Developing a Sweet sorghum Ethanol value chain

International Crops Research Institute for the Semi-Arid Tropics

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Developing a Sweet Sorghum Ethanol Value Chain

Editors

Belum VS Reddy, A Ashok Kumar, Ch Ravinder Reddy, P Parthasarathy Rao and JV Patil

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We would like to express our gratitude to all those people outside the project who provided support, deliberated, read, wrote, offered comments, allowed us to quote their remarks and assisted in the editing, proofreading and designing of this book.

Contents

Acronyms

AAI	Aakruthi Agricultural Associates of India, Hyderabad
ABI	Agri-Business Incubator, ICRISAT
ANGRAU	Acharya N G Ranga Agricultural University, Hyderabad
BBF	Broad-bed and furrow
CAC	Consortium Advisory Committee
CBO	Community-based Organization
CIC	Consortium Implementation Committee
CMU	Consortium Monitoring Unit
CRIDA	Central Research Institute for Dryland Agriculture, Hyderabad
CSS	Community Seed System
DCU	Decentralized crushing-cum-syrup-making unit
EBPP	Ethanol Blended Petrol Programme
EEI	Extension Education Institute, Hyderabad
EU	European Union
FA	Farmers' Association
GAP	Good Agronomic Practices
GHG	Greenhouse Gases
GOI	Government of India
HPLC	High Performance Liquid Chromatography
HSD	High Speed Diesel
ICAR	Indian Council for Agricultural Research, New Delhi
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICT	Information Communication Technology
IEC	Information, Education and Communication
IICT	Indian Institute of Chemical Technology, Hyderabad
ILRI	International Livestock Research Institute, Patancheru
IVOMD	In-vitro Organic Matter Digestibility

KLPD	Kilo Liters Per Day
KVK	Krishi Vignana Kendras
ME	Metabolizable Energy
MNRE	Ministry of New and Renewable Energy
N	Nitrogen
NAIP	National Agricultural Innovation Project
NDF	Neutral Detergent Fiber
NGO	Non-government Organization
NIRS	Near Infra-Red Spectroscopy
NRCS	National Research Center for Sorghum, Hyderabad
NBCC	National Biofuel Coordination Committee
NREGP	National Rural Employment Guarantee Program
PIA	Project Implimenting Agency
PIU	Project Implementation Unit
PPP	Public-Private-Partnership
PRD	Participating Research and Development
SHGs	Self Help Groups
SNA	Seed Need Assessment
SSCA	State Seed Certification Agency
SSB	Sweet sorghum bagasse
SSBLR	Sweet sorghum bagasse leaf residue
SVVU	Sri Venkateshwara Veterinary University, Tirupati
TCL	Tata Chemicals Ltd, Mumbai
VCM	Value Chain Model

Foreword

In this era of rapid economic development, the thrust on energy sources is gaining importance across the world. Since the time of industrialization that started in the 17th century, fossil fuels are the major energy sources driving the global economies. However, in the recent days, the demand for developing alternative energy sources such as biofuels is increasing owing due to the limitations of fossil fuels in terms of their availability, costs and environmental pollution associated with their extraction and use. Corn, sugarcane, sugar beet, jatropha and pongamia are some of the well-known biofuel feedstocks for bioethanol and biodiesel, the two most prominent biofuels globally. Sweet sorghum is one such alternative biofuel feedstock for bioethanol that is unique since there is no food-fuel tradeoff associated with its use, unlike corn and other grains, which, like sugarcane, also require larger quantities of water for cultivation. Sweet sorghum is also adapted to a wide range of agro-ecologies from tropical to temperate climates, from low input to intensive agriculture, making it amenable for cultivation in many parts of the world.

However, the use of sweet sorghum stalk as biofuel feedstock was pilot tested in the last 5-6 years and there is a need for in-depth understanding of its production and processing for ethanol. The current research work carried out by ICRISAT and its partners on sweet sorghum for ethanol value chain supported by NAIP (ICAR) is a good beginning in that direction. The partners with diverse competencies – DSR, CRIDA, IICT, ILRI, SVVU and Rusni Distilleries – have worked together as a consortium focusing on development of a sustainable sweet sorghum ethanol value chain through innovative interventions involving an array of options. The progress of this work, the experiences and lessons learned from this research and way forward are succinctly presented in this book giving the reader a good understanding about the sweet sorghum ethanol value chain in India, the existing opportunities and the issues involved therein. While considerable progress has been made in improving sweet sorghum for the ethanol supply chain by a combination of centralized and decentralized models, inter alia it calls for firm policy support to sustain the value chain and enforcement of ethanol blending commitments. It is my hope that the necessary policy support will materialize in the near future since some of them are already seriously being considered by various national governments, including India.

I take this opportunity to congratulate NAIP (ICAR) for funding this innovative work and guiding its implementation from time to time. My best wishes to all the contributors and editors for coming up with a scientific narration of the results, lessons learned and the future course of action.

William D. Dar
Director General, ICRISAT

Preface

Sweet sorghum is a fascinating crop by virtue of its rapid growth, high biomass production potential, and adaptability to a range of conditions, high water use efficiency and its multipurpose use. Although scientists have been working on sweet sorghum for many years, the focus was mainly on its fodder value and use. Recognition of its utility as biofuel feedstock is a recent development. Considering the energy requirements, particularly of a rapidly growing economy like India and its ethanol blending commitments, attention to sweet sorghum as an alternative feedstock for bioethanol production is a perfect choice. Keeping this in view, a sub-project on 'Sweet sorghum ethanol value chain development' was developed with the help of consortium partners that included the Directorate of Sorghum Research (DSR), Central Research Institute for Dryland Agriculture (CRIDA), Indian Institute of Chemical Technology (IICT), International Livestock Research Institute (ILRI), Sri Venkateshwara Veterinary University (SVVU) and Rusni Distilleries, which was eventually approved for funding by the National Agricultural Innovation Project under the Indian Council for Agricultural Research (NAIP (ICAR)).

Taking a cue from the on-going genetic and crop management research on sweet sorghum, the sub-project was built on developing a sustainable sweet sorghum ethanol value chain by exploring the various options to increase on-farm productivity, enhance the harvest window, plug loopholes in the supply chain, increase the juice extraction efficiency and its storage, mechanize sweet sorghum production and processing, and efficiently utilize the by-products. These major activities were shared among the partners based on their competencies, and were implemented in letter and spirit to build a successful sweet sorghum ethanol value chain.

The economic competitiveness of sweet sorghum vis-à-vis other feedstocks; economics of sweet sorghum for ethanol production, and the biofuel policy of India are also discussed in detail. The progress made in this endeavor, the experiences gained and lessons learned are thoroughly documented and presented in this book. A few critical issues include favorable policy intervention in terms of stalk pricing (subsidizing raw material cost to the industry) and ethanol pricing (subsidizing current ethanol production cost at an optimum level until the initial teething problems are overcome) and institutional support to help the industry to scale up the processing of sweet sorghum for bioethanol production more rapidly.

This is a joint work of all the partners in the consortium and we have cherished working together. We thank the NAIP (ICAR) for funding this work and providing us an opportunity to work together to provide a road map for promotion of sweet sorghum towards ethanol production. We are confident that this report gives a realistic depiction of state-of-the-art technologies, the progress made in developing sweet sorghum, the opportunities and issues involved and the way forward to make the sweet sorghum ethanol value chain successful and sustainable.

–***Sweet sorghum project consortium members***

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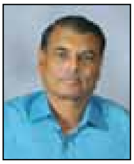

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Chapter I: Sweet sorghum for ethanol: A new beginning

A Ashok Kumar, Ch Ravinder Reddy, JV Patil and Belum VS Reddy

I. Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is an important dryland cereal grown in India (7.8 million ha) and around the world (45.8 million ha) for food, feed, fodder, bioenergy and fiber. Sweet sorghum is similar to grain sorghum and are generally tall (3.0-4.0 m), late maturing (20-30 days) and relatively photoperiod-sensitive; produce 2-3 t ha^{-1} grain yield with higher stalk yields (50-60 t ha^{-1} of fresh biomass).

Sweet sorghum is a new generation bioenergy crop that has potential to accumulate sugar (10-15%) in its stalk similar to sugarcane, apart from producing grains. The bagasse, remnant stalk after extraction of juice, can be used as animal feed or for vermicomposting to generate power. The crop has the ability to adapt to various agro-climatic conditions and reasonably tolerates drought and saline-alkaline conditions. The crop is raised from seed and is of shorter duration (115-120 days) than sugarcane (12-18 months) making it amenable for multiple cropping systems. Water use or seasonal evapotranspiration (ET) for sorghum is 508 mm while it is 1257 mm for sugarcane. Water requirement of this crop is one-third that of sugarcane on a comparable time scale. Also, sweet sorghum requires about 22% less water than maize. With these advantages, sweet sorghum is a good bioenergy crop and can complement the available feedstocks for biofuel production.

For use as a biofuel feedstock, it is important to choose appropriate cultivars of sweet sorghum and follow improved crop management practices to achieve higher yields. The distillery/industry should develop a command area for supply of raw material. Sweet sorghum cultivation on a commercial scale is yet to pick up speed in India and other countries.

The uncertainty of the fossil fuel supplies, sharp escalation of international crude oil prices, and the need to protect the environment has forced several countries to look for renewable energy, especially for transportation fuels. Ethanol is the most popular biofuel used either directly or blended with gasoline for fueling automobile engines. Use of sugarcane, corn, sugar beet and cassava for large-scale ethanol production is a common practice. There are, however, concerns about the future of the biofuel program since there is an apprehension that these feedstock intensive programs will reduce the availability of grains for human consumption or take up land that could be used for food production in the face of policy induced demand for biofuels, leading to food and feed insecurity. Sweet sorghum is a crop of great potential that can overcome some of these concerns related to food, fuel and fodder security and rising grain prices since it produces sugar-rich stalks for ethanol production without sacrificing grain production. Sweet sorghum produces food/feed, fodder and fuel, without significant tradeoffs in any of these uses in the production cycle. Under NAIP Component 2, an innovative Ethanol Value Chain Model involving sweet sorghum development for ethanol production was undertaken with collective action, of public–private sectors partnership and involvement of farmers' groups in the value chain.

II. Project objectives

- Assess economic and environmental viability, enabling policies and institutions for promoting cultivation of sweet sorghum for bioethanol production and its impact on environment, rural incomes, livelihoods and social capital development.
- Develop and establish pilot-scale Public-Private-People-Partnerships (PPPPs) value chain bioethanol enterprise models through 'Seed-to-Tank' approach encompassing sweet sorghum production, processing, value addition, marketing and protecting the environment.
- Farmers' participatory multilocation testing of the improved biomass (stalks and grain) and juice yielding sweet sorghum cultivars under on-farm situations, and development of production and seed systems in the targeted area.
- Fine-tuning a package of practices for increased harvest window, mechanization and development of protocols for by-product utilization.
- Capacity building and skill development of all the stakeholders including rural communities in the enhanced sweet sorghum production and value chain for bioethanol production.

III. Project rationale

The available energy sources fail to meet the energy needs of the world's poor with 2.4 billion people relying on traditional biomass for energy and 1.6 billion people not having any access to electricity. At the same time, awareness has grown across the world about the impact of human energy consumption and land-use changes on our environment through increased release of greenhouse gases (GHG).

With the growing economy and improved living standards, India needs annually about 175 million metric tons (MMT) of petrol, and 60% of it is imported. Increasing fossil fuel consumption and associated contribution to increasing of GHGs concentration by developing countries like China, India and Brazil has become a point of contention during the G8 discussions on putting a mechanism in place for GHG emission-reduction plans by 2012, when the Kyoto protocol expires.

Globally there are efforts to develop a sustainable bio-energy framework, and international agencies such as UN-Energy7 have identified a framework for addressing sustainability issues. UN-Energy uses the definition of sustainable development adopted by the UN Commission on Sustainable Development (SD) ie, "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". UN-Energy has identified nine key sustainability issues facing bio-energy development:

- The ability of modern bioenergy to provide energy services for the poor;
- Implications for agro-industrial development and job creation;
- Health and gender implications;
- Implications for the structure of agriculture;
- Implications for food security;
- Implications for government budget;
- Implications for trade, foreign exchange balances, and energy security;
- Impacts on biodiversity and natural resource management; and
- Implications for climate change.

The proposed project has all elements to make it a sustainable bio-energy option to increase the incomes of the rural poor without sacrificing food and fodder security while protecting the environment. When the project is implemented it is expected to bring about the following outcomes.

- The ethanol produced from sweet sorghum can be used for blending with petrol and will contribute to energy security.
- The commercialization of technology will lead to establishment of large scale agro-industries particularly the ethanol distilleries, refineries and micro-entrepreneurship in villages.
- It will improve general health by reducing the pollution both during processing and utilization, and will empower women by involving them in production and processing.
- Incomes from agriculture will increase through strong crop-livestock integration.
- There will be enhanced food production with the better availability of superior genotypes, better management, seeds and other inputs.
- The government's import bills on fossil fuels will be reduced.
- There will be an increase of the area under sorghum; many new sweet sorghum cultivars will be used in feedstock production thereby increasing biodiversity. Being a C_4 crop with high water use efficiency, sweet sorghum can be cultivated without a drain on natural resources.
- Sweet sorghum being a CO_2 neutral crop (also during production, processing and utilization), its cultivation protects the environment without adding any extra CO_2 through ethanol combustion than the CO_2, it sequesters during photosynthesis. Thus the crop and the proposed value chain development will contribute to overall improvement of incomes, employment generation, food and energy availability and environmental protection.

The Government of India's (GOI) policy calls for mandatory blending of petrol with ethanol @ 5% by 2006 and 10% by 2008. This has already created huge demand for ethanol and the demand is likely to increase with the increased percentage of blending and increase in usage of fuels. The vast demand for biofuels accompanied by the enabling policies has triggered the industries to undertake bioethanol production. ICRISAT pioneered the Public-Private-People Partnership (PPPP) initiative with bioethanol and biodiesel producing companies in Andhra Pradesh (AP). For bioethanol, sorghum researchers at ICRISAT in collaboration with partners in India have identified a number of lines of sweet sorghum with high brix content varying from 16-23% and high biomass production.

The new cultivars bred by Indian partners, eg, SSV 84, SSV 74 and NSSH 104 have already been released for sweet sorghum cultivation. ICRISAT in partnership with national agricultural research services (NARS) is already testing sweet sorghum lines with high sugar content and juice yield in India, the Philippines and Uganda.

ICRISAT has incubated sweet sorghum ethanol production with Rusni Distilleries through its Agri-Business Incubator. Rusni is a 40 kilo liters per day (KLPD) unit located in Medak district of Andhra Pradesh (25 km from ICRISAT). It is the world's first sweet sorghum based ethanol production distillery. It is a multi-feedstock processing unit and can use other feedstocks like broken/damaged grain, cassava, sugarcane, cashew-apple and mahua. The ethanol production process is patented. Commercial ethanol production commenced at Rusni during June 2007.

IV. The approach

Strategic interventions were jointly made by ICRISAT and the consortium partners to train the farmers, build their technical capabilities and further provide them with information on improved crop production practices to enhance the yields per unit area. Institutional linkages with various actors in supply and market chains helped the farmers in reducing the overall production and postharvest handling costs. However, it is a well-known phenomenon that the farmers in the absence of sufficient funds for crop production and technology fail to enhance overall productivity and improve their livelihoods.

Traditional approaches to agricultural research and technology development assumed a flow of science-based knowledge transfer from researchers to farmers. This approach did not capture the complex relationships among researchers, farmers, government, civil society, extension workers, donors, universities and private sectors, nor the factors that condition successful development and utilization of research outputs. Integrated market oriented development and innovation system concepts are now gaining popularity as a framework for analysis on how knowledge is generated and used. The stakeholders in an innovation system seek relationship to improve their knowledge and make changes in their practices, resulting in development of new methods and materials, or adaptation of ideas and practices.

1. Project implementation through the consortium approach

- The project adopted an innovation consortium approach between sorghum scientists, economists, fodder scientists, feed manufactures, agro engineering scientists, seed industry, sorghum growing farmers, NGOs and other community-based organizations (Fig. 1).
- Farmers were trained in the use of improved crop production technologies, for enhancing productivity of stalks for ethanol production and grain for food and bagasse for fodder, meeting all requirements of small-scale farmers.
- The Farmers' Associations were formed and linked with input and credit agencies.

2. Consortium approach imperatives and sustainability

Under this arrangement the joint efforts of all the partners were synchronized to meet the overall goal of raising the incomes of small-scale sweet sorghum producers. The sustainability of the project is being ensured by institutionalizing the linkages created under the project:

- Institutionalizing the Farmers' Associations
- Strengthening infrastructure facilities

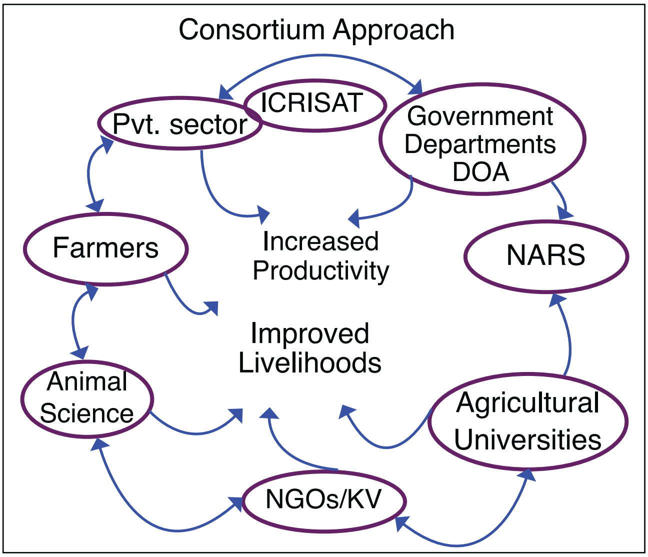

Fig. 1. Consortium approach flow diagram.

- Further training of farmer representatives on production technologies and operation and management of decentralized crushing units (DCU)
- Strengthening marketing linkages through agreements with distillery for supply of stalks and for syrup

3. Essential elements to maintain strong coherence

Promoting strong coherence among the consortium partners involves adoption of principles and practices of give and take between the partners for the overall benefit of the target community. The approach used was decentralization of responsibilities for implementation.

The following elements were promoted in the consortium to maintain a strong coherence among the stakeholders:

- There was a common trust among stakeholders that institutions working with them (ICRISAT & partners) have a credible commitment to the livelihood improvement of small-scale farmers in the SAT region.
- Although stakeholders (consortium partners) came from different backgrounds, they evened out the differences in language, orientation, culture and ideology.
- Clearly stated work plans designed and delineated responsibilities with budgetary allocations and timeline.

The approach involves investigating and strengthening the institutional context of the research undertaken, with a view to building human capital and local innovation system capacity. The focus of the consortium type project is specified in broad development terms (rather than narrow scientific terms) so as to articulate the identified problem in a way that includes the interests of both non-scientific as well as scientific stakeholders.

V. Partnerships

1. Multi-stakeholder consortium partnership

The multi-stakeholder consortium partnership (Fig. 1) initiative was taken up from its inception to building public-private-people-partnerships (PPPP) to help reach the goals by better harnessing the capacities, capabilities and technologies available with partner organizations, towards making sweet sorghum a commercially viable supplement feedstock for ethanol production.

Many institutions (Table 1) have been partners in this project. The institutions involved in the multi-stakeholder consortium include farmers associations, NGOs, private sector companies (crusher manufacturers and seed companies), public sector organizations – national research institutions, agricultural and veterinary universities, along with ICRISAT as Project Executing Agency.

Table 1. Consortium partners

S. No.	Consortium Partners	Name of the CoPIs	Designation	Full address with Phone Fax and Email
1	ICRISAT	Dr Belum VS Reddy, Consortium Principal Investigator	Principal Scientist (Breeding)	ICRISAT, Patancheru, 502 324, Andhra Pradesh Ph: 040-30713487 b.reddy@cgiar.org a.ashokkumar@cgiar.org
2	NRCS	Dr SS Rao	Principal Scientist	National Research Centre for Sorghum (NRCS), Rajendranagar, Hyderabad 500 030. AP, India Ph: 040-24015225; Fax: 040-24016378 ssrao@nrcsorghum.res.in
3	CRIDA	Dr Venkateswarulu	Director	CRIDA, Santoshnagar, Hyderabad 500 059 Ph: 040-24530161; Fax: 040-24531802. isvas@crida.ernet.in grkorwar@crida.ernet.in
4	IICT	Dr Ahmed Kamal	Scientist	Indian Institute of Chemical Technology, Hyderabad - 500 007 Ph: 040-27160123; Fax: 040-27193370. ahmedkamal@iict.res.in cgkumar@iictnet.org

Continued

Continued

Table 1. Consortium partners

S. No.	Consortium Partners	Name of the CoPIs	Designation	Full address with Phone Fax and Email
5	ILRI	Dr Michael Blummel	Principal Scientist, Animal Nutrition	ILRI, C/o ICRISAT, Patancheru PO 502 324 (AP) Ph: 040-30713653; Fax: 040-30713074. m.blummel@cgiar.org
6	SVVU	Dr Y Ramana Reddy	Associate Professor	Department of Animal Nutrition College of Veterinary Science Rajendranagar; Hyderabad 500 030, AP Ph: 23746032; Mobile: 98850-51280 Email: ramanayr19@yahoo.co.in
7	Rusni Distilleries Pvt. Ltd.	Dr AR Palaniswamy	Managing Director	Rusni Distilleries Pvt Ltd., 411 HIG, BHEL, RC Puram Hyderabad 502 032 Ph: 040-23025310 Email: rusnispirit@rediffmail.com
8	NGO	Mr Subba Rao	CEO	Aakruthi Agricultural Associate of India 6-3-903/A/3, Suryanagar Colony, Raj Bhavan Road, Somajiguda, Hyderabad-500 082 Ph: 040 40038381 Email: aai_aakruthi@yahoo.com

VI. Project implementation

For continuous production of ethanol by the distillery, sweet sorghum feedstock is required on a regular and continuous basis. The farmers can take advantage of the new market opportunity and supply the feedstocks in large quantities on regular basis to the industry through an innovative Value Chain Model that provides linkages between farmers, input dealers and processors. The model involves collective action and partnership through the production of sweet sorghum and establishment of DCUs in a cluster of villages. Two models developed for centralized and decentralized areas encompassing various project activities such as supply of inputs, technical backstopping and capacity building of stakeholders in various crop production activities, DCU operations and linking farmers to the industry/distillery. The responsibilities of project implementation process have been designated to consortium partners based on the outputs of the project (Table 2).

Table 2. Responsibilities of consortium partners.

Partner	Major responsibilities
ICRISAT	ICRISAT is the consortium leader. The major responsibility of project planning, implementation and reporting lies with it: 1. Baseline characterization, assessment of economic competitiveness of sweet sorghum for bioethanol, documentation and analysis of existing policies 2. Establishment of decentralized crushing units (DCU), their maintenance and operation and process documentation for SWOT analysis 3. Linking the farmers with decentralized units and distillery and technical back stopping for increased productivity 4. Identification of promising sweet sorghum cultivars for the target region through farmer participatory multilocation on-farm evaluation 5. Development of institutional mechanisms for input supply 6. Seed multiplication and distribution for large scale cultivation 7. Increasing the harvest window to supply feedstocks for longer times and simulation studies 8. Development and evaluation of protocols for use of sweet sorghum stillage as organic matter 9. Capacity enhancement of farmers, community-based organizations (CBOs), development personnel and distillers 10. Development of training and information, education and communication (IEC) materials and providing access to self-help groups (SHGs) for these materials.
CRIDA	1. Providing technical support to farmers for enhanced crop productivity 2. Evaluation and refinement of suitable machines for harvesting, leaf/sheath stripping and crushing of stalks 3. Training of various stakeholders

Continued

Continued

Table 2. Responsibilities of consortium partners.

Partner	Major responsibilities
NRCS	1. Assessment of economic competitiveness of sweet sorghum for bioethanol, documentation and analysis of existing policies 2. Providing technical support to farmers for enhanced crop productivity 3. Identification of promising sweet sorghum cultivars through farmer participatory multilocation on-farm evaluation 4. Taking part in development and assessment of biochemical quality parameters of sweet sorghum juice for optimizing recovery, minimizing storage losses and improved fermentation efficiency 5. Refinement of agronomy for increased harvest window 6. Training of various stakeholders.
ILRI	1. Development and evaluation of protocols for production of animal feed, organic matter and fuel from the sweet sorghum stillage 2. Standardizing the ratios and methods of making feed blocks from sweet sorghum stillage 3. Comparison of stillage feed blocks as animal feed with other common raw material in the feed blocks
IICT	1. Development and assessment of biochemical quality parameters of sweet sorghum juice for optimizing recovery, minimizing storage losses and improved fermentation efficiency 2. Capacity enhancement of distillers and other stakeholders for minimizing the storage losses
Rusni Distilleries Pvt. Ltd.	1. Assessment of biochemical quality parameters of sweet sorghum juice for optimizing recovery, minimizing storage losses and improved fermentation efficiency 2. Seed multiplication and distribution and technical back stopping for increased productivity 3. Mechanization aspects of sweet sorghum cultivation in centralized growers model 4. Protocols for utilization of stillage as fuel 5. Training of farmers, CBOs and development personnel
SVVU	1. Comparison of stillage feed blocks as animal feed with other common raw material in the feed blocks 2. Capacity enhancement of farmers, CBOs, development personnel and distillers
NGO	1. Selection of farmers in the cluster villages 2. Participation in the selection of cluster villages 3. Facilitate in training programs to farmers and other stakeholders 4. Identification of farmers and supply of seed and fertilizers 5. Facilitation in harvesting and transportation and crushing the stalks at DCU 6. Helping the farmers' associations in book keeping and records of crushing and syrup production.

VII. Project operation area

The criteria behind selecting Medak district in Andhra Pradesh for implementing this project and establishment of DCUs is based on the sorghum acreage and suitability of agro-ecology in addition to the location of Rusni Distilleries. There is good scope for area expansion under sweet sorghum in this area because traditionally sorghum is a popular crop during the rainy and postrainy seasons. Grain quality of rainy season sorghum is generally affected by the grain mold at maturity stage, which makes it unsuitable for human consumption. Ethanol production from such grains and sweet sorghum stalks provides additional income to the farmers without compromising the food/feed security. Based on the above criteria the Ibrahimbad cluster comprising of seven villages was selected (Table 3) ofter conducting Group discussions with farmers, local leaders and village administration. (Fig. 2 & 3).

Fig. 2. Group discussions with farmers, local leaders and village administration.

Fig. 3. Target Area – Ibrahimbad village, Narsapur Mandal, Medak district in Andhra Pradesh.

Table 3. Details of villages in the Ibrahimbad cluster.

Village	No. of households
Ibrahimbad	192
Errakuntla Thanda	67
Seethya Thanda	21
Durgam Thanda	20
Umla Thanda	19
Sikindlapur Thanda	123
Lasman Thanda	54
Total	514

VIII. Value chain model for bioethanol production

1. Methodologies

To develop the value chain model (VCM), the methodology is to adopt innovative strategies to address all the issues holistically by harnessing the strengths and synergies of consortium partners. The concerns of all the stakeholders will be addressed to ensure that the value chain becomes stronger and successful. Farmers' participation and collective action is the core of the value chain development.

Farmers' participatory multilocational testing for identification of suitable high sugar and grain yielding cultivars, increasing the harvest window, organizing the farmers' groups, input (seed and fertilizers) supply, technical backstopping, micro-entrepreneurship development in villages, linking farmers to markets, providing for better utilization of by-products, capacity enhancement of stakeholders are the major innovations aimed in the project. The strategy will be people-centric and environment-friendly.

2. Innovations

These specific innovations form the pillars of the strategy in the value chain development:

- Holistic systems approach encompassing seed to tank to give a sustainable and up scalable 'sweet sorghum ethanol' model

- Use of whole plant for processing and value addition
- Participatory Research and Development (PR&D)
- Training and human resource development by adopting knowledge management and sharing systems
- Use of information and communication technology (ICT) to enhance reach
- 4 Cs and 4 Es: Consortium, Convergence, Collective action and Capacity building; Equity, Environment protection, Efficiency and Economic benefits
- Research mediated value chain as we will undertake strategic research for identifying new valuable by-products as well as continually strive for increasing efficiency of operations
- Unique partnership of agricultural scientists with basic science scientists, engineers, industrialist, government departments, development agencies and farmers to harness the benefits from 'Genes to Engines' through value chain of ethanol produced from sweet sorghum
- Decentralized crushing approach to reach the scale of operations, so as to have decentralized micro-entrepreneurship development in villages and ensuring stable feedstock supply to the distillery

3. Holistic approach for whole plant utilization of sweet sorghum

The project aims at the utilization of the whole sweet sorghum plant according to the demand of its raw materials and by-products. Introduction of decentralized models of extracting juice at the community level leaves large quantities of by-products like leaves and bagasse. The by-products can be utilized either for making feed for animals, compost or co-generation. This ultimately leads to a win-win situation wherein the farmer gets more income from his produce and the industry gets the feedstock at a lower rate, beside benefits to community and the environment. The scale of operation will generate large quantities of by-products, opening up new vistas for identifying new value added products such as fodder, feed, compost or source of bio-energy through biogas production or by directly using it as fuel.

4. Value chain model

Through the innovative 'seed to tank' approach, value is added to the sweet sorghum bioethanol production process through decentralized crushing units, community seed systems, input supply, technical backstopping, credit and market linkages. The issues and interventions are shown in the flowcharts (Fig. 4).

The seed-to-tank approach is a core component of the project. It encompasses: the identification of areas for sweet sorghum production, suitable cultivars through on-farm trials, increasing the harvest window, establishment of decentralized crushing cum syrup making units, organizing the farmers and linking them to decentralized syrup units and distillery, linking the farmers to inputs agencies, refinement of machinery for large scale cultivation, increasing the shelf life of juice and efficiency of processing, most economic and efficient utilization of by-products, micro-entrepreneurship development and capacity enhancement.

The project aims to demonstrate a successful model for up- and out-scaling sweet sorghum cultivation for ethanol production to increase farmers' incomes, reduce

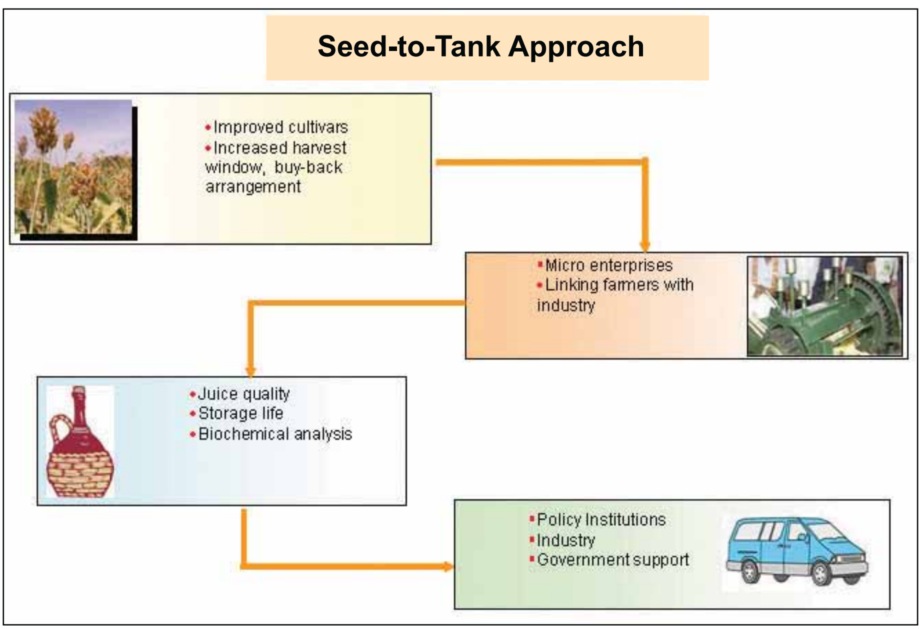

Fig. 4. Line diagram showing sweet sorghum crop from sowing to ethanol production.

environmental pollution without compromising the food or fodder needs of farmers. This paves way for the most efficient whole plant utilization of sorghum, one of the most promising crops for the tropics particularly in the light of climate change. The project intends to increase the area of sweet sorghum up to 5000 acres by the end of the project directly benefiting at least 2000 farmers.

