# Enhancing the harvest window for supply chain management of sweet sorghum for ethanol production

**A Ashok Kumar*, Belum VS Reddy, Ch Ravinder Reddy, Michael Blümmel, P Srinivasa Rao, B Ramaiah** and **P Sanjana Reddy**

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India

*Corresponding author. a.ashokkumar@cgiar.org

Citation: Ashok Kumar A, Reddy BVS, Ravinder Reddy Ch, Blümmel M, Srinivasa Rao P, Ramaiah B and Sanjana Reddy P. 2010. Enhancing the harvest window for supply chain management of sweet sorghum for ethanol production. Journal of SAT Agricultural Research 8.

## Introduction

Sweet sorghum (*Sorghum bicolor*) is similar to grain sorghum but accumulates high amounts of sugar in the stems that can be used for a variety of uses such as food, feed, fodder, fuel and fiber befitting the sobriquet 'SMART CROP'. It is well adapted to the semi-arid tropics and is one of the most efficient dryland crops to convert atmospheric $CO_2$ into sugar (Schaffert and Gourley 1982). Of late, the crop is gaining importance as an alternative feedstock for bioethanol production (Reddy et al. 2005, 2008, Lau et al. 2006). While the commercial ethanol production from sweet sorghum is a reality, there are several issues to be addressed to make the sweet sorghum ethanol value chain economically viable and sustainable. Sweet sorghum being a seasonal crop, the period of raw material (green stalks) availability for ethanol production is limited to 2–2.5 months from two growing seasons in a year. This poses the biggest challenge for commercial expansion of sweet sorghum ethanol production. Increasing the crop harvest window by genetic and agronomic approaches, planting the crop in wider areas and establishment of decentralized crushing units (DCU) to produce syrup are proposed to augment the raw material supply to distilleries for ethanol production (Ashok Kumar et al. 2010). The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and partners have been working on sweet sorghum improvement for increasing the biomass, juice content, Brix% and grain yield in different maturity backgrounds and efforts are also underway to develop sweet sorghum cultivars for postrainy season adaptation with stay-green trait, which contribute to increased harvest window (Reddy et al. 2008, Rao et al. 2009). Over the years, ICRISAT developed a number of sweet sorghum hybrid parents, hybrids and varieties and yield-tested them for grain and sugar contents in on-station trials. The genotypes found superior in the on-station trials need to be tested under on-farm conditions to test their suitability in the sweet sorghum command areas. Similarly the trade-offs between stalk sugar traits, grain yield and feed quality traits need to be examined to select the genotypes for efficient whole plant utilization. Also, the changes of sugar content in syrup on storage need to be understood for its long-term storage to augment the feedstock supply for ethanol production. The work presented here had four objectives: (1) to identify promising sweet sorghum genotypes under on-farm conditions for future use; (2) to identify promising sweet sorghum genotypes for fodder quality traits; (3) to study the association between agronomic traits, stalk sugar traits and animal feed quality traits; and (4) to assess the sugar content of syrup during long-term storage.

## Material and methods

To identify promising sweet sorghum cultivars, an on-farm trial was conducted during rainy season in 2008 and 2009 at a site in Ibrahimbad village in Medak district, Andhra Pradesh, India using a set of four elite sweet sorghum genotypes that included newly developed sweet sorghum hybrids (2) and varieties (2) along with two controls, CSH 22SS (hybrid check) and SSV 84 (varietal check). The trial was planted in a randomized complete block design (RCBD) with three replications in a farmer's field. The area of each plot was 0.2 ha. Recommended fertilizer management practices (80N:40P:0K) were followed to raise a good crop so as to evaluate the genotypic differences. Data were recorded on the agronomic traits, viz, plant height (m), time to 50% flower (days), fresh stalk yield (t ha$^{-1}$), grain yield (t ha$^{-1}$), soluble solids concentration (Brix%), juice yield (t ha$^{-1}$), sugar yield (t ha$^{-1}$) and bagasse yield (t ha$^{-1}$) using the standard procedures. Juice Brix% was recorded with a digital hand-held refractometer. Sugar yield was computed using juice yield and Brix% (Wortmann et al. 2010). Data on animal feed quality traits, viz, content of ash (%), nitrogen (%) over dry matter (dm) (%), neutral detergent fiber (%) over dm (%), acid detergent fiber (%)

over dm (%), acid detergent lignin (%) over dm (%), metabolic energy required for digest (mg $kg^{-1}$) and in-vitro organic matter digestibility (IVOMD) (%) were recorded using near-infrared spectroscopy.

