Sorghum Physiology-Kharif and Rabi seasons 2017-2018

Technical Report · July 2018

DOI: 10.13140/RG.2.2.18344.26882

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PROGRESS REPORT

Physiology

Annual Sorghum Group Meeting, 21-23 April, 2018

All-India Coordinated Research Project on Sorghum

Indian Institute of Millets Research

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Sorghum Physiology - Kharif 2017

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C o n t e n t s

Executive summary

Trial 1K. Physiological basis of assessing the genetic progress in yield potential of kharif sorghum historical released cultivars: Twelve kharif sorghum released cultivars (6 hybrids + 6 verities) were assessed for physiological basis of genetic gains in the yield potential. CSV 20 and SPV462 were the earliest for flowering. Mean plant height has shown significant positive relationship (P≤0.05) with total dry biomass and 1000- seed mass. Latest cultivars CSV23 and CSV 27 produced higher leaf mass, SLA and SLW . In total biomass, CSH 27 and CSH 16 in hybrids, CSV 23 and SPV 462 in varieties were superior. Modern hybrids (CSH 30) produced higher biomass in GS3 than older. Biomass in GS3 showed significant (P≤0.05) positive relationship with source to sink ration. In general, hybrids produced higher grain yield than varieties. Hybrids CSH27 and CSH 30 produced more grain yields than others but still these are on par with older hybrid such as CSH 14 under current season climatic conditions. In varieties, CSV 23 and CSV 20 were superior. In general, hybrids recorded higher HI than varieties. Modern hybrids had greater HI (44.1 to 53.7 %) than older ones. CSH27 and CSH 30 in hybrids and CSV 15 in varieties were superior for HI. Interestingly, per day grain yield productivity showed very high significant positive (P≤0.05) relationship with HI, grain /panicle, and grain yield. On the other hand sink potential i.e., grain /panicle and grain/m2 had significantly positively (P≤0.05) related with grain yield.

Trial 2K: Physiological basis of assessing the genetic progress of kharif sorghum parental lines (old and new) for yield potential: Sixteen kharif sorghum parental lines (8- B lines + 8- R lines) were assessed for physiological basis of genetic gains in the yield potential. Mean plant height has shown significant positive relationship (*P*≤0.05) with total dry biomass. In general, all R-lines had recorded higher LAI at flowering than B-lines. LAI did not improved much in the recently developed R-lines (CB 11, CB 33) excepting Indore 12. Latest lines CB 33 and Indore 12 have produced higher leaf mass, biomass in GS3 and total biomass. In SLW, lines RS 29,KMS 14B, and AKR 150 were superior. R-lines in general were superior to B-lines for biomass. In source to sink ratio, B-lines in general were superior to R-lines. Biomass in GS3 showed significant ($P \leq 0.05$) positive relationship with grains /panicle, and grain yield. Latest R-line CB33, produced more grain yields than older lines C43, and RS 627.Modern R-line CB33 produced higher sink number followed by CS3541,and PMS 28 B. Per day grain yield productivity showed very high significant positive ($P \leq 0.05$) relationship with HI , grain /panicle , and grain yield. Both 1000- seed mass and grains / panicle were negatively related (r= -0.516; $P \leq 0.05$). On the other hand, sink potential i.e., grain/panicle and grain/m2 had very high significantly positive ($P \leq 0.05$) relationship with grain yield.

Trial 3K. Evaluation of sorghum elite lines (forage/sweet sorghum) for salinity tolerance: Evaluated 19 genotypes (13 entries + 6 checks) under two treatments (Non-saline, 8 dS/m) under pot culture at Hisar. All forage sorghum lines (HJ 541, HJ 513, SSG 59-3, HC 308) were the earliest for flowering both in non-saline and saline conditions. Plant height was reduced by 36.6% under salinity as compared with non-saline. Similarly, on an average the number of leaves , leaf area, fresh biomass and dry weight per plant at flowering were reduced by 16%, 24.0%, 47.3% and 50.6%, respectively, under salinity as compared to non-saline condition. SPV 2531, SPV 2526, and SPV 2462 maintains highest values for fresh and dry biomass than others under salinity stress. An average reduction of 12.6%, 20.6% and 24.5% in RWC, total chlorophyll content and SPAD values, respectively was observed under salinity. SPV 2530, SPH 1858, SPH 1892, and HJ513 were superior. Average ionic content in the leaves across genotypes indicates that accumulation of Na+ ion has increased by 79.8%, but the accumulation of K+ and Ca+ ions decreased by 35.5% and 36.4%, respectively. The maximum Na+ ions were accumulated under salinity in SPH1798 followed by SPV 2462, and HJ 541, whereas minimum was in SPH 2458. The K+ ions accumulation was highest in SPH 1858 followed by SPH 1892 and HJ 541. In general, biomass accumulation was negative with Na+ ion content and positive with K+ and Ca2+ ions contents, respectively, but these relationships was non-significant. The relationship between biomass accumulation under salinity treatment and Ca+ contents was positive (r = 0.336 ns). Ionic ratio of K+/Na+ may be potential selection criteria screening sorghum germplasm for salinity tolerance.

Detailed report

The primary objectives of kharif physiology were:

I. To quantify changes in yield components associated with grain yield progress in sorghum historical released cultivars (hybrids& varieties) and parental lines (B and R-lines).
II. To identify putative physiological traits associated with yield increase and to investigate physiological causes of variation in yield between old and new sorghum cultivars and s parental lines (B and R-lines)..
III. To identify potential donors with salinity tolerance and identify morph-physiological traits associated with salinity tolerance

Three trials were panned for Kharif 2017. Two trials (1K and 2K)were conducted three locations i.e. Parbhani (19^0 08' N; 76^0 50'E), Phaltan (18^0 47' N; 74^0 32'E), Akola (21° N; 77° E) and Hyderabad. The third trial (3K) was a pot experiment conducted at Hisar

Trial 1K. Physiological basis of assessing the genetic progress in yield potential of kharif sorghum historical released cultivars

Twelve kharif sorghum released cultivars (6 hybrids + 6 verities) were assessed for physiological basis of genetic gains in the yield potential. Each genotype was planted in four rows of 5m length (plot size: 1.8 * 5.0m =9.00 m2) in RCB design with three replications. The crops were raised entirely on rainfed condition and were allowed to grow under natural rainfall conditions. The soil was light to medium vertisol. A plant spacing of 45 cm between the rows and 15 cm within the row were adopted.

