1830 recorded significantly the highest grain yield (42.50 qha^{-1}) in the month of October sowing date (Table 10). Significantly the highest (61.28 qha^{-1}) and lowest (18.82 qha^{-1}) biological yield recorded in the month of October and February sowing dates, respectively. Jehangir (2013) [15] also reported that normal sowing date is essential to increase biological yield. The hybrid RMS 2010-10 A x BJV 116 recorded significantly the highest (57.99 qha^{-1}) biological yield. The G x E interaction effect revealed that the hybrid RMS 2010-10 A x BJV116 recorded significantly the highest mean biological yield (88.13 qha^{-1}) in the month of September sowing date (Table 11). Significantly the highest (46.61%) harvest index recorded in the month of October sowing date. The hybrid 104 A x SPV 1830 recorded significantly the highest harvest index (46.50%) and male sterile line 185A recorded significantly the lowest mean harvest index (30.53%). In case of G x E interaction effect, restorer 104 A x SPV 1830 recorded significantly the highest mean harvest index (65.01%) in the month of February sowing and male sterile line 185A recorded the lowest mean harvest index (22.58%) in the month of January sowing date (Table 12). The results are similar to Jangid (2013) [14] who concluded that as compaire to normal sown (S_1), under late sown (S_2) condition harvest index decreased which further declined under very late sown (S_3) condition. Under late sown condition major reduction in grain weight per spike was primarily due to reduction in the 1000 grain weight (test weight) under terminal heat stress. Significant reduction was observed in grain filling duration resulting in reduced grain size and total yield. The findings show that grain yield has positive association with number of grains/ earhead, harvest index and leaf dry matter similar report presented by Pawar (2007) [26] similar findings also presented by Patil (2005) [25].

From the results among the different sowing dates, all the physiological parameters were recorded to be highest in October sowing date and recorded to be lowest at February sowing date than other sowings. The hybrid 104 A x SPV 1830 followed by RMS 2010-10 A x BJV 116 recorded the highest photosynthetic rate (30.01), Canopy temperature depression CTD (-5.59), SPAD value (44.15), transpiration rate (2.80), PAR (708) and stomatal conductance (0.34) while, hybrid RMS 2010-10 A x BJV 116 recorded the highest mean leaf thickness (0.209 mm). shows positive correlation with grain yield.

Table 1: Mean photosynthetic rate (μmol CO_2 m^{-2} S^{-1}) of *rabi* sorghum parental lines and their hybrids as influenced by different environment

Sr. No.	Parental lines	E_1: Aug.	E_2: Sept.	E_3: Oct.	E_4: Nov.	E_5: Dec.	E_6: Jan.	E_7: Feb.	Mean
G_1	104 A	26.11	32.47	37.23	29.23	23.10	21.15	20.18	27.07
G_2	104 B	27.63	32.82	36.71	27.73	25.92	22.75	20.60	27.74
G_3	SPV 1830	26.39	34.46	37.75	30.39	25.86	25.00	21.29	28.73
G_4	104 A x SPV 1830	29.56	36.40	39.03	29.16	26.99	26.33	22.61	30.01
G_5	185 A	26.52	31.59	38.76	27.48	24.81	20.96	17.50	26.80
G_6	185 B	26.58	31.24	37.25	29.73	24.45	23.86	19.86	27.57
G_7	RSV 1130	27.71	36.72	37.95	28.69	26.45	22.42	18.70	28.38
G_8	185 A x RSV 1130	27.10	36.57	40.42	28.36	24.02	21.34	21.26	28.44
G_9	RMS 2010-24 A	26.85	32.40	38.22	27.07	22.04	21.46	20.99	27.01
G_{10}	RMS 2010-24 B	24.97	33.96	38.08	26.77	24.62	24.59	17.79	27.26
G_{11}	RSV 1098	26.54	34.25	37.62	30.09	25.88	23.46	20.88	28.39
G_{12}	RMS 2010-24 A x RSV 1098	25.10	35.37	38.75	27.34	24.93	24.15	23.04	28.38
G_{13}	RMS 2010-10A	27.05	33.80	40.55	29.36	22.44	20.55	18.81	27.51
G_{14}	RMS 2010-10B	27.64	30.96	37.87	30.07	25.05	20.45	19.97	27.43
G_{15}	BJV 116	30.53	32.03	41.27	29.57	22.65	22.18	20.31	28.36
G_{16}	RMS 2010-10 A x BJV 116	28.16	34.49	41.77	30.01	26.26	22.41	19.60	28.96
	Mean	27.15	33.72	38.70	28.82	24.72	22.69	20.21	28.00
		G	E	G x E					
	SE±	0.25	0.22	0.66					
	CD at 5%	0.69	0.68	1.84					