Syrup was produced at the decentralized crushing-cum-syrup making unit by boiling the sweet sorghum juice for 2.5–3.0 hours using chemical clarificants and by stirring the hot juice for removal of the scum. Brix% of syrup is checked using the hand refractometer during the process so that the boiling of juice can be stopped at an appropriate stage (10–15 minutes earlier) to maintain a desired Brix% in the syrup. The syrup with different levels of Brix% (36, 44, 52, 64 and 70) was stored in plastic containers and the Brix% was recorded using a hand-held digital refractometer at monthly intervals to check for the stability of sugar content of syrup during storage.

The data were analyzed using GENSTAT (Edition 10) to test the significant differences among the genotypes, to select the high stalk and grain yielding genotypes with high sugar yields and to estimate correlations among the agronomic traits, stalk sugar traits and the animal feed quality traits.

## Results and discussion

ANOVA showed significant differences among the genotypes and years for the traits studied (data not shown). There were significant differences for time to 50% flower (days), plant height, Brix%, stalk yield, juice yield, bagasse yield, sugar yield and grain yield among the genotypes and years, indicating that there were significant differences between the genotypes for traits studied and the genotypes performed differently in the two years tested. The interaction effects (genotypes × years) were significant for time to 50% flower (days), plant height, stalk yield, juice yield, bagasse yield, sugar yield and grain yield, indicating that the performance of the genotypes varied with the year. The mean performance of the genotypes over two years is given in Table 1; and the means for fodder quality traits estimated in the 2009 rainy season are presented in Table 2.

A comparison of the mean values indicated that among the genotypes tested, the hybrids ICSSH 28 (15% Brix) and ICSSH 39 (15% Brix) showed similar Brix reading as the control CSH 22SS (15% Brix). The hybrid ICSSH 39 showed significantly higher (>10%) stalk yield

**Table 1. Mean performance of sweet sorghum cultivars in on-farm trials during rainy season in 2008 and 2009 at Ibrahimbad in Medak district, Andhra Pradesh, India.**

| Cultivar | Brix (%) | Stalk yield (t $ha^{-1}$) | Juice yield (t $ha^{-1}$) | Estimated stalk sugar yield (t $ha^{-1}$) | Bagasse yield (t $ha^{-1}$) | Grain yield (t $ha^{-1}$) | Time to 50% flower (days) | Plant height (m) |
|---|---|---|---|---|---|---|---|---|
| **Hybrids** | | | | | | | | |
| ICSSH 28 | 15 | 22.5 | 8.3 | 1.3 | 12.2 | 2.4 | 76 | 3.7 |
| ICSSH 39 | 15 | 27.2 | 9.8 | 1.5 | 14.9 | 2.8 | 79 | 3.5 |
| CSH 22SS (control) | 15 | 24.5 | 10.2 | 1.5 | 11.9 | 3.6 | 79 | 2.7 |
| **Varieties** | | | | | | | | |
| ICSV 25274 | 16 | 19.8 | 7.6 | 1.2 | 10.5 | 2.0 | 85 | 3.6 |
| ICSV 25279 | 17 | 30.0 | 10.9 | 1.9 | 15.8 | 2.5 | 73 | 3.1 |
| SSV 84 (control) | 18 | 29.1 | 10.7 | 1.9 | 14.6 | 1.9 | 88 | 3.1 |
| Mean | 16.04 | 25.52 | 9.59 | 1.55 | 13.28 | 2.54 | 80 | 3.28 |
| SE± | 0.70 | 1.86 | 0.93 | 0.16 | 0.81 | 0.29 | 0.81 | 0.16 |
| CD (5%) | 2.06 | 5.46 | 2.73 | 0.48 | 2.39 | 0.85 | 2.38 | 0.46 |