Recommended dose of fertilizer was applied (@ 80:40:0 kg N: P_2O_5: K_2O ha^{-1} in the form of urea, single super phosphate, muriate of potash, respectively) with half N and complete P and K as basal, and balance N was side-dressed at 35-40 DAE based on soil moisture. Furadan 3G (@ 20 kg ha^{-1}) was applied in furrows at planting to control the shoot fly (*Atherigona soccata* R). Need based minimal plant protection measures were followed to control the major insect pests of sorghum. The data were collected as per standard procedures and are presented in tables 1K1.1 to IK1.4.

Phenology: Significant differences ($P\leq0.05$) were observed among the genotypes for phenology (days 50% flowering and physiological maturity) at each location as well as between the averages across locations (Table 1K1.1). In days to 50 % flowering and physiological maturity, genotypes CSH 14 and CSH 27 were the earliest in flowering (mean: 69, and 71 d res.) as well as in maturity (mean: 109 and 110 d res.). The flowering ranged from 69 to 78 days with an average of 74 d. Among the varieties, CSV 20 and SPV462 were the earliest for flowering. The average days to flowering was lowest at Akola (66 d) followed by Parbhani (75 d) and Hyd (80 d) and almost similar trend was observed in days to maturity too (Table 1K1.1). Mean days to flowering has shown significant positive relationship ($P\leq0.05$) with leaf area at maturity, leaf mass at flowering and maturity, SLW at flowering, total dry biomass at flowering & maturity, On the other hand, days to flowering showed significant negative relationship ($P\leq0.05$) with source -sink ratio and harvest index (ns).

Plant height: Plant height varies significantly among genotypes at each location, but the variations among the average heights of genotypes across location was significant ($P\leq0.05$). Average plant height recorded was 194 cm across locations with a range of 150 to 226 cm. The average plant height recorded was maximum at Parbhani (202 cm) followed by Akola (192) and Hyderabad (188 cm). Cultivars CSH 13K & R among hybrids, and CSV 27 in varieties were taller than others (Table 1K1.1). Mean plant height has shown significant positive relationship ($P\leq0.05$) with leaf mass at maturity, total dry biomass at flowering & maturity and 1000- seed mass.

Leaf area index, growth traits and biomass components: Significant differences ($P\leq0.05$) were observed among the genotypes for leaf area, LAI and their components, biomass components among the genotypes (Table 1K1.3-1.4). The LAI at flowering ranged from 2.48 to 4.03 at flowering with an average of 3.10. Older cultivars CSH 14 and CSV 13 still continue to maintain higher LAI than modern ones. Traits such as specific leaf area (SLA), and specific leaf weight (SLW) too differed significantly. Latest cultivars CSV23 and CSV 27 produced higher leaf mass, SLA and SLW. In total biomass production at maturity, CSH 27 and CSH 16 in hybrids, CSV 23 and SPV 462 in varieties were superior than others. In biomass production during GS 3 stage significant differences were observed. Varieties in general produced lower biomass in GS 3 than hybrids means low current photosynthetic assimilates than hybrids. Biomass in GS 3 ranged from 53 to 474 g/m^2 with an average of 266 g/m^2. In hybrids modern ones (CSH 30) produced higher biomass in GS 3 than older. But in varieties, older ones (SPV 462) still continue to produce more biomass in GS 3. In source to sink ratio, the trend was similar to that of biomass in GS3. Biomass in GS3 showed significant ($P\leq0.05$) positive relationship with source to sink ration and per day grain productivity.

Interestingly, source to sink ratio (grain # per unit LAI) has shown significant ($P\leq0.05$) positive relationship with per day grain productivity, HI, grains per panicle, and grain yield. Similarly, high biomass at maturity has shown positive relationship ($P\leq0.05$) with rate of grain filling and 1000- seed mass, while its relationship with HI was turned out to be negative ($P\leq0.05$). CSV 15 and CSV 20 were found to possess higher stay green score at physiological maturity than others.

Grain yield and its components: Grain yield and its components such as grain number, 1000-seed mass, HI differed significantly ($P\leq0.05$) at all locations (Table 1K 1.2). Although variations in the grain yield across locations was significant, but variation mean grain grain yield across locations was non-significant. Average grain yield of 305 g/m2 across locations was recorded with a range of 252 to 369 g/m2. Highest location mean values for grain yield were recorded at Akola (330 g) followed by Hyderabad (280g). In general, hybrids produced higher grain yield than varieties. Hybrids CSH27 and CSH 30 produced more grain yields than others but these are on par with older hybrid such as CSH 14 under current season climatic conditions. Among the varieties, CSV 23 and CSV 20 were superior.

In general, hybrids recorded higher HI than varieties. Modern hybrids had greater HI (44.1 to 53.7 %) than older ones. CSH27 and CSH 30 in hybrids and CSV 15 in varieties were superior for HI. The trend in grain no per panicle and per day grain yield was similar to that of HI. Promising genotypes for both grain number and HI include CSH27, CSH 30 and CSV 15.

The rate of grain filling had shown high significant positive relationship ($P \leq 0.05$) with 1000-seed mass and was negatively related to grains/m2. Interestingly, per day grain yield productivity showed very high significant positive ($P \leq 0.05$) relationship with HI, grain /panicle, and grain yield. 1000- seed mass and grains / panicle were negatively related (r= -0.423; $P \leq 0.05$ ns). On the other hand sink potential i.e., grain /panicle and grain/m2 had significantly positively ($P \leq 0.05$) related with grain yield.

Trial 2K: Physiological basis of assessing the genetic progress of kharif sorghum parental lines (old and new) for yield potential

Sixteen kharif sorghum parental lines (8- B lines + 8- R lines) were assessed for physiological basis of genetic gains in the yield potential. Each genotype was planted in four rows of 5m length (plot size: 1.8 * 5.0m =9.00 m2) in RCB design with three replications. The crops were raised entirely on rainfed condition and were allowed to grow under natural rainfall conditions. The soil was light to medium vertisol. A plant spacing of 45 cm between the rows and 15 cm within the row were adopted.