Table 2: Mean canopy temperature depression (°C) of *rabi* sorghum parental lines and their hybrids as influenced by different environment

Sr. No.	Parental lines	E_1: Aug.	E_2: Sept.	E_3: Oct.	E_4: Nov.	E_5: Dec.	E_6: Jan.	E_7: Feb.	Mean
G_1	104 A	-4.83	-5.43	-5.70	-5.27	-3.87	-3.43	-2.97	-4.50
G_2	104 B	-5.00	-5.53	-5.73	-5.43	-4.40	-4.17	-3.97	-4.89
G_3	SPV 1830	-5.10	-5.57	-6.80	-5.50	-4.73	-4.33	-3.97	-5.14
G_4	104 A x SPV 1830	-5.97	-6.50	-6.77	-6.40	-4.97	-4.43	-4.07	-5.59
G_5	185 A	-4.93	-5.30	-5.73	-5.00	-4.70	-3.93	-2.87	-4.64
G_6	185 B	-5.00	-5.37	-5.63	-5.30	-4.77	-4.30	-3.90	-4.90
G_7	RSV 1130	-5.07	-5.70	-5.83	-5.40	-4.87	-4.33	-4.00	-5.03
G_8	185 A x RSV 1130	-5.33	-5.50	-6.93	-5.43	-5.00	-4.40	-4.23	-5.26
G_9	RMS 2010-24 A	-3.93	-5.47	-5.57	-5.20	-4.77	-3.97	-3.50	-4.63
G_{10}	RMS 2010-24 B	-4.97	-5.50	-5.63	-5.27	-4.80	-4.30	-3.83	-4.90
G_{11}	RSV 1098	-5.00	-5.50	-6.00	-5.43	-4.93	-4.33	-4.10	-5.04
G_{12}	RMS 2010-24 A x RSV 1098	-5.43	-6.03	-6.77	-5.50	-4.97	-4.47	-4.10	-5.32
G_{13}	RMS 2010-10A	-5.07	-5.37	-5.80	-5.30	-4.77	-4.13	-2.90	-4.76
G_{14}	RMS 2010-10B	-4.93	-5.43	-5.67	-5.33	-4.73	-4.37	-3.87	-4.90
G_{15}	BJV 116	-5.20	-5.50	-5.73	-5.37	-4.90	-4.43	-4.03	-5.02
G_{16}	RMS 2010-10 A x BJV 116	-5.37	-5.67	-6.70	-5.50	-4.97	-4.37	-4.13	-5.24
	Mean	-5.07	-5.59	-6.06	-5.41	-4.76	-4.23	-3.78	-4.99
		G	E	G x E					
	SE±	0.02	0.01	0.06					
	CD at 5%	0.06	0.04	0.16					

Table 3: Mean leaf thickness (mm) of *rabi* sorghum parental lines and their hybrids as influenced by different environment