IX. Project monitoring and evaluation

Monitoring indicators

Output No.	Outputs/Activity	Monitoring indicator
1.1	***Economic and environmental assessment of sweet sorghum for ethanol completed*** 1.1.1 Baseline characterization (bio-physical and socio-economic) of the target areas (ICRISAT)	Database and survey report
	1.1.2 Assess economic competitiveness of sweet sorghum as a feedstock for bioethanol with other crops like maize, sugarcane and cassava, and the economics of sweet sorghum cultivation vis-à-vis crops replaced (ICRISAT, NRCS)	Database and reports
1.2	***Enabling policy and institutional mechanisms for sweet sorghum ethanol model documented*** 1.2.1 Documentation and analysis of the existing policies and institutional mechanisms in sweet sorghum ethanol technology (ICRISAT, NRCS)	Policy briefs and reports
2.1	***Pilot model of decentralized crushing cum syrup making unit encompassing*** 2.1.1 Establishment of decentralized juice extraction and syrup making units for value chain development (ICRISAT)	Number of decentralized crushing units operational and running and quantity of syrup produced
	2.1.2 Providing technical support to the farmers for enhanced crop productivity (ICRISAT, NRCS, CRIDA, Rusni)	No. of technologies advocated and adopted; No. of farmers benefited
	2.1.3 Linking farmers to decentralized units and processing industry (ICRISAT)	No. of farmers linked to decentralized units and distillery

Continued

Continued

Output No.	Outputs/Activity	Monitoring indicator
2.2	***Learnings from the innovative and pilot value-chain model of bioethanol production from sweet sorghum documented*** 2.2.1 Process documentation built-in in the pilot model system to identify strengths, weaknesses, opportunities and threats of the model (ICRISAT)	Documentation reports
	2.2.2 Content development of the model to be used as inputs for outputs 1.2 and 5.2 (ICRISAT)	Content development manual
3.1	***Promising sweet sorghum cultivars for target region identified*** 3.1.1 Identification of varieties, hybrid parents and hybrids through multi-location on-farm testing and farmers' participatory cultivar selection (ICRISAT, NRCS)	Number of varieties and hybrids identified
	3.1.2 Development and assessment of biochemical quality parameters of sweet sorghum juice for optimizing recovery, minimizing storage losses and improved fermentation efficiency (IICT, NRCS, Rusni)	Percent improvement in juice quantity and quality; improved methods of juice shelf-life extension and fermentation efficiency
3.2	***Seed and other inputs supply systems for large scale sweet sorghum cultivation established*** 3.2.1 Developing institutional mechanisms for supply of inputs like seed, fertilisers, machinery etc. (ICRISAT)	No. of institutional mechanisms identified and no. of farmers benefited
	3.2.2 Seed multiplication and supply in the target region (ICRISAT, Rusni)	No. of groups/ seed companies organized for seed production; Quantity of seed made available to farmers
4.1	***Production package for increasing the harvest window developed*** 4.1.1 On farm trials for refining agronomic practices for enhancing the productivity and availability of sweet sorghum feedstock to the industry (ICRISAT, NRCS, Rusni)	Mapping of the area for different planting dates; Enhanced period of feedstock availability

Continued

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Output No.	Outputs/Activity	Monitoring indicator
	4.1.2 Generating data to validate the simulation models for identifying potential areas suitable for prolonged availability of feedstock materials to the industry in AP (ICRISAT)	Data base and model validated for sweet sorghum; mapping of potential areas in AP for sweet sorghum
4.2	***Mechanized crop production methods and protocols for by-product utilization developed*** 4.2.1 Evaluation and refinement of suitable machines for harvesting leaf/sheath stripping and crushing (CRIDA, Rusni)	Refined harvesting and leaf stripping machines available for use on the field
	4.2.2 Development and evaluation of protocols for production of animal feed, organic matter and fuel from the sweet sorghum stillage (ILRI, SVVU, ICRISAT, Rusni)	Value addition as livestock feed, organic manure and fuel.
5.1	***Enhanced capacities of various stakeholders to maximize the productivity and profitability of value chain achieved*** 5.1.1Training of farmer groups and CBOs for micro-entrepreneurship and management practices to increase the harvest window (ICRISAT, NRCS, Rusni, CRIDA)	Number of training programs conducted and number of farmer groups and CBOs trained
	5.1.2 Increasing the awareness of various stakeholders through the conduct of field days, training, consultation and provision of IEC materials on sweet sorghum cultivation, processing and ethanol production (ICRISAT, NRCS, Rusni)	Number of field days conducted and number of different IEC materials made available
5.2	***Training material (manuals, protocols and audio video material) on sweet sorghum ethanol production made available*** 5.2.1 Development and popularization of training materials to suit various interest groups (ICRISAT, NRCS, CRIDA)	Number of training materials developed and popularized according to users
5.2.2	Provision of access to these materials to SHGs and other interest groups (ICRISAT)	Number of farmers using training material

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6	Mr P Balakrishna Reddy Member (Farmer)	House No. 1-78, Village: Gunthapally, Mandal: Kondapur, District: Medak, AP	
7	Mr Manne Narasimlu Member (Farmer)	House No. 1-47/2, Village: Posanpally, Post: Choutakur, Mandal: Pulkar, District: Medak, AP	
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Chapter II: Sweet sorghum cultivar options

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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%.

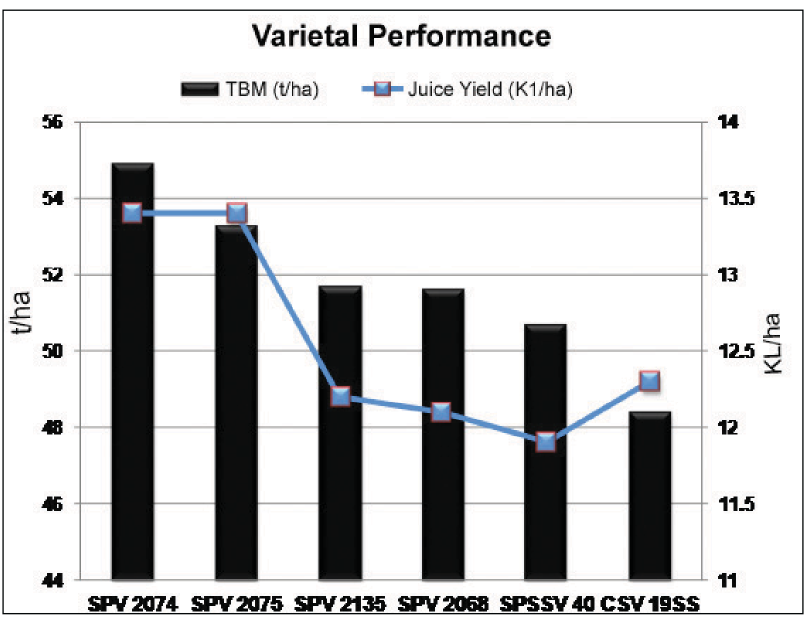

Fig. 1. Performance of test varieties for biomass and juice yields – IAVHT (AICSIP) - Kharif 2011.

- 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}.

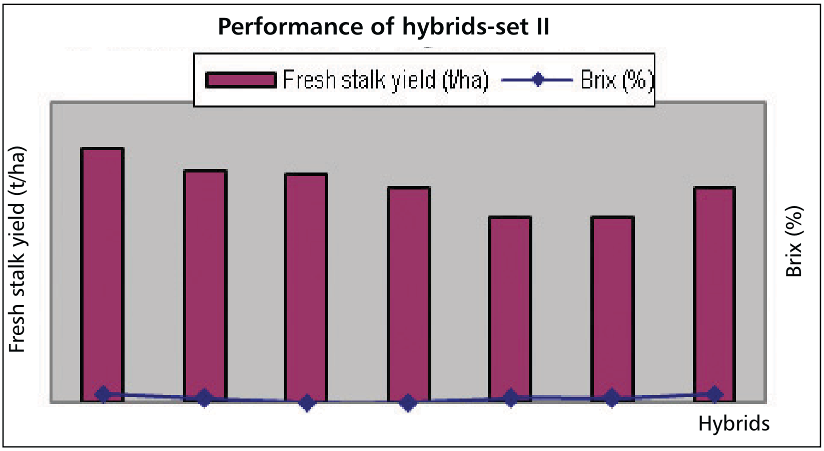

Fig. 2. Performance of promising hybrids for Brix and stalk yields.

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).

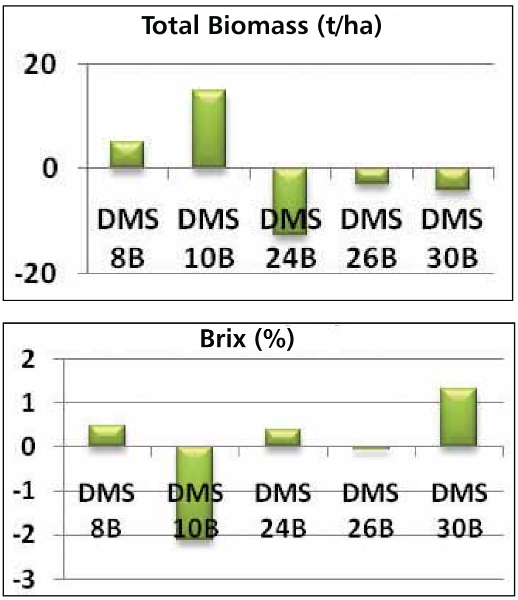

Fig. 3. GCA effects of lines for various characters.

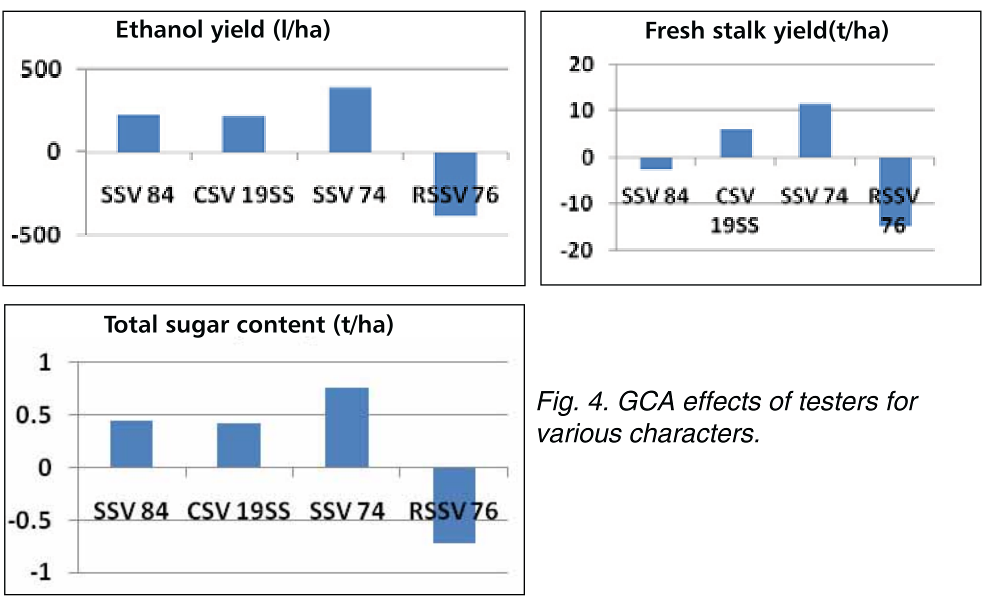

Fig. 4. GCA effects of testers for various characters.

- 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.

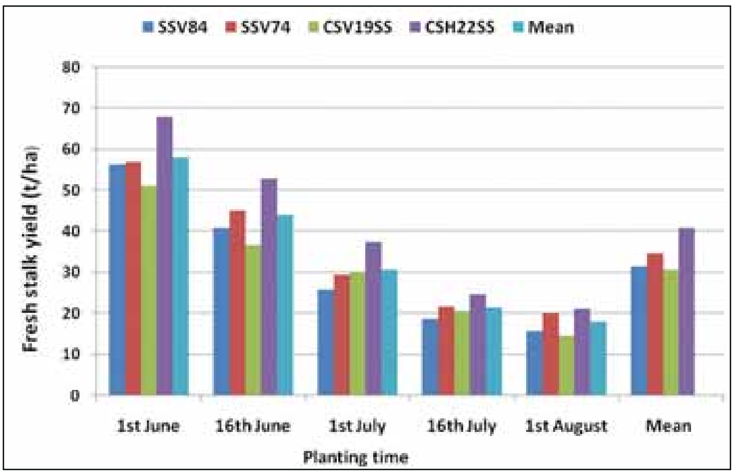

Fig. 6. Sweet sorghum staggering planting effects on stalk yields (mean of 2008 and 2009).

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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Chapter III: Community Seed system: Production and supply of sweet sorghum seeds

Ch Ravinder Reddy, A Ashok Kumar and Belum VS Reddy

I. Introduction

Under the NAIP project activities, it was aimed to develop a community seed system (community seed program) for multiplication of farmer selected sweet sorghum cultivars seeds to enhance their availability and benefit the project farmers. As there are not many seed companies producing seed of sweet sorghum, a community seed program was developed to address sustainability issue of regular seed supply to farmer selected varieties after completion of the project. Hence, a community-based seed system model was developed and implemented in the project area.

II. General issues

The response from farmers to development initiatives varies from one place to another. Some of the factors motivating them as seed growers include a good harvest and increased income from the sale of seed. A poor harvest in the first season discourages them and lead them giving up. While some farmers do become self-reliant within a few seasons, it takes a minimum of five years to develop a sustainable community seed program. The first three years of the project focused on awareness and capacity building such as technical training in seed production, business skills, group dynamics, leadership and getting farmers to understand the seed production process. The last two years of the project were mainly concentrated on exit strategies or the final handing over of the management of seed production to the community. Some of the important activities during this last stage include taking farmers on orientation visits to places such as research stations, seed processing plants (for seed sources) and the State Seed Certification Agencies (SSCAs). These exposure visits acquaint the farmers with seed production and certification procedures and more so on confidence building and awareness on investments and expenses in meeting seed quality parameters. In addition, seed producers (farmers) should visit private. seed companies and other service providers (NGOs, KVKs) as they may act as potential market outlets.

III. The model

A basic model on community seed program developed involving consortium partners. Generally models developed for a specific area/village/region and crop may not yield the same result elsewhere because of the crop, the cropping systems, cultivars used, climatic conditions, variation in the willingness of the stakeholders, and socioeconomic status, political and perhaps biotic factors. The following steps were involved in developing community seed systems (CSS) for multiplication of selected sweet sorghum varieties and distribution to project farmers.

1. Reconnaissance survey

After identifying the areas of operation, the non-governmental organization (NGO) and project implementing agency (PIA) has carried out reconnaissance survey for seed needs assessment (SNA). There is a series of participatory dialogues to engage a community in a diagnosis of the problems relating to seed availability and to secure the community's commitment to develop and act on its own solutions. The SNA will also identify knowledge gaps that can be corrected during training programs. The SNA assisted communities in developing an action plan on what needs to be done, while remembering that the role of the NGO is only to facilitate this process.

2. Participatory selection of varieties

It is for the communities to identify the varieties to be multiplied. There is a tendency for farmers to select only improved Hybrids at the expense of important varieties. Facilitators should check this tendency. Locally adapted varieties would be ideal in the first year. This tends to increase the chances of success since farmers already have adequate experience growing them. The NGO should be proactive in promoting farmers' participation in the selection of varieties for a particular area/region/village.

3. Selection of seed growers

Once the varieties selected for multiplication have been identified through farmers' participatory selection, the community can select individuals who will be the seed growers. Since the seeds are known to be conserved and multiplied mostly by women, it is only appropriate and advantageous that seed production of such crops be done by them. To help farmers carefully select their local seed growers, the NGOs can help facilitate a process developing criteria for selecting SHGs as seed growers. Some suggested criteria adopted in the intervention.

- He/she should be resident of the village and a member of SHG group
- Should be a farmer with land holding
- Willing to attend training programs without fail
- He/she should be friendly in nature and approachable to others
- Inclination to put in sincere efforts
- Must be willing to work in a team
- Experienced in growing one or more of the crops intended for multiplication.
- Must be honest and willing to repay seed loans
- Having such a set of criteria reduces bias and helps farmers to choose appropriate seed growers.

4. Capacity building

After seed growers have been identified, technical training followed. The seed growers are trained in basic seed production techniques including rules and regulations and seed certification methods, seed health management and seed storage and marketing. Training is enhanced by conducting an educational tour to ICRISAT and showed similar programs. This is an interaction of farmer-to-scientist and scientist to farmer learning. Farmers were trained in business skills and some basic group dynamics and leadership.

As with all farmers training, the trainer should be conversant with principles of adult learning and facilitation skills, SHG s were included in all training programs. Training was conducted by competent technical officers so long as they fully understand the basic seed production standards and the Seeds Act. For such innovation projects a consortium approach has yielded good results.

5. Procurement of basic seed and distribution

The NGO or farmers need to secure basic seed (Breeders/foundation seed) for their seed production activities. Basic seed can be difficult to secure. Therefore, ICRISAT and Directorate of sorghum Research (DSR) have been identified as basic seed source. Where poor weather has affected the growing season, it would be imperative to arrange seed for the following season. It is advisable to subcontract breeders recognized by government or research organizations to produce basic seed in specified quantities. We have developed linkages between farmers association and public sector institutions (ICRISAT/DSR) to ensure timely supply of basic sweet sorghum seed.

In the absence of basic seed, a seed grower can plant certified seed, but only for one season. Thereafter farmers must secure basic seed for quality seed and long-term benefits.

6. Formation of seed growers' association

Some seed growers would certainly prefer to work as individuals but in seed growing, forming an association has the following advantages:

- Registration is cheaper for a group than for individuals. Farmers association (An NGO) or Self-help groups (SHGs) can take up this activity right away as they are registered community based organizations.
- It is cost-effective to work as a team when procuring basic seed and selling seed: There is the benefit of bulk buying and selling.
- Group contributions can be used for paying for activities such as crop inspections, seed sampling and testing.
- During the early years of seed growing the team is important for providing mutual support, encouragement and a collective voice.
- However, for farmers to work effectively as a group, needs assessment can determine whether they need to be trained in group dynamics, leadership, record keeping, conflict management and business skills.
- The seed growers association would be required, in the longer term, to mobilize funds to sustain their seed growing activities.

7. Seed marketing

The success of a community seed project lies in the ability of the seed growers to sell their produce. Some farmers have used field days, weekly village markets, village local market days, local newspaper as a way of advertising. Others have used public meetings and ceremonies in their villages to sell seed. Seed growers should be innovative in adopting ideas that are workable within their rural setup. They, however, should be careful not to price their seed beyond the local farmers' willingness to pay.

Wherever possible, the project partners were helpful in linking farmers to credit institutions for short term crop loans. Seed storage is a big issue in the villages; a proper storage facility will encourage farmers to store seed for at least 6-8 months before they sell seed. A revolving fund facility in the project will be highly helpful to establish community seed system. This will enable community-based organizations for initial investments to buy inputs like breeders seed, chemicals, fertilizers, gunny pages for packing seed, and other seed storage materials and marketing requirements. The repayment of fund ensured after sale of seed, which will then generate new loans for resource-poor farmers. Some farmers do loan seed to other farmers, to be repaid later in the form of grain, labor or loaning livestock for field operations.

Farmers' knowledge and capacities were strengthened in the project villages to produce quality seeds to meet their own requirements in DCU area is a success story. Seed production method adopted by SHGs under technical guidance and supervision of ICRISAT, DSR has produced 1300 kg of ICSV 93046 variety seed and distributed to farmers in the cluster villages around the Ibrahimbad village in Medak district. The local newspaper has disseminated the NAIP project story had a good impact on marketing the seed produced by SHGs. Alternate uses of sweet sorghum for fodder and grain purpose has spread like wild fire and there is a great demand for seed in the peri-urban and Medak district private dairy farms and spreading to other areas of the state.

IV. Advantages

- Availability of seed of improved varieties in sufficient quantities within the village.
- Assured and timely supply of seed material to farmers.
- Decentralized seed production.
- Availability of improved-variety seed at lower prices.
- Improved seed delivery to resource-poor farmers.
- Reduced dependence on external seed sources and effective curbs on spurious seed trade.
- Good opportunity for SHGs to invest and develop a village seed enterprise.
- Encourages village-level trade and improves village economy.

- Social responsibility of seed production and delivery system.
- A step toward sustainable crop production.
- Avoid introduction of diseases carried through seed (seed-borne pathogens) produced and imported from other agro-ecoregions.
- Scope for farmer-participatory varietal selection and feedback to the scientific community on the performance of cultivars.
- Availability of true-to-type varieties and healthy seed within the reach of farmers at affordable prices.
- The probability of sustainability is high because involving farmers from the beginning of VSB establishment, seed production, storage and marketing through their own investment and sharing the benefits.

V. Constraints

- Willingness of farmers to adopt quality seed production practices.
- Additional investment for inputs in seed production.
- Buy-back assurance to farmers from Farmers' Associations (FA)/SHGs/ non governmental organizations (NGOs).
- Proper seed storage facilities and management at village level.
- Availability of funds with FA/SHGs/NGOs for seed procurement, packing, storage and transportation.
- Fixing minimum support price for seed procurement.
- Technical support for seed production and its monitoring.
- Responsibility of quality control aspects and monitoring of seed production.
- Availability, access and procurement of breeder seed from research institutes for seed production at regular intervals.

VI. Conclusion

Many development projects have used community level seed production as the starting point for commercial seed development. The results have been disappointing with little commercial sustainability. The reasons for this lack of success are two fold: a lack of attention to transaction costs (for making contracts for source seed, ensuring quality control and obtaining information) and a lack of experience and resources for marketing. Community-level seed projects need more appropriate goals to be successful, such as testing and disseminating new varieties, developing farmers' experimentation capacities, and forming better links between farmers and researchers.

The farmers' association in the project area and SHGs were trained in seed production methods has produced 1300kg of ICSV 93046 a sweet sorghum variety and sold seed to project farmers at the rate of Rs 50 kg^{-1}. With this experience of benefits from seed production farmers are enthusiastic about developing this initiative into a small-scale seed enterprise.

Farmers as seed producers can be quite efficient and some will have potential to expand as specialized, small-scale seed enterprises. Seed trade associations, government agribusiness promotion programs, and especially NGOs, SHGs, and Krishi Vignana Kendras (KVKs) have a potential role in promoting improvement in production, marketing and distribution systems for traditional farmers seed producers. Key to success in strengthening informal seed systems will be improving farmer and seed producer access to information on product and seed price and market options.

The approach involves farmer participation directly in the program, where the farmers are empowered to produce quality seeds and manage seed bank for the timely availability of seeds, under DCU area. The model 'community seed systems' can be promoted to avail quality seeds of sweet sorghum at right time and affordable prices for the resource poor farmers. The system will reduce the dependence on external seed sources and encourages village level trade improving village economy. The breeder seed supply linkages developed with public sector research institutions for long term benefits and sustain seed production activity is key to success in production of quality seed. For hybrid seed supply, farmers will be linked to private seed companies/agencies.

Chapter IV: Production technologies for enhancing sweet sorghum yields

Suhas P Wani, Gajanan L Sawargaonkar, E Pavani,
SS Rao and HC Sharma

Adoption of good crop and soil management practices are important for maximum productivity and to make the system sustainable in the long run. This chapter describes the cultivars and good cultural practices that are to be followed to raise successful crops in farmers' fields thereby achieving higher yields.

I. Adaptation and growing conditions

Sweet sorghum is a warm-season crop that matures earlier under high temperatures and short days. It tolerates drought and high-temperature stress better than many crops and hence adapts well to sub-tropical (Rego et al. 2003) and temperate regions of the world and is highly efficient in biomass production, with a low water requirement (Girma 1989 and Mastrorilli et al. 1990) and short growing season (Roman et al. 1998). Rainfall of 500-600 mm distributed ideally across the growing period is best, unless the soil can hold much water. The crop does not prefer high rainfall as high soil moisture or continuous heavy rain after flowering may hamper its sugar content. Air temperatures suitable for its growth vary between 15 and 37°C. Sorghum being a C4 tropical grass is adapted to latitudes ranging from 40^{o}N to 40^{o}S of the equator.

II. Rationale for development of improved cultural practices

Sweet sorghum yields vary considerably depending on the varieties, location grown, soil, water, climate, pests and diseases, inputs and agronomic practices. Significant research has taken place during past two decades, not only limited to ethanol production (Linton et al. 2011; Massoud and Abd El-Razek 2011), but also to improve crop yield and resources utilization efficiency (Zegada-Lizarazu and Monti 2012). These point to an option of a potential cash crop that can be cultivated with marginal input resources. Sweet sorghum can transform the available water more efficiently into dry matter than most of the other C_4 crops (Dercas and Liakatas 2007) and may uptake water from as deep as 270 cm soil depth (Geng et al. 1989). The major constraints in sweet sorghum production include non-availability of a suitable cultivar which can fit well in to the available growing season window coupled with poor agronomic management practices. This chapter elaborates the concept of good agronomic practices (GAPs) which will lead to bridge the yield gap between potential yield and on-farm yield.

III. Land preparation

Sweet sorghum is particularly well suited for cultivation on marginal lands. It is a C4 crop plant with tolerance to drought, water logging, high salinity and acidic soils. For the rainy season crop, with onset of rains in May-June, the field is plowed once or twice to obtain a good tilth. Harrowing of soil should invariably follow after each plowing to reduce the clod size. After the initial plowing, the subsequent plowing and harrowing are carried out when the moisture content of the clods are reduced. Field preparation depends on the system of sorghum sowing. The carrier Tropicultor has the provision of attaching different implements to a tool bar for field operations such as plowing, cultivator and blade harrow operation by which different operations are carried out. Similarly operations like broad-bed and furrow (BBF) formation and ridge and furrow (R&F) land configurations are possible with the attachment of ridger and chain (Fig. 1).

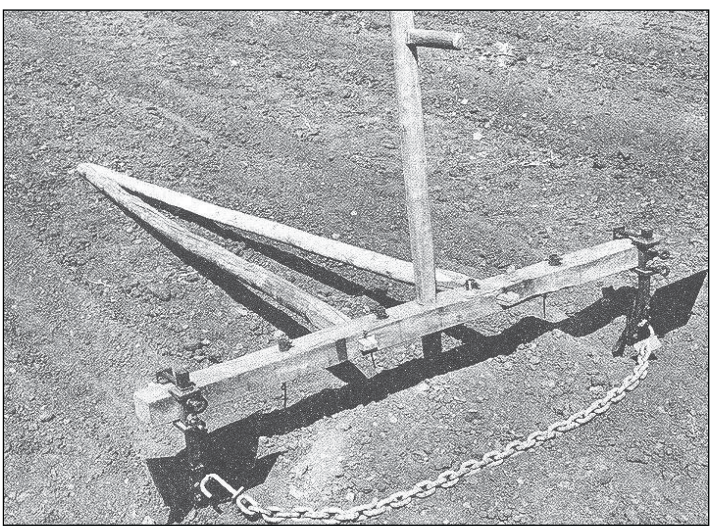

Fig.1. Chain attached to a wooden frame of a plow to level the land.

Three systems of sorghum sowing are followed: a) sowing on a flat surface, b) using ridge-and-furrow system and c) broad bed-and-furrow system.

The broad bed-and-furrow system is highly suitable for vertisols whereas flat sowing followed by the opening of furrow in every row/alternate by ridger at inter-cultivation (20 DAS) is effective for alfisol or lateritic soils under rainfed situations or conservation furrows along with contour sowing. If sowing is done on a flat surface, the land should be leveled after final plowing using bullock-drawn or tractor-drawn levelers (Fig. 1).

The R&F system (Fig. 2) is effective under irrigated conditions. Here ridges are made using either tractor or animal drawn ridge plows at 60-75 cm spacing (Fig. 3, 4 and 5).

Fig. 2. The ridge-and-furrows system.

Fig. 3. Tractor-drawn ridger.

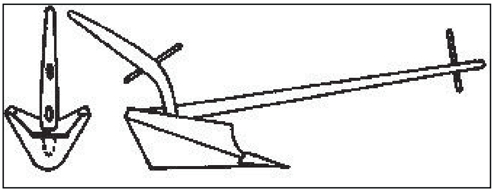

Fig. 4. Animal drawn wooden ridge plow.

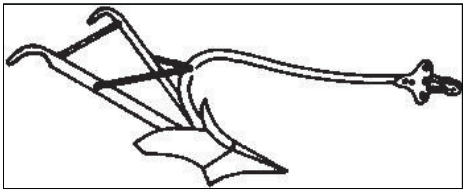

Fig. 5. Animal drawn iron ridge plow.

IV. Tropicultor – multi-tool carrier for rainfed systems

The carrier Tropicultor can be used for all field operations with bullock or tractor power. It has the provision of attaching different implements to a tool bar with simple flexible U-clamp system with a handle for lowering and raising the implements. Field operations such as plowing, cultivating and harrowing are done by changing the required implements (Fig. 6). The tool bar of the tropicultor is attached with 2 ridgers at 150 cm apart with a chain attachment to both the ridgers behind to form a bed approximately 100 cm and furrow of 50 cm continuously after one key line with required gradient (Fig. 7). Since the furrow is exclusively for the traffic zone where the bullock and wheels of tropicultor will move, all field operations like sowing, fertilizer application at required depths, row spacing with optimum population and required fertilizer rate for sorghum crop is possible. Inter cultivation is done with different size duck-foot shoes based on the crop row spacing that is attached to toolbar for inter row tilling and ridger (without wings to shape the furrow).

Fig. 6. Set of implements for the Tropicultor.

Fig. 7. Land preparation & BBF formation with the Tropicultor.

Fig. 8. A bullock-drawn Tropicultor bearing a fertilizer-cum-seed drill.

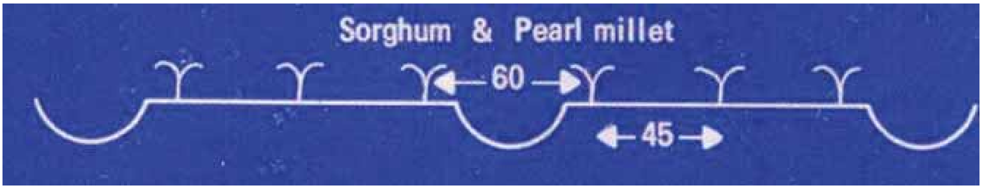

Fig. 9. An illustration of the broad bed-and-furrow method.

- The Tropicultor covers 2 ha in a day whereas it plows 1 ha for BBF formation and tilling with left and right plows. (Fig. 9 and 10).
- There is great reduction of cost for planting, fertilizer application and seed by 50%, and labor cost by 40% for weeding. (Fig. 8).
- Sorghum (2 rows) with pigeonpea (1 row) intercrop is possible with the Tropicultor.
- It is possible to place seed and fertilizer at required depth in the moisture zone for good crop establishment.
- There are lower operational costs for sowing and inter-culture operations and higher income with increased crop yields. The operations are very efficient, economical and time saving. As a bonus the operator can sit on tropicultor and carry out all field operations.

Fig. 10. (Contd. on next page).

Fig. 10. Sweet Sorghum at various growth stages raised on the broad bed-and-furrow system.

V. Planting time

Sweet sorghum can be grown during rainy season (kharif), postrainy season (rabi) and summer season depending upon the availability of soil moisture/irrigation sources and with suitable temperature regimes (Rao et al. 2008).

