Cultivar options for salinity tolerance in sorghum

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Introduction

Sorghum (*Sorghum bicolor*) is the fifth most important cereal crop of the world and is a major source of food, feed and fodder in the semi-arid tropics (SAT). It is the third most important staple food crop after rice (*Oryza sativa*) and wheat (*Triticum aestivum*) for millions of people in India. The grain molds, shoot fly and prolonged dry spells are main reasons for low productivity in India. Of all the soil mineral stresses or chemical toxicities, acidity, and associated Al^{3+} toxicity and salinity are probably the most important constraints to sorghum productivity in tropical environments. Saline and sodic soils cause mineral stresses on approximately 0.9 billion ha of land (Gourley et al. 1997). In addition, the problematic soils that include saline soils which constitute 15% (approx.) of total cultivable area in India, reduce crop productivity leading to food insecurity and rendering crop production non-remunerative. The increased demand for sorghum, especially for feed uses in SAT regions (Kleih et al. 2000) imposes extension of sorghum cultivation in saline soils. Soils with an ECe of <4 dS m^{-1} (Shannon 1997) are considered non-saline; an ECe of 4 to 16 dS m^{-1} are moderately saline and an ECe of >16 dS m^{-1} are highly saline (www.cahe.nmsu.edu). Development of cultivars tolerant to soil salinity along with appropriate management practices is required for enhanced production under saline conditions (Ramesh et al. 2005). Salinity causes reduction in germination (Igartua et al. 1994), growth (Maiti et al. 1994) and yields of sorghum (Macharia et al. 1994) and modifies the physiological and biochemical processes of the plant (Dubey 1994). Salinity causes more serious damage in the seedling emergence stage than in any other stage in sorghum (Macharia et al. 1994). Though sorghum is known to be relatively more tolerant to soil salinity than maize (*Zea mays*) (Igartua et al. 1994, Krishnamurthy et al. 2007), genetic enhancement of sorghum for salinity tolerance would further increase sorghum productivity in such soils.

An evaluation of a limited number of germplasm lines, breeding lines and a few popular cultivars both at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and Directorate of Sorghum Research (DSR) had indicated existence of significant genetic variability in sorghum for grain yield and other agronomic traits under saline soil conditions (Ramesh et al. 2005). Similarly, Krishnamurthy et al. (2003) at ICRISAT have identified some elite sorghum varieties and improved lines promising for agronomic traits and also having better salinity tolerance under induced salinity (at 250 μM NaCl solution; ECe 23.4 dS m^{-1}) in a series of pot-culture experiments. The varieties and hybrids (developed based on the selected A-/B-lines and R-lines) identified in the above studies were re-evaluated in the natural saline soils with an average ECe of 10 dS m^{-1} at Agricultural Research Station (ARS), Gangavathi, Karnataka, India. This is a part of the collaborative project involving ICRISAT, Patancheru, India; International Center for Biosaline Agriculture (ICBA), Dubai, UAE; and ARS, Gangavathi. The idea was to identify promising sorghum hybrids, varieties and hybrid parents that give higher grain yields under moderately high saline conditions.

Materials and methods

During the rainy season 2006, two separate trials were conducted at ARS, Gangavathi to test the salinity tolerance and agronomic desirability of sorghum hybrids in one trial and varieties/restorers in the other. The varietal trial was repeated during rainy season 2008 in similar conditions of soil salinity. In the hybrid trial, 27 hybrids plus three checks (CSH 16, SP 40646 and ICSB 406) and in the varietal/restorers trial, 26 varieties/restorers with three checks (S 35, SP 40646 and ICSB 406) were evaluated in randomized complete block design (RCBD), each with three replications in the natural saline soils with an average ECe of 10 dS m^{-1}. All the hybrids used in the study were newly developed by crossing 12 parents (selected for tolerance to soil salinity over seasons and locations) in various combinations. The varieties/ restorers represent a wide genetic base and were tested for 2–3 seasons in the past for salinity tolerance. In these trials, each entry was grown in 4 rows of 3 m length with 45 cm interrow spacing. A 10-cm intra-row spacing between plants was followed. The net plot included two rows (2.7 m^2). All the recommended practices, to raise a good crop, were followed. Data were recorded for the varieties on the traits, plant height, agronomic desirability score, stay green score, charcoal rot score and grain size during 2006 and on time to 50% flower, plant height and agronomic desirability score during 2008 adopting standard methods. The agronomic desirability score is the plant appearance visual score taken at maturity on a scale of 1 to 5, where 1 = agronomically most desirable with good grain and fodder yield potential and 5 = least desirable with poor grain and fodder yield potential. For grain yield, the produce from net plot leaving the border plants was harvested to get the net plot yield and extrapolated to t ha^{-1}. The data on the trials conducted during rainy season of 2006 and 2008 was subjected to individual analysis of variance. The error variance for the common traits recorded during both the years, ie, plant height, agronomic desirability and grain yield was homogeneous and hence subjected to combined analysis of variance. The analysis was done using GENSTAT 10th edition.