Sr. No.	Parental lines	E_1: Aug.	E_2: Sept.	E_3: Oct.	E_4: Nov.	E_5: Dec.	E_6: Jan.	E_7: Feb.	Mean
G_1	104 A	0.173	0.207	0.223	0.193	0.170	0.167	0.140	0.182
G_2	104 B	0.190	0.193	0.233	0.183	0.170	0.167	0.150	0.184
G_3	SPV 1830	0.197	0.200	0.223	0.207	0.187	0.183	0.150	0.192
G_4	104 A x SPV 1830	0.183	0.220	0.293	0.213	0.170	0.150	0.137	0.195
G_5	185 A	0.187	0.203	0.220	0.190	0.180	0.173	0.160	0.188
G_6	185 B	0.193	0.207	0.227	0.197	0.167	0.157	0.153	0.186
G_7	RSV 1130	0.210	0.213	0.227	0.213	0.157	0.177	0.177	0.196
G_8	185 A x RSV 1130	0.220	0.240	0.250	0.193	0.170	0.167	0.153	0.199
G_9	RMS 2010-24 A	0.187	0.233	0.213	0.190	0.147	0.137	0.137	0.178
G_{10}	RMS 2010-24 B	0.167	0.203	0.233	0.197	0.167	0.153	0.147	0.181
G_{11}	RSV 1098	0.180	0.243	0.207	0.207	0.163	0.163	0.157	0.189
G_{12}	RMS 2010-24 A x RSV 1098	0.197	0.223	0.237	0.217	0.167	0.167	0.160	0.195
G_{13}	RMS 2010-10A	0.177	0.210	0.223	0.210	0.170	0.163	0.140	0.185
G_{14}	RMS 2010-10B	0.160	0.207	0.227	0.197	0.160	0.143	0.140	0.176
G_{15}	BJV 116	0.197	0.217	0.217	0.200	0.183	0.170	0.170	0.193
G_{16}	RMS 2010-10 A x BJV 116	0.183	0.230	0.280	0.207	0.187	0.187	0.187	0.209
	Mean	0.188	0.216	0.233	0.201	0.170	0.164	0.154	0.189
		G	E	G x E					
	SE±	0.002	0.002	0.005					
	CD at 5%	0.005	0.005	0.013					

Table 4: Mean SPAD chlorophyll meter reading (SCMR) of *rabi* sorghum parental lines and their hybrids as influenced by different environment

Sr. No.	Parental lines	E_1: Aug.	E_2: Sept.	E_3: Oct.	E_4: Nov.	E_5: Dec.	E_6: Jan.	E_7: Feb.	Mean
G_1	104 A	42.60	45.87	47.20	44.53	40.80	39.20	37.37	42.51
G_2	104 B	42.57	44.87	47.40	44.70	42.20	40.47	37.93	42.88
G_3	SPV 1830	44.40	46.13	47.77	44.83	42.63	40.83	38.17	43.54
G_4	104 A x SPV 1830	44.73	47.53	47.60	46.40	42.50	41.50	38.77	44.15
G_5	185 A	42.87	45.77	46.83	45.07	41.00	40.20	36.23	42.57
G_6	185 B	43.07	45.30	46.73	45.13	40.13	39.57	36.43	42.34
G_7	RSV 1130	43.57	45.83	47.73	45.27	41.07	40.47	36.80	42.96
G_8	185 A x RSV 1130	42.57	46.13	47.13	45.50	42.13	40.87	37.37	43.10
G_9	RMS 2010-24 A	43.53	45.03	47.63	45.47	41.47	38.43	35.80	42.48
G_{10}	RMS 2010-24 B	43.13	45.40	47.77	44.87	42.07	38.33	36.23	42.54
G_{11}	RSV 1098	44.20	46.13	48.00	45.67	42.80	38.70	37.03	43.22
G_{12}	RMS 2010-24 A x RSV 1098	44.73	45.57	48.10	45.50	44.70	38.87	38.40	43.70
G_{13}	RMS 2010-10A	42.00	44.87	46.23	45.70	41.70	40.30	37.27	42.58
G_{14}	RMS 2010-10B	41.90	45.20	47.27	45.37	40.50	40.40	37.27	42.56
G_{15}	BJV 116	43.87	45.73	48.20	45.87	42.03	40.50	37.67	43.41
G_{16}	RMS 2010-10 A x BJV 116	44.40	46.80	47.67	45.13	42.50	41.03	38.53	43.72
	Mean	43.38	45.76	47.45	45.31	41.89	39.98	37.33	43.02
		G	E	G x E					
	SE$\pm$	0.17	0.14	0.46					
	CD at 5%	0.48	0.42	1.28					

Table 5: Mean transpiration rate (mmol H_2O m^{-2} s^{-1}) of *rabi* sorghum parental lines and their hybrids as influenced by different environment