1. Kharif crop (June–October): Sowing should be undertaken immediately after the onset of monsoon, preferably from first week of June to first week of July (depending on the onset of monsoon). The seeds (two to three) must be sown in a furrow opened by the bullock-drawn plow or locally available implement. In the ridges and furrow method, planting is done on the top or at the side of the ridge at 5 cm depth at a distance of 10-15 cm by planter as hand sowing is laborious, time consuming and a costly exercise. In this method, the rainwater is conserved in the furrow and avoids water logging. The farmer must make sure that soil has fully charged with rainwater or irrigation at least in the top 15 cm soil (plow layer) to ensure good and uniform germination and seedling emergence.

2. Rabi crop (October–February): Planting should be done from the last week of September to the end of October. The night temperature should be above 15°C at the time of sowing. The farmer must irrigate the crop if there is no rainfall at the time of sowing to ensure uniform germination and establishment. Ridges and furrow method of planting should be followed to conserve irrigation water just as with the rainy/kharif crop.

3. Summer crop: Planting is done from mid-January to February-end under supplemental irrigated conditions. The night temperatures should be above 15°C at the time of sowing. Summer planting on ridges and furrow will realize excellent cane yield provided irrigation water is available.

The following are the instructions to farmers in order to raise optimum crops of sweet sorghum.

A. Sowing

- Deep black soil (vertisol) or deep red loamy soil (alfisol) with a soil depth of 1 m is preferred. Seed rate is 8-10 kg ha^{-1}.

- Treat the seed with Carbendazim or Thiram @ 2 g per kg of seeds and with Azospirillum @ 600 g per 10 kg of seeds.
- Spacing: 45-60 cm_12-15 cm; (Row to row distance: 45-60 cm; plant to plant distance: 12-15 cm).
- Two to three seeds are dibbled in each hill/planting hole and the seedlings are to be eventually thinned to one per hill.
- If a planter is used, then the seed rate must be reduced to 8 kg.
- Pre-monsoon sowing or dry sowing of sweet sorghum is effective in improving rainfall use efficiency as the crop takes advantage of early monsoon without considerable effect on germination.
- Sowing starts in June for rainy season; and in October for the postrainy season. However, sowing should be avoided during cold months. For summer irrigated crops, sowing during February is feasible.
- Delayed sowing of sweet sorghum beyond 5th July attracts shoot fly.
- Crop rotation with legumes is necessary for sustainability of yields on a long term basis.
- Sweet sorghum/pigeonpea (2:1) intercropping is also viable in vertisols.
- Dry sowing cum fertilizer application with Tropicultor is advised.
- Planting on light shallow soils should be avoided.
- The ideal pH range is 5.0-8.5.

B. Thinning

The first thinning is to be done at about 12-15 days after planting (DAP) to retain two seedlings per hill at 15 cm apart. The second (and final) thinning is done at about 20-25 DAP to retain single plant per hill. The thinning operation is very essential for uniform stand establishment and the growth of plants. If this is not done, very thin stalks of uneven size are produced leading to crop lodging and low yields. Lack of crop uniformity will also pose problems in deciding when to harvest as well.

C. De-tillering

Remove the basal tillers that occur at the base of the plant manually if they occur within 20-25 DAP. Tillers are produced mainly due to planting in late rabi (Oct-Dec) coupled with low temperatures during the early vegetative stage, as well as due to shoot fly attacks.

D. Plant population

A good crop may have about 1,20,000 to 1,40,000 plants ha^{-1} (40000 to 48000 plants/acre). Maintain a minimum of about 10 plants per sq m. Cultivating sweet sorghum with greater plant population than recommended will result in thin stalks that may lodge due to heavy winds and/or rains.

VI. Nutrient management

- It is necessary to apply nutrients based on soil testing.
- Application of nitrogen @ 90 kg ha^{-1} is recommended for sweet sorghum along with 40 kg ha^{-1} P2O5. In lateritc soils, application of K2O is also necessary at 40 kg ha^{-1}.
- ICRISAT realized that there was widespread deficiency of S, Zn and B in the soils and therefore recommended per hectare application of 200 kg Gypsum, 50 kg Zinc sulfate and 1.25 kg of Agribor or 2.5 kg Borax (Boron) as a treatment once in three years to correct the deficiencies in the soil.
- Half of total N, entire P and K must be applied as basal dressing and the remaining N applied at 30 DAS.
- Micronutrients and secondary nutrient to be applied as basal dressing.

1. Importance of improved management practices

Studies conducted by ICRISAT under on-farm and on-station situations clearly revealed the importance of improved management practices including clean cultivation and balanced nutrient management. The data presented in Table 1 highlighted that grain yield and green stalk yield of sweet sorghum are higher with improved practice (90:40:40 kg NPK ha^{-1} along with 30 kg Sulphur, 10 kg Zn and 0.5 kg Boron ha^{-1}) compared with farmers practice (1 bag Urea + 1 bag di -ammonium phosphate ha^{-1}).

Table 1. Comparison of mean grain and stalk yields of sweet sorghum under improved management (IP) versus farmers' practices (FP).

Particulars/ Year	Average grain yield (q ha^{-1})		Green stalk yield (t ha^{-1})	
	IP	**FP**	**IP**	**FP**
On Station				
2008	11.80 (8.62-14.09)*		26.40 (18.84-31.89)	
2009	24.20 (17.41-27.83)	9.60 (7.5-12.7)	52.70 (40.5-61.3)	19.60 (15.6-22.4)
2010	22.39 (15.94-28.96)		33.58 (23.9-43.4)	
On farm				
2009	11.80 (9.2-14.7)		28.40 (21.1-35.8)	
2010	11.50 (5.9-16)	8.70 (4.8-11.1)	37.70 (29.8-47.1)	23.30 (17.3-27.3)
2011	18.50 (10.8-23.5)		48.60 (39.7-57.6)	

VII. Weed management and intercultivation

- Weed management is critical in sweet sorghum.
- Intercultivation with blade harrow or cultivator or Tropicultor (Fig. 11) once or twice between 25 and 35 days after sowing (DAS) followed by hand weeding is essential.
- The second interculture is to be followed by the earthing up of crop rows with bullock or tractor drawn implements to prevent lodging especially after flowering.
- Application of selective pre emergence herbicide Atrazine is recommended @ 0.2 kg ai ha^{-1} or Atrataf R @ 1 kg ha^{-1}.

Fig. 11. Intercultural operation with Tropicultor.

VIII. Irrigation/rainwater management

1. Kharif

Normally the crop raised under rainfed conditions in areas receiving rainfall of 550-800 mm does not require additional irrigation if the rains are adequate and well distributed during the crop growth period. In the case of late onset of monsoon, plant the crop and irrigate immediately. Also, irrigate the crop if the dry spell continues for more than two weeks especially at critical crop growth stages such as panicle initiation (35-40 DAS) and boot stages (55-65 DAS). Maintain soil moisture profile at or near field capacity. Always drain out the excess irrigation water or rainfall from the fields to avoid water logging. By and large, 2-3 irrigations may be required for a kharif crop depending on the planting time, soil type and rainfall distribution at a particular location.

2. Rabi and summer crops

Arrange first irrigation immediately after sowing if no rainfall occurs. Subsequently, irrigate the crop at 15 DAS, 30 DAS, 55 DAS and 75-80 DAS for realizing good stalk yields. Thus, a total of 4-5 irrigations are required for rabi and summer crops. Apply irrigation water of about 50 mm each time. During the initial stages of crop, up to 30 DAS sprinkler irrigation is preferable to flood since the crop needs less water compared to later stages – which helps save the precious resource.

IX. Harvesting

Harvest the crop at about 35-40 days after flowering of the plants ie, at physiological maturity of grain (Fig. 12 B) where the black spot appears on lower or hylar end of the grain.

Fig. 12. Physiologically matured seed show a black spot at the hilar end (B) and immature do not show the spot (A).

Alternately, the Brix of standing crop can be measured using a hand refractometer just as with the sugarcane crop. The methodology of pre-harvest crop quality survey and assessment as followed for sugarcane (ie, use of refractometer) is recommended for sweet sorghum also. Harvest the crop if stalk Brix reaches about 16-18% at physiological maturity of the grain. Additionally, the plants can also be sampled for small mill test (SMT) to know the juice Brix and other quality parameters as with sugarcane. Cut the plants to the ground level using sickle or knife and remove the leaves including sheaths. Remove the panicle with the last internode and thresh the grains separately followed by drying. The freshly cut canes can be made into small bundles of 10-12 kg and must be transported within 24 hours of harvesting to the mill for crushing.

X. Detrashing

Detrashing refers to removal of unwanted bottom dry and green leaves at regular intervals as with the sugarcane crop (Fig. 13). Sweet sorghum stalk bears more number of leaves (10-15) equal to the number of inter-nodes under good management systems. These leaves on sweet sorghum stalks reduce juice quality, sugar, and ethanol obtainable from the crop, and reduce the payload of the crop. It is highly desirable to develop a commercial leaf stripper that can save cost of detrashing in sweet sorghum. However, a simple, compact, reliable, and safe device using rubber fingers to remove the leaves from rows of standing stalks was developed, tested and evaluated (Monroe et al. 1983) but still a more reliable harvesting machinery need to be developed, which will also reduce the cost of harvesting.

Fig. 13. Stalk of CSH 22 SS, with leaves and without leaves (detrashed).

XI. Pest management

The important pests which cause significant damage to sweet sorghum are described below.

1. Sorghum shoot fly, *Atherigona soccata*

- Shoot fly females lay cigar shaped eggs singly on the lower surface of the leaves at the 1 to 7 leaf stage.
- The larva cuts the growing point, resulting in wilting and drying of the central leaf known as 'dead heart' (Fig. 14).
- The damaged plants produce side tillers, which may also be attacked (Fig. 15).
- During the rainy season, shoot fly damage is greater in crops planted 15-20 days later than the first monsoon rains or when the rainfall is erratic and farmers resort to staggered plantings.
- Shoot fly infestations are normally high in the postrainy season, when the crop planted in September-October.

2. Stem borers, *Chilo partellus* and *Sesamia inferens*

- The first indication of stem borer infestation is the appearance of small elongated windows or round holes on the young leaves (Fig. 16) due to feeding by the young larvae. These damage symptoms on the leaves appear on crop that is 15 to 25 days old.
- The third-instar larvae migrate to the base of the plant, bore into the shoot and damage the growing point resulting in the production of a dead heart in 25 to 45 days-old crop (Fig. 18). Normally, two leaves dry up as a result of stem borer damage, while only one leaf dries up due to shoot fly damage.
- Stem borer larvae also feed inside the stem and cause extensive tunneling (Fig. 16), which is not apparent unless the stems are split open.
- Heavy damage in the stems and peduncle result in peduncle breakage or partial seed set.
- Extended period of drought and poor plant growth result in greater damage by the stem borer.
- Spotted stem borer (Chilo partellus) is important in the rainy season crop, while pink stem borer (Sesamia inferens) (Fig. 17) is predominant in the postrainy season crop.

A. Integrated pest management practices

Instructions to farmers on integrated pest management practices include:

Fig. 14. Dead heart of sorghum caused by shoot fly.

Fig. 15. Tillers produced due to shoot fly in sorghum.

Fig. 16. Shot-holes caused by stem borer, in sorghum leaves.

*Fig. 17. Pink stem borer (*Sesamia inferens*) and Chilo damage in sorghum.*

- Adopt synchronous and timely/early sowings of cultivars with similar maturity over large areas to reduce the damage by shoot fly, midge and head bugs.
- Apply balanced fertilizers having adequate N and P to promote better plant growth that results in reduced damage by shoot fly and stem borers.
- Use high seed rates and delay thinning (to maintain optimum plant stand) to minimize shoot fly damage.
- Rotate sorghum with cotton, groundnut or sunflower to reduce the damage by shoot fly, midge and head bugs.
- Intercropping sorghum with pigeonpea, cowpea or lablab also reduces the damage by stem borers.
- Collecting and burning of stubbles and chaffy earheads, and feeding the stalks to cattle before the onset of monsoon rains reduces the carryover of stem borers and midge.
- Plant sorghum varieties with less susceptibility to insect are relatively less damaged by shoot fly and stem borers.
- Treat seeds with carbofuran (5% a i), thiamethoxam (9.0 ml kg^{-1} seed), or imidacloprid (0.165 mg kg^{-1} seed) to improve plant stand, seedling vigor, and reduce the damage by shoot fly and to some extent stem borer, and maize aphid.
- When the shoot fly damage reaches 5 to 10% of the plants with dead hearts (Plate 1), the crop may be sprayed with cypermethrin 10 EC (750 ml ha^{-1}) or endosulfan 35 EC (350 g ai ha^{-1}). Alternatively, carbofuran granules (5 to 7 granules/plant) may be applied in the leaf whorls (Fig. 16).
- For stem borers, dusts or granules can be applied in the whorl leaves of damaged plants or the entire field can be sprayed with endosulfan, fenvalerate or cypermethrin.
- Neem seed kernel extract (5 kg ha^{-1}) or Bacillus thuringiensis (Bt) formulations can be sprayed for the control of stem borers, armyworms and head caterpillars.
- For sorghum midge, the crop may be sprayed at the 50% flowering stage (1 midge/panicle) with endosulfan or cypermethrin. Early and uniform planting of the crop in a geographical area minimizes shoot fly, midge and head bug damage.
- For earhead bugs (1 to 2 bugs per panicle) and head caterpillars (2-3 larvae per panicle), the crop may be sprayed at the completion of flowering and at the milk stage with endosulfan or cypermethrin.

- Use of insect tolerant varieties such as ICSV 700 and ICSV 93046 minimizes losses due to shoot fly and stem borer.
- Use of intercrops such as pigeonpea and mung bean minimizes the risk of crop failure and reduces insect damage.
- Use of carbofuran or imidachloprid seed treatment (@ 10 g/kg of seed) in case of delayed sowing or application of carbofuran granules in the soil (1.0 kg ai ha^{-1}) at the time of sowing to controls shoot fly. After seedling emergence, 15-20 carbofuran granules are placed in the leaf whorls to control shoot fly, stem borer, aphids and shoot bug or imidachloprid or acephate are sprayed to control the aphids and shoot bug.
- Carbaryl (0.5-1.0 kg a I ha^{-1}) or fenvalerate (75-100 g ai ha^{-1}) or endosulfan (700 g ai ha^{-1}) are sprayed at 50% flowering to control sorghum midge (when we see > 1 midge fly per panicle) and at completion of flowering (1 bug per 2 panicles) for head bugs. At the milk stage, endosulfan or fenvalerate is sprayed if there are 5 to 10 nymphs per panicle.

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Chapter V: Mechanization of sweet sorghum production and processing

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I. Introduction

Sweet sorghum is a unique multipurpose crop and of late widely promoted as biofuel crop. Its ability to produce grains for food/feed and stalks for fuel/feed makes it one of the popular choices in the dryland regions. This crop is now widely grown in many of the countries as a feasible biofuel crop under different climatic conditions because of short its growing period and low water requirement (Soltani and Almodares 1994) as compared to sugarcane. When compared to other biofuel crops, sweet sorghum is best suited for ethanol production because of its higher total reducing sugar content (Huligol et al. 2004). Further, its suitability for mechanized crop production, seed propagation and higher ethanol production capacity of sweet sorghum have drawn the attention of researchers. The bagasse from sweet sorghum after the extraction of juice has a higher biological value in terms of micronutrients and minerals than the bagasse from sugarcane when used as animal feed (Seetharama et al. 2002). It can also be processed as a feed for ruminant animals. The crushed stalk contains similar levels of cellulose as sugarcane bagasse, and therefore is a good prospect as raw material for pulp and briquette making (for fuel purposes). Many attempts were made to use sweet sorghum for ethanol production in a centralized model of crushing the stalk for juice at the industry level. However, this model had some difficulties as the raw material availability was restricted for small period in a year apart from the problems of transportation of stalk from the farmer's fields to distillers.

To address this, a decentralized model that involved the production and crushing of sweet sorghum stalks at the village level was tried in Medak district of Andhra Pradesh. This model involves collecting sweet sorghum stalk at the village level and crushing them in small-scale crushers established in nearby areas. To make this model viable, we attempted to reduce the cost of cultivation by mechanizing the crop production from sowing to harvesting under on-farm conditions as mechanization of crop production appropriately handled may reduce the crop production cost by 30%. The experiences of our work on mechanization of sweet sorghum production is discussed here.

II. Mechanization of sweet sorghum sowing operation

In sweet sorghum crop, the best sowing window is limited to 2 to 5 days after monsoon arrival, depending on the moisture availability. Success of sweet sorghum farming depends on the completion of sowing operation within this limited period. Otherwise the entire crop cycle becomes affected by the delayed sowing.

The recommended plant to plant spacing was 20 cm and row to row spacing was 60 cm. However in our interactions, most of the farmers were not convinced about this spacing as they had preconceived apprehensions about yield. So the seed drill setting was changed to 20 cm and 45 cm respectively. In conventional practice, sowing operation was done by a country plow to open the furrow, which was followed by two women laborers to place the seed and fertilizer. This used result in poor germination as there was no synchronization between the workers. To overcome this, improved seed drills implements suitable for the cluster were introduced to improve timeliness and precision so that sowing could be completed within the short sowing window. The implements included in the trials were: 4-row bullock drawn planters, 6-row and 9-row tractor drawn planters which were designed and developed by Central Research Institute for Dryland Agriculture (CRIDA) that were extensively popularized in dryland regions of India. Specifications of 4-row and 9- row planters are given below (Table 1).

Table 1. Specifications of the CRIDA planters.

Specification	4-row Planter	6-row planter
Weight (kg)	120	240
Source of power	Bullock	Tractor (35 hp)
Plant to plant spacing (cm)	20	20
Row to row spacing (cm)	45	45
Row coverage	3	4
Field coverage (ha^{-1} day)	3-3.5	7-8
Cost of operation (₹ ha^{-1})	800	600

Initially, to propagate the concept of mechanization among the project's farmers in Medak district, a field demonstration cum training was arranged in farmers' fields at Ibrahimbad village. This sought to demonstrate the working of the planter and to create awareness about crop mechanization. During field testing, the performance of the 4-row bullock-drawn and 6-row tractor-drawn planters was found to be satisfactory. The farmers could not use the 9-row tractor-drawn planter since their land holdings are very small. Some modifications with regards to the seed metering mechanism were made to achieve 20 cm plant to plant spacing. Though the row to row distance of 60 cm is recommended for sweet sorghum, the farmers would not adopt it because of strongly held preconceived ideas that the reduction in plant population would result in less yield. So a demonstration was conducted with 45 cm row to row spacing. As part of the training programme, farmers were also trained in repair and maintenance of planters which helped them understand the basic principles of the machinery. The poor response received for bullock-drawn planters was because it covers lesser area in the limited sowing window available. The field evaluation of CRIDA's 6-row planter is given in Table 2. The crops grown with the CRIDA planter (Fig.1) and conventional method (Fig. 2) are shown below for comparison.

It was observed that mechanized sowing helped save time by 65% when time was of the essence. The bullock-drawn planters were introduced, but it was found very difficult to popularize among the farming community owing to its poor per day coverage.

Table 2. Performance of the CRIDA planter for sweet sorghum.

Method of sowing	Average plant to plant spacing (cm)	Average row to row spacing (cm)	Biomass yield t ha^{-1}
Farmers' practice (country plough)	10	40	20
CRIDA's 6-row planter	20	45	23

Fig. 1. Mechanized sowing.

Fig. 2. Farmers' practice.

1. The effect of mechanized sowing on crop growth

As expected, mechanized sowing improved the crop growth in terms of plant height and stem girth which influence the juice recovery of sweet sorghum. The plant height and thickness of stalk for the three years were recorded to address the performance of seed drills and their influence on productivity is presented in Table 3.

The stem diameter and height of the crop under mechanized sowing was higher compared to the performance under farmers' practices, which may be attributed to the proper placement of fertilizer and seed in with the planter when compared to the way the farmers tend to. The well spaced row sowing improved yields considerably apart from making the stem grow higher and therefore more suitable for crushing.

Table 3. Effect of sowing method on crop morphology.

Methods	Plant height at harvest (cm) (in 100 m x 100 m plot)	Stem diameter at harvest stage (mm)
Farmers' practice	294	17.4
Mechanized sowing	315	21.2

2. Mechanization of intercultural operations

In majority of dryland regions, weeds compete with crops for moisture, nutrition, light and space among several other factors required for plant growth. Moisture conservation is key for achieving high yields in drylands as crops are grown under limited moisture conditions. Intercultural tools remove weeds between crop rows but create soil mulch which helps in moisture conservation. Effective and timely weed control in sweet sorghum crop plays a very important role in improving crop productivity. Conventionally farmers use hand tool slike *khurpi* (hand shovel), wooden hoes, bullock drawn *guntaka* (blade) etc, which covers less area per day and is labor intensive. This leads to prolonged operations leaving weeds in the field for longer, depleting soil resources (Srinivas et al. 2010). Therefore, new power operated tools such as the power weeder and improved manual weeder were identified for weeding in sweet sorghum and introduced in the villages. The details of the mechanization process introduced are given below.

A) CRIDA manual weeder

The CRIDA manual weeder has a wheel mounted on a pipe frame, which has the weeding tool mounted on the frame and runs behind the wheel. Its efficiency is about 10 times faster than weeding with the khurpi (shovel). It is operated by the push-pull mode and is comfortably operated by women. It also improves the ergonomic efficiency of the operator.

B) Bullock-drawn weeders (*guntaka*)

Bullock-drawn power weeders can be used comfortably between the rows and it has the added benefit of earthing up as well during weeding. They are available at the local markets with 30 cm and 45 cm blades which can be easily drawn by a pair of bullocks.

C) Mini power weeder

This is a self-propelled moving type intercultural implement. It has rotary tynes as the moving element which are mounted below the front end of the frame. The handle body with clutch and gear lever arrangement is attached to the rear side. A 1.5 hp engine provides power for forward movement and a rotary blade attached to the frame removes the weed and pulverizes the soil. This machine has better maneuverability in the field during operation. Weed control was effective and created soil mulch which is desirable under dryland conditions.

D) Power weeder

The power weeder (Fig. 3) was demonstrated in the cluster village for creating awareness among farmers. The farmers were satisfied with its working and appreciated it for its utility in sweet sorghum crop with its efficiency and superior maneuverability in the field. It works with 1.5 hp petrol engine. Clutch can be used to engage and disengage the rotor during operation. Training cum demonstration was planned at Ibrahimbad village to test its feasibility and also to create awareness during the season.

Fig. 3. Woman farmer using CRIDA manual weeder at her farm.

E) Farmers' experience with power weeders

Many farmers felt that the power weeders were very useful in the present conditions of labour and bullock power shortage, where it equally essential that weeding and intercultural operations be completed in time. They had observed that delay in weeding operation by 10 days affected crop yields significantly. The cost of power weeding worked out to around Rs 625 ha^{-1}. The plant damage was also minimized with the power weeders when compared to the other methods.

3. Mechanization of harvesting operations

It was observed that the harvesting operation of sweet sorghum cost 30% of the whole cost of cultivation apart from high drudgery involved. Women, who are mostly involved in this operation, suffer a lot under the scorching heat. Since there were no small- to medium-scale harvesters available in the market, experiments were conducted with the modified self-propelled reapers which were normally used for paddy and other fodder crops. These modifications were carried out at CRIDA, Hyderabad, India, based on initial feedback from the farmers after testing the equipment in the field.

A) Modification of front mounted reaper as sweet sorghum harvester

A front mounted reaper which can be attached to the tractor was modified to suit the harvesting operation of sweet sorghum crop (Fig. 4). The reaper was a multi-crop harvester and is suitable to harvest soybean, paddy, wheat and other crops. It consists of a cutting bar and guiding wheels to bring the crop close to the cutting blade. The cut crop stalks are conveyed to the side to form a windrow via a belt.

Fig. 4. Demonstration and training of the power weeder.

Since the height of the sweet sorghum crop was more than 240 cm, the reaper was not suitable for harvesting it. Besides, the stalk thickness was more than the normal sorghum, and so the cutting blades were not suitable either. Modifications were carried out by increasing the height of the reaper to support the sweet sorghum stalk and conveying them to the top of the harvester. One more set of guiding wheels were fixed to the conveyer (as shown in Fig. 5) to bring the stem close to the vibratory cutting blade.

Field testing of the modified tractor-drawn front mounted reaper revealed that it required some more modifications to cut and carry the stalks properly. Hence it was decided that modification work should be carried on a small-scale harvester for effective cutting and conveying the sweet sorghum stalk.

B) Modification of self propelled harvesters

Three models of advanced and commercially available self-propelled reapers (harvesters) were modified to harvest sweet sorghum crop. The height of the front frame was increased to 120 cm and an additional chain for conveying the stalks was also arranged (Fig. 6).

Fig. 5. Field testing of the modified harvester.

Fig. 6. Field testing of the modified reaper.

The models which are modified and tested were:

- 6.5 hp petrol engine driven P D KV, Akola model
- 5 hp diesel engine driven Kisankraft reaper
- 5 hp diesel engine driven Greaves reaper

Field tests revealed that these reapers were not suitable to harvest the sweet sorghum crop which grows taller than 2.4 m in height. As the stem girth was also more than the conventional sorghum, it was found hard to cut the stem with the scissor type cutting mechanism.

C) Results from mechanized harvesting experiments

All the three models of harvesters were evaluated in field trials and the physical and experimental observations are given below.

- The success rate of the self propelled harvester in the sweet sorghum crop was only 70%.
- It was found difficult to operate in loamy and sandy soils as the traction power is poor.
- Perfect stem cutting was not achieved in the trials of conventionally sown fields as large number of plants per hill was observed in many places.
- Precision machine control provisions were not available in the three models because of the difficulty in operating in loamy soils.
- Some promising results were achieved with the newly designed self propelled harvester; however, some more modifications are needed to commercialize the same for sweet sorghum harvesting operation.

D) Development of single row self-propelled harvester

As sweet sorghum was taller (around 320-350 cm) than the normal sorghum with higher stem girth (ranging from 16-30 mm), it was found very difficult to use the commercial self-propelled reapers which were available in the market. Apart from the problems of cutting, conveying the stalk to the side was found very difficult because of its size and weight. To solve this problem, a new machine was conceptualized and developed at CRIDA's workshop.

This is mainly powered by 6.5 hp petrol engine which reduced normal vibrations. A 3-tier conveying system with chain mechanism was developed by anchoring the two sides with mild steel mesh panels. A horizontal 3-blade cutting disc was used to cut the stems as the machine moved forward (Fig. 6). The RPM of the blade was adjusted to 850. The conveying speed was adjusted to synchronize with walking speed (3-3.5 km per hour). Initial trials showed promising results and the design is under final refinement before commercializing it. It was also planned to develop a tractor-drawn harvester to make it suitable for 2-3 rows.

4. Improvements in crushers to increase the juice recovery

A) Trials with existing crusher

As one of the main objectives of the project was to increase the juice recovery of the stem, studies were conducted on existing crushers and also on modified crushers which were selected based on the availability of power at the location.Two models of modified crushers were used in the cluster area and the performance was evaluated in comparison to the existing crusher. Three samples weighing 100 kg were fed to the crushers and the weight of the juice recovered was recorded.

The specifications of the tested crushers are:

- Crusher 1: 20 hp 2-roller crusher
- Crusher 2: 10 hp 4-roller crusher
- Crusher 3: 10 hp 3-roller crusher

All the three crushers were installed at the decentralized unit and the performance was evaluated during the season (Table 4).

Table 4. Performance of crushers.

Type of crusher	Juice recovery (%)	
	Conventional sown crop	Mechanized sown crop
10 hp, 4-roller	21.40	23.26
10 hp, 3-roller	28.00	31.40
20 hp, 2-roller (conventional)	26.20	28.40

The 3-roller crusher with 10 hp power gave juice recovery of 31.40% which is 3% more than the conventional crusher of 3-roller with 20 hp power. This can be attributed to the zig-zag arrangement of well designed flutes on the rollers which were very suited to the sweet sorghum fiber configuration by compressing them more. It also helped in reducing energy requirement of the crushers by 30%, when compared to the conventional method. As the existing crusher did not give the expected juice recovery, it was planned to work with the changes in the existing designs and specifications.

Fig. 7. The 3-pass 6-roller crusher and its testing.

B) Development of 3-pass 6-roller crusher for increased juice recovery and energy reduction

A 3-pass 6-roller (Fig. 7) crusher was designed, fabricated and tested for extracting more juice with less energy consumption. This was operated by 10 hp electrical motor. During the crushing, the stems pass through different rollers with differently configured flutes for effective shear and compression. Trials of the crusher were made and the juice recovery was found to be increased by 6% compared to existing crushers.

C) Development of high recovery 3-roller 25 hp crusher

A crusher fabricated according to the specific needs of the sweet sorghum stems was installed at Parbhani (Maharashtra) cluster under the Common Fund for Commodities – Food and Agriculture Organization (CFC-FAO) Project. As a collective effort, the crusher was modified by making crossed flutes on the rollers and it was evaluated for its performance at the cluster in order to use the same at Ibrahimbad cluster in Andhra Pradesh. It was observed that the juice recovery was found to be 45% with a capacity of 1200 kg per hour which was lesser than the designed capacity of 2000 kg per hour. It was also observed that some more modifications in the feed input mechanism may increase the input capacity with the same applied power (Fig. 8).

Fig. 8. The 3-roller 25 hp crusher.

III. Conclusion

Mechanization was partly successful in sweet sorghum crop production and our efforts helped identify the gaps in the presently available technologies. Much more refinement in harvesting machinery is needed to reduce the harvesting cost and drudgery in harvesting operation to make the crop a viable biofuel crop. Further refinement in crushing technology is also needed to reach the targeted recovery of 45% juice to enable a DCU to break even. Future efforts in this direction are underway at CRIDA.

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Chapter VI: Models for sweet sorghum feedstock management for ethanol

Ch Ravinder Reddy, P Parthasarathy Rao, SM Karuppan Chetty, A Ashok Kumar and I Srinivas

I. Introduction

Technological change, competition and globalization are leading to a restructuring of agri-business research and development processes and strategies across the world. Technology transfer is not simply copying technologies passively from others, but an active and creative process of adaptation that recognizes indigenous capabilities. The establishment of small-scale industries in rural areas will help in reducing poverty and unemployment. At the same time, it is an efficient way of preventing migration from the rural areas to urban by creating new employment opportunities in the villages. The majority of rural populations in developing countries and least developed countries are lacking agro based small-scale enterprises that give judicious income to farmers through value addition to their agri-produce. What is needed is a fresh and comprehensive approach, integrating crop production enhancement and value addition of the produce through village-based agro-industries, involving farmers as stakeholders in processing their own produce.

The advantages of small-scale agro-industries are that they: (i) do not require large amount of capital and high technologies; (ii) can create employment facilities with relatively small investment; and (iii) are flexible enough to adjust to changing conditions during periods of economic recession or crises. Therefore, a business model for small-scale farmers that helps them add value to their produce will result in improved livelihoods and help in protecting the environment at the same time.

II. Background and rationale

Food and energy security are critical for the sustenance of modern civilization. Considering the volatility in the availability of fossil fuels, their costs and the associated environmental pollution, there has been renewed interest in biofuels globally. Biofuel crops, particularly sweet sorghum, offer dryland farmers an opportunity to increase their income while at the same time protecting the environment without sacrificing food and fodder security. Sweet sorghum is a C4 plant with high photosynthetic efficiency. It produces high biomass (up to 40-50 t ha^{-1}) in a short time (four months) under rainfed conditions. It is a SMART crop that produces food, feed and fuel at one go (grain for food, sweet juice for ethanol after fermentation and bagasse for animal feed/compost).

ICRISAT is working on sweet sorghum improvement and has incubated the sweet sorghum ethanol production technology with Rusni Distilleries through its Agri-Business Incubator. The sweet sorghum ethanol distillery established by Rusni Distilleries Pvt. Limited took advantage of this value chain model. The chain of project activities involved in producing sweet sorghum-based bioethanol encompasses capacity building of stakeholders in sweet sorghum crop production, stalks harvesting, and transportation; forward linkages with private sector (distillery) for crushing and processing of the juice for ethanol production and decentralized stalks crushing and syrup making at village and supplying syrup to various end-users. A consortium of partners including ICRISAT, National Agricultural Research Services (NARS), private sector, NGOs, farmers associations actively contributed in developing this value chain.