Results and discussion

ANOVA of the sorghum hybrids evaluated during 2006 rainy season (data not shown here) depicted significant differences among the hybrids for all the traits. Of the 27 hybrids tested, grain yield of 17 hybrids was similar to that of the best check CSH 16 (6.6 t ha^{-1}) in the moderate saline conditions of Gangavathi (Table 1). Nine hybrids recorded significantly higher 100-grain weight (3.06 to

Table 1. Performance of sorghum hybrids in the sorghum salinity screening trial at ARS, Gangavathi during the rainy season 2006.

Hybrids	Plant height (m)	Agronomic desirability score[1]	Stay green score[2]	Charcoal rot score[3]	Grain size (g 100^{-1})	Grain yield (t ha^{-1})	Rank
ICSA 405 × JJ 1041	2.4	1.7	1.7	1.0	3.30	6.0	2
ICSA 707 × ICSV 745	3.0	1.0	2.3	1.3	3.22	5.9	3
ICSA 766 × ICSV 96020	2.2	1.7	1.7	1.3	2.76	5.9	4
ICSA 707 × ICSR 170	2.2	2.0	2.0	1.0	3.23	5.6	5
ICSA 276 × ICSV 93048	3.0	2.0	1.7	1.3	2.88	5.6	6
ICSA 276 × S 35	3.0	1.0	1.7	1.0	2.87	5.6	7
ICSA 405 × ICSR 93034	2.7	1.3	2.3	2.0	3.28	5.3	8
ICSA 405 × ICSV 93048	1.9	2.3	1.7	1.0	3.56	5.2	9
ICSA 766 × JJ 1041	2.6	1.3	2.3	1.0	2.99	5.2	10
ICSA 707 × ICSR 196	2.2	1.7	2.0	1.3	3.12	5.2	11
ICSA 276 × SPV 1022	3.0	2.0	2.7	2.0	2.74	5.2	12
ICSA 405 × S 35	2.6	2.3	1.7	1.0	3.67	5.2	13
ICSA 405 × ICSV 745	1.9	2.0	2.3	1.0	2.86	5.1	14
ICSA 276 × ICSV 93046	3.2	1.0	2.0	2.0	2.84	5.0	15
ICSA 405 × ICSV 96020	2.9	2.3	2.0	2.0	3.06	5.0	16
ICSA 405 × ICSV 93046	2.6	1.3	1.0	1.0	3.38	4.8	17
ICSA 405 × CSV 15	2.6	1.7	2.7	1.7	2.94	4.7	18
Controls							
CSH 16	2.0	2.0	2.7	1.7	2.58	6.6	1
SP 40646	1.7	2.0	1.3	1.0	3.22	2.5	28
ICSB 406	1.0	3.0	2.7	1.0	2.74	1.5	30
Mean	2.33	1.88	2.04	1.32	3.03	4.6	
CV (%)	7.9	24.13	23.2	21.09	9.74	24.73	
CD (5%)	0.3	0.74	0.78	0.46	0.48	1.86	

1. Agronomic desirability score taken at maturity on a 1 to 5 scale, where 1 = agronomically most desirable and 5 = least desirable.
2. Stay green score taken at maturity on a 1 to 5 scale, where 1 = most green and 5 = least green.
3. Charcoal rot score based on plants lodged taken at maturity on a 1 to 5 scale, where 1= no lodging and 5 = full lodging.