Recommended dose of fertilizer was applied (@ 80:40:0 kg N: P_2O_5: K_2O ha^{-1} in the form of urea, single super phosphate, muriate of potash, respectively) with half N and complete P and K as basal, and balance N was side-dressed at 35-40 DAE based on soil moisture. Furadan 3G (@ 20 kg ha^{-1}) was applied in furrows at planting to control the shoot fly (*Atherigona soccata* R). Need based minimal plant protection measures were followed to control the major insect pests of sorghum. The data were collected as per standard procedures and are presented in tables 2K2.1 to 2K2.4.

Phenology: Significant differences ($P \leq 0.05$) were observed among the genotypes for phenology (days 50% flowering and physiological maturity) at each location and across the locations (Table 2K2.1). In days to 50 % flowering and physiological maturity, entries 279B, AKMS 14B, 415B in B-lines and AKR 150 and CS 3541 in R-lines were the earliest. The flowering ranged from 72 to 82 days with an average of 76 d. The average days to flowering was lowest at Akola (72 d) followed by Parbhani (74 d) and Hyd (82 d) and almost similar trend was observed in days to maturity too (Table 2K2.1). Mean days to flowering has shown significant positive relationship ($P \leq 0.05$) with leaf mass at flowering and maturity, total dry biomass at flowering. On the other hand, days to flowering showed significant negative relationship ($P \leq 0.05$) with rate of grain-filling and HI.

Plant height: Plant height varies significantly among genotypes at each location and also across location ($P \leq 0.05$). Average plant height recorded was 146 cm across locations with a range of 110 to 185 cm. The average plant height recorded was maximum at Parbhani (154 cm) followed by Hyderabad (138 cm). Genotype RS 29, CB 33, and 27 B were taller than others (Table 2K2.1). Mean plant height has shown significant positive relationship ($P \leq 0.05$) with leaf mass at maturity, total dry biomass at flowering & maturity.

Leaf area index, growth traits and biomass components: Significant differences ($P \leq 0.05$) were observed among the genotypes for leaf area, LAI and their components, biomass components among the genotypes (Table 2K2.3-2.4). The LAI at flowering ranged from 0.99 to 3.00 at flowering with an average of 1.59. Older B-lines 296 B still continue to maintain higher LAI than recent lines. In general, all R-lines had recorded higher LAI at flowering than B-lines. LAI did not improved much in the recently developed R-lines (CB 11, CB 33) excepting Indore 12, which had higher LAI of 3.0 and is also possessed staygreen trait. Lines Indore 12, CS 3541, and CB 11 were superior for LAI. Lines Indore 12, CS 3541, and CB 11 were superior for LAI. Mean LAI at flowering has shown significant positive relationship ($P \leq 0.05$) with leaf mass at flowering and maturity, total dry biomass at flowering. Traits such as specific leaf area (SLA), and specific leaf weight (SLW), SPAD values at flowering, source to sink ratio too differed significantly($P \leq 0.05$).

Latest lines C43, CB 33 and Indore 12 have produced higher leaf mass, biomass in GS3. In SLW, lines RS 29,KMS 14B, and AKR 150 were superior. While for SPAD at flowering, older lines 27B, RS 29, and 296 B still maintaining higher chlorophyll content than others. In total biomass production at maturity, R-lines in general were superior than B-lines. Recently developed R-line CB33 recorded higher biomass at maturity followed by RS 29. In recently produced B-lines, biomass production is still on par with older ones and PMS 28B and 27 B were superior. In biomass production during GS 3 stage significant differences were observed. In general, R-lines produced more biomass in GS 3 than B-lines which means high current photosynthetic assimilates in them.

C43 still continues to produce higher biomass in GS 3 followed by RS 27, and CB 33. In source to sink ratio, B-lines in general were superior to R-lines. In source to sink ratio, newer B-lines such as 415B was on par with older lines such as 2219B, AKMS 14B. Lines Indore 12, CB 33 were found to possess higher stay green score at physiological maturity than others.

Correlations: Biomass in GS3 showed significant ($P \leq 0.05$) positive relationship with per day grain productivity, grains /panicle, and grain yield. Interestingly, source to sink ratio (grain # per unit LAI) has shown significant ($P \leq 0.05$) positive relationship with HI. Similarly, high biomass at maturity has shown negative relationship ($P \leq 0.05$) with rate of grain filling and HI

Grain yield and its components: Grain yield and its components such as grain number, 1000-seed mass, HI differed significantly ($P \leq 0.05$) at all locations (Table 2K 2.2). Although variations in the grain yield at individual locations was significant, but variation mean grain yield across locations was non-significant. Average grain yield of 271 g/m2 across locations was recorded with a range of 224 to 364 g/m2. Highest location mean values for grain yield were recorded at Akola (358 g) followed by Hyderabad (184g).

In general, R-lines produced higher grain yield than B-lines. Latest R-line CB33, produced more grain yields than older lines C43, and RS 627. Among the B-lines, latest lines 415 B and MS 7B were superior. Lines recorded higher HI include MS 7B, 415B, AKMS 14B and C43 than others. In grain no per panicle, latest R-line CB33 produced higher sink number followed by CS3541,and PMS 28 B.

The rate of grain filling had shown high significant positive relationship ($P \leq 0.05$) with 1000-seed mass and was negatively related to grains/m2. Interestingly, per day grain yield productivity showed very high significant positive ($P \leq 0.05$) relationship with HI , grain /panicle , and grain yield. Both 1000- seed mass and grains / panicle were negatively related (r= -0.516; $P \leq 0.05$). On the other hand, sink potential i.e., grain/panicle and grain/m2 had very high significantly positive ($P \leq 0.05$) relationship with grain yield.

Trial 3K. Evaluation of sorghum elite lines (forage/sweet sorghum) for salinity tolerance

Pots experiments were planned to evaluate the selected set of elite lines of forage/sweet sorghum for salinity tolerance at three locations- Hisar, Bapatla and Gangawati. We could not executed the trial at Gangawati, as we could not get the naturally salinised plots, and no responsible person was there to execute the trial. The trial at Bapatla was not conducted as the Rice fallow sorghum centre was closed. Therefore, we are presenting the results from one location i.e., Hisar. At this location the trial was conducted at three level of salinity (Non-saline, 8 dS/m and 10 dS/m).