An assured supply of raw materials is critical for the success of any industry. Sweet sorghum being a season-bound crop, its stalks are available for crushing only for a limited period (3-4 months) during different seasons of the year. To ensure a viable ethanol industry, assured and continuous supply of raw material is essential for at least 8-9 months of the year. Therefore, to extend the period of raw material availability, ICRISAT is working on both centralized (farmers supplying stalks directly to distilleries) and decentralized (farmers supplying stalks to the village level crushing units) models for the benefit of farmers and industry. A combination of the two models, centralized and decentralized, helps in supply chain management.

III. Value chain models

1. Centralized model

While centralized distilleries crush the stalks in bulk quantities and produce ethanol, the decentralized units crush the stalks at the village level and convert the sweet juice into syrup. The centralized model requires high volumes of stalk and the costs of transportation therefore are high (Fig. 1).

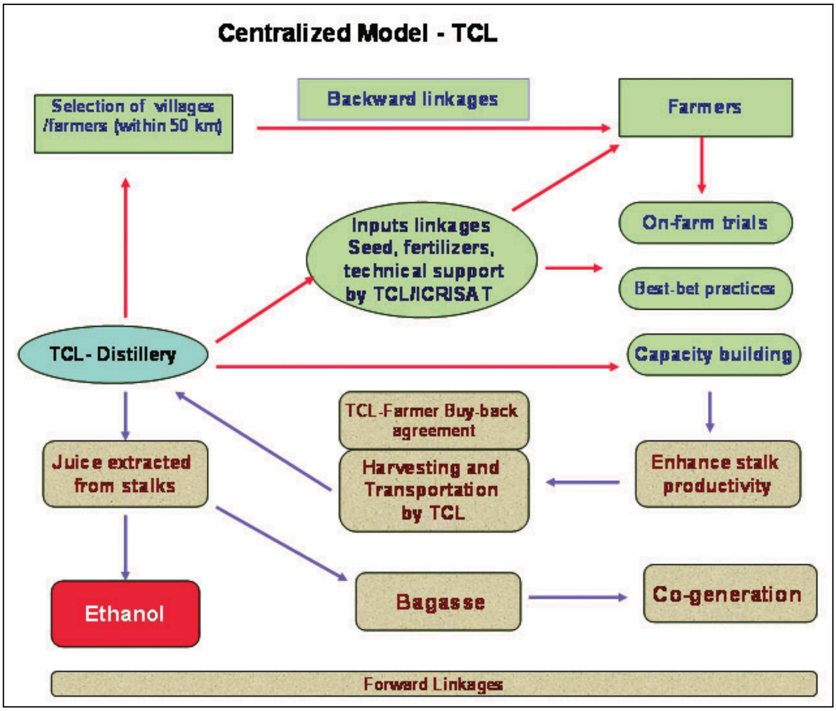

Fig. 1. Centralized model: linking farmers to distillery.

A) Rationale

In the centralized model, a typical 40 kilolitres per day (KLPD) ethanol distillery requires feedstock from 8000 ha of crop area per year spread over two seasons – 3500 ha in the rainy season (rainfed) and 4500 ha in the postrainy season (irrigated). As farmers supply stalks directly to the distillery, it requires mobilization of farmers in villages within 50 km radius of a distillery so that the time for and cost of transportation of stalks is kept at minimum.

However, the centralized model has some limitations:

- Farmers located more than 50 km from the distillery will be burdened by high transportation costs owing to the bulk of stalks.
- Delay in crushing stalks beyond 24 hours of harvest causes a 6% reduction in juice yield.
- Delay in transportation of stalks to distilleries by 24 hr after harvest leads to reduction in stalk weight up to 20%, depending on climatic conditions causing a financial loss to the grower.

- Finding 4500 ha with irrigation facilities within the stipulated radius during the postrainy season is a daunting task in SAT areas. Organizing such a large number of farmers to undertake sweet sorghum cultivation is also difficult.
- Growing other crops like soybean, maize, rice and wheat may be more economical than sweet sorghum under irrigated conditions.

The decentralized model overcomes some of these difficulties.

B) Institutional arrangement for linking farmers to biofuel industry

Under the centralized model, a cluster of villages within a radius of 50 km from the distillery are targeted to grow the crop and transport sweet sorghum stalks to the distillery within 24 hours of harvesting to prevent losses in juice recovery and quality. Typically, agro-processors have to run the processing unit to full capacity, otherwise it will not be economical for them. The processing unit needs continuous supply of quality raw material round the year. Companies cannot produce required amount of raw material by themselves, as land is a constraint for them. Companies are therefore entering into contractual agreements with the small farmers to overcome the land constraint. Contract farming has been adopted as form of commercial agricultural production since many years and both the companies and farmers benefit from it.

Production activities must be seen as part of the whole supply chain to ensure sustainable income growth of farmers. “Linking farmers to markets” will develop long-term business relationships among farmers and different stakeholders as it includes backward and forward linkages for sustainable livelihoods through value addition and harnessing Public-Private-People Partnerships (PPPP). This type of linkage model is beneficial for all stakeholders who are involved in it either directly or indirectly. Stalks buyers (distillery) provide all inputs (seeds, fertilizers, pesticides and weedicide) on credit basis as well as technical guidance to farmers to enhance productivity, during harvesting and in supplying stalks to the distillery. The ICRISAT–Rusni partnership provides improved crop production technology and technical backstopping to the partners and farmers on various activities in ethanol value chain. The model developed was used for scheduling of feedstock growing and supply to the industry during different crop seasons (based on multilocation on-farm evaluation for identifying suitable sweet sorghum cultivars and agronomic manipulation to increase the harvest window). The farmers were linked with distillery through a signed buy-back agreement for smooth supply of inputs to farmers and stalks to distillery. Inputs are supplied to farmers on credit basis and cost of inputs were recovered from the cost of stalks supplied to distillery.

Farmers' associations were formed and strengthened to develop negotiation skills so that they can have edge over buyers in dealing with contract agreement. Mutual trust is key factor for successful business relations among the parties involved in linkages and linkage activities have to concentrate on developing trust. The private sector needs to play a key role in fostering linkages with the farming community, but the government can improve efficiency of linkages by providing required infrastructural facilities and policy framework.

C) Issues in the centralized model

- Fixing stalk procuring price by the distillery
- Timely harvesting and transportation of stalks to distillery
- Quality of stalk based on sugar content (Brix %)
- Staggered planting for continuous stalks supply
- Availability of cultivars of varying maturity period (early-< 90 days; medium-90 to 120 days; late > 120 days) for widening harvesting window
- Availability of cultivars for postrainy season cultivation
- Stability of fermentable sugars in juice and syrup

2. Decentralized Crushing Unit Model

A) Rationale

The purpose of setting up decentralized crushing units (DCU) at the village level is to crush sweet sorghum stalks, extract and boil the juice to produce syrup. It aids the supply chain management particularly by reducing the volume of feedstock that would otherwise have to be supplied to centralized crushing units and increasing the period of feedstock (supply of syrup) availability to industry to make sweet sorghum ethanol a commercial reality. The by-product, bagasse (crushed stalk) is left in the village to be used as animal feed or as organic matter to enrich the soil. This paves the way for a more efficient whole-plant utilization of sweet sorghum. Also the DCU serves as a model for farmer-centric, farmer-driven rural industry for improving the livelihoods of small-scale sorghum farmers (Fig. 2).

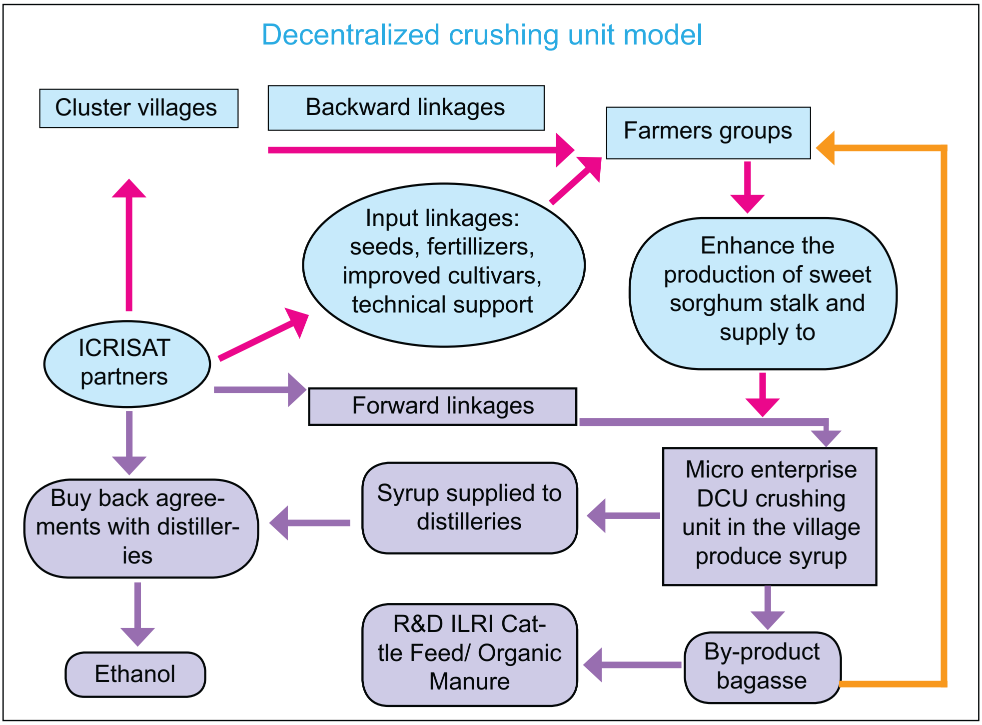

Fig. 2. Decentralized model: Linking farmers to DCU.

B) Farmer linkages

Under the decentralized model, villages located at more than 50 km distance from the distilleries (TCL-Nanded) will be served by decentralized crushing units (DCU) managed by farmers group/micro-entrepreneurs for extracting the juice and syrup production from sweet sorghum stalks in the village itself.

The model strengthens the farmers through capacity building and linking farmers to input supply agencies including credit/financial institutions and output markets. Initially the project supplies all inputs to participating farmers at the right time and facilitates the signing of a stalks buy-back agreement with pre-agreed stalk procurement price and recovery of all input cost from the farmers after crop harvest and supply of stalks to the DCU. The model also envisaged to link the DCU with the distillery with buy-back agreement for supply of syrup on a pre-agreed price

C) Issues with DCUs

- High initial investment for the establishment of DCU.
- Assurance by distillery only for small quantities of syrup procurement from DCU.
- Criteria for price fixation for syrup for industry and payment schedule.
- Basis for payment to farmers (stalk weight, syrup (Brix %) or any other).
- Procedure for giving back bagasse to farmers or use of bagasse by the DCU.

D) Establishment of DCUs

i) Selection of villages and site for DCU

An exhaustive survey needs to be conducted to select appropriate villages for establishing DCUs for syrup production. In the ICRISAT-NAIP (National Agricultural Innovation Project) initiative on ‘Sweet Sorghum Ethanol Value Chain Development’ the villages were selected on the basis of (i) their accessibility; (ii) natural resources (soil, water, topography, etc); (iii) social harmony; (iv) dryland cropping systems; (v) sources of irrigation; (vi) farmers’ response to the idea and their willingness to participate in the project activities; and (vii) the feasibility of growing sweet sorghum and finding a suitable site for setting up a DCU. Scientists from ICRISAT and a non-governmental organization (NGO) teamed up to select the villages and to identify an appropriate site for establishing the DCU. After the reconnaissance survey in different areas of Medak district in Andhra Pradesh, India, tentative clusters of villages (Ibrahimbad, Erragunta Thada, Seethaya Thanda, Durgaya Thanda, Umla Thanda, Sikindalpur Thanda and Laxman Singh Thanda under Narsapur Mandal) were identified. In-depth discussions were held with the village administration, ie, the village sarpanch, secretary, village leaders and lead farmers in the cluster villages to obtain basic information on cropped area, crops grown, irrigated area, types of soil, yields of different crops, markets, political affiliations and the possibility of securing panchayat land (community land) to set up the DCU.

After analyzing the merits and demerits of the different clusters, it was found that the Ibrahimbad cluster in Medak district was suitable for large-scale sweet sorghum cultivation and for establishing the pilot DCU. Subsequently, seven villages were identified (Table 1) in this cluster within a 5-7 km radius from Ibrahimbad, the nucleus village.

Table 1. Total number of villages and households in Ibrahimbad cluster.

S.No	Village name	Number of households
1	Ibrahimbad	192
2	Errakuntla Thanda	67
3	Seethya Thanda	21
4	Durgaiah Thanda	20
5	Umla Thanda	19
6	Sikindlapur Thanda	123
7	Laxman Thanda	54
	Total	514

As there was no panchayat land available in the village, a couple of farmers offered their land on lease for establishing a DCU. Of three sites inspected, an easily accessible tract of land with a power line, water facility and a blacktopped approach road was chosen. The owner of the site agreed to lease 0.4 ha of land for a five-year period @ Rs 10,000 (USD 200) per annum. It was proposed at the meeting that the lease amount would be paid by the group of sweet sorghum farmers and this was agreed upon unanimously by the farmers. The land owner agreed to abide by the village farmers' decision on the annual land rent and the concurrence of the gram sabha (village meeting) was taken to this effect. A lease agreement was signed between the land owner and the farmer group in the presence of the village administration to facilitate the establishment of the DCU.

ii) Design and layout of the site

ICRISAT and partners jointly designed the DCU layout plan to position plant and machinery for easy and convenient operations of weighing, crushing and chaff cutting (the bagasse). The site is close to the Ibrahimbad village and located alongside a main road that connects the cluster village to the Narsapur Mandal headquarters in Medak district, Andhra Pradesh. It has water facility and a power connection. Based on the dimensions of the site, the layout of roads, location of the crusher and other machinery was planned (Fig. 3).

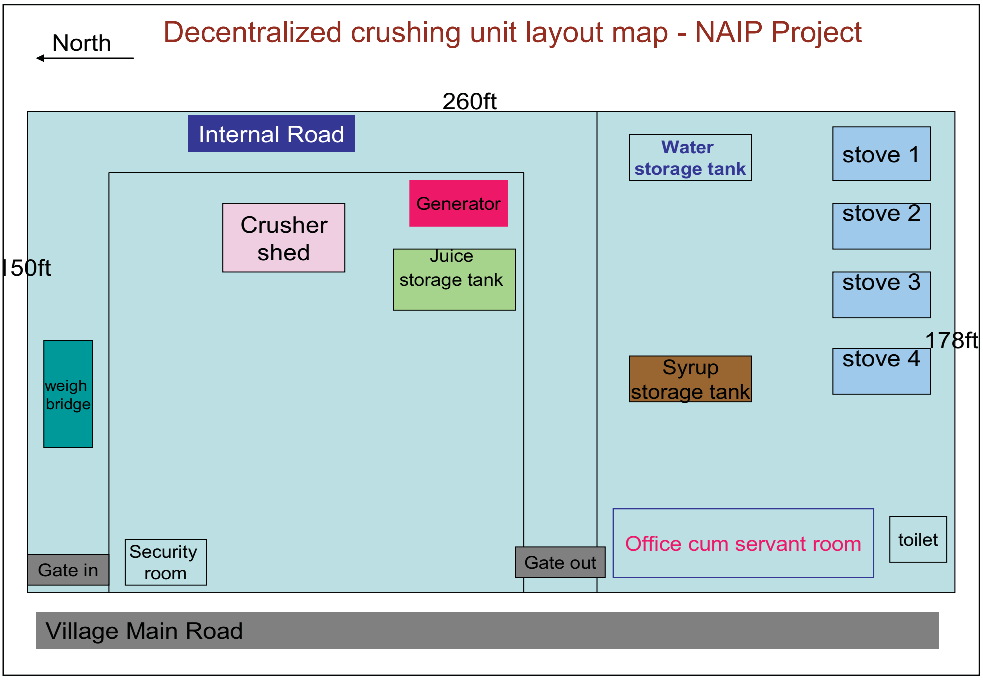

Fig. 3. Layout of the decentralized crushing unit at Ibrahimbad village, Medak.

iii) Plant and machinery

In order to procure reliable and efficient machinery for the DCU, enquiries were made with local jaggery making farmers and industry personnel. The following pieces of equipment and machinery were procured for the DCU.

- Crusher
- Weigh bridge
- Generator
- Chulhas (stoves)
- Juice boiling pans
- Juice boiling accessories (stirrer, dragger, sieves and scum storing drum)
- Electric motors and pumps
- Supply pipelines
- Juice storage tank
- Steel baskets
- Motors

a) Crusher: The crusher is an important component of the DCU. It is required to crush the sweet sorghum stalks to extract the juice. In this project, a popular sugarcane crusher model with three rollers, 2 t hr^{-1} crushing capacity was chosen after consultations with local dealers, jaggery making farmers and a couple of crusher manufacturers. To improve the crushing efficiency, the rollers of the crusher were modified to suit sweet sorghum stalks to increase juice extraction. The crushing efficiency is calculated by the quantum of juice extracted from a ton of stalks, which varies with the genotype, season of crushing and time laps between harvesting and crushing. The modified crusher efficiency was 300 liters t^{-1} of stalk compared to sugarcane crusher which was around 260 l t^{-1}. The crusher being critical in DCU should have minimal maintenance costs and relatively fewer mechanical problems. Its spare parts and repairing facilities are easily available. The specifications of the crusher are presented in Fig. 4.

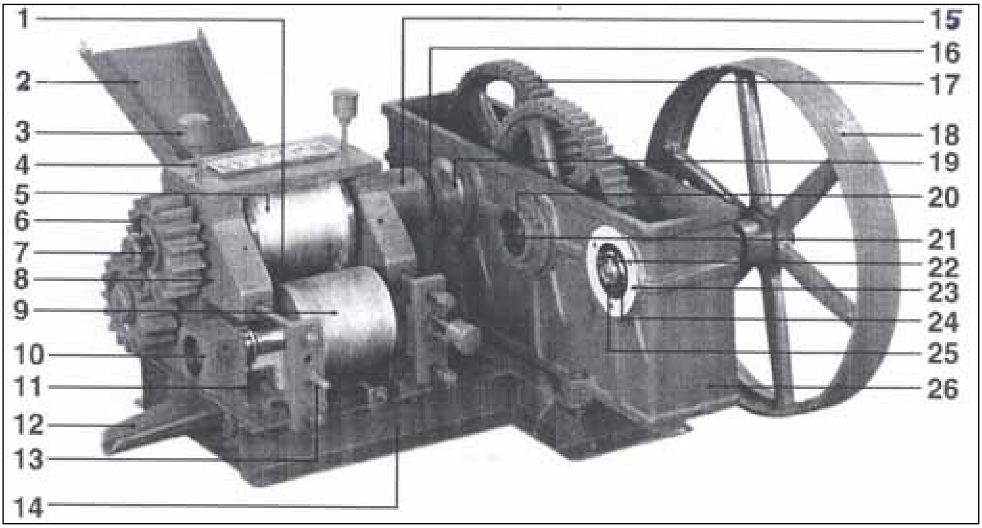

Fig. 4. Crusher parts.

1. A rail scraper
2. Feeder
3. Grease cup
4. Grease pipe
5. Railer
6. Key for upper gear
7. Steel gear (16 teeth)
8. Side plate
9. BC railer
10 Bearing holder
11. Railer bush GM
12. Juice outflow channel
13. Head screw 14. Base frame plate
15. Joint coupling
16. Axial
17. Steel gear 62 teeth
18. Pulley
19. Hosing
20. Center bolt
21. Counter axel
22. Bearing seal
23. Hosing packing
24. Bearing 32211
25. Main drive
26. Gear box

The crusher at DCU-Ibrahimbad, Medak Dist. has a capacity of 2 t hr^{-1}. It can be operated with a 20 hp electrical motor connected with a pulley and V-belts. During crushing, the juice flows through a preliminary juice collection and filtration pit beside the juice outlet channel. From this outlet, the filtered juice flows into a juice collecting drum (900 l capacity) placed beneath the soil surface for convenience. The juice collected in the drum is pumped by a motor into boiling pans through an industrial hosepipe.

b) Weigh bridge: Farmers bring their stalks in tractors, bullock carts and sometimes on trucks. It is important to weigh the stalks coming to DCU for crushing as payments to farmers will be made based on the quantity of fresh stalks they supply to DCU. In this project, we installed a surface mounted weigh bridge with a capacity to weigh up to 50 tons stalk load. If a weigh bridge facility is available within the village limits or nearby DCU, such an investment can be avoided. The weight of the stalks are recorded in a computer attached to the weigh bridge which issues stalk weight slips with the farmer's name and other details.

c) Generator: Three-phase (industrial) power supply is required to run the crusher. That makes it convenient and cheaper. There was no industrial power line close to the village, and there is frequent power shutdown in rural areas. Hence, power supply to the DCU was arranged by installing a captive 40 KVA generator. DCU operations were seasonal and operated 30-40 days a year in the rainy season.

d) Chullas: These are earthen stoves for boiling the juice. They are made of bricks and cemented with pressed mud. Each chulla measures 2 m in diameter, and is embedded at 1 m. depth beneath the soil surface. An exhaust outlet 3 m high was erected 2 m from the chullas, also made of bricks and pressed mud. Each chulla has a 3 m long air passage channel below the soil surface connecting the stove and exhaust tower. The bagasse feeding opening is of 0.4 m length, located on the rim of the chulla.

e) Boiling pans: The standard sugarcane juice boiling pans were adopted. They are made of 18 gauge thick galvanized mild steel sheets, with a diameter of 2 m and a depth/height of 0.5 m . Each pan can hold 700-750 liters of juice per cycle. The boiling pan has to be put aside for cooling of syrup before filling syrup into plastic cans for storage. One additional set of boiling pans are necessary for the convenience of continuous operations.

f) Juice boiling accessories: Several small tools are needed for syrup production. Metallic sieves are required to remove unwanted contaminants floating on the surface of the boiling juice and to remove the froth or scum which rises to the surface during boiling. Wooden draggers are needed to scrape the bottom of the pan and to stir the juice frequently. A scum storing drum is used to collect the scum removed during boiling. All these accessories are custom made locally.

g) Motors, juice collection tank, steel baskets and pipeline: Motors are required to lift and pump juice from the juice collection tank to the boiling pan with a connecting hose pipe. The juice collection tank is placed near the crusher (in a pit) connected with an outlet pipeline from the crusher delivery channel. Steel baskets (1 m length and 1 m width) are used to shift the bagasse from the crushing site to the drying yard.

iv) Other facilities

a) Water: Fresh water is required for cleaning the crusher, boiling pans and other tools every day. A reliable water facility and a motor to pump this water is a prime requirement. For this project, we used the water from the lease farmer's bore well.

b) Technician: Trained local technicians must be engaged for maintenance of the plant and machinery and trouble shooting. We made arrangements with local technicians to render their services as and when required.

c) Sheds: It is important to protect the chullas and crusher from the rain and sun. Also, erecting a shed with tin or asbestos sheet roofing will enhance labor efficiency.

IV. Command area development

The sweet sorghum command area needs to be developed to meet the raw material requirement of the DCU. In the present project, as there was a limited area available under irrigation, major emphasis was placed on sweet sorghum cultivation in the rainy season. Inputs like seed, fertilizer and herbicide were supplied on credit to enable local farmers cultivate sweet sorghum. The costs of the inputs were recovered while making payments for the stalks supplied by farmers to the DCU for crushing. Appropriate capacity building activities like awareness camps, exposure visits, on-farm and on-station training programs on crop production, integrated pest, disease and nutrient management practices, farmers' participatory field trials and demonstrations in the cluster villages were undertaken to enhance productivity.

Under the present project, the services of an NGO, and farmers' association were utilized to complement the project team particularly on identification of participating farmers, supply of seeds and other inputs, in staggering the planting and ensuring that the farmers adhered to the recommended package of practices (thinning, weeding, topdressing, etc) for production enhancement and developing harvesting schedules for the supply of sweet sorghum stalks to the DCU. The objective of including the NGO and farmers' association in project activities from the beginning of the project and in all activities is to strengthen these community based organizations (CBOs) in operation and management of the DCU, so that these stakeholders will continue the project activities even after completion of the project period to sustain project interventions.

V. Crushing and syrup production

1) Procurement of raw materials

Procurement of raw materials is critical to the success of the model as it involves winning the confidence of farmers through timely harvest (Box 1), stalk procurement and prompt payment. Under the ICRISAT–National Agricultural Innovation Project under the aegis of the Indian Council for Agricultural Research (ICRISAT-NAIP-ICAR), the services of Farmers' Association were used to link the farmers to the DCU. This involved community mobilization for various activities of the project including scheduling the harvesting process to facilitate a steady supply of stalks for crushing at the DCU (Box 1) and payments for stalks were made on pre-agreed price (buy-back agreement) per ton of stalk.

Box 1

Stalk supply work contract model

Issues: During 2008 (the first year of project implementation) some difficulties were observed in harvesting of stalks, loading, transporting, unloading and crushing of stalks leading to delayed crop harvesting, delayed transport, delayed crushing and finally low juice recovery due to desiccation of stalk. The labor problem was rampant in all the project villages and it also coincided with harvesting of paddy crop in the villages.

Educating farmers: The crushing capacity at DCU was increased by 50% by adding additional crusher for 2009 season. All the farmers were educated from day one during the 2009 season that the sweet stalks should be harvested at right time (physiological maturity) and the stalks should be transported to DCU on the same day on a cart by cart basis soon after harvesting. They were also told that attending to harvesting on time and transporting cart by cart to the DCU would help to retain the original weight of the crop.

Innovation: Looking into the economics of syrup production, timely harvesting, stalk supply, crushing and converting into syrup on the same day is beneficial for both to the farmers and syrup making unit. Keeping in view the requirements of the DCU and prevailing labor problems, the project and sweet sorghum farmers in the village evolved a work contract model through negotiations with the bullock cart owners that involves harvesting, loading of stalks in farmers filed, transportation and unloading of stalks at DCU at one go by the cart owners/ their appointees. ICRISAT scientists and AAI facilitated the dialogue between bullock cart owners and farmers to arrive at common price for the entire task. As per this understanding, the farmers have to pay the contractor Rs 220 per ton of stalk for the entire task. It is being run smoothly.

Benefits:

- The sweet sorghum crop was harvested in a timely manner.
- There was no time lag between harvesting of stalks and their transportation to DCU.
- Timely crushing of stalks at DCU lead to increased juice recovery.
- This enabled farmers to attend to other work (most farmers are working at DCU during this period)
- This served to give gainful employment to a group of laborers through sweet sorghum harvesting and transportation.
- There was increased efficiency of the DCU in terms of timeliness of operations like crushing stalks and producing syrup.

2) Crushing

Sweet sorghum stalks should be crushed on the same day of harvesting. Any delay in crushing results in low juice recovery and eventually low syrup yield. The DCU established at Ibrahimbad village, Narsapur Mandal, Medak district, Andhra Pradesh, has the capacity to crush 2 t hr^{-1} and can crush stalk from a 25 -30 ha area during the rainy season (kharif) in 30 days of operation working one shift of 8 hours per day. Usually the start of crushing operations depends upon the sowing date and generally crop is harvested at physiological maturity (110 days after sowing). The juice yield depends on cultivar, time of harvest (age of crop), duration between harvest time and crushing, and temperature. Generally sugarcane crushers are used for crushing sweet sorghum; here, however we have modified the crusher rollers to improve crushing efficiency (Box 2).

BOX 2

Improved efficiency of the crusher

The development of a high juice recovery 3-roller crusher with 25 hp motor was developed with the help of private sector company Adarsh Engineering Company, Nagpur, Maharashtra. The rollers of the crusher were designed specifically for sweet sorghum so as to crush the stems completely, as sweet sorghum stems are softer than those of sugar cane. The grooves on the rollers are flat with a channel on either side to drain out the juice conveniently. As a collective effort (public-private-partnership), the crusher was evaluated for its performance using different cultivars, which were crushed after 24-hr to 36-hr after harvest. It was observed that the average juice recovery from the sweet sorghum cultivars (RSSV 9, CSH 22SS and ICSV 93046) ranged from 350 to 425 l t^{-1} of stalk. The percentage increase in juice recovery when compared to the sugar cane crusher (260 l t^{-1}) was found to increase by 34 %. With this increased efficiency, the average productivity of syrup has increased by 25% and overall syrup production cost decreased by 22%. This innovation will have positive effect on viability of DCU operations and economics.

3) Bagasse

The solid bagasse which remains after crushing sweet sorghum stalks is a by-product of the DCU which has several potential uses. Bagasse is used as fuel in chullas at DCU for boiling juice in syrup making. Other potential use is as source of animal feed, directly after chopping or after ensiling. It has also been used as a source of pulp for the paper industry. At DCU, 50% of bagasse is consumed as fuel for making syrup and the rest as fodder for livestock supplied to farmers and fodder agents (Box 3).

BOX 3

Bagasse as fodder

Issues: During 2008 (the first year of project implementation)some difficulties were observed in sweet sorghum bagasse utilization. A large amount of bagasse piled up while crushing the sweet sorghum stalks for juice extraction. Though we encouraged the farmers to take the bagasse for use as animal feed, they did not come forward with the apprehension that animals don't like the bagasse. We have since conducted on-farm experiments with farmers' participation where the bagasse was fed to their milch cattle that demonstrated higher intake by the animals that resulted in increased body weight, milk output and marginal increase in fat content of the milk.

Educating farmers and fodder agents: Keeping in view our experiences during the 2008 rainy season, we started sensitizing farmers about the advantages of using sweet sorghum bagasse as animal feed from the beginning of the 2009 rainy season. Simultaneously, we also sensitized the fodder agents who supply the sorghum stover to the dairy industry in Hyderabad on the utility and markets opportunities of sweet sorghum bagasse as animal feed.

Innovation: Our partners SVVU and ILRI took a lead role in facilitating fodder value chain development. ILRI installed a chopper at the DCU to chop the fresh and dried bagasse. The fodder agents were roped in from the beginning of the crushing season and supplied with the samples of fresh and chopped bagasse. The fodder agents arranged to lift the fresh baggasse immediately after crushing from DCU and supply to private dairy farms on the same day. The agents initially offered Rs 0.5 kg^{-1} for the bagasse citing that it may not be favored in the fodder market. But on the contrary, by the end of the crushing season the consumers demand for sweet sorghum baggasse went up and agents offered Rs 1.2 kg^{-1}. The demand for bagasse has given a clear indication that private dairy farms are preferring sweet sorghum bagasse in place of other feeds. Therefore, there is a great scope for promoting sweet sorghum bagasse as animal feed through innovative linkages and value chain development.

Benefits:

- The sweet sorghum bagasse augments the fodder requirements of the farmers.
- It makes available a new fodder variant in the market.
- It creates an opportunity for additional incomes to farmers.
- Increased availability of fodder in the fodder market.
- Safe disposal of sweet sorghum bagasse at the DCU.

4) Syrup making

A) Syrup making process

The syrup making process involves collection of juice from the crushing point and boiling it to evaporate the water and concentrate the sugars in the juice. The juice from the crushing point is pumped to the boiling pans for making syrup with constant boiling and stirring. Chemicals like calcium (garika soda), castor oil, limestone, super phosphate and okra (lady's finger) fruit powder are added to the boiling juice in different concentrations to avoid froth formation and for coagulation of unwanted materials that float on the surface of the boiling juice (Box 4).