Sr. No.	Parental lines	E_1: Aug.	E_2: Sept.	E_3: Oct.	E_4: Nov.	E_5: Dec.	E_6: Jan.	E_7: Feb.	Mean
G_1	104 A	2.70	3.06	3.08	2.95	2.09	2.07	1.57	2.51
G_2	104 B	2.73	3.27	3.54	2.95	2.37	2.32	1.86	2.72
G_3	SPV 1830	3.03	3.12	3.36	3.09	2.44	2.12	2.07	2.75
G_4	104 A x SPV 1830	3.00	3.12	4.20	2.93	2.32	2.07	1.95	2.80
G_5	185 A	2.80	3.47	3.50	2.98	2.58	1.58	1.52	2.64
G_6	185 B	2.59	3.32	3.35	2.81	2.57	2.55	1.53	2.67
G_7	RSV 1130	2.72	3.57	3.57	2.96	2.74	2.37	1.58	2.79
G_8	185 A x RSV 1130	2.93	3.14	3.88	2.97	2.10	2.07	1.92	2.71
G_9	RMS 2010-24 A	2.51	3.39	3.41	2.86	2.49	2.27	1.63	2.65
G_{10}	RMS 2010-24 B	2.95	3.22	3.47	3.23	2.30	2.15	1.74	2.72
G_{11}	RSV 1098	2.72	3.24	3.96	2.95	2.43	2.30	1.77	2.77
G_{12}	RMS 2010-24 A x RSV 1098	2.96	3.07	3.77	3.09	2.46	2.07	1.90	2.76
G_{13}	RMS 2010-10A	2.78	3.14	3.40	2.89	1.96	1.93	1.92	2.58
G_{14}	RMS 2010-10B	2.79	3.20	3.55	2.96	2.44	2.29	1.61	2.69
G_{15}	BJV 116	3.08	3.12	3.52	3.04	2.54	1.96	1.86	2.73
G_{16}	RMS 2010-10 A x BJV 116	2.99	3.05	3.63	3.21	2.55	2.23	1.70	2.76
	Mean	2.83	3.22	3.57	2.99	2.40	2.15	1.76	2.70
		G	E	G x E					
	SE$\pm$	0.06	0.05	0.15					
	CD at 5%	0.16	0.16	0.43					

Table 6: Mean photosynthetically active radiation (PAR) (nm) of *rabi* sorghum parental lines and their hybrids as influenced by different environment

Sr. No.	Parental lines	E_1: Aug.	E_2: Sept.	E_3: Oct.	E_4: Nov.	E_5: Dec.	E_6: Jan.	E_7: Feb.	Mean
G_1	104 A	686	770	776	747	643	516	442	654
G_2	104 B	726	769	786	748	679	595	471	682
G_3	SPV 1830	742	769	788	759	701	672	483	702
G_4	104 A x SPV 1830	765	783	794	769	695	637	515	708
G_5	185 A	711	765	776	746	648	527	335	644
G_6	185 B	750	778	786	720	709	571	341	665
G_7	RSV 1130	744	786	799	751	732	651	384	692
G_8	185 A x RSV 1130	740	780	794	758	742	693	388	699
G_9	RMS 2010-24 A	708	761	785	768	619	524	371	648
G_{10}	RMS 2010-24 B	717	784	792	752	686	602	384	674
G_{11}	RSV 1098	732	785	795	780	700	688	372	693
G_{12}	RMS 2010-24 A x RSV 1098	769	789	795	780	731	606	394	695
G_{13}	RMS 2010-10A	724	770	774	750	629	539	434	660
G_{14}	RMS 2010-10B	736	774	779	760	635	562	459	672
G_{15}	BJV 116	747	778	785	761	679	593	488	690
G_{16}	RMS 2010-10 A x BJV 116	748	788	787	775	698	635	493	704
	Mean	734	777	787	758	683	601	422	680
		G	E	G x E					
	SE$\pm$	2.07	1.56	5.48					
	CD at 5%	5.77	4.82	15.27					

Table 7: Mean stomatal conductance (moles m^{-2} s^{-1}) of *rabi* sorghum parental lines and their hybrids as influenced by different environment