**Table 2. Performance of sweet sorghum cultivars for fodder traits harvested from on-farm trial at Ibrahimbad in Medak district, Andhra Pradesh, India in 2009 rainy season.**

| Cultivar | Ash (%) | Nitrogen (%) over dm (%) | Neutral detergent fiber (%) over dm (%) | Acid detergent fiber (%) over dm (%) | Acid detergent lignin (%) over dm (%) | Metabolic energy required for digest (mg $kg^{-1}$) | In-vitro organic matter digestibility (%) |
|---|---|---|---|---|---|---|---|
| ICSSH 28 | 6.8 | 0.7 | 62.7 | 39.2 | 4.7 | 7.8 | 52 |
| ICSSH 39 | 7.6 | 1.1 | 63.0 | 38.4 | 4.9 | 7.8 | 53 |
| ICSV 25274 | 6.8 | 0.2 | 63.4 | 41.4 | 4.1 | 7.9 | 52 |
| ICSV 25279 | 5.5 | 0.6 | 59.6 | 35.7 | 4.0 | 8.5 | 56 |
| SSV 84 (control) | 6.0 | 0.6 | 63.1 | 40.2 | 5.3 | 7.5 | 50 |

(27.2 t ha$^{-1}$) over CSH 22SS (24.5 t ha$^{-1}$) with similar sugar yield (1.5 t ha$^{-1}$). ICSSH 28 was earlier by three days for flowering compared to CSH 22SS (79 days). The two hybrids tested were taller (up to 27%) compared to CSH 22SS (2.7 m). The hybrid ICCSH 39 showed 17% more bagasse yield (14.9 t ha$^{-1}$) compared to CSH 22SS (11.9 t ha$^{-1}$). These hybrids can potentially diversify the genetic base of sweet sorghum cultivars as there is only one released hybrid (CSH 22SS) available to farmers for commercial cultivation in the sweet sorghum command areas.

The performance of varieties ICSV 25274 (16%) and ICSV 25279 (17%) was similar to that of control SSV 84 (18%) for Brix%. Sugar yield (1.9 t ha$^{-1}$) and plant height (3.1 m) of ICSV 25279 were same as in the control SSV 84, but the variety was significantly early (73 days to 50% flower) by 15 days with 14% higher grain yield (2.5 t ha$^{-1}$) compared to SSV 84 (88 days for flowering and grain yield 1.9 t ha$^{-1}$), indicating its potential to contribute to extend the harvest window in sweet sorghum. Also, the variety gave 8% higher bagasse yield than SSV 84. ICSV 25279 with higher stalk yield (30 t ha$^{-1}$) showed higher IVOMD (56%) compared to SSV 84 (IVOMD 50%), indicating its suitability as animal feed along with its potential for ethanol production.

**Correlations.** Estimated stalk sugar yield showed significant positive correlation with stalk yield, juice yield, Brix% and plant height indicating that these traits need to be focused in sweet sorghum improvement for increased ethanol production (Table 3). Interestingly, no significant correlation was observed between grain yield and sugar yield, indicating that they may be under the control of different genomic regions and therefore, there are no trade-offs while simultaneously improving sweet sorghum for sugar and grain yields. Similar findings were reported earlier (Smith and Reeves 1979, Jadhav et al. 1994, Reddy et al. 2008). The bagasse yield showed significant positive correlation with stalk yield, juice yield and sugar yield. This has significance in augmenting the animal feed supply as earlier efforts showed that sweet sorghum bagasse is an excellent source of animal feed and can be used as a replacement for sorghum stover in the commercial feed blocks (Blümmel et al. 2009). Significant strong negative correlation was observed between late flowering and IVOMD, indicating that early maturing genotypes may have higher IVOMD, which is a desirable animal feed quality trait. The high IVOMD (56%) in the earliest flowered genotype in the trial ICSV 25279 indicated this. However, this genotype falls under the medium maturity category (flowering in less than 65 days early maturing; 65–75 days medium maturing and more than 75 days late maturing).

**Table 3. Correlation coefficients for sweet sorghum cultivars in on-farm trials in 2008 and 2009 rainy season at Ibrahimbad in Medak district, Andhra Pradesh, India[1].**