BOX 4

Producing syrup from sweet sorghum juice

1. Extraction of juice

The ear heads are harvested at physiological maturity, followed by stalks which are transported to DCU for crushing and extraction of juice. The percentage of juice extracted depends on the time lag between harvesting and crushing. A 24-hr to 48-hr delay in crushing will result in reduction of juice output by 20-30% depending on relative humidity and temperature as well as the crusher type. Generally sugar cane crushers yield 260 l t^{-1} of stalk. A modified crusher developed for crushing sweet sorghum stalk yields 350-425 l t^{-1} stalk. In large scale crushing the average juice production was 300 l t^{-1} stalk.

2. Filtration of juice

- The juice extracted from the crusher is strained through a wire screen to remove big particles of crushed material
- The juice is again filtered using fine wire mesh before allowing it into juice collection tank to remove all the solid particles present in the juice.
- After crushing the juice has to be boiled immediately to stop the fermentation process to restore the conversion of fermentable sugars.
- The juice extraction and pumping juice into pans is a simultaneous process to stop fermentation.

3. Boiling of juice

The extracted juice is transferred to boiling pans that have the capacity to hold 700 l. The following precautions are taken at this stage.

Box 4 Continued

- Steady evaporation is the most important process of making syrup.
- Evaporation should be done with uniform heating for obtaining good quality syrup.
- Slow heating is required to prevent syrup from burning.
- Initially coagulation starts when juice temperature increases.
- As the temperature increases during boiling the juice scum is formed on the surface of the juice which is removed.
- Syrup quality improves with continuous removal of coagulated materials from the surface of the boiling liquid in the pan.

4. Clarificants (chemicals) for removal of impurities and as preservatives

Quantities of chemicals used for boiling one pan of juice (700 l):

- Super phosphate (single) 2 kg.
- Lime (sodium carbonate) 1 kg.
- The chemicals, which remove dirt from the juice, are mixed with the liquid before boiling.
- Hibiscus (ladies finger powder)- 10 g added after filling the juice in the pan
- Caustic Soda (Sodium hydroxide) - 50 g to be added during boiling.
- Castor oil – 100 g (causes froth on the boiling juice, which collects all the dirt, which is later decanted)
- Sodium hydrosulphite – 50 g (added last at 70% Brix. Chemical is added to the syrup just before removing the syrup from the pan, and stirred well. This also restores the color of the syrup.

5. Evaporation process

- The density of juice increases (Brix%) as the boiling temperature rises.
- When the temperature of the juice reaches 105 °C to 107°C, the Brix of the
- syrup should be 65-70 %.
- The Brix and temperature of the boiling juice must be monitored at regular intervals.

6. Cooling of syrup

- Syrup should be cooled immediately to avoid burning.
- Syrup should be brought down to 85°C to 80° C within 10-15 mins to avoid

7. Syrup yield

- Syrup yield: 50-55 kg t^{-1} (15-18% of juice v/w) at 70-80% Brix.
- Syrup yield depends on initial Brix% of juice and final Brix% of syrup.
- The color of the syrup varies with the genotype and season of growth.

Box 4 Continued

8. Syrup storage

- The syrup can be stored up to two years without any deterioration of sugars at room temperature (Annex. 1 and 2)
- Syrup should be stored in air tight containers, leaving some gap on top of the container.
- The syrup can be stored in plastic cans or in polythene coated bags at room temperature.

9. Points to remember

- Delay in harvesting of stalks, after more than 130 days will reduce the juice content in the stalks.
- Brix of the stalks should be more than 15% for producing good quality syrup.
- Filtration of juice must be done to remove stalk particles before boiling.
- Effective removal of coagulated material and scum during juice boiling is very important for good quality syrup.
- The syrup should not be heated above 105°C to 107°C.
- The syrup should be rapidly cooled within 10-15 mins.

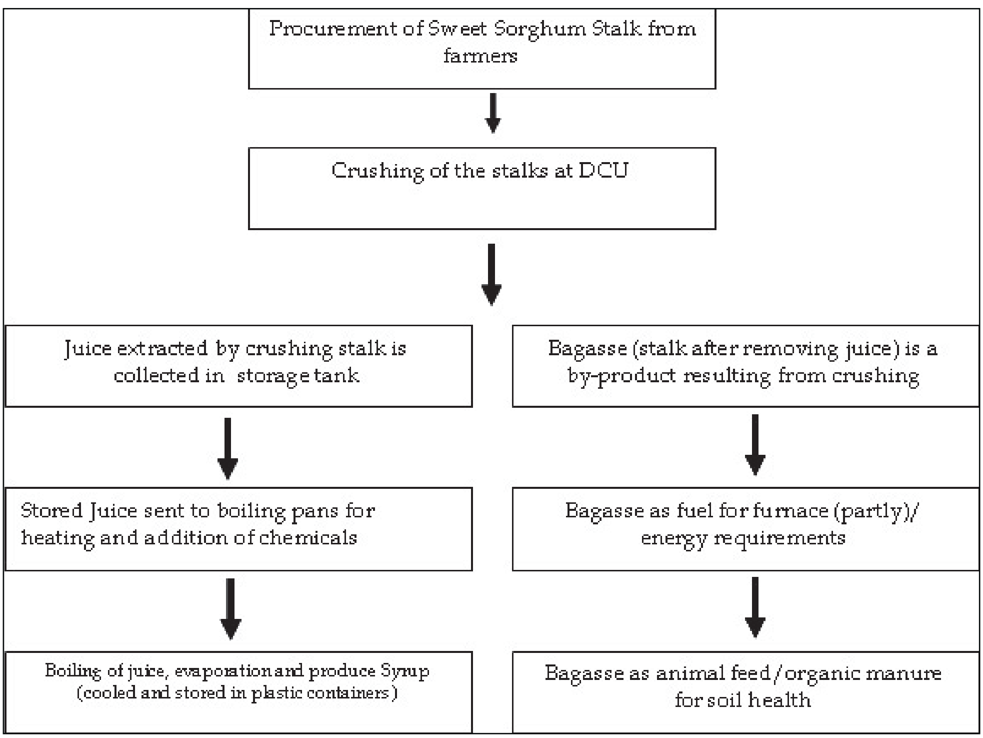

Fig. 5. Operations of the decentralized crushing unit.

The juice in the pan is constantly stirred. During the boiling, some undesirable contents coagulate. These materials (skimmings) are removed frequently. The skimmings are generally rich in protein and starch as well as some sugar and can be used in preparing animal feed. As the syrup density increases, the boiling temperature is increased gradually. The boiling pans are removed from the burners (chullas) when the temperature reaches 226-230°F (108°C to 110°C) or when the syrup attains a density of 70% Brix tested with a syrup hydrometer or sugar refractometer. The final syrup is allowed to cool to 140-160°F and stored in air-tight plastic containers.

B) Syrup Storing

The finished syrup is strained with a mesh to remove any crushed plant materials or other inert foreign materials. The syrup is stored in clean, air-tight plastic containers with wide-mouth at room temperature. The shelf life of the syrup at 70% Brix stored at room temperature is around 24 months.

VI. Training stakeholders in DCU operations

Under the ICRISAT-CFC project, the DCU was established to crush stalk for rainy seasons for a period of 30-40 days in a year. Initially the crushing unit and its operations (Fig. 5.) were carried out by the farmers' group under the direct supervision and management of project scientists. All operators, daily-wage laborers and project staff were trained in handling the operations of the DCU before starting crushing. Since utmost care needs to be taken while the DCU is in operation, particularly handling the crushers and chullas, training programs were conducted to enhance capacities of farmers' groups like farmers' associations, local CBOs, partner institutions, staff and NGOs, to operate and manage the DCU. The training programs included hands-on-training in overall maintenance and repairs, trouble shooting, stalk supply chain management and assessing quality parameters like juice and bagasse output, accounts and book keeping in effective management of the DCU operations. The farmers' group will be linked to the ethanol or other related industries with formal buy-back agreements for purchase of the syrup produced by the DCU.

VII. Conclusion

The decentralized crushing system was established to overcome some of the shortfalls of the centralized system where the stalks have to be crushed for ethanol immediately after harvest within a short span of time to avoid drying-up of stalks and consequent loss of juice. The delay in transportation of stalks to the centralized distillery was a major obstacle in processing and higher recovery of ethanol. The establishment of decentralized crushing units on pilot basis close to the vicinity of cultivation of sweet sorghum helped in processing sweet sorghum juice to syrup, which can be stored upto a year (if required) before processing to ethanol. Economic assessment of crushing sweet sorghum and value addition under a decentralized unit as showed that production of syrup can be made viable by improving yield of sweet sorghum stalks, system efficiencies like crushing and labor use and mechanization of whole process. The decentralized system was managed by the growers of sweet sorghum (farmers' associations) who crushed it to produce syrup. This was a new area for them. Given this, the management of a crushing unit at farm level would vary significantly and hence the high processing cost.

The initial technology used for crushing sweet sorghum for producing syrup was not tailor-made for a crop like sweet sorghum. The value realized by supplying syrup to the distillery was also low because of further processing costs incurred by the processor to convert it to bioethanol. Consequently, the decentralized unit was incurring losses. A major challenge, therefore, is to bring down the cost of processing syrup in the decentralized unit. As indicated in the paper, this can be achieved only through a combination of several factors. For example, a modest decline in labor cost of processing by 40%, increase in syrup yield vis-a vis increasing efficiency in recovery of juice and syrup per ton of stalk through crushing and fermentation efficiency, increase in value addition by better utilization of bagasse can make sweet sorghum a remunerative feedstock for processing to bioethanol and has great potential for future bioethanol production in developing countries like India.

In view of the above mentioned benefits of sweet sorghum, efforts should be made in the direction of improving technology in processing of sweet sorghum syrup to reduce cost in bioethanol production, value addition in bagasse utilization and capital assistance for small scale entrepreneurs. In the long run this will be a boon for both smallholder farmers of rain-fed regions and industry in production of bioethanol.

VIII. Summary

To summarize, availability of feedstock for longer periods in a year (more than 6 months) is a critical factor limiting the expansion and suitability of the sweet sorghum ethanol industry. The decentralized model enables supply of feedstock to the distillery over a longer period of time in a year through syrup route. The DCU in general will serve as an extended arm of the distillery and operate as a stand-alone self-sustaining unit. At present, all the syrup produced (5 t) at DCU, was supplied to Rusni Distilleries, Sangareddy for ethanol production.

Each decentralized unit provides employment to 20-30 people during the crushing season. The major beneficiaries of the DCU are likely to be small and marginal farmers who form the core of the target group as they get ready inputs, guidance and an assured market for their produce. Women's participation is high in all DCU operations, thereby aiding women's empowerment. The success and overall economical viability of DCU depends on its operational efficiency and market linkages with distilleries and other industries to obtain a better price per unit of syrup. Once the model is found to be viable and sustainable, efforts will have to be made to up- and out scale the model. This paves the way for micro entrepreneurship development in villages that increases the income and employments options and reduces migration to cities. With the establishment of DCU with essential plant and machinery, the costs minimized if a farmer establishes it with his own investment on his own land and involving his own family labor as given in Table 2.

Table 2. Cost of essential equipment, plant and machinery required for establishment of DCU at the village level.**

	Particulars	Cost (Rs ’00000)*
a)	Sweet sorghum crusher (2 t/hr): Motor for crusher 20HP, V Belts, gear oil	4.5
b)	Syrup boiling pans – 2 m dia. and accessories (such as stirrers, dragger, sieve, scum storage drum etc)	0.36
c)	Generator: 40 KVA capacity with Ashok Leyland engine coupled with alternator mounted on a common base frame with control panel fuel tank, battery and leads and accessories	4.62
d)	Pumps and motors 1 hp for pumping water process like cleaning the tanks, crushers and pans: 1 no.	0.04
e)	Rubber/PVC hose pipe 1” dia, 200 m length	0.16
f)	Syrup storage plastic drums industrial use (50 kg capacity)	0.30
g)	Crusher shed with local available materials (palm tree leaves/bamboo thatched sheets/paddy straw covering)	0.2
h)	Chulla shed with local materials (palm tree leaves/ bamboo thatched sheets/paddy straw covering)	0.2
i)	Foundation for generator placement	0.10
j)	One utility room construction with asbestos sheet	0.4
k)	Construction of 2 ft height basement for crusher placement 6 x 3 ft with iron channels, nuts and bolts fitting	0.19
l)	Construction of 3 chullas for boiling juice	0.49
m)	Electrical wiring, switches, control panel etc	0.10
	Total amount (INR)	11.66

** Works and equipment prices quoted by local agents/dealers in Andhra Pradesh, India.

Chapter VII: Economics of sweet sorghum feedstock production for bioethanol

P Parthasarathy Rao, G Basavaraj, Kaushik Basu, Ch Ravinder Reddy, A Ashok Kumar and Belum VS Reddy

I. Introduction

Sweet sorghum is similar to grain sorghum but possesses sugar-rich stalks, with higher juice content. Because of its rapid growth, high sugar accumulation, high biomass production potential and wider adapt ability, sweet sorghum can be grown in different agro-climatic conditions. The sugar content in the juice extracted from sweet sorghum varies from 16-23% Brix. It has good potential for jaggery and syrup production besides ethanol. The grain can be used as food and the bagasse after extraction of juice from stalks is an excellent livestock feed. The potential food vs. fuel conflict from the diversion of crop land for cultivation of 'bioethanol' crops does not arise with sweet sorghum as it meets the multiple requirements the food, fuel and fodder.

In view of the potential benefits of sweet sorghum as a feedstock for bioethanol production, a pilot value chain model of sweet sorghum as a food-feed-fodder-fuel was tested in Andhra Pradesh, India, to augment incomes of farmers while developing a sustainable sweet sorghum–ethanol value chain under ICRISAT-NAIP (ICAR) Sweet Sorghum Value Chain Project by linking sweet sorghum farmers to ethanol industry.

The economic analysis of sweet sorghum cultivation for ethanol production was carried out under two different production systems: centralized and decentralized. The economic analysis in this chapter will provide evidence on the competitiveness of sweet sorghum as an alternative crop in the farmers' fields. The rationale for developing two different models for linking sweet sorghum farmers to bioethanol industry economics of sweet as a feedstock for ethanol production are discussed in other chapters in this book.

Based on the real time data available from the farmers' fields from pilot testing sites/clusters, the cost of production of sweet sorghum was collected along with similar costs for competing crops that sweet sorghum could replace (partially). The data on cost of conversion to ethanol from both the centralized model (stalks' juice converted to ethanol) and decentralized systems (syrup converted into ethanol) are analyzed and presented in other chapters in this book.

II. Data source, sampling framework and methodology

The primary source of data was the farmers cultivating sweet sorghum under the project. Detailed and structured farm survey instruments were developed to elicit information from farmers on the cropping pattern, production practices of sweet sorghum, utilization of grain and stalk, farmers' perceptions on growing sweet sorghum vis-à-vis other competing crops and input-output relationships. Data on constraints to growing sweet sorghum and competing crops (technology related) and postharvest constraints were also collected. The primary data on sweet sorghum cultivation under centralized locations was collected for the crop year 2007-08 from Daultabad cluster in Medak district of Andhra Pradesh, while for the decentralized locations, data was collected for the crop years 2008-09, 2009-10 and 2010-11 from Ibrahimbad village in Medak district of Andhra Pradesh. The details on the number of sample farmers and number of villages selected for data collection is presented in Table 1. Standard random sampling procedures were used to draw sample of farmers from the selected villages. While sampling, adequate representation was given to include small, medium and large farmers based on size of landholdings.

Table 1. Sweet sorghum sample size year-wise under centralized and decentralized locations, Medak districts, Andhra Pradesh.

Indicator	Centralized	Decentralized		
	2007	2008	2009	2010
Number of villages	5	9	11	11
Number of sample farmers	64	29	45	49

The data collected was analyzed for various costs, gross and net returns and input-output ratios of the crops. The costs of cultivation that were covered include both paid-out costs and imputed costs. Paid-out costs included hired labor (human, animal and machinery); expenses on material inputs such as seed, fertilizer, manure, pesticides and irrigation; and rent paid for leasedin land. Since some of the inputs used in the production process came from family sources, the value of these inputs was imputed. The method of imputing these costs was on the basis of the prevailing market rates for labor and materials and postharvest prices of the main product and by-product. However, in calculating the net returns to crop cultivation only cost concept A1 was considered, ie, the value of paid-out costs such as hired labor and expenses on materials while the imputed cost of family labor was not included. All the costs and returns were based on the actual area reported by the farmers. Yields were calculated based on the measured area that was found to be less in most cases compared to the actual area reported by the farmers. For the purpose of this analysis actual area reported by farmers was considered.

III. Economics of sweet sorghum cultivation – Centralized operations

In the centralized system, the farmers were directly linked to the distillery for supply of sweet sorghum stalk. Under the centralized operations, during rainy season of 2007, a cluster of villages in Medak district, Daultabad Mandal, Andhra Pradesh, in the radius of 50 km from the distillery covering an area of 538 hectares targeting 791 farmers growing NTJ variety of sweet sorghum was taken up by Rusni Distilleries Pvt. Ltd. The distillery had entered into a buy-back agreement with farmers to purchase the stalks at an agreed price. A local NGO acted as an intermediary between Rusni and the growers for providing seed, technical backstopping and ensuring timely delivery of stalks to industry and payments to farmers. The NGO was also liaising with research organizations for providing the latest technology and technical backstopping related to crop production.

1. Costs

The sum of all costs (labor and materials) per hectare of sweet sorghum was Rs 11,510 during 2007. Costs incurred in fertilizing the field and in intercultivation and weeding account for the largest share at 18% each. Farmyard manure (FYM) was the next most expensive component accounting for 17% of the total expenses. Harvesting and threshing accounted for 15% of the total expenses (Fig. 1).

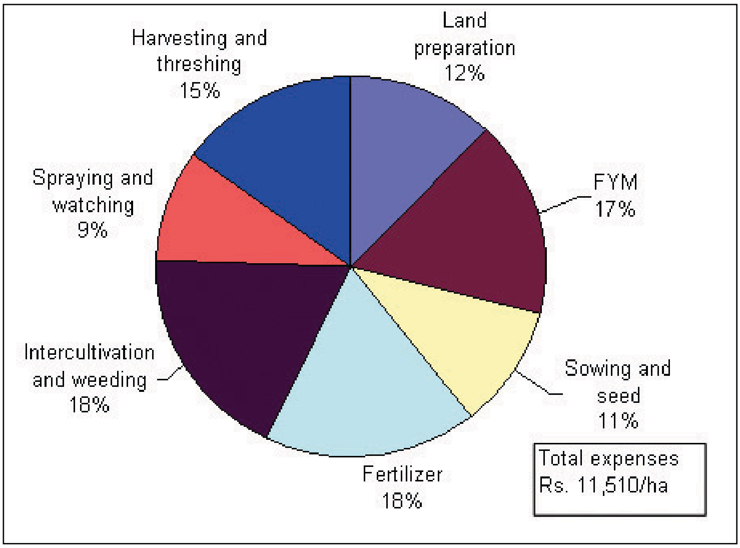

Fig. 1. Activity-wise break up of cost of cultivation for sweet sorghum.

2. Returns

The net revenue for the marginal farmers was Rs 2,986 ha^{-1}, for the small farmers it was Rs 3,514, and for the medium farmers it was Rs 3,897 ha^{-1} (Table 2). While there was not too much of a difference in the gross revenue and costs, net revenues increases marginally with the landholding size. There were no specific reasons for the increasing net revenues as we moved up the landholding class, except that the small and medium farmers seemed to have waited for the crop to fully mature prior to harvesting and thus harvested more grains compared to the marginal farmers.

There was considerable variation in the net revenues for sweet sorghum-based on the soil type it was grown. Net revenue for farms with shallow red soil was Rs 3,624 ha^{-1}, for deep red soils Rs 2,089 ha^{-1}, for medium to shallow black soils was Rs 2,418 ha^{-1}, and for medium black soils it was 4,116 ha^{-1} (Table 3). The break-even yield was 24.13 t ha^{-1} of stalk priced at Rs 600 t^{-1}. Twenty six farmers (13%) achieved stalk yields higher than the break-even yields.

Table 2. Summary of sweet sorghum cost of cultivation according to landholding class, 2007.

Category	All categories	Marginal	Small	Medium
Grain yield (kg ha^{-1})	346	255	449	299
Grain value (Rs ha^{-1})	2,214	1,617	2,865	1,912
Stalk yield (q ha^{-1})	141	150	136	145
Stalk value (Rs ha^{-1})	8,504	9,009	8,170	8,714
Gross income (Rs ha^{-1})	10,718	10,626	11,036	10,626
Total expenses excluding family labor (Rs ha^{-1})	7,719	7,641	7,522	6,729
Net revenues (excluding family labor) (Rs ha^{-1})	2,999	2,986	3,514	3,897

Note: Marginal farmers, n=21; Medium farmers, n=1; Small farmers, n=28. Large farmers included in all categories.

Table 3. Summary of sweet sorghum cost of cultivation by soil type, 2007.

Category	All soil types	Shallow red soils	Deep red soils	Medium to shallow black soils	Medium black soils
Grain yield (kg ha^{-1})	346	366	141	272	389
Grain value (Rs ha^{-1})	2,214	2,447	988	1,840	2,398
Stalk (q ha^{-1})	142	147	136	146	155
Stalk value (Rs ha^{-1})	8,504	8,821	8,187	8,788	9,428
Gross income (Rs ha^{-1})	10,718	11,268	9,174	10,628	11,826
Total expenses excluding family labor (Rs ha^{-1})	7,716	7,643	7,086	8,211	7,710
Net income (excluding family labor)	3,002	3,624	2,089	2,418	4,116

Note: Shallow red soils, n=28; Deep red soils, n=3; Medium to shallow black soils, n=8; Medium black soils, n=25.

3. Competitiveness of sweet sorghum for cultivation: Centralized operations

The cropping pattern of the sample farmers showed that the main competing dryland crop is maize. Maize was either sole cropped or intercropped with pigeonpea. Detailed cost of cultivation data was elicited from 29 farmers growing a sole crop of maize and 13 farmers growing maize intercropped with pigeonpea in order to gauge the competitiveness of sweet sorghum vis-à-vis maize.

Table 4 shows the costs and revenues of maize cultivation. The average net revenue for sole cropped maize was Rs 7,396 ha^{-1} which was higher than that for sweet sorghum. The total costs of maize cultivation were also higher compared to sweet sorghum at Rs 9,386 ha^{-1}, as also the gross revenue at Rs 16,782 ha^{-1}.

Table 4. Costs and revenues from maize cultivation, 2007.

Category	Value
Grain yield (kg ha^{-1})	2,434
Grain value (Rs ha^{-1})	15,855
Fodder yield (t ha^{-1})	35
Fodder value (Rs ha^{-1})	927
Gross income (Rs ha^{-1})	16,782
Total expenses (Rs ha^{-1})	13,306
Total expenses excluding family labor (Rs ha^{-1})	9,386
Net income excluding family labor (Rs ha^{-1})	7,396
Number of households	29

The average net revenue from maize intercropped with pigeonpea was higher than both sweet sorghum and the sole maize at Rs 10,137 ha^{-1}. Total expenses for this cropping system were lower than the sole cropped maize system at Rs 8,330 ha^{-1}, while gross revenue was much higher at Rs 18,466 ha^{-1} (Table 5).

Table 5. Costs and revenues of maize intercropped with pigeonpea.

Category	Value
Maize grain yield (kg ha^{-1})	1,938
Maize grain value (Rs ha^{-1})	12,438
pigeonpea (kg ha^{-1})	285
pigeonpea value (Rs ha^{-1})	4,8967
Maize fodder yield (q ha^{-1})	37
pigeonpea fodder yield (q ha^{-1})	8
Total fodder value (Rs ha^{-1})	1,132
Gross income (Rs ha^{-1})	18,466
Total expenses (Rs ha^{-1})	13,094
Total expenses excluding family labor (Rs ha^{-1})	8,329
Net income excluding family labor (Rs ha^{-1})	10,136
Number of households	13

A cropping system-wise comparison of total expenses (excluding family labor) and gross revenues is shown in (Fig. 2). The most probable reasons of sweet sorghum performing relatively poorly compared to competing crops are:

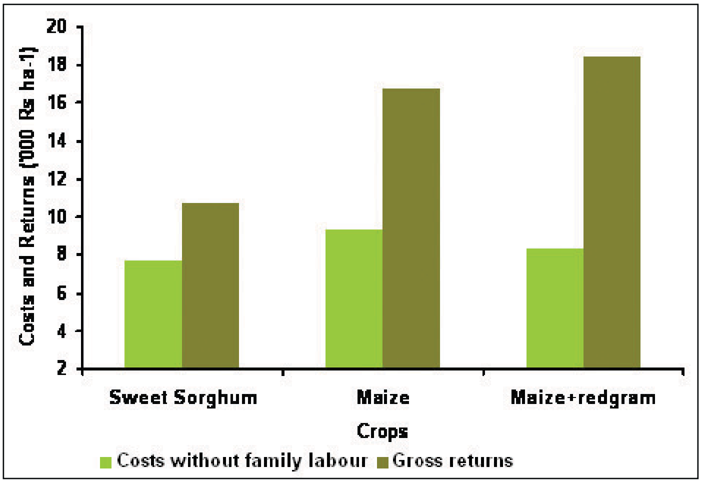

Fig. 2. Crop-wise cost of cultivation (excluding family labor) and gross revenues.

- The supply of only one variety of sweet sorghum to the farmers (suitable hybrids for the farmers' fields not made available).
- The variability of the quantity and quality of the seed supplied to the farmers.
- Farmers are not fully aware of the full range of practices.
- Harvest window not staggered.
- Grain maturity and yield compromised.

4. Farmers' perception of sweet sorghum cultivation

A greater proportion of small and medium farmers grew sweet sorghum when compared to the large and marginal farmers. Supply of inputs on credit basis, low cost of cultivation, low risk and short duration of the sweet sorghum crop compared to maize, were cited as the main reasons for growing sweet sorghum. However, only 38% of households who grew sweet sorghum were interested in expanding the area under sweet sorghum in the coming years. Of these households 55% stated that they would replace maize with sweet sorghum, while 21% of households would expand the area under sweet sorghum in fallow lands. The main reason that was given for planting sweet sorghum in the coming years was the availability of inputs on credit. The prospect of income from the sale of both grain and stalk as well as the lower cost of cultivation and lower risk were also strong incentives that guided the respondents to state that they would be planting sweet sorghum in the coming years. There was also a perception that there would be fewer attacks by wild boars. 53% of households who grew sweet sorghum were not interested in increasing the area mainly due to non-availability of dryland and was less profitable than other crops, such as maize. The remaining 9% did not respond to this question.

IV. Economics of sweet sorghum cultivation – Decentralized system

As mentioned, to overcome some of the shortfalls of the centralized unit system where it was found that delays in transporting stalk to industry resulted in loss of juice yield and hence its area of procurement of stalk would have to be restricted to farmers close to the industry, a decentralized crushing unit was set up at Ibrahimabad village, Medak district, on a pilot basis. The decentralized unit model was experimented with wherein the stalk will be crushed close to the villages where it is grown and the juice is converted into syrup and stored in cans. The syrup is transported to the ethanol industry for further processing into ethanol. The main advantage of this model is that the syrup can be stored for 6-8 months before it is converted into ethanol thus allowing flexibility in transportation and conversion into ethanol.

Accordingly, the area under cultivation, input supply, production (grain and stalk), gains in productivity, cost, returns, gains in productivity were monitored and recorded for the agricultural years 2008-09, 2009-10 and 2010-11 for economic analysis.

1. Cost of Cultivation

In 2008, total cost of cultivating sweet sorghum was Rs 15,804 ha^{-1}(including family labor). Land preparation and composting with 26% was the highest component of cost of cultivation of sweet sorghum followed by harvesting and threshing activity with 22%. Among resources utilized for cultivation of sweet sorghum, human labor with 56% was the highest resource component followed by bullock labor with 19%. However, the cost of cultivation both for 2009 and 2010 declined by 27 and 21% respectively compared to 2008. In

2008 besides FYM farmers applied tank silt supplied by the government, but incurred labor cost for spreading the silt. In 2009 and 10, cost of FYM came down since no tank silt was applied. The cost of cultivating sweet sorghum was Rs 11,502 ha^{-1} during 2009 and Rs 12,414 ha^{-1} for 2010. The activity-wise break-up of cost for 2009 and 2010 presents similar findings of that observed during 2008 (Table 6). The inputs utilization for cultivation of sweet sorghum for all the three agricultural years is presented in Table 7.

Table 6. Activity wise costs break-up (% share) for sweet sorghum cultivation, Ibrahimbad.

Variables	2008	2009	2010
Land preparation + Compost	26.5	16.6	19.3
Ploughing/Sowing	12.6	21.3	16.5
Fertilizer	14.8	17.7	22.5
Interculture, weeding & thinning	17.6	20.6	22.9
Watching & irrigation	6.2	1.0	1.3
Harvesting & Threshing	22.3	22.8	17.5
Total	100.0	100.0	100.0

Table 7. Input utilization of sweet sorghum, Ibrahimbad, Medak, Andhra Pradesh.

		Year		
		2008	**2009**	**2010**
Inputs utilized (ha^{-1})				
Labor (days)	Male Hired	15	10	9
	Male Family	25	8	6
	Female Hired	45	38	30
	Female Family	28	15	13
Bullock pair (days)	Hired	3	8	4
	Own	9	3	4
Tractor (hr)	Hired	7	2	7
	Own	0	0	0
FYM (kg)	Own	1800	800	600
	Buy	100	200	300
Seed (kg)	Own	0	0	0
	Buy	7	5	6
Total fertilizer (kg)		275	257	280
Irrigation/machinery (hr)		1	0	
Thresher (days) (hired & family)		0	0	3

2. Returns to cultivation

The net returns realized in cultivation of sweet sorghum excluding family labor was Rs 6,490 ha^{-1} during 2008. Net returns excluding family labor obtained from sweet sorghum was negative by Rs 441 ha^{-1} during 2009 due to dry spell after one month of sowing. In addition, earheads were also not harvested therefore no additional income from grains resulting in negative returns being realized. Net returns further declined to Rs 1833 ha^{-1} during 2010 due to heavy rains before harvest leading to loss in both stalk and grain yields (Table 8). However, in 2011 farmers obtained positive net returns of around Rs 1500 ha^{-1} due to better climatic conditions. The final analysis is not yet complete.

Table 8. Gross and net returns to cultivation of sweet sorghum, Ibrahimbad, Medak, Andhra Pradesh.

Indicators	Year		
	2010	2009	2008
Stalk quantity (t ha^{-1})	6.7	14	18
Stalk price (Rs t^{-1})	800	700	600
Grain (kg ha^{-1})	301	119	954
Grain price (Rs kg^{-1})	8	7	8
Gross income (Rs ha^{-1})	7,664	10,530	18,255
Total costs excluding family labor (Rs ha^{-1})	9,496	10,971	11,765
Net returns excluding family labor (Rs ha^{-1})	(1,833)	(441)	6,490

3. Competitiveness of sweet sorghum for cultivation - Decentralized operations

Net returns excluding family labor obtained from sweet sorghum was the highest among rainfed competing crops in Ibrahimbad during 2008. Returns realized from sorghum + pigeonpea intercrop was the next highest with Rs 4,309 ha^{-1} followed by maize + pigeonpea with Rs 3,567 ha^{-1} and Rs 3,466 ha^{-1} for maize. However, during 2009 and 2010 net returns obtained were negative for sweet sorghum and its competing crops due to adverse climatic conditions during sowing and harvesting stages in Ibrahimbad. The net returns for competing crops was more negative for sorghum + pigeonpea intercrop at Rs (5403 ha^{-1}) compared to sweet sorghum at Rs (1833 ha^{-1}) during 2010.

The benefit-cost presented in Table 9 indicated sweet sorghum had better ability to withstand adverse climatic conditions since the loss incurred by sweet sorghum was only - 0.19 compared to sorghum–pigeonpea intercrop at -0.41 while maize was marginally better by -0.03.

Table 9. Benefit-Cost ratio of sweet sorghum and competing crops, Ibrahimbad.

