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I. Introduction

Sweet sorghum can be grown under dryland conditions with annual rainfall ranging from 550-750 mm. The best areas to produce this crop are Central and South India, subtropical areas of Uttar Pradesh and Uttaranchal. It can be grown on well-drained soils such as silt loam or sandy silt clay loam soils with a depth of 0.75 m. Atmospheric temperatures suitable for sweet sorghum growth vary between 15 and 37°C. Sorghum being a C_4 species is adapted to a wide range of environments with latitudes ranging from 40°N to 40°S of the equator. Sorghum in general has relatively a deep root system (>1.5 m), and has the unique feature of being 'dormant' under unfavorable conditions and resume growth once environmental conditions are favorable.

The productivity of sweet sorghum in postrainy (rabi; October-November planted) season is 30-35% less than that in rainy (kharif) and summer seasons because of short day length and low night temperatures. In order to meet the industry demand for raw materials especially during lean periods of sugar cane crushing, there is a need to develop sweet sorghum cultivars that are photoperiod- and thermo-insensitive with high stalk and sugar yields in different maturity backgrounds.

II. Sweet sorghum research and development efforts – past work

Initial attempts have been made to develop sweet sorghum by crossing indigenous germplasm with exotic ones that led to the identification of superior ones with high stalk yield and Brix, with moderate grain yield (Rajavanshi and Nimbkar 1996). Evaluation of some exotic sweet sorghum genotypes for stalk yield and quality characters resulted in identification of promising entries such as 'Cart', 'Willey' and 'Rio' (Kishan Singh and Bakhtawar Singh 1986).

The first major attempt in India was made at the International Crops Research Institute for Semi-Arid Tropics (ICRISAT) to evaluate and identify useful high biomass producing sweet sorghum germplasm from world collections (Seetharama and Prasada Rao 1987). The sweet sorghum improvement program during last two decades at the National Research Center for Sorghum (NRCS) and All India Coordinated Sorghum Improvement Project (AICSIP) centers resulted in development of number of breeding lines which led to national level release of several varieties such as SSV 84 (High Brix: 18%), CSV 19SS (RSSV 9) and hybrid CSH 22 SS (NSSH 104) with productivity ranging from 40-50 t ha^{-1}. ICRISAT has developed a number of sweet sorghum breeding materials, varieties, experimental hybrids having higher stalk sugar content and superior biomass yields (Reddy et al. 2005).

Directorate of Sorghum Research (DSR, formerly called NRCS) has conducted pilot studies on sweet sorghum-based ethanol production in collaboration with many distilleries and stakeholders (Dayakar Rao et al. 2004, Ratnavathi et al. 2005, Holigal et al. 2004) and alcohol yield realized in these pilot studies was from 25 to 40 liters t^{-1} of stalks crushed. Techno-economic feasibility studies have shown that the cost of alcohol production from sweet sorghum was Rs 1.87 less than that from molasses (Dayakar Rao et al. 2004). ICRISAT through its Agri-Business Incubator (ABI) collaborating with Rusni Distilleries, in Sangareddy, Andhra Pradesh, is promoting sweet sorghum as bio-fuel crop. Rusini Distilleries along with other partners has already started producing ethanol from sweet sorghum (ICRISAT 2006), funded by the Indian government. The work carried out under the project and the cultivars tested under the project are briefly described here in this chapter.

III. Stalk yield and quality parameters of commercial cultivars

The following table 1 gives details of the cane, grain, stalk juice, ethanol yields and stalk juice content of nationally released sweet sorghum cultivars under good crop management practices during the *kharif* season. However, these yields may vary according to the location, date of planting, soil type, rainfall distribution etc.

Table 1. Stalk yield and quality traits of commercially released sweet sorghum cultivars (mean of four years).

Sl. No.	Cultivar	Stalk yield (t ha^{-1})	Juice yield (kl ha^{-1})	Juice extraction (%)	Juice Brix (%)	Ethanol yield (L ha^{-1})	Grain yield (t ha^{-1})
1	SSV 84	35-40	12-14	40-45	17-18	1000	1.0-1.5
2	CSV19 SS (RSSV 9)	35-40	12-14	40-45	17-18	1000	0.8-1.0
3	CSH 22 SS (NSSH 104)	40-45	14-16	40-45	17-18	1134	1.0-1.5

IV. Sweet sorghum cultivars grown on farmer holdings

If a new cultivar is to introduce or grow in large area in the command area of the distillery, initial yield trials has to be conducted and estimate both stalk and ethanol yields on a pilot scale basis. This calls for adoption of good crop and crop management practices to maintain the production system sustainable in the long run.