3.56 g) compared to the check CSH 16 (2.58 g). Twelve hybrids recorded charcoal rot score of 1.0 and for stay green, 11 hybrids had significantly superior scores than the control (2.7) demonstrating their capability to withstand moisture stress which is usually experienced by sorghum in major growing regions in general and saline soils in particular. Three hybrids recorded significantly superior agronomic desirability score (1.0) compared to the check (2.0). For plant height, 14 hybrids recorded significantly higher values (2.4 to 3.2 m) compared to the best control, CSH 16 (2.0 m) indicating their superior fodder value. A hierarchical cluster analysis (using Ward's ISS method) for grouping the 30 hybrids (including three checks) into representative groups on the basis of their grain yield under saline conditions and all the other desirable characteristics listed in Table 1 showed that the hybrids ICSA 405 × JJ 1041, ICSA 766 × ICSV 96020, ICSA 707 × ICSV 745, ICSA 276 × ICSV 93048 and ICSA 276 × S 35 clustered with CSH 16 indicating that these hybrids are best adapted for the salinity level and the iso-environments of Gangavathi.

In varietal/restorers trial, the data on plant height, agronomic desirability and grain yield, recorded during both 2006 and 2008 rainy season was subjected to combined analysis for variance (data not shown here) as the error variances across the years were homogeneous for these traits. The variance due to year was high for grain yield as seen from the greater mean sum of squares (102.87 for grain yield, 14.52 for plant height) compared to that of genotypes (4.10 for grain yield, 0.52 for plant height) and genotype × year interaction (2.40 for grain yield, 0.21 for plant height). Though the genotype × year interaction was significant for both these traits, the interaction was non-cross over type as seen from the significant rank correlation. From these results it is suggested that the environment (year of evaluation) has significant influence on the plant height and grain yield and since genotype × year interaction is non-cross over type, the resistant genotypes can be selected from the pooled data. The grain yield among the sorghum varieties tested ranged from 1.5 to 4.6 t ha^{-1} (3.5 t ha^{-1} in best check S 35) across 2006 and 2008 rainy season in the moderate saline conditions of Gangavathi (Table 2). JJ 1041 had the highest grain yield (4.6 t ha^{-1}) followed by two other varieties ICSB 707 (4.2 t ha^{-1}) and CSV 15 (4.1 t ha^{-1}). These varieties were significantly superior to all other varieties and S 35 for grain yield. The plant height among the varieties ranged from 1.1 to 2.3 m. Of these, JJ 1041 (2.1 m) and CSV 15 (1.9 m) showed good plant height which may serve as promising sources of fodder in areas with problematic soils. There were no significant differences among the varieties for stay green score and charcoal rot score. The grain size ranged from 1.75 g 100^{-1} grains (SP 39262) to 3.65 g 100^{-1} grains (ICSR 170). The time to 50% flower ranged from 62 days (SP 39262) to 85 days (ICSV 93048). The top three best performing varieties for grain yield had a grain size of 2.5 g 100^{-1} grains (3.4 g 100^{-1} grains in check S 35) and among these, CSV 15 flowered early in 69 days (66 days in check S 35). A similar clustering exercise as mentioned for grouping of hybrids to have all the other desirable traits along with grain yield showed that the varieties JJ 1041, ICSB 707, SP 47529, SPV 1022 and CSV 15 clustered as one top tolerant group and therefore are the best adapted ones for the saline rainy-season environment of Gangavathi.