Crop	2008	2009	2010
Sweet Sorghum	1.55	0.96	0.81
Maize–Pigeonpea	1.30	NA	0.97
Sorghum–Pigeonpea	1.37	0.97	0.59

V. Conclusions

Cultivation of sweet sorghum under centralized operations has shown that it is profitable even with the existing yield levels of 14-15 t ha^{-1} which are considered to be low when compared to farm trials which range between 30-40 t ha^{-1}. In comparison to grain sorghum, sweet sorghum is definitely profitable. Grain sorghum and sweet sorghum returns were compared outside the cluster villages since within the cluster not many farmers were growing sorghum. In comparison to competing crops like sole maize and maize intercropped with pigeonpea under rainfed conditions, the net returns are marginally better for sweet sorghum in a few years and for maize in another year. However, since there is significant scope for yield potential to be realized under farm conditions and with the improvement in technology and improved agronomic practices (farmers are still not fully conversant with the practices for a relatively new crop of sweet sorghum), sweet sorghum becomes viable option with assured incomes for cultivation under dryland conditions for smallholder farmers.

Chapter VIII: Sweet sorghum ethanol production – An economic assessment

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I. Background

Over the past two decades, India's economy has grown on average at the rate of 5-6% per annum. Energy consumption is one of the major indicators of the country's economic progress and is one of the major inputs whose use increases with economic growth and development. India ranks the sixth in terms of energy demand accounting for 3.6% of the global energy demand (Prasad et al. 2007) and this is expected to increase by 4.8% in the next few years (Gonsalves 2006). Currently, India's energy demand is primarily met through non-renewable energy sources like fossil fuels (coal, natural gas and oil). Being short in domestic production, India mainly depends on crude oil imports that have risen from 57.8 mt in 1999-2000 to 140.4 mt in 2009-10 which accounts for about 81% of the oil consumption in the country (GOI 2009).This in turn puts pressure on scarce foreign exchange resources (for instance, the import bill of $75.6 billion in 2009-10). In the near future the imports are slated to rise further with no major breakthrough in domestic oil production and rise in vehicular population that has grown at 10% per annum between 2001 to 2006 and expected to continue in the near future.

In lieu of the growing concerns of energy security and environmental pollution due to high dependence on fossil fuels, globally, the focus has shifted to resource augmentation through renewable alternative energy sources to meet the energy demand (GOI 2009). To accomplish this, mandatory blending requirements of automotive fuels with ethanol have been introduced across several countries[1] and this has promoted research efforts towards energy sources that are sustainable and economically viable.

Among several alternative renewable energy sources like wind, solar, hydro and plant biomass, energy derived from plant biomass is gaining importance

[1] The mandatory blending requirements across different countries are: 3% in the United States; 25% in Brazil; 5.75% in the European Union; 10% in China and Indonesia; 5% each in Canada, United Kingdom, Australia and India.

worldwide (Rao et al. 2007). Bioenergy derived from plant based biofuels has been the major thrust across countries as alternative energy source. Bioethanol and biodiesel[2] are the two most common biofuels that are commercially exploited. Palm, jatropha and switch grass are some of the feedstocks that are used for production of biodiesel while sugarcane, corn, sugar beet are commonly commercially exploited feedstocks for bioethanol. In India, molasses, a by-product from sugar production, is commonly used for alcohol and ethanol production. However, current estimates indicate that ethanol from molasses alone will not be able to meet the mandated requirement of blending. There is thus a need for alternative feedstock to augment ethanol production. One such feedstock that can be commercially exploited for ethanol production is sweet sorghum.

II. Sweet sorghum processing for ethanol production

In view of the potential benefits of sweet sorghum as a feedstock for bioethanol production a value chain approach model of sweet sorghum as a food-feed-fodder-fuel is being tested on a pilot basis in Andhra Pradesh to augment incomes of farmers while promoting a sustainable sweet sorghum–ethanol value chain. As part of the ICRISAT-ICAR (NAIP) sweet sorghum value chain project, ICRISAT through its Agri-Business Incubator has incubated the sweet sorghum ethanol production technology with Rusni Distilleries. Sweet sorghum being a season-bound crop can produce stalks for crushing only for a limited period (3-4 months) during the year. The stalks have to be crushed within a short span of time after harvest to avoid loss of juice due to drying-up of stalks. Hence harvesting and crushing of stalk to process into ethanol have to go hand in hand for an effective source-sink mechanism. If the processing unit or the distillery (referred to as the centralized unit (CU) throughout the chapter) is located further away from the source of cultivation, delays in transportation would lead to losses in juice content both at farm and distillery levels effecting ethanol recovery and profitability. Hence, the cultivation of sweet sorghum for the CU has to be in close proximity (< 50 kms) of the distillery. Additionally, the CU requires assured and continuous supply of raw material for at least 8-9 months of the year for economic sustainability.

[2] For the details of future prospects of biodiesel production in India, see Biswas et al. (2010).

To overcome this problem and also allow farmers further away from the distillery to benefit from the sweet sorghum ethanol value chain, a crushing unit at the village level (referred to as decentralized crushing unit (DCU) throughout the chapter), is established in the close vicinity of the farmers' fields such that the harvested stalk is crushed on the same day for juice, boiled and converted to syrup. The syrup, which can be stored for a longer time period than the juice (over 9 months without loss in quality), can be transported to the distillery for processing into ethanol, as needed. It is in this context, that the chapter looks at the economics of processing sweet sorghum for ethanol production under the two different units, CU and DCU.

Specifically the economics looks at:

- Economics of ethanol production from sweet sorghum under CU.
- Supply and demand for ethanol in India and potential for sweet sorghum as an alternative feedstock.
- Future area requirement for sweet sorghum cultivation to meet a small proportion of mandated blending requirements if sweet sorghum is commercially exploited.
- Economics of syrup production for ethanol under DCU.
- Economic viability of DCU.

III. Economics of ethanol production under centralized unit (CU)

1. Cost and returns of sweet sorghum production and processing

The economics of processing sweet sorghum for ethanol production was analyzed based on the discussions with Rusni Distilleries (CU) on recovery of ethanol per ton of stalk and the costs incurred in processing. The economics of ethanol production without accounting for capital costs is presented in Table 1. Based on an average recovery rate of ethanol at 4.5% (45 l $t^{-1}$of stalk), feedstock priced at Rs 600 t^{-1} and ethanol priced at Rs 27 l^{-1}, the benefit cost ratio worked out to 1.22.

However, since the results presented in Table 1 did not account for capital cost of establishment of the distillery, economic viability assessment was carried out taking into consideration the various economic and financial cost in establishment of the distillery. The economic viability assessment of ethanol production from sweet sorghum was carried out through discounting techniques to examine whether ethanol production is profitable along the different segments of the supply chain of sweet sorghum under CU.

The data on various parameters used for economic viability assessment of ethanol production from sweet sorghum were collected from the distillery and presented in Table 2. For certain of the parameters where the data was not available assumptions were made based on expert opinion and secondary literature review for financial analysis.

The capacity of the plant is 40 kilo liters per day (KLPD) operating for 180 days. The reference year chosen is 2010 and the economic life of the project is 20 years. All economic costs and benefits (including by-products) are valued at current prices. The prevailing administered price of Rs 27 l^{-1} of

Table 1. Costs and returns of sweet sorghum production, Medak, Andhra Pradesh, 2007, Centralized Unit.

Sweet Sorghum (production)	
Average stalk yield (t ha^{-1})	14.7
Variable costs of production excluding family labor (Rs ha^{-1})	7,716
Gross returns (Rs ha^{-1})	10,718
Net returns excluding family labor (Rs ha^{-1})	2,999
Sweet Sorghum (ethanol production)	
Cost of the raw material (Rs t^{-1})	600
Cost of processing (Rs t^{-1})	384
Recovery of ethanol (l t^{-1})	45
Cost of ethanol (Rs l^{-1})	22
Price of ethanol received (Rs l^{-1})	27*
Benefit cost ratio	1.22

*The price of ethanol was Rs 21.5 when centralized unit was established and increased to Rs 27 l^{-1} during 2010.

ethanol announced by Government of India and recovery rate of 4.5% per ton of sweet sorghum[3] was considered for financial and economic viability assessment. The landed cost of feedstock during 2010 was Rs 1200 t^{-1} of stalk.

[3] A range was provided by the distillery on the recovery of ethanol which varies between 4 to 4.8 %. For economic feasibility assessment an average recovery of 4.5% is considered for analysis.

Table 2. Details of the indicators used in financial feasibility assessment*.

Labour cost (Rs $KLPD^{-1}$)	400
Cost of power (Rs KL^{-1})	2500
Chemical cost (Rs KL^{-1})	1000
Operation and maintenance cost (Rs/annum)	30000
General costs Rs (for entire life of project)	3000000
Marketing and other expenses (Rs KL^{-1})	1000
General inflation (%)	3
Output (main product and by-products)	
Recovery of ethanol per ton of stalk (l)	45
Output of ethanol (KLPD)	40
Selling price of ethanol (Rs l^{-1})	27
Escalation in price of ethanol (%)	1.5**
Recovery of CO_2 (t/40 KLPD)	20
Selling price of CO_2 (Rs t^{-1})	10000
Additional recovery of bagasse (t/40 KLPD)	150

* The interest on working capital is taken as 13% and debt to equity ratio as 60:40. The term loan interest assumed is 6% as loans provided for biofuels are classified as priority sector lending. A depreciation rate of 5% is assumed on the capital expenditure and repayment of 10 years.

** Though the demand for alcohol from potable and alcohol are growing at 4% per annum, the escalation in prices of alcohol is assumed on a conservative basis.

2. Methodology and data on indicators for economic feasibility assessment

The evaluation of investments on long term projects from economic assessment perspective is through discounted cash flow technique. The net present value (NPV) and internal rate of return (IRR) are commonly used measures to evaluate the projects' economic performance and investment risks. Accordingly, these two measures are used in our analysis.

3. Net present value (NPV)

NPV is an important financial index which plays a key role in decision making of long-term investment projects. A positive, higher NPV indicates that the net profits are higher so the investment may have favorable economic performance or investment is considered as economically feasible.

NPV is calculated as:

$$NPV = \sum_{n=0}^{N}(B_n - C_n)/(1+d)^n$$

Where $B_n = P_n x\ Q_n$

B_n is Benefits or the returns from the distillery by selling ethanol and by-products P_n is the ethanol selling price during year n,

Q_n is the annual production volume of ethanol in year n, d is the discount rate (the required rate of return), n is the economic life of the investment.

4. Internal rate of return (IRR)

The IRR is the rate of return refers to the average earned capacity of an investment/project during its economic life. It equals the discount rate when NPV is set to zero. In general, the IRR should be greater than the discount rate for a project for economic feasibility.

IRR is calculated as

$$IRR \Rightarrow \sum_{n=0}^{N}(B_n - C_n)/(1+d)^n = 0$$

B^n is Benefits or the returns from the distillery by selling ethanol

P^n is the ethanol selling price during year n,

Q^n is the annual production volume of ethanol in year,

d is the discount rate (the required rate of return), and n is the economic life of the investment.

5. Results and discussion

The indicators of economic viability (Table 3) showed negative NPV of the project at a discount rate of 10% (bank rate) and benefit cost ratio of 0.89 with feedstock price at Rs 1200 t^{-1} and ethanol price of Rs 27 l^{-1}. Clearly, the cost of ethanol is highly sensitive to ethanol price, feedstock price and recovery rate. It would thus be difficult for the industry to take off under the current scenario of ethanol price, feedstock price and recovery rate.

Table 3. Indicators of economic viability assessment for ethanol production from sweet sorghum.

Indicators	Feed stock price (Rs t^{-1})	Recovery rate (%)	Ethanol price (Rs l^{-1})
	1200	4.5	27
NPV (million rupees)		(344)	
Benefit cost ratio		0.89	

6. Sensitivity analysis

Sensitivity analysis was performed to derive the values of the key parameters where the project NPV becomes zero. The key parameters identified include, recovery rate, feedstock price and ethanol price.

Two scenarios were developed, one based on increase in feedstock prices and the other on anticipated increase in price of ethanol as gasoline prices are also increasing. In the first scenario, at an optimistic recovery rate of 4.9% and feedstock price fixed at Rs 1200 t^{-1} of stalk, the price of ethanol should be Rs 29 l^{-1} of ethanol where the project NPV becomes positive (Table 4). With the rise in cost of cultivation of sweet sorghum, if the stalk price increased to Rs 1500 t^{-1} with the recovery rates at 4.9% the price of ethanol has to be increased to Rs 36 l^{-1}.

In the second scenario, since it is mandated to blend petrol with ethanol, it is anticipated that ethanol prices are expected to increase, with the increase

Table 4. Scenario 1: Sensitivity analysis with change in feedstock prices.

Conversion rate (%)	Feedstock price (Rs/ton)	IRR	Expected ethanol pricing (Rs/liter)
4.9	1200	10.53	29
	1500	13.19	36

in prices of petrol. If the ethanol price was increased to Rs 37 l^{-1}, even with a lower recovery of 3.7% the centralized unit can break even. If the feedstock price was increased to Rs 1500 t^{-1} of stock with the ethanol prices remaining unchanged, the expected ethanol recovery should be 4.6% to generate zero NPV (Table 5). Sensitivity analysis carried out had shown that even with a marginal improvement in recovery the NPV becomes positive.

Table 5. Scenario 2: Sensitivity analysis with change in ethanol and feedstock prices.

Feedstock price (Rs t^{-1})	Ethanol pricing (Rs l^{-1})					
	27		32		37	
	IRR	Expected Ethanol recovery (%)	IRR	Expected ethanol recovery (%)	IRR	Expected ethanol recovery (%)
1200	8.10	5.3	13.7	4.3	9.60	3.7
1500	12.83	6.7	13.7	5.5	8.91	4.6

7. Some lessons learnt from pilot model for crushing sweet sorghum for ethanol production

The CU did not realize potential benefits from sweet sorghum value chain due to few shortcomings. One of the major shortcomings is extensive co-ordination and planning requirements in the supply chain management. Delay in crushing stalks beyond 24 hours of harvest causes low recovery of ethanol per ton of stalk. Additionally, the distillery faced some teething issues in terms of functioning of crushers, boilers and other equipment. A 40 KLPD ethanol distillery requires feedstock from 8000 ha of crop area per year spread over two seasons – 3500 ha in the rainy season (rainfed) and 4500 ha in the postrainy season (irrigated). Hence mobilizing farmers to cultivate sweet sorghum and sourcing the raw material becomes difficult. However, the observations have shown that under the centralized system, considerable scope exists to increase the efficiency of the value chain both at crop production and processing stages.

One of the major limitations of the financial viability assessment studies is that they look at benefits only from financial returns. The same limitation holds good here also. The environmental benefits in cultivation of sweet sorghum for ethanol production incorporated in viability assessment should be more attractive and hence make a case for justifying policy support and enabling environment which does not exist in the current scenario.

8. Sustainability of ethanol production from molasses and competitiveness of sweet sorghum as an alternate source

The Government of India has set an indicative target of 20% blending of ethanol with petrol and also for diesel with biodiesel across the country by

2017. Given the mandatory blending and projected demand for petrol in India, ethanol demand for blending are estimated at 5, 10 and 20% blending mandates (Fig. 1). Based on the projections, it is estimated that bioethanol requirement would be 3.46 billion L in 2020 at the rate of 10% blending.

Currently the entire bioethanol requirement has to come from molasses, a by-product of sugarcane. The availability of molasses to meet blending mandates depends on cane and sugar production that are cyclical in nature. Lower molasses availability will put pressure on molasses prices and availability of molasses for ethanol production. For instance, molasses prices in the last decade have fluctuated between Rs 1000 and Rs 5000 t^{-1} (Shinoj et al. 2011). Additionally, ethanol produced has many other alternative uses such as in the potable alcohol, chemical and pharmaceutical industry. During a normal year, cane converted into sugar generates enough molasses to produce alcohol that can meet the needs of both potable and chemical sectors (30-40% each). Another 20-30% surplus alcohol is available for conversion into ethanol for blending. During 2009, though the total supply of ethanol (2.4 million tons) was sufficient to meet total amount demanded (1.80 million tons), the utilization was more towards potable and industrial uses due to inability of the oil marketing companies (OMCs) to procure the required amount of fuel ethanol at prevailing market prices (Shinoj et al. 2011). Import of ethanol for fuel usage is currently restricted through policy and even if made free, would cost the exchequer very dearly, as the international markets for ethanol are already very tight due to demand from other biofuel-consuming countries.

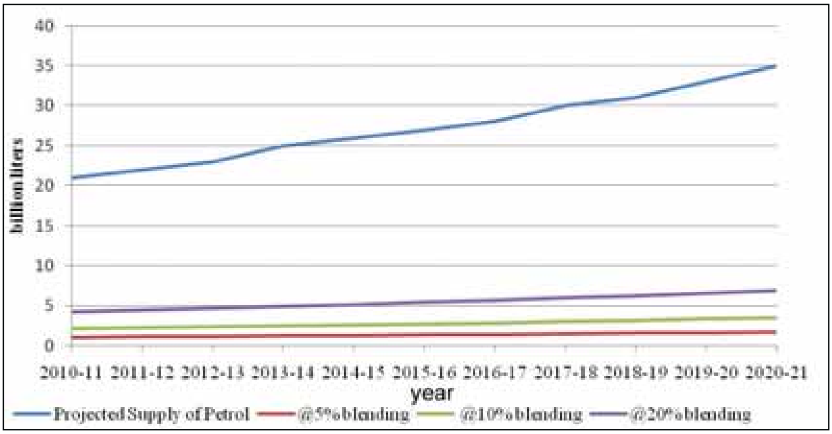

Fig. 1. Projected demand for petrol and ethanol for blending in India.

Given the scenario of 10% blending requirement, the growing demand for alcohol from potable and chemical sector (growing at 3-4% per annum) and the highest available alcohol from molasses pegged at 2.3 billion L, there will be shortage of alcohol for blending (Table 6). If molasses alone has to meet the entire requirement, an approximate area covering 10.5 million ha with 736.5 million ton of sugarcane has to be produced to meet the 10% blending requirement (around 20–23% in excess of what is required for meeting the corresponding sugar demand) which translates into doubling of both area and production. Presently, the country lacks both technology and infrastructure required to implement this. Further, it is not possible to increase the area under sugarcane beyond some limit given the fact that sugarcane is highly water intensive with a water requirement of 20000–30000 m^3 per ha per crop. Bringing additional area under sugarcane will be at the cost of diverting land from other staple food crops (Shinoj et al. 2011). Hence, ethanol production has to be augmented from alternative feedstocks like sweet sorghum.

Table 6. Availability and utilization of ethanol in India.

Year	Highest quantity of alcohol from molasses (bl)	Ethanol utilization (bl)			Ethanol for blending (bl)	
		Potable	Industry	Balance	@ 10%	Deficit/ surplus
2010-11	2.3	0.86	0.82	0.62	1.53	-0.96
2011-12	2.3	0.89	0.84	0.57	1.64	-1.14
2012-13	2.3	0.91	0.87	0.52	1.70	-1.32
2013-14	2.3	0.94	0.90	0.46	2.02	-1.53
2014-15	2.3	0.97	0.94	0.39	2.13	-1.76
2015-16	2.3	1.00	0.97	0.33	2.23	-1.99
2016-17	2.3	1.03	1.00	0.27	2.34	-2.24
2017-18	2.3	1.06	1.04	0.2	2.46	-2.51
2018-19	2.3	1.09	1.07	0.14	2.58	-2.78
2019-20	2.3	1.12	1.11	0.07	2.71	-3.09
2020-21	2.3	1.16	1.15	-0.01	2.85	-3.42

Source: Planning Commission (2003) estimates on highest available alcohol from molasses

9. Economic competitiveness

The result of relative economics of ethanol production from different feedstocks in India favors ethanol conversion from molasses (Table 7).

Table 7. Relative economics of ethanol production from different feedstocks in India.

Parameter	Sweet sorghum	Sugarcane molasses	Sugarcane juice	Grains (pearl millet & broken rice)
Cost of raw material (Rs t^{-1})	700*	3000-5000**	1200+	8000+
Cost of processing (Rs t^{-1})	384	1890	490	2800
Total cost of ethanol production (Rs t^{-1})	1084	4890-6890	1690	10800
Output of ethanol (l)	45	270	70	400
Value of ethanol (Rs t^{-1})	1215	7290	1890	10800
Net Returns (Rs t^{-1})	131	2400-400	200	0
Cost of feedstock (Rs l^{-1})	15.56	11.11-18.51	17.14	20.0
Cost of ethanol (Rs l^{-1})	24.08	18.11-25.51	24.14	27
Profit from ethanol (Rs l^{-1})	2.91	8.88-1.48	2.85	0

Note: The information on the parameters is collected from Rusni Distilleries for sweet sorghum, Nizam Deccan Sugars Pvt. Ltd. for molasses and AGRO Bio-tech, Ajitgarh, Rajasthan for grains.

*The value of by-products is not considered in the analysis. Even when the feedstock is priced at Rs 800, it becomes profitable to produce ethanol from sweet sorghum without accounting for capital costs. However, the cost of feedstock has varied between Rs 700 and 1200 t^{-1}.

**Molasses prices have ranged between Rs 3000 and 5000 t^{-1} during the last few years and hence the profitability of molasses ethanol production is highly sensitive to fluctuating molasses prices.

+The data on all the other feedstocks cost is for the year 2009. The prices of feedstock (sugarcane and grains) have increased in the recent years.

Sweet sorghum is the second best alternative for ethanol production. Though economics favors production of ethanol from molasses, there is the problem of sustainability due to the reasons already discussed. The direct conversion of sugarcane juice to ethanol is also not economical and additionally there exists concerns of food security due to diversion of land for cultivation. Similar concerns (food security, increase in prices and economic viability) exist for conversion of grains for ethanol production. Given the scenario, sweet sorghum serves as an excellent alternative source to augment ethanol production to meet the blending mandates as sweet sorghum has a few advantages:

- It does not compromise on food and feed security.
- It has a short growing period and low water requirement.
- It is a familiar crop that has a low cost of cultivation.
- Pollution levels from ethanol production are low.

The economic viability assessment does not favor well for ethanol production from sweet sorghum in the current scenario of feedstock and ethanol prices. Hence policy and enabling environment support plays a crucial role in promotion of ethanol production from alternate feedstocks like sweet sorghum.

If an enabling environment is in place it would be interesting to know what would be the future area required to cultivate sweet sorghum. A land requirement exercise was carried out to understand this.

10. Land requirement assessment for sweet sorghum ethanol production

To understand how the ethanol blending demand would translate into future requirement of sweet sorghum area and production, an analysis was performed to assess the land requirement for sweet sorghum cultivation by 2020, if it is commercially exploited for alternate source of ethanol production. It is expected that a crop like sweet sorghum would only bridge the gap in ethanol requirement supply from the existing feedstock ie, molasses. The land requirement assessment for cultivation of sweet sorghum and production is undertaken with certain assumptions with sweet sorghum meeting the entire deficit or partially in varying proportions.

Land requirement for sweet sorghum cultivation is dependent on farm productivity and recovery rate of ethanol. On farms trials have shown that farmers can harvest upto 40 t h^{-1} of sweet sorghum and there is significant scope to improve productivity on farmers' fields. Taking into consideration the research efforts to improve the productivity of sweet sorghum with higher recovery rates, the assessment is developed based on the existing scenario of 20 t h^{-1} with 4.5% recovery and a case where productivity improves to 30 t h^{-1} with 4.5% ethanol recovery. Since in the short run it would not be possible to bring larger area under sweet sorghum cultivation, the following scenarios are developed to meet the deficit of ethanol for blending at 10% mandatory blending:

a) to meet 30% of the ethanol deficit for blending;

b) 50% of the ethanol deficit for blending; and

c) 80% of the ethanol deficit for blending.

The estimates showed that to meet deficit at 10% blending by 2020 (3.47 billion liters), at 20 t ha^{-1} productivity and 4.5% recovery, the area required will be about 1.16 million hectare with the assumption that 30% of the deficit is met from sweet sorghum (Table 8). However, with the improvement in productivity at 30 t ha^{-1}, the requirement of land would be only 0.77 mh. Assuming that 80% of the deficit ethanol requirement for blending is met through sweet sorghum still a modest area of about 2.06 mh will be required to cultivate sweet sorghum. This would amount to about 50% of the current kharif (rainy season) sorghum area which is under cultivation. Given that grain sorghum area under rainy

Table 8. Land assessment for sweet sorghum cultivation in ethanol production.

Year	Deficit @ 10% blending requirement (billion liters)	Area requirement (million hectare)					
		Meeting 30% of the deficit		Meeting 50% of the deficit		Meeting 80% of the deficit	
		20 tons yield & 4.5% recovery	30 tons yield & 4.5% recovery	20 tons yield & 4.5% recovery	30 tons yield & 4.5% recovery	20 tons yield & 4.5% recovery	30 Tons yield & 4.5% recovery
2011-12	-1.66	0.55	0.37	0.92	0.62	1.48	0.99
2012-13	-1.83	0.61	0.41	1.02	0.68	1.63	1.09
2013-14	-2.01	0.67	0.45	1.11	0.74	1.78	1.19
2014-15	-2.19	0.73	0.49	1.22	0.81	1.95	1.30
2015-16	-2.38	0.79	0.53	1.32	0.88	2.12	1.41
2016-17	-2.58	0.86	0.57	1.43	0.96	2.29	1.53
2017-18	-2.79	0.93	0.62	1.55	1.03	2.48	1.65
2018-19	-3.01	1.00	0.67	1.67	1.11	2.67	1.78
2019-20	-3.23	1.08	0.72	1.80	1.20	2.87	1.92
2020-21	-3.47	1.16	0.77	1.93	1.29	3.08	2.06

season sorghum in Maharashtra is declining at an alarming rate, cultivation of sweet sorghum in these rainfed areas will provide income for farmers provided there is enabling environment in place to support sweet sorghum production for ethanol production.

IV. Economics of processing sweet sorghum for syrup production under decentralized unit

The purpose of setting up decentralized crushing units (DCU) at the village level was to crush sweet sorghum stalks and extract the juice, which then is boiled to produce syrup. It aids supply chain management particularly by reducing the volume of feedstock that would otherwise have to be supplied to centralized crushing unit and by increasing the period of feedstock availability (supply of syrup) to industry to make sweet sorghum ethanol a commercial reality. The DCU also serves as a model for farmer-centric, farmer-driven rural industry towards improving the livelihoods of small-scale sorghum farmers.

The process of DCU site selection, selection of villages and farmers, supply chain management, process of crushing and syrup production has been described in other chapter of this book. This section provides an overview of the economics of the DCU and options to increase its economic viability.

1. Operations of decentralized unit

During 2009 kharif (rainy) season under the project, 53.6 ha was under sweet sorghum cultivation involving 94 households. Sweet sorghum stalk was harvested from only 29.8 ha and crushed for syrup production since the germination was poor in the remaining area and hence was abandoned by the farmers.

From the sweet sorghum harvested area a total of 599.9 t of sweet sorghum stalk was produced in kharif 2009 with an average yield of 20 t ha^{-1}. There was however considerable variation in the yield levels, varying between 3 t to 31 t ha^{-1}. Relative to the kharif 2008 season, average stalk yield per hectare was higher by 34% increasing from 15 to 20 t ha^{-1}. The entire stalk of 599.9 t was crushed in 27 days with an average crushing capacity of 22 t day^{-1}. The average labor requirement was 54 man days with an average sweet sorghum juice production of 5,897 l day^{-1}.

The total quantity of juice extracted from crushing 599.9 t of sweet sorghum was 161,565 l and fresh bagasse weighed 419 t. In comparison to 2008, juice yield extracted from the stalk improved by about 3% in 2009. The total quantity of syrup produced from boiling 161,565 l was 28.8 t. The average syrup production per ton of stalk is 48 kg, which was 20% higher compared to syrup production of 40 kg in 2008 (Table 9).

Table 9. Comparison of sweet sorghum cultivation and crushing indicators under DCU, Ibrahimbad, Andhra Pradesh.

Indicator	2008	2009	% change
Number of farmers	102	94	-
Number of villages	7	11	-
Area sown (ha)	42	53.6	28
Area harvested (ha)	37	29.8	(19)
Stalk yield (t ha^{-1})	15	20	33
Average stalk crushed (t/day)	13	22	69
Crushing days	43	27	(37)
Average labor/day	NA	54	
Juice extracted/t of stalk	261	269	3
Syrup yield/100 L of juice	15	18	20
Average syrup/t of stalk	40	48	20

Note: % figures in parenthesis show a decline from the previous recording.

2. Cost of processing stalk to syrup

The total cost of production of 28.8 tons of sweet sorghum syrup from crushing 600 t of stalk was Rs 739,528 and the net return realized in rupees was Rs 384,248. The breakup of cost indicated that the procurement of sweet sorghum stalk as the raw material for extracting juice accounts for 57% of the total costs followed by labor cost of 29% and fuel cost of 6% besides other miscellaneous costs accounting for the remaining amount. On an average, the cost incurred in processing 1 kg of syrup was Rs 25.65 (Table 10, Fig. 2). The cost per kg of syrup production declined from Rs 31.4 kg^{-1} in 2008 to Rs 25.6 kg^{-1} in 2009. The decline in cost of production was Rs 6 kg, which is an 18% decline relative to 2008.

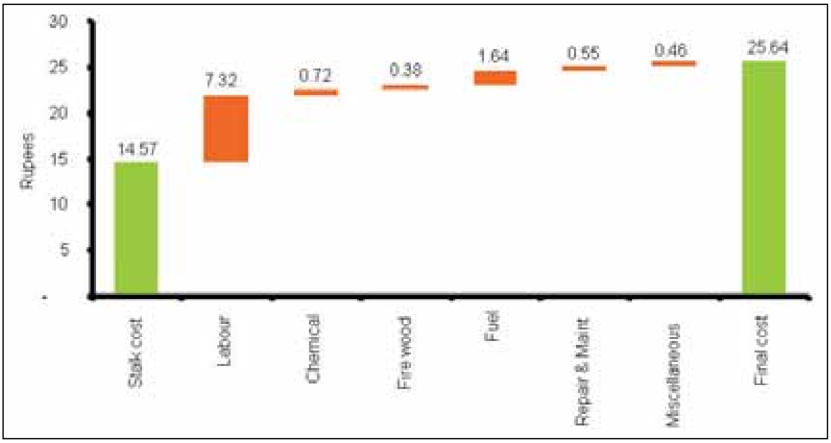

Fig. 2. Item-wise break-up of costs of processing sweet sorghum to syrup production.

Table 10. Cost of syrup production in decentralized unit, kharif 2009, Ibrahimbad, Medak, Andhra Pradesh.

Cost of item	Total costs (Rs)	Cost/kg syrup	Percent to total costs
Cost of raw material			
Cost of stalk (Rs)	419,930	14.57	57
Processing costs			
Labor costs	210,830	7.32	29
Chemical costs	20,850	0.72	3
Firewood	10,825	0.38	1
Operating expenses			
Fuel costs	47,359	0.08	6
Repair & maintenance	15,869	0.03	2
Miscellaneous	13,265	0.46	2
Total costs	739,528	25.65	100

A further break-up of labor costs revealed that the cost incurred for drying the bagasse after crushing the stalk accounted for 39% of the total labor costs t^{-1} of stalk. A total of 694 man days of labor is used for drying bagasse and is the highest labor requirement, followed by 33% for crushing and 17% for boiling juice to syrup. On an average, about 52 man days of labor are required to convert one ton of stalk to syrup, which at current wage rates amounted to Rs 8,800.

3. Returns from processing sweet sorghum

The cost incurred and returns realized per hectare and per ton of stalk for production of syrup from sweet sorghum stalk are presented below (Table 11). The gross returns and total costs per hectare realized from sweet sorghum for syrup production worked out to Rs 9,670 and Rs 24,783, respectively, with a net deficit of Rs 15,113.

Table 11. Costs and returns from sweet sorghum from syrup production (in Rs).