| Trait | Time to 50% flower (days) | Plant height (%) | Brix (%) | Stalk yield (t ha$^{-1}$) | Juice yield (t ha$^{-1}$) | Sugar yield (t ha$^{-1}$) | Bagasse yield (t ha$^{-1}$) | Grain yield (t ha$^{-1}$) | Nitrogen (%) | Neutral detergent fiber (%) | Acid detergent fiber (%) | Acid detergent lignin (%) | Metabolic energy required for digest (mg kg$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plant height (m) | −0.085 | 1.000 | | | | | | | | | | | |
| Brix (%) | 0.263 | −0.898* | 1.000 | | | | | | | | | | |
| Stalk yield (t ha$^{-1}$) | −0.193 | −0.864* | 0.592 | 1.000 | | | | | | | | | |
| Juice yield (t ha$^{-1}$) | −0.142 | −0.902* | 0.653 | 0.997** | 1.000 | | | | | | | | |
| Sugar yield (t ha$^{-1}$) | −0.044 | 0.968** | 0.816* | 0.949** | 0.970** | 1.000 | | | | | | | |
| Bagasse yield (t ha$^{-1}$) | −0.342 | −0.756 | 0.424 | 0.978** | 0.959** | 0.867* | 1.000 | | | | | | |
| Grain yield (t ha$^{-1}$) | −0.762 | 0.191 | −0.564 | 0.261 | 0.187 | −0.033 | 0.457 | 1.000 | | | | | |
| Nitrogen (%) | −0.426 | −0.011 | −0.379 | 0.506 | 0.437 | 0.216 | 0.645 | 0.833* | 1.000 | | | | |
| Neutral detergent fiber (%) | 0.729 | 0.559 | −0.428 | −0.575 | −0.573 | −0.584 | −0.607 | −0.352 | −0.101 | 1.000 | | | |
| Acid detergent fiber (%) | 0.837* | 0.450 | −0.176 | −0.674 | −0.641 | −0.556 | −0.767 | −0.672 | −0.499 | 0.911** | 1.000 | | |
| Acid detergent lignin (%) | 0.504 | −0.092 | 0.020 | 0.279 | 0.267 | 0.210 | 0.230 | −0.105 | 0.447 | 0.573 | 0.344 | 1.000 | |
| Metabolic energy required for digest (mg kg$^{-1}$) | −0.817* | −0.157 | 0.031 | 0.184 | 0.169 | 0.144 | 0.280 | 0.494 | 0.029 | −0.870* | −0.791 | −0.844* | 1.000 |
| In-vitro organic matter digestibility (%) | −0.864* | −0.182 | −0.036 | 0.311 | 0.283 | 0.209 | 0.433 | 0.659 | 0.250 | −0.866 | −0.876* | −0.716 | 0.974** |

1. df (n−2=4; * = Significant at 5% level; ** = Significant at 1% level.

**Table 4. Shelf life of the syrup produced in 2008 rainy season during storage for one year (up to October 2009).**

| Date of syrup collection | Initial Brix reading | Brix[1] (%) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Oct 08 | Nov 08 | Dec 08 | Jan 09 | Feb 09 | Mar 09 | Apr 09 | May 09 | Jun 09 | Jul 09 | Aug 09 | Sep 09 | Oct 09 | Mean |
| 18-10-08 | 36.2 | 36.4 | 37.4 | 37.5 | 37.0 | 37.0 | 37.4 | 37.0 | 38.6 | 37.0 | 36.0 | 36.0 | 36.0 | 35.9 | 36.8 |
| 18-10-08 | 44.2 | 44.1 | 44.0 | 44.1 | 44.0 | 44.3 | 45.2 | 45.6 | 45.5 | 46.0 | 46.0 | 46.1 | 46.2 | 45.0 | 45.1 |
| 18-10-08 | 52.2 | 51.7 | 50.6 | 50.8 | 51.0 | 52.0 | 50.1 | 50.0 | 52.8 | 52.0 | 53.0 | 52.7 | 52.7 | 53.1 | 51.8 |
| 30-10-08 | 64.0 | 65.4 | 65.4 | 65.8 | 65.5 | 65.6 | 65.3 | 65.6 | 64.5 | 65.2 | 65.1 | 64.9 | 65.0 | 64.6 | 65.2 |
| 30-10-08 | 70.0 | 69.8 | 69.8 | 69.7 | 69.8 | 69.7 | 69.7 | 69.7 | 69.7 | 69.7 | 69.7 | 69.7 | 69.7 | 69.7 | 69.7 |

1. Mean of three replications.

**Syrup storage studies.** Concentrating the sweet sorghum juice into syrup was proposed to increase the storability of the feed stock for ethanol production. However, there is no literature available on Brix% of syrup that can be stored at room temperature without deterioration in the sugar content. An experiment was conducted at DCU to study the long-term storability of syrup with 40, 50, 60 and 70% Brix levels at room temperature. The sugar content (measured as Brix%) of syrup produced at DCU at monthly intervals during long-term storage is presented in Table 4. The results indicated that syrup can be stored at room temperature for one year without significant changes in the Brix% of the syrup at several Brix% levels. This helps in augmenting the feed stock supply to ethanol distilleries.