Twenty genotypes (include two sweet sorghum checks and four forage sorghum checks) were sown at three levels, but most of genotypes performed very poorly under highest levels of salinity after few days of seedling growth. Many genotrypes at 10 Ec did not produce growth or grain yield. Hence we analysed the data of 19 genotypes (13 entries + 6 checks) under two treatments (Non-saline, 8 dS/m). The genotype SPV 2324 even did not germinated and hence totally deleted. The data are presented in tables 3K1.1. In general, differences for treatments, genotypes and their interactions were significant ($P \leq 0.05$) for all the traits.

Phenology: Data on mean 'days to flowering' varied significantly between two treatments i.e. Non-saline and 8 dS/m. While genotypes also differed significantly within each treatment, in general all forage sorghum lines HJ 541, HJ 513, SSG 59-3, HC 308, CSV19SS, and SPH 1895 were the earliest both in non-saline and saline conditions .

Growth parameters at flowering: The average plant height and number of leaves at flowering stage were reduced significantly under salinity as compared with non-saline. On average the plant height was reduced by 36.6% under salinity as compared with non-saline treatment. SPH 1798 was the tallest followed by SSG 59-3, and SPV 2531. Similarly, on an average the number of leaves, leaf area, fresh biomass and dry weight per plant at flowering were reduced by 16%, 24.0%, 47.3% and 50.6%, respectively under salinity as compared to non-saline treatment. The genotypes SPV 2531, SPV 2526, and SPV 2462 maintains highest values for fresh and cry biomass than others under salinity stress.

Physiological parameters at flowering: Three parameters, Relative water content (RWC), total chlorophyll content and SPAD values were recorded in all the genotypes under both non-saline and saline treatments. On an average, a reduction of 12.6%, 20.6% and 24.5% in RWC, total chlorophyll content and SPAD values, respectively was recorded under salinity as compared to non-saline treatment. SPV 2530, SPH 1858, SPH 1892, SPH 1893, and HJ513 were superior for these physiological traits under salinity.

Ionic contents: Most of the genotypes accumulates the Na+ under, whereas there is reduction in K and Ca contents. Average ionic content in the leaves across genotypes indicates that accumulation of Na+ ion has increased by 79.8%, but the accumulation of K+ and Ca+ ions decreased by 35.5% and 36.4%, respectively. The maximum Na ions were accumulated under salinity in SPH1798 followed by SPV 2462, and HJ 541, whereas minimum were accumulated in SPH 2458 followed by SPH 1892 and SPH 1858. The K ions accumulation was highest in SPH 1858 followed by SPH 1892 and HJ 541, whereas, the accumulation of K ions were minimum in SPV 2462 followed by 2530 and 2526.

Relationship between biomass accumulation and Ionic content: Although the trend of relationships of biomass accumulation in 19 genotypes evaluated was negative with Na^+ ion content and positive with K^+ and Ca^{2+} ions content, respectively, but these relationship was non-significant. The relationship between biomass accumulation under salinity treatment and Ca^+ contents was positive (r = 0.336 ns). But the relationship of the ratio of K^+/Na^+ ions in leaves with biomass accumulation under salinity treatment although was poor, but positive. This indicates that ionic ratio of K^+/Na^+ may be potential selection criteria.

Sorghum Physiology - Rabi 2017-18

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Contents

Executive summary

Trial 1R: Preliminary evaluation of diverse germplasm for rabi adaptation: Thirty-seven rabi sorghum landrace germplasm along with three checks were evaluated at six locations. Mean days to flowering and days to physiological maturity differed significantly ($P \leq 0.05$) and were ranged from 68-77 d and 110-119 d, respectively. Six entries recorded early flowering than check CSV 22R (75) include CRS 70, CRS 72, CRS 73, PEC 15, VJV 109, RSV 1988 (68-71 d). Days to flowering had shown significant ($P \leq 0.05$) positive relationship with total biomass and dry fodder yield. Entries maintained higher SPAD include EP 98, EP85, RSV 2234, RSV 2209, VJV 112 (56.2-58.6) than check CSV 22R. Genotypes maintained higher RWC values include PEC 23, RSV 1837, RSV 1988 and PVRL 16-2 (79.6-85.7%) than check CSV 22R. Photosynthesis rate (Pn rate) varied from 71.1 to 85.7% with an average of 75.9%. Entries maintained higher Pn rate CRS 74, VJV 106, VJV 109, and RSV 1837 than check CSV 22R. Total biomass at maturity showed significant positive relationship with dry fodder yield (r=0.684**)and grain yield (r=0.409**). In grain yield none was significantly superior to best check *Phule Suchitra*. However, entries were on par with check include PVR 947, RSV 1921, RSV 1945 and RSV1837 (10.4- 41.7 g/pl than check *Phule Suchitra* (41.5 g/pl). HI was negatively related (r=-0.373*) to dry fodder yield, while its relationship was significantly positive (r= 0.612**) for with grain yield under drought conditions.

Trial 2(M) & 3(S): Phenotyping advanced rabi sorghum entries for drought adaptation traits in medium and shallow soils: Sixteen advanced rabi-adapted sorghum genotypes were phenotyped in both medium and shallow soils at Bijapur, Rahuri, Solapur, Parbahnai and Tandur. As regards DSI for plant height, entries *Phule Suchitra (*0.603) RSSV 1910 (0.692) and BJV 125 (0.764) showed less DSI means more plant height stability. Plant height has shown significant positive correlation with days to flowering, leaf mass and total biomass (r= 0.801, 0.535, 0.548; $P \leq 0.05$ resp.; N=16) in medium soil. Days to flowering showed positive relationship with leaf mass (r=0.630**), and biomass (r=0.512*) in shallow soil. RSV 1736 and CRS 65 recorded higher LAI, while, BJV 362, and RSV 2138 showed least reduction in LAI under shallow soil stress condition and were stable across the soil depths. Average biomass production at maturity decreased by 24% in shallow soil over medium. Entries BJV 362, and RSV 1910 recorded lower DSI for biomass and were stable across the soil depths. SPAD and total chlorophyll content values had decreased by 25% in shallow soil stress conditions over medium. *Phule Anuradha* alone was stable across the soil depths for SPAD. In Pn rate, RSV 1910, RSV 1736 in medium soils, and RSV 2121, RSV 2138 were superior to checks. Stomatal conductance reduced by 17% in shallow soil over medium. Pn rate showed significantly positively relationship with biomass maturity, and fodder yield in both soils at Rahuri. Mean grain yield ranged from 2626 to 3247 kg ha^{-1} and 1002 to 1842 kg ha^{-1} in medium and shallow soil, respectively. In shallow soil, entries BJV 362 and BJV 371 were on par with check *Phule Suchitra.* Harvest index showed significant positive correlation with grain yield (r=0.537*, and 0.917** for medium and shallow soil, res.), while its relationship with dry fodder yield was significantly negative ($P \leq 0.05$). Grain yield decreased by 50% in shallow soil depth over medium. In terms of DSI for grain yields, RSV 1910 (DSI=0.686), and BJV 362 (DSI=0.749) and BJV 371 (DSI=0.762) and BJV 129 (DSI=0.785) were relatively more stable than checks under terminal drought and heat stress conditions.