CSH 22SS, the first high-yielding sweet sorghum hybrid

Concerted research efforts during last two decades at DSR and its cooperating centers in different state agricultural universities and at ICRISAT have resulted in excellent sweet sorghum varieties for use in ethanol production by the sugar industries/alcohol distilleries and for use as green/dry fodder. Varieties are more photoperiod sensitive than hybrids and the latter are mid-late and have significant heterosis (30-40%) for cane, juice and sugar yields over the the former. The development and release of CSH 22SS, the first sweet sorghum hybrid during 2005 is a standing testimony for the success of Indian sweet sorghum improvement program. It was derived by crossing ICSA 38 with SSV 84. The female parent ICSA 38 was developed by ICRISAT and the male parent was bred by Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, Maharashtra. This is a sweet stalk hybrid which has high commercial stalk sugar. The plant is tan colored with green leaves and white midribs, red glumes without awns, semi loose symmetric panicle and white and circular grains. Endosperm is yellow and corneous. Based on its performance in AICSIP trials, it has been recommended for cultivation in Maharashtra, Andhra Pradesh, Karnataka, Tamil Nadu and parts of Madhya Pradesh and Gujarat.

The salient features of CSH 22 SS include:

- Parentage: ICSA 38 x SSV 84
- Medium duration hybrid: 120 days
- Days to 50% flowering: 80 to 88 days
- Plant height: 280-350 cm
- Stalk yield: 48 t ha^{-1}.
- Ethanol yield: 1296 L ha^{-1}
- Juice yield: 16.7 K L ha^{-1}
- Juice extraction %: 37%.
- CCS: 3.8 t ha^{-1}
- Grain yield: 2.1-2.6 t ha^{-1}
- Tolerant to anthracnose, grain mold and downy mildew
- It can be cultivated in dryland areas of Maharashtra, Andhra Pradesh, Karnataka, Tamil Nadu and parts of Madhya Pradesh and Gujarat
- Suitable for cultivation in rainy season as rainfed crop and assured irrigation is required during postrainy and summer seasons

This hybrid recorded 29% to 30% higher stalk yields, 33% and 24% higher juice yields, 43% and 34% higher ethanol yields than the check varieties SSV 84 and CSV 19SS respectively.

SSV 84

It is the first sweet sorghum variety developed by AICSIP, Rahuri, in 1992. It produces stalk yield of about 37.5 t ha^{-1} with a Brix of 18.6%. It can be cultivated in the dryland areas of Maharashtra, Andhra Pradesh, Karnataka, Tamil Nadu and parts of Madhya Pradesh and Gujarat. It is suitable for cultivation in rainy season as rainfed crop and assured irrigation is required during postrainy and summer seasons.

- Pedigree: SSV 84
- Days to 50% flowering: 84 days
- Plant height: 2.65 m
- Plant girth: 19.13 mm
- Bio-mass yield: 52.7 t ha^{-1}
- Juice yield: 11.3 KL ha^{-1}

- Juice extraction: 40.3%
- Brix: 17.5%
- Grain yield: 1289 kg ha^{-1}
- Male fertility restoration: 90%
- Sucrose: 3.99%
- Glucose: 0.42%
- Fructose: 0.18%
- pH of juice : 5.2
- Electrical conductivity of juice: 7.2 m S m^{-1}
- Tolerance to: Shootfly, Aphids, Rust
- Adaptation: Rainy season

CSV19 SS (RSSV 2*SPV 462)

This is the second sweet sorghum variety developed by AICSIP, Rahuri, in 2004 and has shoot fly tolerance and rabi adaptation and is relatively photoperiod insensitive. It produces stalk yield of 37.7 t ha^{-1} with a Brix of 16.7%.