Sr. No.	Parental lines	E_1: Aug.	E_2: Sept.	E_3: Oct.	E_4: Nov.	E_5: Dec.	E_6: Jan.	E_7: Feb.	Mean
G_1	104 A	0.27	0.34	0.44	0.32	0.21	0.19	0.18	0.28
G_2	104 B	0.28	0.38	0.44	0.34	0.26	0.20	0.19	0.30
G_3	SPV 1830	0.33	0.41	0.50	0.36	0.29	0.24	0.22	0.33
G_4	104 A x SPV 1830	0.34	0.36	0.50	0.35	0.31	0.24	0.23	0.34
G_5	185 A	0.24	0.36	0.42	0.33	0.23	0.19	0.17	0.28
G_6	185 B	0.28	0.38	0.45	0.34	0.26	0.19	0.17	0.30
G_7	RSV 1130	0.30	0.39	0.47	0.35	0.27	0.21	0.20	0.31
G_8	185 A x RSV 1130	0.33	0.41	0.47	0.35	0.28	0.24	0.22	0.33
G_9	RMS 2010-24 A	0.26	0.35	0.44	0.35	0.25	0.21	0.16	0.29
G_{10}	RMS 2010-24 B	0.26	0.37	0.46	0.33	0.25	0.22	0.19	0.30
G_{11}	RSV 1098	0.32	0.40	0.47	0.36	0.26	0.23	0.19	0.32
G_{12}	RMS 2010-24 A x RSV 1098	0.34	0.41	0.48	0.39	0.27	0.23	0.20	0.33
G_{13}	RMS 2010-10A	0.30	0.36	0.44	0.34	0.25	0.23	0.21	0.30
G_{14}	RMS 2010-10B	0.23	0.40	0.45	0.34	0.25	0.19	0.18	0.29
G_{15}	BJV 116	0.30	0.40	0.51	0.35	0.26	0.25	0.19	0.32
G_{16}	RMS 2010-10 A x BJV 116	0.31	0.42	0.51	0.37	0.27	0.23	0.20	0.33
	Mean	0.29	0.38	0.47	0.35	0.26	0.22	0.19	0.31
		G	E	G x E					
	SE±	0.005	0.004	0.013					
	CD at 5%	0.014	0.013	0.037					

Table 8: Mean number of grains per earhead of *rabi* sorghum parental lines and their hybrids as influenced by different environment

Sr. No.	Parental lines	E_1: Aug.	E_2: Sept.	E_3: Oct.	E_4: Nov.	E_5: Dec.	E_6: Jan.	E_7: Feb.	Mean
G_1	104 A	765	870	1277	820	645	514	459	764
G_2	104 B	1076	1289	1949	1243	907	681	474	1088
G_3	SPV 1830	1625	1836	3028	1707	1550	939	715	1629
G_4	104 A x SPV 1830	1638	1875	2744	1795	1476	1236	983	1678
G_5	185 A	771	908	1295	803	571	409	325	726
G_6	185 B	1215	1415	1620	1301	1092	740	477	1123
G_7	RSV 1130	1706	1966	2496	1853	1512	1178	697	1630
G_8	185 A x RSV 1130	1705	2145	2268	1841	1633	1249	852	1671
G_9	RMS 2010-24 A	841	1364	1421	1256	762	664	391	957
G_{10}	RMS 2010-24 B	1005	1192	1863	1132	884	713	351	1020
G_{11}	RSV 1098	1761	2285	2336	1799	1643	1292	738	1693
G_{12}	RMS 2010-24 A x RSV 1098	1719	1886	2621	1778	1657	1268	966	1699
G_{13}	RMS 2010-10A	934	1368	1416	989	869	752	453	969
G_{14}	RMS 2010-10B	1164	1347	2028	1254	1127	883	728	1219
G_{15}	BJV 116	1726	1900	2756	1838	1651	1288	976	1734
G_{16}	RMS 2010-10 A x BJV 116	1810	2230	2441	1981	1712	1219	929	1760
	Mean	1341	1617	2098	1462	1231	939	657	1335
		G	E	G x E					
	SE±	7.25	7.10	19.19					
	CD at 5%	20.22	21.87	53.49					

Table 9: Mean thousand grain weight (g) of *rabi*sorghum parental lines and their hybrids as influenced by different environment