Trial 4RF and 4Irrg: Phenotyping sorghum for key root traits associated with drought adaptation: Thirteen advanced rabi sorghum genotypes checks were characterized for root and shoot related traits in controlled above ground root chambers for drought tolerance. Mean plant height, decreased by 24% in rainfed than irrigated. Mean LAI and SPAD declined by 32%, and 7.0% under moisture stress over control. CRS 66 and RSV 1986 were superior for above traits across moisture regimes. There was 30% decrease in biomass at flowering and maturity under moisture stress than irrigated control. RWC, Pn rate, TP rate and stomata conductance differed significantly. Genotypes BJV 129, and BJV 125 alone recorded higher biomass across the rainfed and irrigated conditions. The mean fresh root biomass, root length, root volume, and root numbers declined by 42%, 39%, 27%, and 15 %, respectively in rainfed condition than in irrigated. Mean root length at physiological maturity under rainfed condition varied from 40 to 122 cm/plant. Root number per plant at maturity varied in 31 to 55 in stress conditions. Root mass under moisture stress ranged 23 to 75 g/plant. Entries, BJV 129, BJV 125, RSV 2145, and RSV 1986 were relatively superior to superior to checks for key root traits under stress and non-stress conditions.

Detailed Report

Sorghum (*Sorghum bicolor* (L.) Moench) is one of the important nutritional cereal crops grown for food, feed, and fodder and bioenergy production in India and around the world. In India, it is grown over 7.00 m ha both in kharif (3.00 m ha) and Rabi (4.30 m ha) seasons. Drought and temperature stresses (low and high) occurring during seedling, pre-and postflowering stages are major environmental constraints limiting sorghum productivity besides other biotic stress conditions. Average yields are$\leq$1.0 t ha $^{-1}$ due to negative impacts of these abiotic and biotic stresses. Furthermore, climate change especially short episodes of heat stress (above optimum) are projected to impact the sorghum yields considerably.

In coordinated rabi sorghum physiology program, five trials were conducted at six locations Bijapur, Parbhani, Rahuri, Solapur, Tandur, and Gulbarga. The objectives of the rabi sorghum crop physiology program were to 1) evaluate preliminary and advanced landrace germplasm (primarily local *durra biological races*) for traits related to drought adaptation, 2) to quantify selectable crop physiological traits governing higher biomass and grain productivity combining drought and temperature stress (low and high) tolerance under stored soil moisture conditions and 3) identify potential and durable sources for utilizing in crop improvement programs. Identification of stress tolerant and early maturing genotypes combining higher yields is important in view of current climate change and its variability. This ultimate goal of the program is to identifying contrasting sources/traits for tolerance/susceptibility that determine broad adaptation to climate change (drought, heat stress & combined (drought & heat)) that facilitate mapping population (RILs)/cultivar development, and QTL identification/analyses.

Soils and planting: The soils where trials were planted varied from medium deep black (vertisols) to shallow vertisols. Planting was mainly done between mid-September and first or second week of week of October.

1. Environmental conditions at different test locations

(Tables 1-6)

Akola: Total rainfall received was 492 mm at Akola during kharif and rabi cropping period which was about 34% lower than normal (745 mm). The rainfall received in kharif cropping season was low with early and mid-season drought and heat stresses occurring in early August and Sept. The rainfall distribution was highly erratic and bimodal with peak rainfall events occurred in the month of late August and late August. There was no rainfall occurred during the entire rabi season. The accumulated thermal time (or growing degree days (GDD)) was 2251 and 1865 °Cd, respectively for kharif and rabi cropping periods. There was 15.0 % less GDD available for rabi than kharif cropping season that might be one of the reasons for lower productivity of sorghum planted in rabi season. Weekly mean minimum and maximum temperatures were ranged from 8.7 to 26.0 °C and 29.0 to 37.4 °C, respectively. The weekly mean open-pan evaporation too ranged between 2.8 to 11.0 mm, respectively across kharif and rabi cropping period.

Hyderabad: Total rainfall received was 984 mm at Hyderabad which was about 36% higher than normal (722 mm) during kharif and rabi cropping seasons. The rainfall received in kharif cropping season was adequate except mild dry spell in late July. The rainfall distribution was highly favorable for kharif cropping with bimodal distribution coinciding peaks in October and June. The high intense rainfall occurred in October resulted in severe grain mold in late maturing sorghum cultivars. No rainfall occurred from November onwards. The accumulated thermal time (or growing degree days (GDD)) was 2292 and 1855 °Cd, respectively for kharif and rabi cropping periods. There was 18.0 % less GDD available for rabi than kharif cropping season that might be one of the reasons for lower productivity of sorghum planted in rabi season. Weekly mean minimum and maximum temperatures were ranged from 8.6 to 22.90 °C and 28.1 to 32.0 °C, respectively. The weekly mean open-pan evaporation too ranged between 2.9 to 5.9 mm, respectively during kharif and rabi cropping period.