SSV 74

This is a sweet sorghum cum forage variety released by the University of Agricultural Sciences, Dharwad. It produces stalk yield of 40.5 t ha^{-1} 37.7 t ha^{-1} with a Brix of 17.6%

CSV 24SS

A new sweet sorghum variety CSV 24SS was recommended for notification and release as a central variety by the 60th Meeting of Central Sub-Committee on Crop Standards, Notification and Release of Varieties for Agricultural Crops held on 28th June, 2011 at NBPGR, New Delhi (Gazette Notification S.O. No. 2326(E) dated 10th October, 2011).

At the national level over three years, it gave 24.21% and 33.06 % more juice yield than the check SSV 84 and CSV 19SS respectively. It also recorded 39.1 t ha^{-1} fresh cane yield which was 9.72% more than the check variety SSV 84 and 8.91% more than check variety CSV 19SS. It had 1239 L ha^{-1} ethanol yield which was 27.01% and 44.24% more than the checks SSV 84 and CSV 19SS respectively. CSV 24 SS yielded 1273 kg ha^{-1} grain yield in the multi-locational trials which is 17.77% and 18.06% more than the checks SSV

84 and CSV 19SS respectively. Also, it matures in 119 days which is 3 days earlier than the check variety SSV 84.

CSV 24 SS is more resistant to shoot fly and stem borer compared to check SSV 84, but not better than CSV 19SS. However, lesser proportion of plants showed stem borer leaf injury. This variety was recommended for release and cultivation in all the sorghum growing areas of the country in kharif season under assured irrigated condition.

V. Improved sweet sorghum cultivars developed in recent years

ICRISAT and Indian NARS are actively pursuing sweet sorghum improvement. Over the years, cultivars SSV 84, CSH 22SS and RSSV 9 have been released in India and many new varieties and hybrids are ready for release. Some of the released cultivars and important lines ready for commercial cultivation are described here.

ICSV 93046

This is a sweet stalk variety developed at ICRISAT-Patancheru and stood first in AICSIP multilocation trials during 2005-07. It is derived by pedigree selection from a cross between ICSV 700 and ICSV 708. It is suitable for cultivation in both rainy and postrainy seasons. It has tan plant color, thick and juicy stems with 13% sugar. It matures in 125 to 135 days and grows to a height of 3.0 to 3.2 m producing a millable cane yield of 40 to 50 t ha^{1}, juice yield of 20-25 kl ha^{-1} and has a Brix of 16-17%. It gives a grain yield of 2.5 to 3.0 t ha^{-1} and a fodder yield of 10.0 to 11.0 t ha^{-1}. The variety is tolerant to shoot fly, stem borer and leaf diseases. It ratoons well and has stay green trait (ie, stems and leaves even after physiological maturity).

ICSV 25274

This is a sweet sorghum variety developed at ICRISAT and stood first in AICSIP multilocation trials during 2008-09. It is derived by pedigree selection from a cross between DSV 4 and SSV 84. This variety can be cultivated in both rainy and postrainy seasons. It flowers in 85 days, grows to a height of 3.0-3.5 m and has a Brix of 18%. It gives a sugar yield of 3.5 t ha^{-1} apart from a grain yield of 3.0 t ha^{-1}. It is tolerant to downy mildew.

ICSV 700

This is a sweet sorghum variety developed at ICRISAT that performed very well in conditions in the Philippines. The variety flowers in 80-85 days, grows to a height of 3.0-3.5 m and has a Brix of 17-19%. It gives a sugar yield of 3.5-4.0 t ha^{-1} apart from a grain yield of 3.0 t ha^{-1}. It is tolerant to anthracnose and downy mildew.

ICSSH 39

This is a sweet stalked hybrid developed from a cross between ICSA 702 and SSV 74 at ICRISAT. The hybrid is recommended for rainy season cultivation. It has tan plant color with thick and juicy stems. It flowers in 76 days and reaches a height of 3.5 m in rainy season. It produces a millable cane yield of 45 t ha^{-1}, juice yield of 20.2 kl ha^{-1}, Brix of 15% and a sugar yield of 3.1 t ha^{-1}.

ICSSH 58

This is a sweet stalked hybrid developed from a cross between ICSA 731 and ICSV 93046. It has tan plant color with thick and juicy stems. It flowers in 80 days and reaches a height of 3.2-3.4 m in rainy season. It produces a millable cane yield of 45-50 t ha^{-1}, juice yield of 22-25 kl ha^{-1}, Brix of 16% and a sugar yield of 4.0 t ha^{-1}.