## Conclusions

To expand the commercialization of sweet sorghum ethanol, it is important to address the issue of harvest window. On-farm testing of elite high sugar yielding cultivars identified in on-station trials helps in identification of promising genotypes for immediate commercialization. The present study revealed that the harvest window in sweet sorghum can be extended by growing the high sugar and grain yielding sweet sorghum cultivars with different maturity durations. However, other options like agronomic practices and decentralized syrup production need to be explored. It would seem that there are no trade-offs between stalk sugar traits, grain yield and animal feed quality traits, indicating that simultaneous improvement for these traits is feasible. Syrup at 35% Brix and above can be stored for one year at room temperature without reduction in sugar content and this allows ethanol production in lean season. ICSSH 39 and ICSV 25279 were found suitable to extend the harvest window in sweet sorghum ethanol production by extending the harvest window further by 6 days. Overall, there was 15 days difference between the early and late flowering genotypes compared to 9 days difference between the two controls, without reduction in the sugar yields. The genotype ICSV 25279 appears to be excellent animal feed in addition to its high ethanol yielding capacity. This genotype can be utilized in commercial ethanol production as it was found superior for stalk yield and sugar yield under on-farm testing in sweet sorghum command area in Ibrahimbad village in Medak district as well as by the animal feed industry.

**Acknowledgment.** Financial support from NAIP-ICAR to carry out this work under the ICRISAT-NAIP-ICAR sub-project on “Sweet sorghum ethanol value chain development” is greatly acknowledged.

## References

**Ashok Kumar A, Reddy BVS, Blümmel M, Anandan S, Reddy YR, Reddy ChR, Rao PS** and **Reddy PS.** 2010. On-farm evaluation of elite sweet sorghum genotypes for grain and stover yields and fodder quality. Animal Nutrition and Feed Technology, Volume 1, Special issue, pp. 56–66.

**Blümmel M, Rao SS, Palaniswami S, Shah L** and **Reddy BVS.** 2009. Evaluation of sweet sorghum [*Sorghum bicolor* (L.) Moench] used for bio-ethanol production in the context of whole plant utilization. Animal Nutrition Feed Technology 9:1–10.

**Jadhav MM, Chougule BA, Chavan VD** and **Adsule RN.** 1994. Assessment of juice quality in the improved sweet sorghum varieties. Journal of Maharashtra Agricultural Universities 19:233–235.

**Lau HM, Richardson JW, Outlaw JL, Hotzapple MT** and **Ochoa RF.** 2006. The economics of ethanol from sweet sorghum using Mix Alco process. AFPC Research Report 06-2, August 11, 2006. Texas, USA: Agricultural and Food Policy Center, Texas A&M University.

**Rao PS, Rao SS, Seetharama N, Umakanth AV, Sanjana Reddy P, Reddy BVS** and **Gowda CLL.** 2009. Sweet sorghum for biofuel and strategies for its improvement. Information Bulletin no. 77. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 80 pp.

**Reddy BVS, Ramesh S, Ashok Kumar A, Wani SP, Ortiz R, Ceballos H** and **Sreedevi TK.** 2008. Bio-fuel crops research for energy security and rural development in developing countries. Bioenergy Research 1:248–258.

**Reddy BVS, Ramesh S, Reddy PS, Ramaiah B, Salimath PM** and **Kachapur R.** 2005. Sweet sorghum – a potential alternative raw material for bio-ethanol and bio-energy. International Sorghum and Millets Newsletter 46:79–86.

**Schaffert RE** and **Gourley LM.** 1982. Sorghum as an energy source. Pages 605–623 *in* Sorghum in the eighties: Proceedings of the International Symposium on Sorghum, 2–7 Nov 1981, ICRISAT Center, India. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

**Smith BA** and **Reeves SA.** 1979. Sweet sorghum biomass. Part II. Plant composition. Sugar Y. Azucar 74:34–35.

**Wortmann CS, Liska AJ, Ferguson RB, Lyon DJ, Klein RN** and **Dweikat I.** 2010. Dryland performance of sweet sorghum and grain crops for biofuel in Nebraska. Agronomy Journal 102(1):319–326.