Bijapur: At Bijapur, the total rainfall received during kharif and rabi seasons was 686 mm which is less than normal rainfall for this location (normal: 595 mm). The rainfall distribution revealed the kharif season cropping period too received some amount of rainfall during July and August. The Rainfall distribution was bimodal with peaks of rainfall occurring in mid-July and mid October. The rainfall distribution was similar to kharif cropping region. The rainfall received during mid September and October was highly adequate to plant the rabi sorghum with stored soil moisture. Subsequently, some amount of rainfall occurred which was coincided with PI stage. Following this, the crop experienced severe drought conditions in during reproductive (GS2) and ripening phases (GS3). The crop had to depend entirely on the September and October rainfall for growth and yield formation. Temperature data showed that the diurnal variation in maximum and minimum was wide in rabi cropping season than kharif (Met Table 1). The minimum temperature dropped to about 10.0-11.0°C which was coincided with flowering and subsequent grain-filling. The accumulated thermal time recorded was 2275 and 1902 °Cd, respectively for kharif and rabi cropping periods. Thus, the lower availability (15.0 % less than kharif) of accumulated growing degree days (GDD) for the rabi cropping period is one of the reasons for lower productivity of rabi sorghum, besides occurrence of drought stress during pre-(GS2) and post-flowering (GS3) stages. Weekly mean minimum and maximum temperatures recorded were from 11.0 to 22.4 °C and 29.0 to 33.5 °C, respectively. The weekly mean open pan evaporation too ranged from 3.5 to 7.0 mm during kharif and rabi cropping period. The evaporation values were lower in the rabi cropping period than kharif.

Solapur: The rainfall received at Solapur during kharif and rabi cropping period and was 480 mm which was 24% less than normal (635 mm). The rainfall distribution revealed that kharif season cropping period did not receive any much rainfall until mid August. (Met Table 1).The Rainfall distribution was bimodel with peaks of rainfall occurring in first week of June and last week of August. The rainfall received during the first fortnight of September was just adequate to plant the rabi sorghum with stored soil moisture. Subsequently, some rainfall occurred in last week of October which was coincided with seedling stage of the crop (GS1). Temperature variability was almost similar to Bijapur excepting prevalence of relatively higher minimum temperatures during GS3 stage. The crop was exposed to seedling pre (GS2)- and post-flowering (GS3) stage drought and heat stresses from October last week onwards until maturity. This erratic distribution of rainfall at Solapur resulted in poor performance of the crop especially in shallow soils. Weekly mean minimum and maximum temperatures recorded were from 11.4 to 23.9°C and 31.0 to 35.0°C, respectively.

Rahuri: The total rainfall received during kharif and rabi seasons (standard week 24 to 5) was 510 mm which amounts to a deficit of just 14% than long term normal (595 mm). The rainfall distribution revealed that in kharif season cropping period, some amount of rainfall occurred from June to July followed by torrential rain in third week of October. The Rainfall distribution is unimodel with peak rainfall (218 mm) occurring in third week of August. The rainfall received in September was normal to plant rabi sorghum in stored soil moisture conditions. Subsequently, the rainfall ceased from late October onwards. Following this, the crop experienced severe atmospheric and soil drought conditions during reproductive (GS2) and ripening phases (GS3). Temperature data showed that the diurnal variation in maximum and minimum was rather very wide in rabi cropping season than kharif (Met Table 1). Immediately after sowing of rabi crop, the minimum temperatures dropped continuously reaching a low of about 9.4° C which coincided with flowering to soft-dough stage. The accumulated thermal time recorded was 2367 and 1928 °Cd, respectively for kharif and rabi cropping periods. Thus, the lower availability (19.0 % less than kharif) of accumulated GDD for the rabi cropping period is one of the reasons for lower productivity of rabi sorghum, besides occurrence of drought stress during pre-(GS2) and post-flowering (GS3) stages. Weekly mean minimum and maximum temperatures recorded were ranged from 9.4 to 27.6 °C and 28.1 to 35.0 °C, respectively. The weekly mean open-pan evaporation too ranged between 3.4 to 7.8 mm during kharif and rabi cropping period.

Tandur: The total rainfall received during kharif and rabi seasons (standard week 24 to 5) was 693 mm which was close to the normal amount (750 mm). The rainfall distribution revealed that in kharif season cropping period, good amount of rainfall occurred in the first fort-nights of June and September (Met Table 1). The Rainfall distribution was bimodal with peaks of rainfall occurring in second week of June and September. The rainfall received in September and October was adequate to plant rabi sorghum with stored soil moisture. Subsequently, no rainfall received from November onwards. Following this, the crop was subjected to severe atmospheric and soil drought conditions during reproductive (GS2) and ripening phases (GS3). Temperature data showed that the diurnal variation in maximum and minimum was rather narrow at this location too (Met Table 1).

The accumulated thermal time recorded was 2465 and 2126 °Cd, respectively for kharif and rabi cropping periods. Thus, the lower availability (15.0 % less than kharif) of accumulated GDD for the rabi cropping period is one of the reasons for lower productivity of rabi sorghum, besides occurrence of drought stress during pre-(GS2) and post-flowering (GS3) stages. Weekly mean minimum and maximum temperature recorded was ranged from 9.4 to 25.0 °C and 29.1 to 39.7 °C, respectively.

2. Trial 1R: Preliminary evaluation of diverse germplasm for rabi adaptation

(Table 1R.1.1 – 1R.1.10)

Thirty-seven rabi sorghum landrace germplasm along with three checks were evaluated at six test locations (Parbhani, Tandur, Bijapur, Solapur, Gulbarga, and Rahuri) with an objective of identifying potential donors for rabi adaptation traits such as phenology, key physiological traits, components of biomass, and grain yield. All the accessions were primarily belongs to the biological races either *durra types.* The crops were grown on medium vertisols under stored soil moisture rainfed conditions. The data are presented in table's 1R.1.1 – 1R.1.10.

Phenology and plant height: Mean days to flowering and days to physiological maturity differed significantly ($P \le 0.05$) and were ranged from 68-77 d and 110-119 d, respectively. In general, average time taken for flowering was longer at Bijapur (79 d), and Rahuri (78 d). Least time to flowering was recorded at Solapur (62 d). Six entries recorded early flowering than check CSV 22R (75) include CRS 70, CRS 72, CRS 73, PEC 15, VJV 109, RSV 1988 (68-71 d). The trend in days to physiological maturity was similar to flowering. Plant height differed significantly ($P \le 0.05$) at different locations and ranged from 184 to 223cm with an average of 209 cm. Majority of entries were tall typical of rabi land races. Plant height recorded was more at Rahuri followed by Parbhani. Days to flowering had shown significant ($P \le 0.05$) positive relationship with total biomass and dry fodder yield.