In addition to the cultivars developed by public sector institutions, the cultivars developed by private seed companies such as Sugargraze, JK Recova and Urja are also under commercial cultivation in India.

VI. Performance of the cultivar in the sub-project area

1. Multi-location on-farm testing and farmers' participatory cultivar selection

As discussed above, considerable progress has been made in breeding for improved sweet sorghum lines with higher malleable cane and juice yields in India (Table 2). Though there have been significant achievements in terms of development of genotypes with all the sweet stalk productivity traits, many researchable issues like photosensitivity, sugar content, biotic and abiotic

stress tolerance, suitability to target environments exist. Efforts were made under the project to identify stable cultivars for the targeted environments through multilocation and on-farm testing. The achievements made in this regard during the project period are presented below.

- In the multilocation trials of 2011, the hybrid SPH 1713 bred under the project recorded the highest ethanol yields of 1199 l ha^{-1} (Table 2) and has shown 23% superiority for computed ethanol yields over the check CSH 22SS (977 l ha^{-1}).
- Similarly, the variety SPV 2074 developed under the project showed a superiority of 13% for stalk yields and 10% for juice yields over the check variety CSV 19SS in multilocation trials of 2011 (Fig. 1).
- In the on-station trials at DSR, the hybrids DMS 8A x RSSV76 (ethanol yield 3304 l ha^{-1}), DMS 26A x SSV 74 (ethanol yield 2807 l ha^{-1}), DMS 30A x SSV 74 (ethanol yield 2794 l ha^{-1}) showed a superiority of 21-43% compared to control CSH 22SS (ethanol yield 2306 l ha^{-1}).
- Out of four hybrids contributed to SFPCT-2011K, the hybrid DSRH 3 was found superior for fresh stalk yield, juice yields and Brix content by 25%, 31% and 13%.

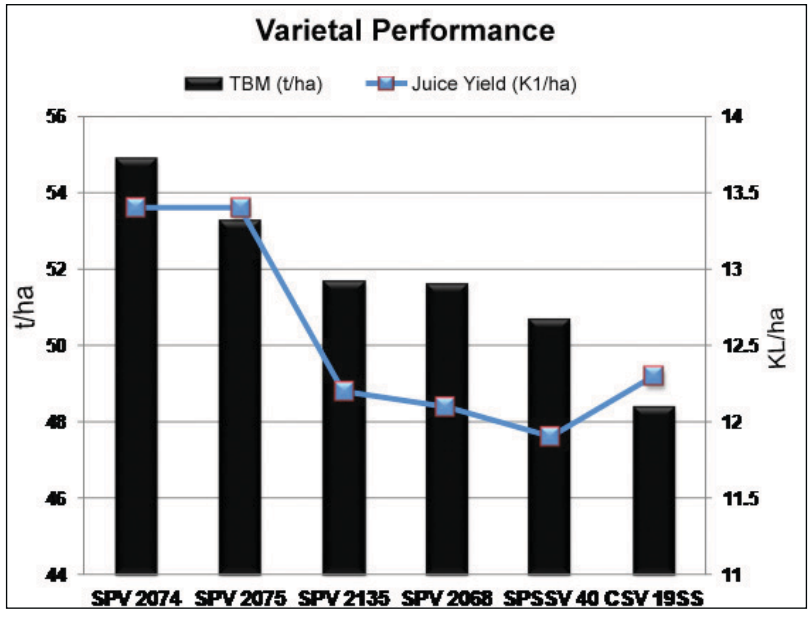

Fig. 1. Performance of test varieties for biomass and juice yields – IAVHT (AICSIP) - Kharif 2011.

- Bioethanol yields ranged from 475 to 1732 l ha^{-1}. SPSSV 34 has recorded 19% higher ethanol yields than SSV 84 (C) followed by SPSSV 33 (17% more) and SPSSV 27 (16% more).
- In hybrids, ICSSH 58 had high resource use efficiency in dryland conditions.
- Fresh stalk yield had shown high positive correlation (R2=0.9108**) with ethanol yields and it could be used as surrogate to estimate the ethanol yields in large scale filed trials.

Table 2. Performance of hybrids for sugar traits during initial & advanced varietal & hybrid trials by AICSIP – Kharif 2011.