The results indicated that considerable variability exists among the sorghum hybrids and varieties tested for salinity tolerance in terms of grain yield, fodder yield measured through plant height and other characteristics providing adequate choices for selection. The hybrids ICSA 405 × JJ 1041, ICSA 766 × ICSV 96020, ICSA 707 × ICSV 745, ICSA 276 × ICSV 93048 and ICSA 276 × S 35 and the varieties JJ 1041, ICSB 707, SP 47529, CSV 15 and SPV 1022 clustered into one group and are suitable for iso-climatic conditions as that of Gangavathi. Further, the hybrids used in this study were not assessed previously for their salinity reaction while the varieties, which represent a broader genetic base (owing to their large and diverse pedigrees), were assessed for salinity tolerance in the past at different locations. The grain yield of hybrids is superior to that of varieties though less than the hybrid check CSH 16. Previous studies (Rao et al. 1988, Igartua et al. 1994, Azhar et al. 1998) have also shown that the hybrids are superior in their stand establishment and productivity under saline conditions. It is important to develop diverse parental lines with salinity tolerance to produce more heterotic hybrids that suit different environments. Till that time the varieties identified in this study will be good enough for use in cultivation under saline soil conditions.

Table 2. Mean performance of sorghum genotypes under salinity stress (ECe 10 dS m^{-1}) at ARS, Gangavathi during rainy season in 2006 and 2008.

	Pooled data (2006 and 2008)			2006 rainy season			2008
Variety/Restorer	Plant height (m)	Grain yield (t ha^{-1})	Agronomic desirability score[1]	Stay green score[2]	Charcoal rot score[3]	Grain size (g 100^{-1})	Time to 50% flower (days)
JJ 1041	2.1	4.6	1.7	3.3	2.0	2.5	75
ICSB 707	1.6	4.2	2.7	2.3	1.3	2.5	74
CSV 15	1.9	4.1	2.3	3.0	2.0	2.5	69
SP 47503	1.8	4.0	2.3	3.3	1.7	2.7	76
SP 39105	2.0	3.9	1.8	2.0	1.0	2.8	71
SP 47513	1.6	3.8	1.8	2.0	1.0	2.9	80
SP 47529	1.6	3.8	2.3	3.0	2.0	2.6	72
SPV 1022	1.8	3.7	2.2	3.0	1.7	2.4	67
ICSR 93034	1.9	3.6	2.0	3.3	1.7	3.5	76
S 35 (control)	1.8	3.5	2.8	3.3	1.0	3.4	66
SP 47519	1.4	3.5	2.0	3.0	1.3	2.4	70
ICSV 112	1.7	3.5	1.5	3.0	1.0	2.1	72
ICSR 170	1.5	3.5	2.7	2.0	1.0	3.7	83
ICSV 96020	1.7	3.4	2.2	2.3	2.0	2.3	78
NTJ 2	1.6	3.3	2.3	3.0	1.3	3.4	69
A 2267-2	1.8	3.2	2.5	3.3	1.0	2.2	79
ICSV 745	1.8	3.1	2.3	2.7	1.3	2.6	72
SP 39007	1.6	2.9	2.2	2.0	1.0	3.4	75
ICSV 93048	1.6	2.8	1.5	2.7	1.0	2.6	85
ICSV 93046	2.1	2.7	2.0	3.3	1.7	2.9	81
SP 40646 (control)	1.5	2.6	2.8	1.0	1.0	3.3	82
SP 40567	1.5	2.5	2.7	3.3	1.0	2.8	74
GD 65008 (brown)	2.3	2.4	2.5	2.0	1.0	2.7	74
ICSR 93024-1	2.3	2.2	3.5	2.0	1.0	2.0	75
SP 39053	2.1	2.0	3.2	3.0	1.3	3.0	69
ICSB 676	1.1	1.9	2.8	2.3	1.0	2.6	77
SP 36257	1.3	1.8	2.8	2.3	1.3	2.7	76
ICSB 406 (control)	1.1	1.7	2.9	3.0	1.0	1.9	77
SP 39262	1.9	1.5	3.3	1.7	1.0	1.8	62
Mean	1.7	3.1	2.4	2.7	1.4	2.7	74.4
LSD (P <5%)	0.3	0.6	0.7	1.1	0.5	0.4	7.0
CV (%)	16.9	16.8	25.6	24.7	23.1	9.4	5.7

1. Agronomic desirability score taken at maturity on a 1 to 5 scale, where 1 = agronomically most desirable and 5 = least desirable.
2. Stay green score taken at maturity on a 1 to 5 scale, where 1 = most green and 5 = least green.
3. Charcoal rot score based on plants lodged taken at maturity on a 1 to 5 scale, where 1 = no lodging and 5 = full lodging.

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