Indicator	Per ton of stalk	Per ha
Syrup yield (kg)	48	967
Total cost	1,232	24,783
Gross returns (Rs @ 10/kg)	480	9,670
Net returns	(752)	(15,113)

4. Break-even scenario and sensitivity analysis

The decentralized unit can be made viable either by increasing revenues through better technical outputs (juice, syrup yield) or increasing the price of syrup and other by-products sold to the end user. The second alternative is to reduce costs of processing. A combination of the two would be the best option for economic viability. Break-even scenarios of syrup production per ton of stalk and per hectare of sweet sorghum are presented (Table 12). The figures in bold indicate the break-even scenario pertaining to syrup production.

Sensitivity analysis for the break-even scenario of syrup production from sweet sorghum reveals that syrup production from the existing level of 48 kg of syrup per ton of stalk has to be increased to 124 kg of syrup, or alternatively, the price of syrup has to be increased to Rs 26 kg^{-1} to make the unit viable.

Table 12. Break-even scenarios for syrup production from sweet sorghum (per ton and per hectare of stalk).

Indicator	Break-even scenario/ton of stalk			
	Current scenario	Juice & syrup yield increase	Price increase	Cost decrease
Syrup yield (kg)	48	124	26	48
Total cost (Rs)	1,232	1,232	1,232	480
Gross returns (@ Rs10/kg)	480	1,240	1,248	480
Net returns (Rs)	-752	8	16	0
Break-even scenario/ha				
Syrup yield (kg)	967	2,480	967	967
Total cost (Rs)	24,783	24,783	24,783	9,670
Gross returns (@ Rs 10/kg)	9,670	24,800	24,794	9,670
Net returns (Rs)	-15,113	17	11	0

5. Options for increasing returns

Currently, the pricing of syrup for ethanol is at Rs 10 kg^{-1}. Since a monopsonic (only buyer) market exists in the industry, there is no better bargaining power to increase the prices. In the long run, with the establishment of additional industries for processing syrup to ethanol, higher prices realized will help in making the unit more viable. Other options include sale of syrup to the food industry. Under the project, a small quantity of sweet sorghum syrup was sold to the food industry on a trial basis (as the use of sweet sorghum syrup is still being evaluated by the industry). As the opportunity of marketing syrup for the food industry (confectionary, pharmaceutical, bakery, etc) opens up, efforts should be made to link these markets to the decentralized unit. Since we can expect a higher price for syrup from the food industry and associated industries, this would help in making the decentralized unit viable for syrup production, supplying syrup both for bioethanol and allied sectors.

To optimize returns from syrup production, sensitivity analysis was carried out with various scenarios developed for cost decline, efficiencies in juice and syrup yield, utilization of bagasse and selling syrup in alternative markets such as food and pharmaceutical industry individually and in combination. Accordingly, an Excel-based Visual Basic (VB) tool was developed to report the economic viability of syrup production under various scenarios.

6. Viability of DCU

Currently, the DCU is managed by farmers themselves. Since the cultivation of sweet sorghum and the processing of sweet sorghum to syrup is new to the farmers, there are limitations for efficiency gains. The current production cost of sweet sorghum syrup at Rs 26 kg^{-1} needs to be reduced by increasing the juice recovery and % Brix content. Reducing unit cost of processing by improving labor efficiency will also significantly help in reducing the unit cost of syrup.

A) Importance of syrup recovery and quality

The present recovery of juice per ton of stalk is 26.9% (269 l of juice t^{-1} of stalk). If the juice recovery increases to 32% (320 l $t^{-1}$of stalk) with cost of processing remaining the same at Rs 25.65, the total yield of syrup will be 57 kg t^{-1} of stalk, instead of the present 48 kg. Hence, the cost per ton of syrup will be reduced by Rs 4.00, which is a 15% decline, or the increase in gross returns will be to the extent of Rs 4 kg of syrup.

Present recovery of syrup per ton of stalk is 48 kg at 70-80% Brix. With the increase in Brix content by 1%, the increase in recovery of syrup will be by 6%, ie, from 48 kg of syrup to 50.88 kg. With the increase in Brix content, the reduction in unit cost of syrup will be by Rs 1.44 from the current level (Rs 25.65 to 24.20), a decline of 6%. Alternatively, both increases in juice and syrup recovery will have a multiplicative effect on productivity gains (Fig. 3).

Fig. 3. Reduction in unit cost of syrup due to improvement in juice yield.

B) Importance of selling bagasse as fodder

Presently, the price received for bagasse sold to the fodder industry is Re 1 kg^{-1}. Since there is scope for value addition from bagasse sold for fodder, efforts should be made in this direction to market a better product to realize higher prices.

The current rate of conversion of a ton of stalk to juice is 26.9% (269 l) with 700 kg available as wet bagasse. Only about 30% (210 kg) of the wet bagasse (700 kg) can be used as fuel and fodder for livestock after drying. About 45% of the dry bagasse (94.5 kg) is utilized as fuel for converting juice to syrup and the remaining 55% (115 kg) of the bagasse left over can be sold as fodder for livestock.

With the assumption that value realized from a kilogram of bagasse is Re 1, the total value for 115.5 kg of bagasse that is left over after use as fuel for the pans will be Rs 115.5. With better utilization of bagasse, the cost of processing a ton of stalk (Rs 1,231 for both raw material and processing) will reduce by Rs 115.5 (1,231-115.5=1,115.5), and hence the unit cost of syrup production will reduce from Rs 25.65 to Rs 23.23, a decline of Rs 2.40 kg-1 or 9% decline in cost. In other words the gross returns will increase by Rs 2.40 kg^{-1} of syrup due to additional returns from selling bagasse. Fig. 4 below presents a graphical representation of reduction in unit cost of syrup/ increased returns because of additional returns from bagasse.

C) Importance of labor efficiency

At present, the labor cost of producing syrup from sweet sorghum stalk is high, and comprises 29% of the total processing cost. There is scope for improving labor efficiency and crushing efficiency through mechanization to reduce the cost of processing by 40 to 50%. Of the total cost of processing ie, Rs 11.07 for one kg of syrup (excluding cost of raw material), the labor cost is Rs 7.32. If the labor efficiency improves by 30%, the reduction in cost of labor will be Rs 2.19. The labor cost will thus be reduced from Rs 7.32 to Rs 5.12 and the reduction in cost of syrup because of labor efficiency alone would be by 8%, ie, from Rs 25.65 to Rs 23.45. If the labor efficiency improves by 40%, the reduction in cost of syrup will be by Rs 2.92, ie, to Rs 22.72 from Rs 25.65, and 50% improvement in labor efficiency will reduce the cost by Rs 3.66.

To optimize returns from syrup production and reduce the cost of syrup production, sensitivity analysis was carried out with various scenarios. Thus there is scope to improve overall efficiency gains in labor, juice and syrup recovery and by-product utilization to reduce per unit cost of syrup production. One of the scenarios developed below shows that a modest increase in syrup and juice efficiency by 40%, decline in cost of labor by 40% and additional returns from utilization of bagasse for livestock feed by 15% will reduce cost of syrup production to Rs 17 kg^{-1} from Rs 25.65.

V. Summary and conclusions

The economic and financial viability analysis under the CU has shown that viability of ethanol production from sweet sorghum depends on the ethanol and feedstock pricing, besides the recovery rate of ethanol. A marginal improvement in recovery to 4.9 % from the current level of 4.5%, with feedstock price fixed at Rs1200 t^{-1} of stalk ethanol production becomes attractive at Rs 29 l^{-1}. The current administered price of ethanol in India is Rs 27 l^{-1}. With the rise in cost of cultivation of sweet sorghum, if the stalk price increases to Rs1500 t^{-1} with the recovery rate remaining the same at 4.5%, the price of ethanol has to be increased to Rs 36 l^{-1}. This analysis does not take into account the expected environmental benefits of producing ethanol from sweet sorghum due to unavailability of data. The economic viability assessment would become more attractive with the environmental benefits incorporated and can make a better case for justifying policy support. With further improvements in crop and processing technology for ethanol production, the overall profitability of sweet sorghum cultivation and processing can be increased.

The estimates on the demand side of ethanol blending show deficits from the current level of supply. The estimates show that the demand is going to outstrip supply. With the highest available alcohol from molasses at 2.3 billion l and further with the inability to increase area under sugarcane (due to adverse impacts on food production), the future supply of bioethanol has to be augmented through alternative feedstock. Hence, it calls for the attention of policymakers to provide policy support to the industries in the form of ‘infant industry sops’ in the initial years so that they can sustain the losses incurred in the beginning.

The potential food versus fuel conflict from the diversion of crop land for cultivation of sweet sorghum does not arise as it meets the multiple requirements of food, fuel and fodder for the smallholder farmers. Land requirement assessment for sweet sorghum cultivation has shown the area required for cultivation to be a modest 1.16mh with the assumption that 30% of the mandated 10% blending deficit is met from sweet sorghum at 20 t^{-1} ha productivity with 4.5 % recovery.

Given that grain sorghum area under rainy season in Maharashtra (the biggest state cultivating sorghum in India) has decelerated in the last decade, cultivation of sweet sorghum in these rainfed areas will provide income for farmers provided there is enabling environment in place to support ethanol production from sweet sorghum under CU. The relative economics augur well in the agro-ecological regions of Maharashtra and Andhra Pradesh where predominantly sorghum is cultivated. Since ethanol production is from the stalks the harvested grain from sweet sorghum it adds to the food basket and the diverted land for ethanol production will not compromise on food production.

The results of the economic assessment of crushing sweet sorghum and value addition under the DCU has shown that production of syrup can be made viable by improving yield of sweet sorghum stalks, system efficiencies such as crushing and labor use, and mechanization of the whole process. The decentralized system was managed by the growers of sweet sorghum (farmers' association). This was a new task area for them, and there are limitations of efficiency gains leading to high processing costs. The initial technology used for crushing the stalks was not tailor-made for a crop like sweet sorghum. The value realized by supplying syrup to the distillery was also low because of further processing costs incurred by the processor to convert it to bioethanol. Consequently, the decentralized unit was incurring losses. A major challenge, therefore, is to bring down the cost of processing syrup in the decentralized unit. In view of the potential benefits of syrup for bioethanol production and food industry, efforts should be made to improve the technology for processing of sweet sorghum syrup, reduce cost of bioethanol production, add value to bagasse utilization, and provide capital assistance for small-scale entrepreneurs. In the long run this will be a boon for smallholder farmers of rainfed regions as this will aid in development of agro-enterprise development at the village level and contribute in enhancing their income through generation of additional employment.

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Chapter IX: Sweet sorghum growing domains: Potential for up-scaling

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I. Introdution

Sweet sorghum cultivation as part of the NAIP-ICAR sub-project on the sweet sorghum to ethanol value chain was being pilot tested in Medak district of Andhra Pradesh (Map 1). Preliminary analysis of farm-level data from the project sites indicate that sweet sorghum is a commercially viable crop and is able to compete with other dryland crops such as grain sorghum, sorghum and pigeonpea intercrop and maize. One of the challenges before and after the completion of the project is up-scaling of sweet sorghum production to larger areas to make a viable alternative complement as feedstock for ethanol production. In this chapter we examine potential areas where sweet sorghum cultivation can be taken up in India. This is of course, subject to the establishment of a distillery in close proximity (50-100 kms from the farms).

II. Methodlogy Selection

In order to select appropriate sites for up-scaling sweet sorghum cultivation in India, meso-level district data, and expert opinions from crop scientists and extension agents were used. Geographically, the Deccan Plateau and the Eastern Ghats were selected as a suitable starting point as this region is the main sorghum growing region in the country and has a large area under rainfed crops. Eleven sub-regions were chosen based on shared common agro-ecological characteristics which would enable the easy location of the growing domains with the greatest potential for growing sweet sorghum. The coastal sub-regions were not considered as these typically had high rainfall and high irrigation potential, and therefore more suitable for high value crops. The agro-ecological zones are grouped using dominant soil types, climate, length of the growing period, normal rainfall and soil fertility (Table 1 and Map 2). In addition, the percentage of land under rainy season and postrainy season sorghum were also calculated to identify sub-regions which were already growing sorghum.

III. Potential domains for Cultivation

Of the eleven agro-ecological sub-regions, five were considered to be potential sweet sorghum growing areas. These are 6.1, 6.2, 6.3, 6.4 and 7.2. These sub-regions are mainly semi-arid environments (moist or dry) with the exception of 6.4 which is sub-humid (moist). Additionally these regions had more than 10% of the cropped area under either postrainy season or rainy season sorghum. The one exception to this was 7.2 that has a very low area under the crop (3% under rainy season sorghum and 1.5% under postrainy season sorghum), but this sub-region was selected as there are already other sweet sorghum for ethanol projects underway in this region. There is much variation between the sub-regions based on demographic criteria. With the exception of 6.4, all the sub-regions are predominantly rural with the population density ranging from 2.5 to 5.3 per ha (Table 2). In sub-regions 6.1, 6.2 and 6.4, the proportion of cultivators is higher whereas in 6.3 and 7.4, agricultural laborers form a bulk of the rural population. Three out of the five sub-regions show relatively low mechanization. The use of pump sets is also relatively low with diesel pump sets being the majority. Fertilizer application in the sub-regions is above 125 kg ha^{-1} but most of the fertilizer is being used on crops like fine cereals, cotton, vegetables and fruit crops. The fertilizer application for sweet sorghum as required under the improved package of practices is thus not perceived to be a stumbling block.

Map 1. Districts currently selected for sweet sorghum-ethanol value chain.

Table 1. Agro-ecological characteristics of selected AEZ for up-scaling sweet sorghum.

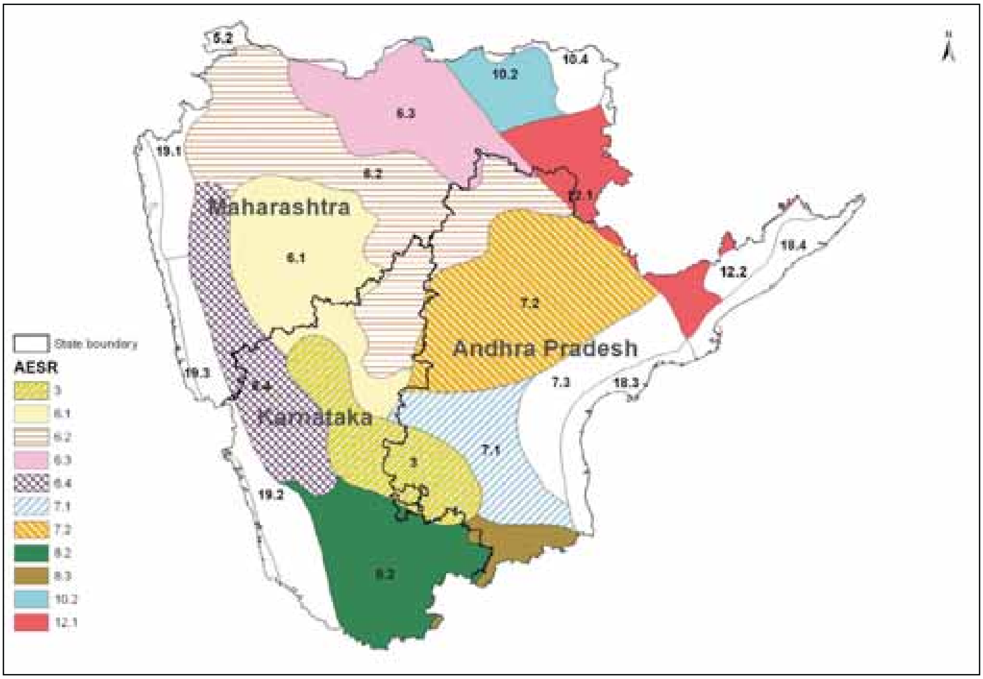
AEZ sub-region	Physiographic	Number of districts	Soil	Climate	Growing season (days)	Normal rainfall (mm)	Soil quality	Soil depth	Soil texture	Rainy season sorghum area ('000 ha)	Postrainy season sorghum area ('000 ha)
3	Deccan Plateau	5	Mixed red and black	Arid (typic)	60-90	592	Low to medium; 50-150 mm	Deep	Loamy and clayey	102.03 (5.23)*	209.62 (8.62)
6.1	Deccan Plateau	8	Shallow black (with medium and deep black soils as inclusion)	Semi-arid (dry)	90-120	686	Medium to high; 100-200 mm	Shallow and medium	Loamy	219.15 (2.58)	2499.30 (25.53)
6.2	Deccan Plateau	13	Shallow black (with medium and deep black soils as inclusion)	Semi-arid (moist)	120-150	885	Medium to high; 100-200 mm	Shallow and medium	Loamy: clayey 15-<35%	569.78 (8.02)	1325.05 (10.31)
6.3	Deccan Plateau	6	Deep black (with shallow and medium black soils as inclusion)	Semi-arid (moist)	120-150	935	Medium to high; 100-200 mm	Shallow	Loamy: clayey 15-<35%	452.70 (15.94)	46.70 (1.40)
6.4	Deccan Plateau	9	Shallow black (with medium and deep black soils as inclusion)	Sub-humid (dry)	150-180	1079	Medium to high; 100-200 mm	Shallow	Loamy: clayey 15 -<35%	164.17 (5.37)	766.54 (9.92)

Table 1. Agro-ecological characteristics of selected AEZ for up-scaling sweet sorghum.

AEZ sub-region	Physiographic	Number of districts	Soil	Climate	Growing season (days)	Normal rainfall (mm)	Soil quality	Soil depth	Soil texture	Rainy season sorghum area ('000 ha)	Postrainy season sorghum area ('000 ha)
7.1	Deccan Plateau	2	Mixed red and black	Semi-arid (dry)	90-120	677	Medium 100-150 mm	Shallow and medium	Loamy: clayey 15 -<35%	6.01 (1.29)	68.85 (9.40)
7.2	Deccan Plateau	8	Mixed red and black	Semi-arid (moist)	120-150	860	Medium to very high; 100-150;>200 mm	Deep	Loamy: clayey 15 - <35%	102.85 (2.91)	64.36 (1.52)
8.2	Deccan Plateau	10	Red loamy	Semi-arid (moist)	120-150	954	Low; 50-100 mm	Medium to deep	Loamy	56.74 (1.77)	15.56 (0.47)
8.3	Eastern Ghats & Tamil Nadu Uplands	1	Red loamy	Semi-arid (moist)	120-150	697	Low; 50-100 mm	Deep	Loamy	1.22 (0.23)	0.00 (0.00)
10.2	Deccan Plateau	2	Shallow black (with medium and deep black soils as inclusion)	Sub-humid (dry)	150-180	1193	Medium to high; 100-200 mm	Shallow and medium	Loamy: clayey 15 - <35%	32.50 (2.99)	3.90 (0.17)
12.1	Eastern Plateau	2	Red and lateritic	Sub-humid (moist)	180-210	1524	Low to medium; 50-150 mm	Deep	Loamy	7.00 (1.18)	19.10 (1.47)

Note: Rows highlighted are the selected sub-regions suitable for up-scaling.

*Figures in parenthesis indicates percent sorghum area to gross cropped area of the sub-region.



Map 2. Agro-ecological zones for up scaling sweet sorghum.

Table 2. Demographic characteristics of the selected agro-ecological zones.

AEZ sub-region	Total population ('000)	% Rural population	Proportion of cultivators (%)	Proportion of agricultural laborers (%)	Rural literacy (%)	Rural population density (number per ha)	Tractors (number per 100 sq km)	Diesel pumpsets (number per 100 sq km)	Electric pumpsets (number per 100 sq km)	Fertilizer consumption (kg ha^{-1})
6.1	24,839	67	24	17	58	2.6	0.6	6.6	0.6	131
6.2	32,191	73	21	19	52	2.9	0.4	6.6	0.6	138
6.3	13,622	73	15	28	64	2.5	0.4	3.8	0.5	125
6.4	35,462	42	24	16	59	3.5	1.6	6.4	0.9	164
7.2	25,874	67	16	23	43	5.3	1.9	27.1	1.2	269

Table 3. Cropping pattern in the selected agro-ecological sub regions.

AEZ sub-region	NCA ('000 ha)	% Irrigated land	Cropping intensity (%)	Fine cereals (% of GCA)	Coarse cereals (% of GCA)	Pulses (% of GCA)	Oilseeds (% of GCA)	Sugarcane (% of GCA)	Cotton (% of GCA)	Others (% of GCA)
6.1	6,386	25	122	10	48	15	14	8	3	2
6.2	7,998	18	128	9	31	24	15	5	15	2
6.3	3,931	8	130	6	14	27	23	1	29	0
6.4	4,206	31	118	14	37	12	15	10	5	7
7.2	3,282	46	119	8	18	14	12	2	16	29

Cropping pattern

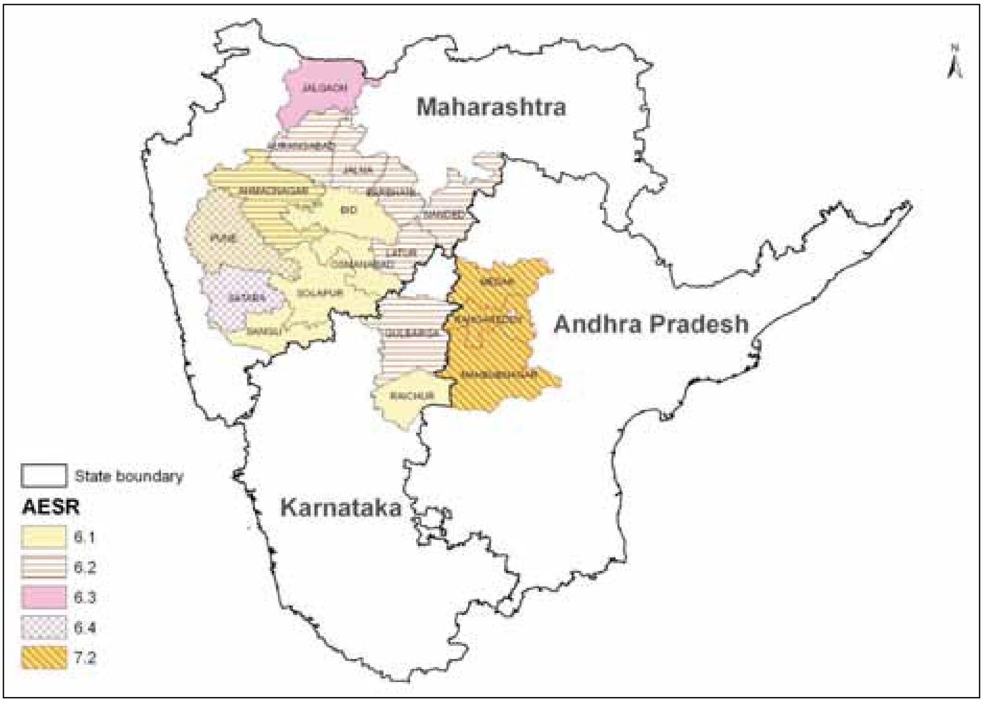
Sub-region 6.2 has the largest net cropped area among the five selected sub-regions (Table 3). The proportion of irrigated land varies widely between the sub-regions, ranging from 8% to 46%. Cropping intensity is relatively high in all the sub-regions. Coarse cereals dominate the cropping pattern of the sub-regions, the only exception being 6.3 where other rainfed crops such as pulses, oilseeds and cotton form the bulk of crops. Pulses are the second-most important crops planted in the sub-regions.

The agro-ecological sub-regions cover a large geographical area and are very diverse in their characteristics. Hence to better target sweet sorghum, the data on districts within each agro-ecological zone was also collected and analyzed. Based on this, eighteen potential districts were selected in the five agro-ecological zones. The details are given in Table 4. The majority of these districts fall in Maharashtra with two in northern Karnataka and three in Andhra Pradesh (Map 3). All the selected districts have over 50,000 ha under sorghum as on 2007 and are potential areas for the first phase of up-scaling sweet sorghum.

Table 4. AEZs and districts within the AEZs for upscaling sweet sorghum.

Agro-ecological sub-region	District
6.1	Raichur*
6.1, 6.2	Ahmednagar
6.1, 6.4	Pune
6.1	Sangli
6.1	Solapur
6.1	Beed
6.1	Osmanabad
6.2	Gulbarga*
6.2	Aurangabad
6.2	Parbhani
6.2	Nanded
6.2	Jalna
6.2	Latur
6.3	Jalgaon
6.4	Satara
7.2	Medak**
7.2	Mahaboobnagar**
7.2	Rangareddy**

*Karnataka, **Andhra Pradesh, rest in Maharashtra.



Map 3. Districts suitable for up-scaling sweet sorghum cultivation in the selected AEZs.

Chapter X: Sweet sorghum bagasse – An alternative feed resource for livestock

Y Ramana Reddy, N Nalini Kumari, M Blümmel and Ch Ravinder Reddy

I Introduction

Livestock production in the developing countries has been one of the most important economic and social activities of human culture. Among the livestock, ruminants have served and will continue to serve a valuable role in sustainable agricultural systems. They are particularly useful in converting vast renewable resources from rangeland, pasture and crop residues into food edible for humans. India has a huge ruminant population comprising of 210.2 million of cattle, 111.3 million buffaloes, 74.0 million of sheep, 154 million of goats, producing 117.0 million tons of milk and 3.4 million tons of meat (FAOSTAT 2010). Since 1970, there has been a consistent rise in the production of milk (4.7%) and meat (3.4%). Growth in livestock output, with the exception of milk, has primarily been driven by an increase in animal numbers. Yield growth in meat has been negligible, more so in the case of sheep and goats. Nutrition remains by far the most critical constraint to increased animal productivity and more efficient performance across the developing countries (ILRI 1995) with the perpetual gap between the demand and supply of digestible crude protein (DCP) and total digestible nutrients (TDN); about 35 and 37 per cent (Ramachandra et al. 2005).

The sustainability of number-driven growth in livestock output would be severely constrained by declining per capita land availability and feed and fodder scarcity, implying higher prices. Further, due to population boom, the available land is mostly diverted for cultivation of cereal and commercial crops to meet the urgent human needs resulting in decrease in land for fodder cultivation and forcing ruminants to depend on crop residues/agricultural by-products. The rising cost of conventional crop residues like sorghum stover, maize stover and paddy straw, which are widely used for feeding lactating animals, is a growing concern. Therefore, exploration of alternate sources of crop residues/agricultural by-products is urgently needed to increase fodder supply and to decrease feeding costs. Under the prevailing circumstances, one option is sweet sorghum bagasse, an agro-industrial by-product of the bioethanol industry.

Sweet sorghum (Sorghum bicolor (L.) Moench) is well adapted to the semi-arid tropics and is one of the most efficient dryland crops to convert atmospheric CO2 into sugar. The crop is more water-use efficient than sugarcane and is recently gaining importance as a feedstock for ethanol production. It is grown in areas with an annual rainfall range of 400-750 mm worldwide on about 44 million hectares in almost one hundred different countries. The major producers are the United States, India, Nigeria, China, Mexico, Sudan and Argentina. Sudan (8.95 m ha) is the largest sorghum grower in the world followed by India (8.45 m ha) and Nigeria (7.81 m ha). India is the third largest producer after USA and Nigeria with 7.15 m tons (FAO 2007). The selling of sweet sorghum stover to distilleries after grain harvest can provide much needed income for dryland farmers, but it also diverts biomass away from livestock, thus potentially worsening problems of feed scarcity. A crop yielding 20-30 ton fresh stalk ha^{-1} and 50% extractability would yield about 10.5-15.8 ton ha^{-1} stalk residue (Ashok Kumar et al. 2010). Recycling of bagasse (residue remaining after extraction of juice from the stems for ethanol production) together with the leaves (Fig. 1), which are mechanically stripped from the stem at the distillery, could compensate for some of the fodder loss. Where juice extraction for bioethanol production is centralized (Fig. 2), conversion of bagasse and stripped leaves into a marketable fodder would provide an additional source of revenue in a sweet sorghum value chain.

Fig. 1. Sweet sorghum bagasse.

Fig. 2. Extraction of juice from sweet sorghum stalks.

II. Physical evaluation

Physical processing methods like chopping, grinding and pelleting of the roughages increase the surface area, density and expose the lingo-cellulosic fractions for easy access to enzymatic digestion. The effect of processing can be evaluated by particle size, bulk density, modulus of uniformity, modulus of fineness and molasses absorbability of sweet sorghum bagasse (SSB). The average absorbability of molasses by ground SSB was 33.0% indicating that 100 kg of SSB has absorbed 33 kg molasses. An improvement of 62.5 per cent was observed in the bulk density of the chopped SSB to ground SSB with a reduction in particle size from 1.5-2.0 cm to 665.303±1.52 μ with 8 mm sieve. The modulus of uniformity (indicative of distribution of particles on coarse, medium and fine mesh screens, respectively) was 5:2:3 suggesting higher proportion of coarse particles. The modulus of fineness (indicative of coarseness of particles) was 5.33. The knowledge of physical characteristics of SSB is helpful in commercial processing and feed compounding.

III. Chemical evaluation

Laboratory analysis suggested that SSB contained 3.94% crude protein and it was comparable with sorghum stover (3.8%) and lower than maize stover (5.5%). The major elements Ca and P content was 0.82 and 0.47%, respectively and the trace elements Cu, Mn, Zn and Fe content of SSB was 57.40, 47.67, 48.78 and 0.27 ppm, respectively. The in vitro dry matter digestibility of SSB was 40.3%.The gross and metabolizable energy content (MJ kg^{-1} DM) of SSB was 16.85 and 7.34, respectively. Metabolizable energy content was higher in SSB compared to maize stover (7.01 MJ kg^{-1} DM) and comparable to sorghum stover (7.29 MJ kg^{-1} DM) (Fig. 3). The DCP value of SSB was .58 and 1.86% in Murrah buffaloes and Deccani sheep, respectively.

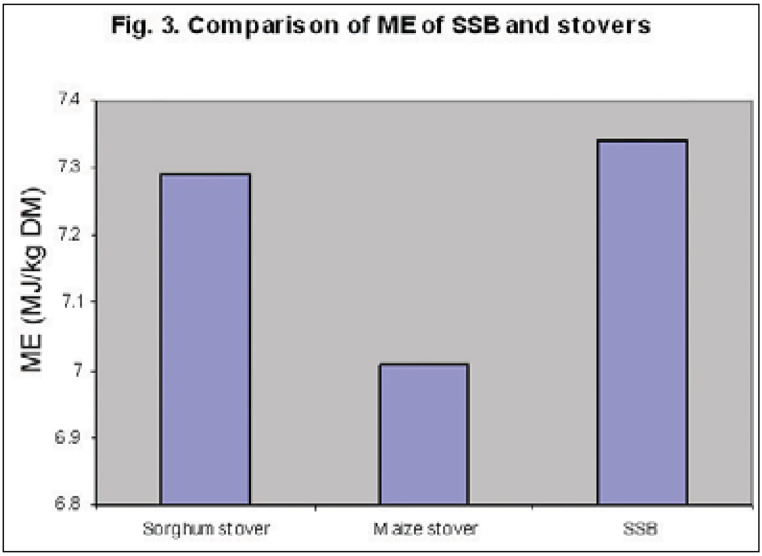


Fig. 3. Comparison of ME of SSB and stovers.

IV. SSB silage

After extracting the juice, the moisture content of the SSB along with leaves was around 50-60 per cent and an attempt was made to ensile the fresh material-whole and chopped without any further addition of moisture or additives to make it cost effective. Chopping is the most commonly used processing method which improves intake and avoids selective feeding. The results have shown that there was no significant difference between Deccani sheep fed chopped and unchopped SSB silage in intake and nutrient utilization. It revealed that the SSB can be made into silage in whole form without reducing the particle size as the disintegrated fibre during the extraction of juice makes the fiber to be acted upon by the microbes in the rumen similar to that of reduced particles in chopping.