Physiological traits: Leaf are index (LAI) at flowering varied significantly ($P \le 0.05$) at different locations and ranged from 2.27 to 3.23 with a mean of 2.67. The LAI was higher at Rahuri and Bijapur .

Relative chlorophyll content (SPAD units) at flowering differed significantly ($P \le 0.05$) and varied from 47.9 to 58.6 with an average of 53.6. Entries maintained higher SPAD include EP 98, EP85, RSV 2234, RSV 2209, VJV 112 (56.2-58.6) than check CSV 22R. Relative water content (RWC) at flowering differed significantly ($P \le 0.05$) and varied from 71.1 to 85.7% with an average of 75.9%. Entries maintained higher RWC values include PEC 23, RSV 1837, RSV 1988 and PVRL 16-2 (79.6-85.7%) than check CSV 22R. Photosynthesis rate (Pn rate), transpiration and stomatal conductance at flowering differed significantly ($P \le 0.05$). Pn rate varied from 71.1 to 85.7% with an average of 75.9%. Entries maintained higher Pn rate CRS 74, VJV 106, VJV 109, and RSV 1837 than check CSV 22R.

Biomass components and fodder yields: Leaf dry weight, stem dry weight, total biomass differed significantly ($P \le 0.05$). Total biomass at maturity and ranged from 93.2 to 123.7 g pt $^{-1}$. None was superior to best check *Phule Suchitra* for biomass at production at maturity. Leaf mass at flowering has shown very high significant positive relationship with biomass (r=0.632**). On the other hand, total biomass at maturity showed significant positive relationship with dry fodder yield (r=0.684**)and grain yield (r=0.409**)

Grain yield components: Grain yield, HI and 1000-seed weight differed significantly ($P \le 0.05$) at all locations. High mean grain yields were obtained at Rahuri followed by Bijapur, and Solapur, while very low grain yields were obtained at Tandur. Average mean grain yield recorded was 42.4, 31.6, 25.0, 36.6, 33.3, and 20.0 g/ plant, at Rahuri, Bijapur, Parbhani, Gulbarga, Solapur and Tandur, respectively. In grain yield none was significantly superior to best check *Phule Suchitra*. However, entries were on par with check include PVR 947, RSV 1921, RSV 1945 and RSV1837 (10.4- 41.7 g/pl than check *Phule Suchitra* (41.5 g/pl). HI was negatively related (r=-0.373*) to dry fodder yield, while its relationship was significantly positive (r= 0.612**) for with grain yield under drought conditions.

3. Trial 2(M) & 3(S): Phenotyping advanced rabi sorghum entries for drought adaptation traits in medium and shallow soils

(Tables 2M 2.1-2M2.5 and 3S 3.1- 3S.3.5)

Sixteen advanced rabi-adapted sorghum genotypes including three checks were phenotyped in both medium (≤75 cm soil depth) and shallow soils (≤45 cm soil depth) at Bijapur, Parbhani, Rahuri, Solapur and Tandur. Plant Breeders from different sorghum centres contributed these test materials which are at the advanced stage of development (stabilized F_6-F_7). These materials were contributed based on their superior performance in the station and state MET trials. The test materials are primarily belongs to biological landrace *durra* which had specific adaptation to rabi season and said to be possessing relatively superior traits conferring tolerance to shoot fly, drought and heat, low temperature, pearly white and bold grain. The objectives of this trial were to evaluate advance rabi sorghum entries for putative traits (phenes) associated with drought adaptation and productivity across the soil depth (medium and shallow soils) and identify potential donors or contrasting parents for further crop improvement work. Testing was done in medium and shallow soils where development of flowering and post-flowering drought stress is rapid than deep soil. The testing hypothesis of genotypes across the soil depths is based on the farmers' practice of growing rabi sorghum with stored soil moisture in both soils in the target production area. Since the same set of entries were grown in both soils, the entries compared for their performance across the soil depths to identify the stable performing genotypes.

Data on important morpho-phenological, physiological traits, biomass, yield and its components were recorded as per standard procedures. Drought susceptibility index (DSI) for plant height, biomass, stover and grain yield was calculated according to the Fischer and Maurer (1978) method, and the same is described below. DSI = (1 – Y/Yp)/D; where Y is the mean grain yield or biomass of a genotype in drought stress condition (shallow soil); Yp is the mean grain yield or biomass of same genotype in nonstress condition (medium soil) and D is the stress intensity D=1– X/Xp; where X is the mean Y of all genotypes; Xp is the mean Yp of all genotypes. DSI is used to characterize the relative drought tolerance of various genotypes (DSI ≤0.50 highly stress tolerant, DSI >0.50 to ≤1.00 moderately stress tolerant, and DSI >1.00 susceptible).

Soil moisture status: Soil moisture content recorded at flowering stage was less than 50% of available in the surface layers indicating the prevalence of drought conditions. The moisture content decreased further decreased at maturity. As discussed previously, no rainfall occurred during G2 and GS3 at all rabi centres indicating the occurrence of pre – and post-flowering drought and heat stress conditions.

Crop phenology and plant height: Days to flowering and days to physiological maturity differed significantly ($P \leq 0.05$). Mean days to flowering differed between the soils depths. None was earlier to early check *Phule Anuradha* in both the soils. Similar trend was observed for days to maturity also. Significant difference ($P \leq 0.05$) was observed in plant height in both the soil depths at all the locations. Plant height ranged from 197 to 237 cm in medium and 138 to 170 cm in shallow soils. Average plant height decreased by 25.0 % in shallow soil over medium. As regards DSI, entries *Phule Suchitra (*0.603) RSSV 1910 (0.692) and BJV 125 (0.764) showed less DSI means more plant height stability. Plant height has shown significant positive correlation with days to flowering, leaf mass and total biomass (r= 0.801, 0.535, 0.548; $P \leq 0.05$ resp.; N=16) in medium soil. Days to flowering showed positive relationship with leaf mass (r=0.630**), and biomass (r=0.512*) in shallow soil.