No	Entry	Brix (%)	Sucrose (%)	TSI (t ha^{-1})	Ethanol yield (L ha^{-1})	Grain yield (kg ha^{-1})
1	SPH 1711	17.8	12.3	2.15	1148	2912
2	SPH 1669	17.6	11.5	1.56	829	3049
3	SPH 1712	17.1	11.5	1.43	760	2348
4	SPH 1713	17.0	11.5	2.25	1199	2828
5	SPH 1670	16.8	10.7	1.96	1045	3082
6	CSH 22SS	16.1	10.0	1.83	977	2862
	C.D. (5%)	1.0	1.6	0.75	398	1074

2. New sweet sorghum hybrids under station trials

Several hundreds of new experimental hybrids were produced and evaluated for sweet sorghum productivity traits during the project period. The hybrids which performed better than the check CSH 22SS are discussed here.

- The hybrids ICSA 560 x IS 17814 (74 t ha^{-1}) and ICSA 560 x IS 21991 (69 t ha^{-1}) recorded superior fresh stalk yields (Fig. 2) compared to the check CSH 22SS (65t ha^{-1}) during 2009.
- ICSA 560 x IS 17814 was the highest juice yielder (34037 l ha^{-1}) while ICSA 675 x IS 5353 recorded highest juice extraction of 44%.
- To identify the promising hybrids with high stalk and sugar contents during 2010, 50 hybrids were evaluated in an RBD and the hybrid RS 1220A x SSV 74 with a total biomass of 84 t ha^{-1} significantly out yielded the check hybrid CSH 22SS (71 t ha^{-1}) by 18%.
- The same hybrid also recorded a significant superiority for early flowering (14%) and maturity (10%) apart from superiority for juice yields (33%) and calculated bioethanol yields (29%) over the check CSH 22SS.

- RS 1220A x RSSV 9 was another early maturing hybrid with a grain yield of 3024 kg ha^{-1} and was significantly superior (67%) to the check (1809 kg ha^{-1}).
- NSS 1007A x RSSV 9 was the highest bioethanol yielder (2157 l ha^{-1}) in the trial and was superior to the check by 32%. It was also promising for juice yield with a juice yield of 25621 l ha^{-1}.

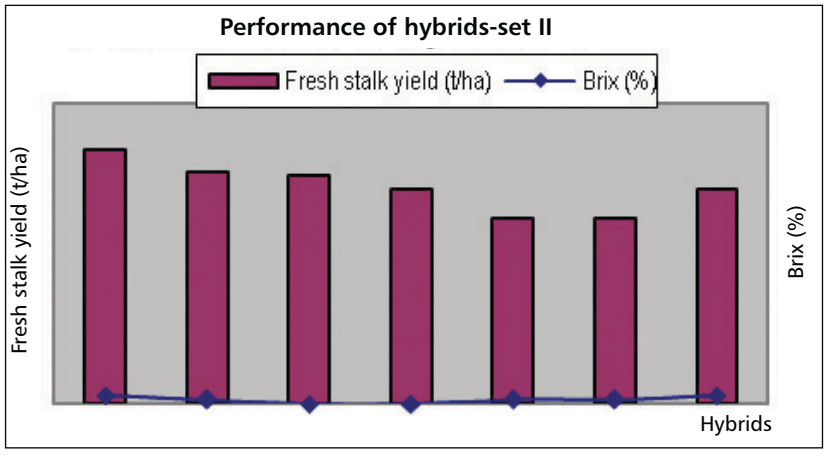

Fig. 2. Performance of promising hybrids for Brix and stalk yields.

3. Combining ability studies

Concerted research efforts during last two decades at DSR and its cooperating centers in different state agricultural universities under National Agricultural Research Systems (NARS) and at ICRISAT have resulted in excellent sweet sorghum varieties for use in ethanol production by the sugar industries/alcohol distilleries and for use as green/dry fodder. However, till date only one sweet sorghum hybrid CSH 22SS has been released (in 2005) for general cultivation in India and the current yield levels of new hybrids are unable to surpass this hybrid. This necessitates the identification of new hybrid parents with good combining ability for different traits of interest. Combining ability studies have been conducted to identify superior parents excelling for specific traits. The salient findings from these studies are summarized below.

- In a study during 2011, line effect was significant for plant height, Brix (%), TSS while the testers showed significance for plant height, total biomass, fresh stalk yield. This indicates that the variation in hybrids in terms of the characters studied is largely influenced by the interaction between lines and testers.