Sr. No.	Parental lines	E_1: Aug.	E_2: Sept.	E_3: Oct.	E_4: Nov.	E_5: Dec.	E_6: Jan.	E_7: Feb.	Mean
G_1	104 A	36.55	38.95	45.10	38.58	31.69	25.59	19.61	33.72
G_2	104 B	33.99	37.81	41.68	34.78	32.94	31.47	20.44	33.30
G_3	SPV 1830	32.06	38.90	40.21	38.23	31.03	29.02	22.45	33.13
G_4	104 A x SPV 1830	35.06	38.26	41.60	36.46	34.35	33.57	32.87	36.03
G_5	185 A	29.93	34.14	39.94	33.24	27.49	24.37	21.85	30.14
G_6	185 B	28.67	36.63	38.75	32.97	25.01	23.82	22.53	29.77
G_7	RSV 1130	35.22	40.13	44.49	37.13	31.14	27.21	26.06	34.48
G_8	185 A x RSV 1130	34.93	38.56	44.65	35.88	28.14	25.47	22.36	32.86
G_9	RMS 2010-24 A	25.29	39.67	47.77	29.12	24.28	21.98	19.78	29.70
G_{10}	RMS 2010-24 B	31.25	38.67	43.30	31.71	29.13	23.05	20.94	31.15
G_{11}	RSV 1098	31.96	39.00	46.03	32.98	28.46	25.64	22.87	32.42
G_{12}	RMS 2010-24 A x RSV 1098	31.72	34.30	44.96	33.33	31.20	25.46	19.62	31.51
G_{13}	RMS 2010-10A	33.09	37.19	41.60	34.05	28.50	26.14	18.87	31.35
G_{14}	RMS 2010-10B	31.15	33.59	36.50	31.68	29.66	29.30	17.62	29.93
G_{15}	BJV 116	31.46	33.66	39.84	32.28	30.82	28.74	22.47	31.33
G_{16}	RMS 2010-10 A x BJV 116	34.67	40.07	43.87	36.76	34.16	33.37	26.62	35.64
	Mean	32.31	37.47	42.52	34.32	29.88	27.14	22.31	32.28
		G	E	G x E					
	SE±	0.11	0.08	0.30					
	CD at 5%	0.32	0.25	0.84					

Table 10: Mean grain yield (qha[-1]) of *rabi* sorghum parental lines and their hybrids as influenced by different environment

Sr. No.	Parental lines	E_1: Aug.	E_2: Sept.	E_3: Oct.	E_4: Nov.	E_5: Dec.	E_6: Jan.	E_7: Feb.	Mean
G_1	104 A	9.97	12.92	17.50	11.25	7.11	4.73	2.93	9.49
G_2	104 B	12.49	19.06	24.15	15.21	11.14	7.87	3.41	13.33
G_3	SPV 1830	22.55	31.54	42.50	28.48	23.11	12.36	6.31	23.83
G_4	104 A x SPV 1830	24.09	30.67	38.59	27.12	19.95	19.78	14.60	24.97
G_5	185 A	6.56	11.88	15.42	8.96	6.46	3.72	2.57	7.94
G_6	185 B	11.05	18.86	18.85	13.50	10.53	6.36	4.00	11.88
G_7	RSV 1130	24.90	33.09	36.72	28.25	20.95	15.12	7.35	23.77
G_8	185 A x RSV 1130	26.26	37.91	33.10	27.09	21.26	15.12	10.68	24.49
G_9	RMS 2010-24 A	7.12	17.52	21.06	10.76	7.42	4.99	2.48	10.19
G_{10}	RMS 2010-24 B	9.11	17.55	25.09	12.02	10.62	5.82	3.11	11.90
G_{11}	RSV 1098	26.30	38.87	37.52	24.33	18.96	16.40	8.65	24.43
G_{12}	RMS 2010-24 A x RSV 1098	26.69	27.09	41.58	24.54	20.69	13.39	10.01	23.43
G_{13}	RMS 2010-10A	12.00	15.52	17.73	12.84	8.91	8.11	3.23	11.19
G_{14}	RMS 2010-10B	12.27	17.54	22.74	13.31	11.56	10.01	4.56	13.14
G_{15}	BJV 116	23.21	28.48	35.11	24.58	24.23	16.96	10.48	23.29
G_{16}	RMS 2010-10 A x BJV 116	28.50	37.85	34.26	29.86	25.56	13.12	6.06	25.03
	Mean	17.69	24.77	28.87	19.51	15.53	10.87	6.28	17.64
		G	E	G x E					
	SE±	0.38	0.36	1.02					
	CD at 5%	1.07	1.12	2.84					

Table 11: Mean biological yield per hectare (qha[-1]) of *rabi* sorghum parental lines and their hybrids as influenced by different environment