Physiological traits: Leaf area index (LAI) varied significantly ($P \leq 0.05$) at all locations in both soils depth. Mean LAI decreased by 31.0 % in shallow soil over medium. RSV 1736 and CRS 65 recorded higher LAI, while, BJV 362, and RSV 2138 showed least reduction in LAI under shallow soil stress condition and were stable across the soil depths. Leaf mass, stem mass, biomass differed significantly at flowering and maturity ($P \leq 0.05$). Average biomass production at maturity decreased by 24% in shallow soil over medium. Entries BJV 362, and RSV 1910 recorded lower DSI for biomass and were stable across the soil depths. LAI showed significant negative relationship with 1000-grain mass (r= -0.588**, and -0.350ns for shallow and medium soil, res.).

Leaf mass at flowering has shown significant positive correlation with biomass flowering in shallow soil at Rahuri (r=0.814**.). Relative leaf water content (RLWC) recorded at flowering significantly ($P \leq 0.05$) varied at different locations. RLWC at flowering reduced by 3.3% in shallow soil stress conditions over medium. SPV 1736 in medium soil and CRS 65 in shallow soil recorded superior crop water status than checks. Interestingly, higher RLWC resulted in more stomatal conductance in shallow stress condition ($P \leq 0.05$).

SPAD values differed significantly ($P \leq 0.05$) in both medium (mean: 49.1) and shallow (mean: 36.9) soils. Higher SPAD values were recorded in medium soil than in shallow soil. Further, SPAD values had decreased by 25% in shallow soil stress conditions over medium. Entries, None was superior to check *Phule Anuradha* for SPAD in both soils. *Phule Anuradha* alone was stable across the soil depths for SPAD. Similar trend was observed for total chlorophyll content.

Photosynthesis rate, transpiration rate, and stomatal conductance at 50 % flowering differed significantly ($P \leq 0.05$) in both soil depths. CRS 65 and BJV 362 in shallow soils were superior to checks in Tp rate. In Pn rate, RSV 1910, RSV 1736 in medium soils, and RSV 2121, RSV 2138 were superior to checks. Pn rate, and Tp rate did not reduced in shallow soil , while stomatal conductance reduced by 17% in shallow soil over medium. Pn rate showed significantly positively relationship with biomass maturity, and fodder yield in both soils at Rahuri. Leaf temperature differential (LTD) recorded at flowering varied significantly ($P \leq 0.05$) among the entries.

Grain yield and its components: Grain yield, HI and 1000-seed mass differed significantly ($P \leq 0.05$) at all locations in both soil depths. Mean grain yield ranged from 2626 to 3247 kg ha^{-1} and 1002 to 1842 kg ha^{-1} in medium and shallow soil, respectively. High mean grain yield was realized at Rahuri followed by Parbhani in medium and Bijapur and Solapur in shallow soil. Significant difference was observed for grain yield at all locations in both soils. On overall mean basis, none was significantly superior to check *Phule Suchitra in medium soil, while in* shallow soil, entries BJV 362 and BJV 371 were on par with check *Phule Suchitra.* Similar trend was observed in case of 1000-grain mass and HI. Harvest index showed significant positive correlation with grain yield (r=0.537*, and 0.917** for medium and shallow soil, res.), while its relationship with dry fodder yield was significantly negative ($P \leq 0.05$). Grains per panicle, HI, 1000 seed mass too differed significantly

Grain yield decreased by 50% in shallow soil depth over medium. In terms of DSI for grain yields, RSV 1910 (DSI=0.686), and BJV 362 (DSI=0.749) and BJV 371 (DSI=0.762) and BJV 129 (DSI=0.785) were relatively more stable than checks under terminal drought and heat stress conditions. In terms of grain yield stability under dryland stress conditions, any cultivar that gives reasonably stable yields is desirable. DSI is calculated according to the Fischer and Maurer (1978) method and is classified the genotypes for their relative degree of tolerance based on these values (DSI ≤0.50 highly stress tolerant >0.50 to ≤1.00 moderately stress tolerant, and >1.00 susceptible).

4. Trial 4 RF and 4 Irrg: Phenotyping sorghum for key root traits associated with drought adaptation

(Tables 4R.4.1 to 4.2)

Thirteen advanced rabi sorghum genotypes including checks were characterized for root and shoot related traits that contribute survival at flowering and postflowering drought and heat stress. Genotypes were evaluated in the specially constructed root structure facility at Rahuri. The root screening facility was specially created above the ground with required soil depth (1.0 m) and compaction as applicable to natural field conditions. This root screening facility was filled with vertisol and irrigated up to saturation prior to the sowing of. Entries were planted in split-plot design with two replications. Two water regimes namely i) rainfed and 2) limited irrigated (control) were assigned main-plots, while genotypes were allotted to sub-plots. The irrigated control treatment received 4-irrigations. The soil was brought back to near field capacity each time whenever irrigated.

Significant differences were observed for main effects and interactions for various physiological, root and shoot related traits ($P \leq 0.05$) at Rahuri. There was significant decrease in root and shoot related traits under rainfed than in irrigated. Mean plant height, decreased by 24% in rainfed than irrigated. Mean LAI and SPAD declined by 32%, and 7.0% under moisture stress over control. CRS 66 and RSV 1986 were superior for above traits across moisture regimes. Total biomass differed significantly among moisture regimes, genotypes including interaction effects. There was 30% decrease in biomass at flowering and maturity under moisture stress than irrigated control. RWC, Pn rate, TP rate and stomata conductance differed significantly.

Genotypes BJV 129, and BJV 125 alone recorded higher biomass across the rainfed and irrigated conditions. Grain yield decreased by 28 % in drought over irrigated and BJV 129, and BJV 125 were superior. The mean fresh root biomass, root length, root volume, and root numbers declined by 42%, 39%, 27%, and 15 %, respectively in rainfed condition than in irrigated. Mean root length at physiological maturity under rainfed condition varied from 40 to 122 cm/plant. Root number per plant at maturity varied in 31 to 55 in stress conditions. Root mass under moisture stress ranged 23 to 75 g/plant.

Entries, BJV 129, BJV 125, RSV 2145, and RSV 1986 were relatively superior to superior to checks for key root traits under stress and non-stress conditions.

5. List of Collaborator from AICSIP centres contributed to the Crop Physiology program

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MPKV, Rahuri	:	Drs. SV Nirmal, MS Shinde, SR Gadakh
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