- Among lines DMS 10B and DMS 8B exhibited significant and positive General Combining Ability (GCA) effects for total biomass and juice yields while for Brix content, DMS 30B was promising (Fig. 3).
- Among testers, SSV 74 and CSV 19SS were promising general combiners for fresh stalk yield while SSV 84 and the former two testers were promising for total sugar content and computed ethanol yields (Fig. 4).

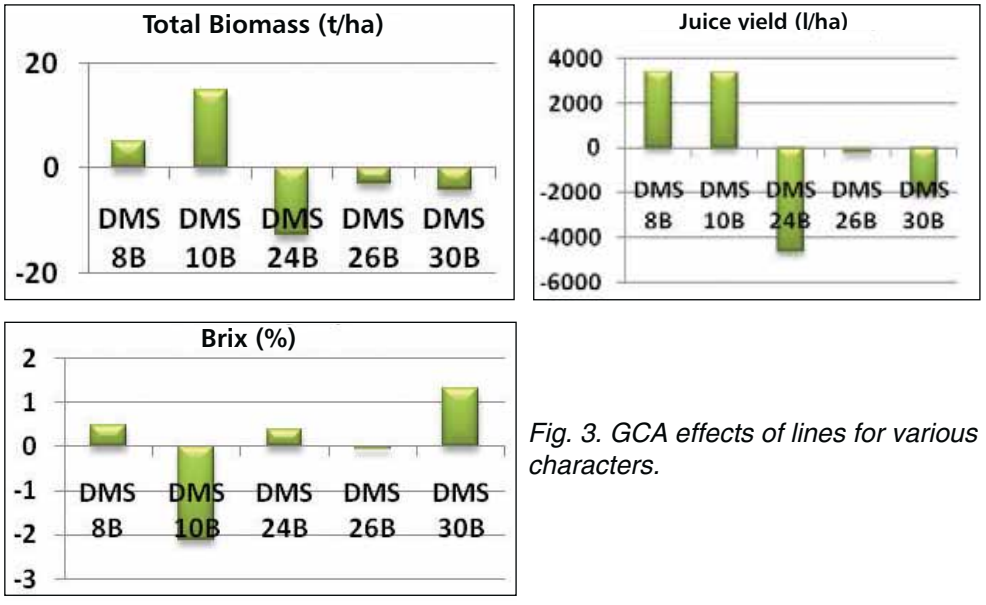

Fig. 3. GCA effects of lines for various characters.

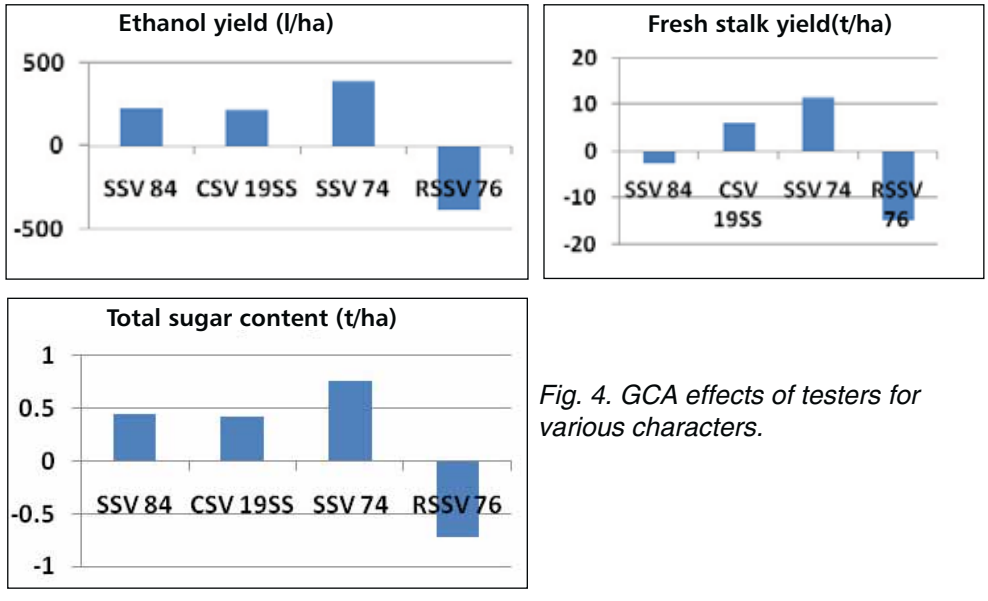

Fig. 4. GCA effects of testers for various characters.