Sr. No.	Parental lines	E_1: Aug.	E_2: Sept.	E_3: Oct.	E_4: Nov.	E_5: Dec.	E_6: Jan.	E_7: Feb.	Mean
G_1	104 A	26.35	39.90	43.13	31.05	24.58	20.88	11.29	28.17
G_2	104 B	36.16	47.98	52.27	40.89	27.36	21.62	14.05	34.33
G_3	SPV 1830	57.98	59.54	73.96	63.05	47.01	41.34	23.76	52.38
G_4	104 A x SPV 1830	60.75	68.45	77.55	64.97	54.65	41.29	22.47	55.74
G_5	185 A	21.10	37.78	38.62	27.87	22.32	14.60	10.47	24.68
G_6	185 B	29.23	43.16	54.64	34.68	30.94	21.58	14.22	32.64
G_7	RSV 1130	57.38	68.51	75.80	61.21	49.79	39.64	24.96	53.90
G_8	185 A x RSV 1130	59.93	71.43	74.41	61.27	54.03	45.14	29.41	56.52
G_9	RMS 2010-24 A	23.95	35.25	38.05	28.22	21.80	17.98	10.39	25.09
G_{10}	RMS 2010-24 B	27.45	46.56	53.96	36.54	33.37	21.78	11.05	32.96
G_{11}	RSV 1098	63.18	70.50	75.07	61.75	46.36	43.80	26.67	55.33
G_{12}	RMS 2010-24 A x RSV 1098	61.80	65.97	79.52	58.19	42.63	38.77	31.92	54.11
G_{13}	RMS 2010-10A	28.39	34.62	38.64	29.01	19.62	19.18	8.97	25.49
G_{14}	RMS 2010-10B	34.41	66.22	55.78	35.22	29.98	27.52	14.50	37.66
G_{15}	BJV 116	61.82	69.19	73.99	61.59	50.23	31.84	20.02	52.67
G_{16}	RMS 2010-10 A x BJV 116	60.45	88.13	75.02	62.72	52.59	39.99	27.05	57.99
	Mean	44.40	57.07	61.28	47.39	37.95	30.43	18.82	42.48
		G	E	G x E					
	SE±	0.32	0.25	0.85					
	CD at 5%	0.89	0.76	2.36					

Table 12: Mean harvest index (HI) (%) of *rabi* sorghum parental lines and their hybrids as influenced by different environment

Sr. No.	Parental lines	E_1: Aug.	E_2: Sept.	E_3: Oct.	E_4: Nov.	E_5: Dec.	E_6: Jan.	E_7: Feb.	Mean
G_1	104 A	37.83	32.43	40.59	36.26	28.86	22.58	25.97	32.08
G_2	104 B	34.54	39.75	46.17	37.22	40.73	36.62	24.26	37.04
G_3	SPV 1830	38.87	52.99	57.51	45.18	49.17	29.89	26.61	42.89
G_4	104 A x SPV 1830	39.70	44.78	49.76	41.75	36.43	48.05	65.01	46.50
G_5	185 A	31.06	31.38	40.08	32.15	28.88	25.52	24.67	30.53
G_6	185 B	37.82	43.69	34.58	38.88	34.03	29.44	28.09	35.22
G_7	RSV 1130	43.32	48.35	48.44	46.12	42.04	38.26	29.51	42.29
G_8	185 A x RSV 1130	43.79	53.05	44.48	44.21	39.40	33.48	36.33	42.11
G_9	RMS 2010-24 A	29.73	49.73	55.61	38.06	34.12	27.67	23.87	36.97
G_{10}	RMS 2010-24 B	33.33	37.62	46.41	32.81	31.84	26.83	28.06	33.84
G_{11}	RSV 1098	41.60	55.15	50.02	39.39	40.89	37.51	32.39	42.42
G_{12}	RMS 2010-24 A x RSV 1098	43.17	41.07	52.28	42.15	48.62	34.58	31.33	41.88
G_{13}	RMS 2010-10A	42.14	44.77	45.94	44.28	45.40	42.25	36.03	42.97
G_{14}	RMS 2010-10B	35.69	26.49	40.75	37.81	38.53	36.54	31.62	35.35
G_{15}	BJV 116	37.55	41.17	47.47	39.92	48.27	53.26	53.09	45.82
G_{16}	RMS 2010-10 A x BJV 116	47.22	42.97	45.74	47.62	48.78	32.70	23.09	41.16
	Mean	38.59	42.84	46.61	40.24	39.75	34.70	32.50	39.32
		G	E	G x E					
	SE±	0.99	0.85	2.61					
	CD at 5%	2.75	2.61	7.27					

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