- The cross DMS 8A x RSSV 76 exhibited significant and positive SCA effects for important traits like total biomass, juice yield, total sugar content and computed ethanol contents.

Stem borer resistance

The quality and yield of sweet sorghum is reduced greatly because of many reasons and the losses caused by insect pests have been considered as most important, of which the stem borer Chilo partellus (Swinhoe) is the major one. With the pest being an internal borer, the frass and feacal matter remain inside the stem, which lowers the quality of juice. Efforts have been made to identify stem borer-resistant sweet sorghum lines through natural and artificial infestation studies and twelve entries – E 27, IS 18162, IS 18164, E 38, ICSV 700, ICSV 24 93046, NSSV 6, GGUB 50, IS 5353, KARS 95, RSSV 9 and IS 2205 – were found resistant to stem borer.

4. Sweet sorghum cultivars adapted to postrainy season

Cv SPSSV 30 produced 15% more stalk yield than hybrid CSH22SS. Among the varieties, SPSSV 30, SPSSV 11, SPSSV 20, SPSSV 40 and SSV74 produced significantly higher yields (>150%) than variety check CSV19SS. Varieties SPSSV 20, SPV 422, SSV 74, SPV 913 produced significantly higher (100 - 126% more) grain yield than check CSV 19SS. Mean computed ethanol yield was 716, 604 and 475 l ha^{-1} at soft dough, hard dough and physiological maturity respectively. Cv SPSSV 30, SPSSV 11, SPSSV 20 and SSV 74 recorded 396%, 128%, 109% and 82% higher computed ethanol yield than check CSV19SS.

Staggering effects of planting (June to Aug) crop height, growth and biomass yield revealed that June 1 planting gave highest mean fresh stalk yield (58.1 t ha^{-1}) across the years (Fig. 5&6). It also gave 42% more stalk and ethanol yields than second and third dates (16th June and 1st July). First week of August planting decreased stalk yield by three fold (>200%) over 1st week of June. Stalk yield decreased by 24 to 69% across plantings (from July 16 to August 1 over June 1, respectively). Based on two years' study, the best sowing window for sweet sorghum planting is from June 1 to July 1. Harvesting at hard-dough stage gave 10% higher stalk yields, sugar content and computed ethanol yields.

Fig. 5. Variation in crop height, growth, and biomass production of sweet sorghum planted at fortnightly interval, DSR, Hyd.

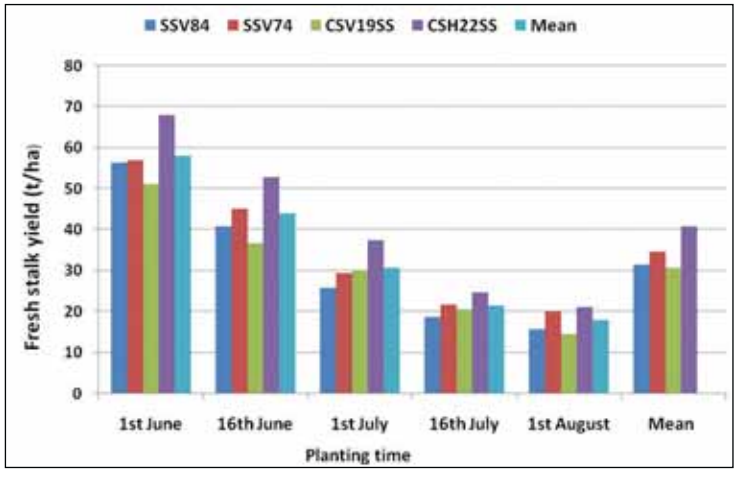

Fig. 6. Sweet sorghum staggering planting effects on stalk yields (mean of 2008 and 2009).

VII. Seed production and supply to the target region

Sweet sorghum hybrid CSH22SS seed was produced by DSR and supplied to NAIP project farmers during the project period. DSR also produced breeder seed of SSV84, SSV74 & CSV19SS for supply to the farmers' trials during the project implementation period.

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