Negative average daily gain (ADG), feed conversion ratio (FCR) and cost economics were recorded in lambs fed sole SSB silage in chopped form (Table 1). However, when SSB silage was supplemented with 170, 225, 280 g of concentrate, the ADG and feed efficiency in ram lambs supplemented with 280 g was significantly higher than those supplemented with 170 g concentrate and sole feeding, but the ADG was comparable with those supplemented with 225 g concentrate. Cost kg live weight gain was lower (P>0.05) by 18.5 and 3 per cent in growing sheep supplemented with 280 g concentrate in comparison to those supplemented with 170 and 220 g concentrate per day to SSB silage. Hence, supplementation of 280 g concentrate to SSB silage is economical in growing Nellore sheep.

Table 1. Effect of feeding SSB silage with different levels of concentrate supplementation on growth rate, feed conversion efficiency and cost economics in growing Nellore ram lambs

Parameter	Ration			
	Sole SSB silage	SSB silage+170g conc	SSB silage+220g conc	**SSB silage+280g conc**
Initial weight (kg)	14.05	14.05	14.00	14.00
Final weight (kg)**	11.91^{c}	18.53^{b}	20.20^{ab}	21.53^{a}
Total weight gain (kg)**	-2.14^{c}	4.48^{b}	6.20^{ab}	7.53^{a}
Average daily gain (g)**	-17.91^{c}	37.26^{b}	51.70^{ab}	62.76^{a}
Silage intake (kg/d)	1.12	1.12	1.07	1.13
Concentrate intake (g/d)	-	170^{c}	225^{b}	280^{a}
FCR (DM intake kg/kg gain)*	-19.61^{c}	13.61^{a}	10.38^{b}	9.67^{b}
Cost of feed/kg (₹) silage	1.25	1.25	1.25	1.25
Concentrate	11.09	11.09	11.09	11.09
Cost/ kg weight gain (₹)*	-77.98^{c}	88.18^{a}	74.18^{b}	71.95^{b}

$^{a, b, c}$ values bearing different superscripts in a row differ significantly *(P<0.05), **(P<0.01)

V. Processing of SSB

Any improvement in the nutritional quality of crop residues and agro-industrial by-products will enhance nutrient supply to the livestock. Nowadays there has been tremendous increase in the development and application of processing methods of feeds for ruminants. Processing methods reduce the wastage, increase the bulk density and increase palatability and feed consumption. It also contributes to the ease of handling, feeding, storage and transport.

In a complete feed, all feed ingredients inclusive of roughages are proportioned, processed and mixed into a uniform blend, which is freely available to the animal to supply adequate nutrients. The product is fed as sole source of nutrients. This system ensures the supply of balanced nutrients, controls the ratio of concentrate to roughage, helps in improved utilization of low grade fibrous agricultural residues. The complete feed can be prepared either in mash, block or pellet (expander-extrusion) form. The expander-extrusion system combines the features of expanding (application of moisture, pressure and temperature to gelatinize the starch portion) and extruding (pressing the feed through constrictions under pressure).

VI. Studies in buffaloes

Table 2. Effect of feeding differently processed sweet sorghum bagasse based complete diets on growth rate, feed efficiency and cost economics in Murrah buffalo bull calves.

Parameter	Complete ration			
	Sorghum stover mash	SSB		
		Chopped	Mash	Pellets
Initial weight(kg)	136.90	137.00	137.30	136.90
Final weight (kg) **	209.60 ^{b}	205.20 ^{b}	209.70^{b}	224.70^{a}
Weight gain (kg) **	72.70 ^{b}	68.20 ^{b}	72.40^{b}	87.80 ^{a}
Average daily gain(g/d) **	484.67 ^{b}	454.66 ^{b}	482.67 ^{b}	585.33 ^{a}
Feed intake (g/d) *	4.50 ^{ab}	4.42 ^{b}	4.49 ^{ab}	4.56 ^{a}
Feed conversion ratio (kg/kg gain) **	9.29 ^{b}	9.84 ^{b}	9.36 ^{b}	7.80 ^{a}
Cost of feed/kg (₹)	7.93	6.33	6.43	6.63
Cost/kg gain (₹) **	74.55^{a}	63.22^{b}	61.07 ^{b}	52.44^{c}

$^{a, b}$ values bearing different superscripts in a row differ significantly,*P<0.05; **P<0.01

SSB-based complete diets (roughage to concentrate ratio of 50:50) processed into chopped (Fig. 4), mash (Fig. 5) and expander extruded pellets (Fig. 6) were evaluated in growing Murrah buffalo bull calves in comparison to conventional sorghum stover based complete diet (50R:50C) in mash form.

Significantly higher feed intake (kg/d) was observed in buffalo calves fed expander extruded diet compared to those fed chopped ration which might be due to more palatability of expander extruded pelleted ration compared to chopped form (Table 2). Significantly higher average daily gain (Fig. 7) and lower feed conversion ratio (FCR) observed in buffalo calves fed expander-extruded pelleted ration compared to chopped, mash and sorghum stover mash rations might be due to higher feed intake and efficient digestibility of

Fig. 4. Concentrate and Chopped SSB.

Fig. 5. Mash form.

Fig. 6. Expander extruded pellets.

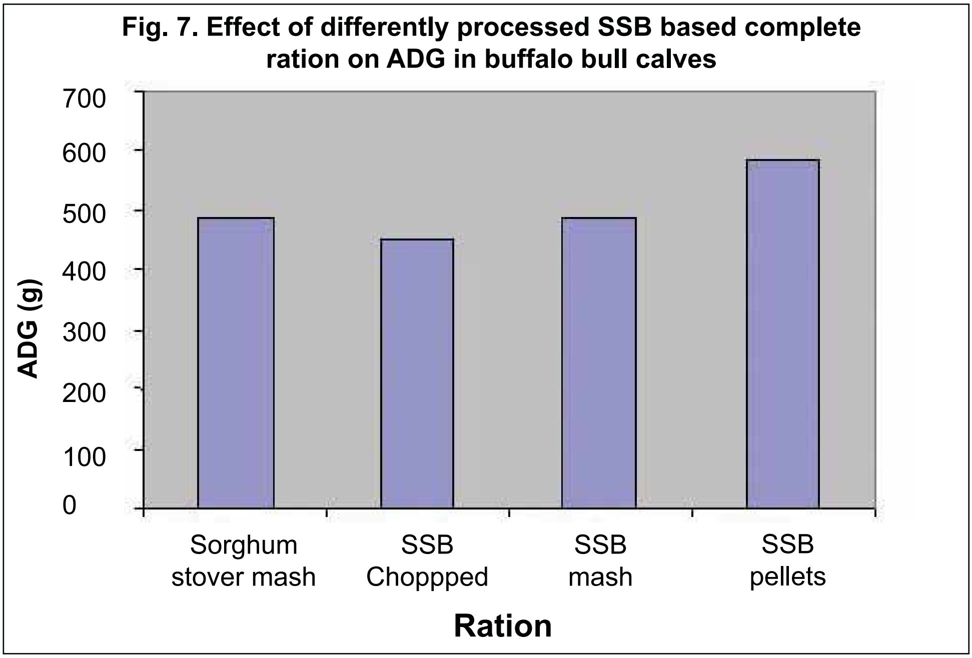


Fig. 7. Effect of differently processed SSB based complete ration on ADG in buffalo bull.

nutrients in expander-extruder rations than chopped and mash form of the rations. However, the average daily gain (g) and FCR was almost similar in buffalo calves fed either sorghum stover or SSB based rations in mash form (Table 2).

The cost per kg gain in buffalo calves fed expander-extruded pelleted ration was significantly lower (P<0.01) compared to those fed chopped, mash and sorghum stover mash rations due to lower FCR in pelleted ration as well as lower cost of SSB than sorghum stover.

In lactating graded Murrah buffaloes feed intake (kg/d) was significantly higher for pelleted ration in comparison to chopped form of SSB based ration but comparable among SSB based (chopped and mash form) and sorghum stover based (mash form) rations. The milk yield (Fig. 8), 6% FCM yield (kg/d) feed efficiency and total solids, solids not fat (SNF), milk fat and protein yields (g/d) (Fig. 9) was significantly higher in the buffaloes fed expander-extruded SSB based ration than those fed SSB based chopped, mash rations and sorghum stover based rations (Table 3). However, the total solids, SNF, milk fat and protein per cent in lactating graded Murrah buffaloes fed differently processed

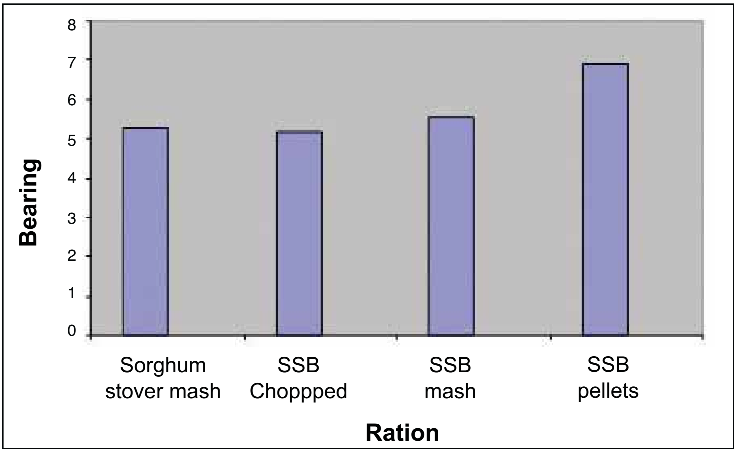


Fig. 8. Effect of differently processed SSB based complete ration on milk yield (kg/d) in lacting Murrah buffaloes.

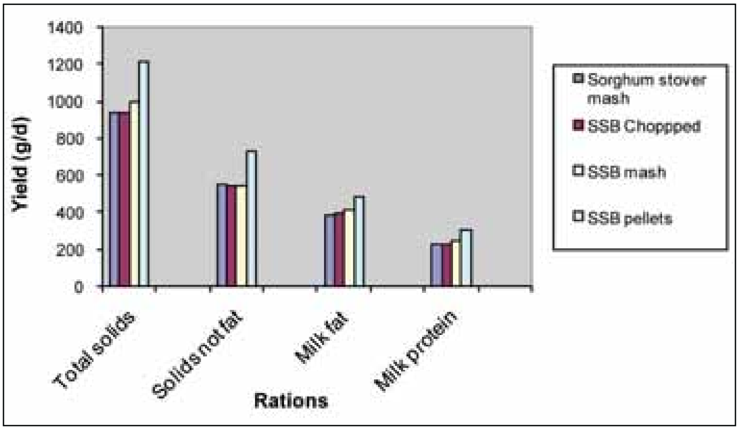


Fig. 9. Effect of differently processed SSB based complete diet on milk constituents.

SSB complete rations and sorghum stover complete mash were comparable. The higher daily milk, milk constituent and feed efficiency was due to efficient digestibility of nutrients in buffaloes fed expander-extruded ration than those fed chopped, mash rations and sorghum stover based rations, which in turn led to lower cost per kg milk yield and per kg FCM yield.

VII. SSB based complete feed blocks

A feeding trial with growing bulls was conducted at ILRI, comparing the SSB based (50%) complete feed block with sorghum stover based (50%) complete

Table 3. Effect of feeding differently processed SSB based complete rations on quality, quantity and economics of milk production in lactating graded Murrah buffaloes.

Parameter	Complete ration			
	Sorghum stover mash	SSB		
		Chopped	Mash	Pellets
Milk yield (kg/d)	5.29[b]	5.17[b]	5.54[b]	6.91[a]
6% FCM yield (kg/d)	6.29[b]	6.24[b]	6.51[b]	7.74[a]
Milk constituents yield (g/d)				
Total solids	937.92[b]	940.94[b]	998.31[b]	1217.54[a]
Solids not fat	549.10[b]	546.99[b]	546.69[b]	731.08[a]
Milk fat	388.82[b]	393.44[b]	411.62[b]	486.46[a]
Milk protein	228.53[b]	226.45[b]	242.65[b]	306.80[a]
Feed intake (kg/d)	12.04[a]	11.76[b]	12.13[a]	12.16[a]
Feed conversion ratio (kg/kg FCM)	1.91[b]	1.88[b]	1.86[b]	1.57[a]
Cost of feed/kg (₹)	7.93	6.33	6.43	6.63
Cost of feed/kg milk (₹)	18.26[a]	14.61[b]	14.29[b]	11.83[c]
Cost of feed/kg FCM (₹)	15.36[a]	12.11[b]	12.16[b]	10.57[c]

[a, b, c] values bearing different superscripts in a row differ significantly ($P<0.05$)

feed block. It is promising to observe that, there was no difference in feed intake between the SSB based block (7.52 kg/d) and sorghum stover based feed block (7.31 kg/d) fed bulls. There was also no significant difference between the daily live weight gains of the bulls fed SSB based block (0.73 g/d) and sorghum stover based feed block (0.82 g/d) which confirms the value of SSB as feed block ingredient (Blümmel et al. 2009).

VIII. Studies in sheep

The level of roughage and concentrate in the complete feed is of major importance for efficient utilization of dietary nutrients for production. Complete diets with different proportions of SSB in mash form were studied in growing lambs with an objective to determine the optimum roughage to concentrate ratio for economic meat production.

In the growth study, four complete diets containing 60, 50, 40 and 30% SSB were fed to growing Nellore x Deccani ram lambs (Fig. 10). The roughage to concentrate ratio did not significantly influence the total weight gain (kg) as well as average daily gain (ADG), feed intake and FCR (Table 4). Higher cost of feed/kg gain in 40% and 30% SSB based diets might be due to increased proportion of concentrates in the above diets. No significant difference and trend was observed in pre slaughter weight, empty body weight, carcass weights, dressing percentage, wholesale cuts and edible and non-edible portions of experimental animals. No significant variation could be seen in bone and meat yield (%) and their ratios in various wholesale cuts among dietary treatments. The roughage to concentrate ratio could not affect the chemical composition of meat. Hence, SSB can be included at 50 to 60 per cent level in the rations of growing ram lambs for economic meat production since there was no significant improvement observed in feed conversion efficiency compared to 50, 40 and 30 per cent levels.

Feeding of SSB based complete diet containing 50:50 roughage to concentrate ratio processed into chopped, mash, expander extruded form in comparison to sorghum stover based complete diet (50:50) in mash form in Nellore x Deccani ram lambs revealed that processing complete diets into different forms significantly influenced body weight gains of lambs (Fig. 11). The total weight gain, average daily gain and feed conversion efficiency of ram lambs fed expander-extruded SSB-based complete diet was significantly

Table 4. Average daily gain, feed conversion efficiency and cost of feeding in growing Nellore x Deccani ram lambs fed rations with different ratios of SSB and concentrate.

	Complete ration			
Parameter	60% SSB	50% SSB	40% SSB	30% SSB
Initial body weight (kg)	10.68	10.65	10.53	10.60
Final body weight (kg)	24.60	25.37	25.98	26.13
Average daily gain (g)	77.31	81.76	85.83	86.30
Feed intake (g/d)	866.82	847.53	867.45	853.10
Feed conversion ratio (kg feed/kg gain)	11.42	10.57	10.17	9.96
Cost of feed/kg (₹)	5.50	6.53	7.55	8.58
Cost/kg gain (₹)	62.83^{c}	69.00^{bc}	76.76^{ab}	85.43^{a}

$^{a, b, c}$ values bearing different superscripts in a row differ significantly (P<0.01)

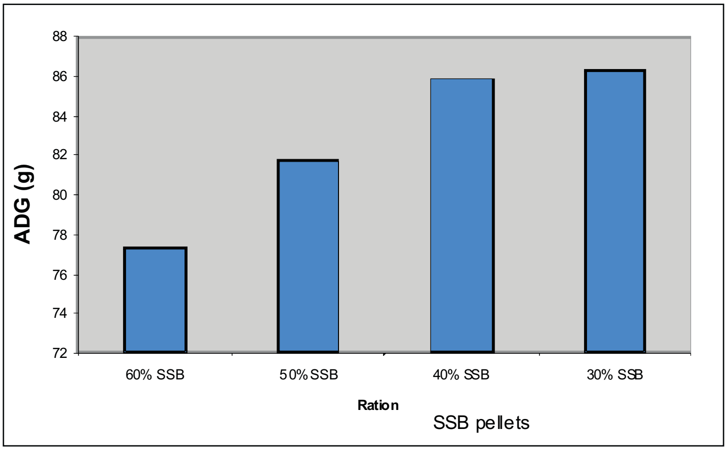


Fig. 10. Effect of different SSB to concentrate proportions of complete ration on ADG in Nellore X Deccani ram lambs.

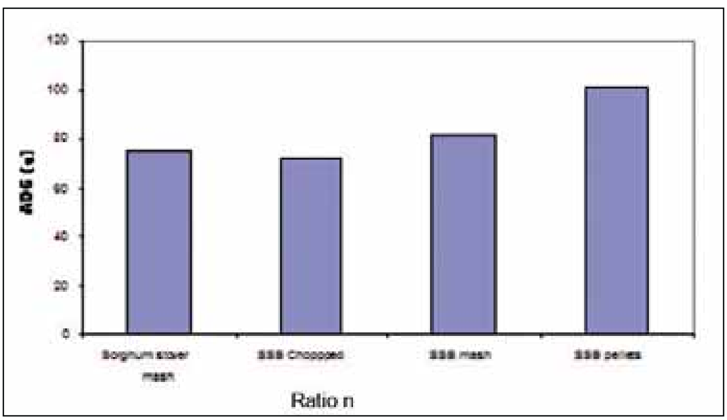


Fig. 11. Effect of differently processed SSB to concentrate proportions of complete ration on ADG in Nellore X Deccani ram lambs.

higher than chopped, mash and sorghum stover mash diets but it was comparable among SSB (chopped and mash form) and sorghum stover (mash form) based complete diets (Table 5). Though feed intake was not significantly different among all the rations, lambs fed pellet and mash diets consumed 16.74 and 6.14 per cent more compared to chopped form was due to the increased palatability.

Efficient utilization of absorbed nitrogen due to matching supply of energy and minerals provided optimum environment on pelleted diet reflected in an increased ADG. The expander-extruded SSB-based complete diet was more economical to gain one kg of body weight than the chopped and sorghum stover mash and it was comparable in ram lambs fed sorghum stover and SSB-based mash diets. The feed intake of lambs fed SSB mash and sorghum stover mash diet was comparable, which indicated the higher palatability and acceptability of SSB as roughage source and it was also equally acceptable and palatable with sorghum stover.

The pre-slaughter weight was significantly higher in lambs fed expander-extruded form ration compared to those fed chopped, mash and sorghum stover mash rations. The carcass weight of pelleted diet fed lambs was 33.37, 21.44 and 24.93 per cent higher than chopped, mash and sorghum stover mash diets. Processing could not influence the dressing percentage, proportions of whole sale cuts, edible and inedible portions, yield of visceral organs, and per cent yield of bone, meat and fat and bone, meat ratio in different wholesale cuts as well as carcass and meat quality.

Table 5. Effect of feeding differently processed SSB-based complete diets on growth rate, feed intake, feed efficiency and cost economics in growing Nellore x Deccani ram lambs.

Parameter	Complete ration			
	Sorghum stover Mash	SSB		
		Chopped	Mash	Pellets
Initial body wt. (kg)	10.57	10.57	10.65	10.53
Final body wt. (kg)**	24.13[b]	23.53[b]	25.37[b]	28.77[a]
Average daily gain (g)**	75.37[b]	72.04[b]	81.76[b]	101.30[a]
Feed Intake (g/d)	804.70	790.31	847.53	910.791
Feed conversion ratio (kg feed/kg gain)*	10.69[b]	11.13[b]	10.57[b]	9.05[a]
Cost of feed/kg (₹)	7.03	6.43	6.53	6.73
Cost/kg gain (₹)*	75.15[b]	71.56[b]	69.00[ab]	60.89[a]

Conclusion

Sweet sorghum bagasse (SSB), an agro-industrial by-product, can replace the traditional sorghum stover as feed resource for ruminants and it can be effectively conserved as silage. The SSB allows incorporation into complete feed at 50-60 per cent level in feeding of growing lambs to meet the growth requirements provided, sufficient digestible protein is made available in the form of concentrate in the ration for economic rearing of ram lambs. Further, feeding of complete rations in the form of expander-extruder pellets proved superior over chopped and mash form of SSB and mash form of sorghum stover rations in sheep and growing and lactating buffaloes.

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Chapter XI: Sweet sorghum bagasse – A source of organic manure

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I. Introduction

Bagasse or silage is an important by-product in the sweet sorghum-based ethanol industry. Above ground biomass distribution in sweet sorghum forms 90% of the total biomass produced and that includes stem, leaves and panicle with grain. It is estimated that bagasse makes 30% of the total biomass of sweet sorghum, which is composed of cellulose (15-25%), hemi cellulose (35-50%) and lignin (20-30%) with Net Calorific value: 4,125 Kcal kg^{-1} (ash free); depending on the genotypes (Grassi 2001). Approximate composition of sweet sorghum bagasse is given in Table 1. It is estimated that 6-7 kg of bagasse will be produced for every liter of ethanol produced from sweet sorghum. Even though bagasse has multiple uses such as being a source for energy cogeneration, animal feed and organic manure, it is important to work out the trade-offs between its uses as a source of bio-fuel and carbon balance in the whole production-to-consumption chain. In this context, recycling of bagasse into organic manure and using it in the crop husbandry is an environmentally safe measure of sequestering carbon in the soil. Sweet sorghum is promoted in the semi-arid regions where organic carbon content in the soil is generally low and the application of bagasse as organic manure assumes great importance for sustaining the soil fertility. The direct application of bagasse to the soil causes temporary lock up (immobilization) of soil nitrogen (N) due to wider C: N (~35:1) ratio and hence, it is important to bring down the C: N ratio by vermicomposting to use it as organic manure. Composting is the value addition method for enriching organic residues with low N content and this can be done either through microbial flora or along with earthworms. Generally, composting of organic residues with earthworms is referred to as vermicomposting, which is a rapid and simple method. The composition of vermicompost is superior in terms of macro and micro nutrients; besides, it is rich in plant growth promoting substances. The composting of sweet sorghum bagasse with earthworms is focused in the project and protocol was standardized for the same through laboratory and on farm trials.

Grassi (2001) reported that vermicompost prepared from sweet sorghum bagasse contains 35.5% carbon, 1.0% nitrogen, 7% ashes and 65.5% volatile matter.

Table 1. Chemical composition of sweet sorghum bagasse analyzed at ICRISAT.

Composition	Content (%)
Carbon	34.5
Nitrogen	1.0
pH	7.0
EC dS/m	3.9

II. Vermicomposting

Vermicomposting is a biological process by which earth worms are used to convert organic materials into compost. Various studies have shown that vermicomposting of organic waste accelerates organic matter stabilization (Neuhauser et al. 1988); (Frederickson et al. 1997) and gives a product rich in chelating and phytohormonal elements (Tomati et al. 1995) which has a high content of microbial agents and stabilized humic substances (Ferruzi 1986). Earthworms consume organic residues equivalent to their body weight and produce 50% of the total intake of organic residues as castings. In short, earthworms, through a type of biological alchemy, are capable of transforming garbage into 'gold' (Vermi Co 2001, Tara Crescent 2003). The worm castings are rich in available nutrients and microbial flora. There are nearly 3600 types of earthworms which are grouped under three types (Box 1).

Box 1

Anecic (Greek for "out of the earth") are burrowing worms that come to the surface at night to drag food down into their permanent burrows deep (3.5 m) within the mineral layers of the soil and produces 5.6 kg casts by ingesting 90 and 10 per cent of soil and organic wastes respectively.

Endogeic (Greek for "within the earth") are also burrowing worms but their burrows are typically shallower, feeding on the organic matter already in the soil and hence coming to the surface rarely.

Epigeic (Greek for "upon the earth") are living in the surface litter and feed on decaying organic matter. They do not have permanent burrows. These "decomposers" are the type of worm used in vermicomposting, which are typically 10 to 15 cm long consuming 90 percent organic waste materials and 10 percent of the soil. Example: Eisenia fetida and Eudrilus eugenae. *Source*: *Card et al. (2004)*

III. Protocol for vermicomposting

The protocol for vermicomposting developed at ICRISAT (Wani et al. 2002) included the following points.

- Vermicomposting involves two stages of decomposition for high cellulosic materials: initial microbial decomposition, followed by vermicomposting through inoculation with earthworms.
- The quantity of raw materials required are organic waste (low N and C
- rich materials) and cow dung slurry (as primer/starter for initiation of decomposition with microbes) in the ratio of 10:15.
- Rock phosphate is also recommended @ 2 kg for every 100 kg of organic materials for improving nutritional quality of the compost.
- Initially, layers of organic materials are spread to a thickness of 15-20 cm
- in the composting pit or tank, over which rock phosphate and cow dung slurry are sprinkled. Then, organic materials, rock phosphate and cow dung slurry are sprinkled repeatedly to a height of one meter from the ground level.
- Finally, the entire heap of materials is sealed with cow dung slurry and allowed for decomposition for 15 to 20 days during which temperature builds up due to microbial decomposition.

- Earthworms are released through cracks developed over the sealing of cow dung after the decomposition is completed. Normally 500-700 earthworms are required for decomposing 100 kg organic materials.
- The composting process is completed in 45 days from the time the earthworm are released into the heap. Low-value organic materials like weeds and parthenium are converted into value-added compost.

Fig. 1. Vermicompost preparation in rings.

Fig. 2. Vermicompost tank.

Fig. 3. Releasing earthworms.

Fig. 4. Sieving vermicompost.

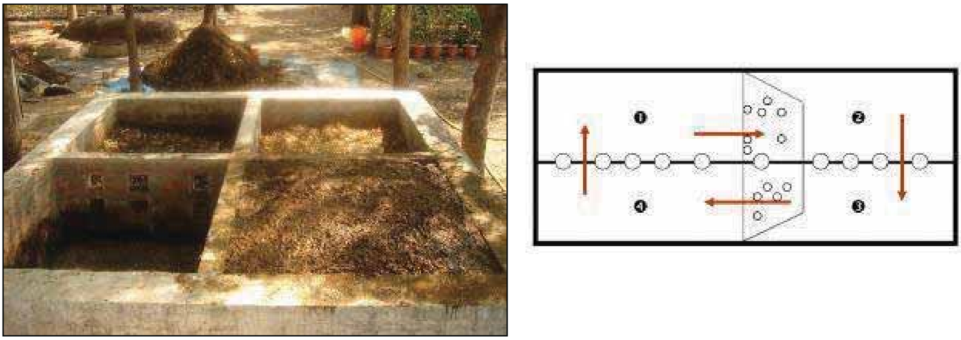

Fig. 5. ICRISAT commercial model with four chambers showing different stages of vermicomposting (left) and diagram showing the cycle of composting and movement of earth worms (right) Source: Nagavallemma et al. (2004).

IV. Commercial production of vermicompost

- The commercial model of vermicomposting developed in ICRISAT consists of four partitions. The walls contain holes that facilitate the movement of earthworms from one chamber to another after the composting process is completed, which helps to continuously generate composts and saves labor (Figs. 1-5).
- Vermicompost is generally applied by the farmers to high-value crops like vegetables and fruits.
- This commercial model is used by village women's self-help groups (SHGs) as a micro-enterprise for earning additional income, as well as a way to dispose of household and farm organic residues in environment-friendly manner. It also provides much needed organic manure for building soil health.

V. Recycling experiment using sweet sorghum bagasse (cement ring method)

An experiment on temperature dynamics during the process of vermicomposting was conducted at ICRISAT, Patancheru, India. Cement rings of 90 cm diameter and 30 cm in height were filled with sweet sorghum bagasse by adding cow dung slurry and rock phosphate on each layer of residue. Then the rings were completely sealed off with thick cow dung paste and watered at regular intervals (2 to 3 days). Both chopped (5-10 cm length) and unchopped bagasse of sweet sorghum was taken in different proportions along with cow dung slurry. Rock phosphate (2 kg) and earthworms (500-750 in numbers) were added in equal proportion in all the treatments and maintained at 50% water holding capacity.

VI. Temperature dynamics during the process

Temperatures in composting bins were recorded from the 3rd day onwards in the rings at every alternate day for about two months ie, before and after release of earthworms and atmospheric temperature was also recorded at the same time. The initial temperatures recorded in bins were very high ranging from 61^{o}C to 53^{o}C while after 15 days the temperatures decreased to 32^{o}C to 36^{o}C. Later there was a gradual decrease in temperature, which stabilized to 29^{o} C to 30^{o} C, which is suitable temperature for earthworm survival. Chemical analysis of bagasse revealed: N- 1.0175%, P -0.09% and K -0.375%.

VII. Compost harvest

Vermicompost prepared from chopped bagasse decomposed faster (within 140 days) than unchopped bagasse (upto 180 days) even though sweet sorghum bagasse overall took a longer period compared to parthenium. Harvested vermicompost was sieved through 2 mm sieve and earthworms were removed and reused for further vermicomposting.

VIII. Chemical parameters of vermicompost

Vermicompost prepared through this method was air dried at room temperature and used for analysis of chemical parameters. Results of analysis revealed that vermicompost prepared from unchopped bagasse showed higher values in all chemical parameters compared with chopped bagasse, and proved to be a rich source of all nutrients (Table 2). Bagasse and cow dung in the ratio 1:5 showed higher values of all chemical parameters followed by bagasse and cow dung in the ratio of 1:2 and 1:3.3.

Table 2. Chemical parameters of vermicompost prepared with sweet sorghum bagasse.

	Bagasse: Cow dung slurry							
	1:3.3		1:5		1:2		Mean	LSD
Parameters	C	UC	C	UC	C	UC	(log10)	(log10)
Chemical								
pH	6.8	7.0	6.7	7.2	6.9	7.1	7.0	0.5
EC dS/m	3.9	3.8	4.1	4.0	3.9	3.7	3.9	1.6
Avail-S in mg kg^{-1}	47.2	27.3	47.1	42.8	41.4	50.0	42.6	18.8
Avail-P in mg kg^{-1}	372.9	425.2	450.3	515.1	528.5	572.5	477.0	126.6
Exch-K in mg kg^{-1}	3280	4146	3811	4338	3797	4172	3924	1071
Exch-Ca in mg kg^{-1}	3170	2966	3414	3682	3543	3618	3399	603
Exch-Mg in mg kg^{-1}	2319	2358	2559	2669	2686	2699	2548	447
Exch-Na in mg kg^{-1}	340.2	598.8	331.9	350.9	339.1	333.9	382	297.9
Avail-Fe in mg kg^{-1}	2.1	1.4	2.4	2.1	2	2	2	0.88
Avail-Zn in mg kg^{-1}	16.3	20.4	27.4	53.1	62.5	28.7	348	50.3
Avail-Cu in mg kg^{-1}	5.8	5.5	6.5	7.8	7.6	8.2	6.91	3.09
Avail-Mn in mg kg^{-1}	27.4	24.7	27.1	30.2	27.4	27.6	27.4	6.6
OC %	8.3	8.7	10.2	11.2	11.2	9.6	9.9	3.8

Conclusion

There is scope for using the bagasse obtained from sweet sorghum as organic manure using the vermicomposting method. We can conclude that vermicompost prepared with sweet sorghum chopped bagasse and cow dung in the ratio of 1:5 has superior biological and chemical parameters and can be commercialized. Commercial scale model could provide valuable source of income for vulnerable groups in village and become an important value chain in disposing the by-product through a win-win approach. The project aims to standardize the economic aspects for preparing vermicompost considering the quantity of bagasse to be recycled through organic manure for registering positive carbon balance in the system. The economic design will be worked out in the context of micro enterprise for preparing vermicompost from bagasse in the decentralized model of sweet sorghum production.

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Chapter XII: Innovative use of sweet sorghum juice and syrup in food industry

Saikat Datta Mazumdar and Ch Ravinder Reddy

I. Introduction

Sugar is one of the vital ingredients in all types of processed foods. Sugar is also extensively used in the pharmaceutical industry. The price of sugar has been rising during last five years. World trade in sugar is expected to decline by 5%, constrained by reduced export availabilities in several sugar producing countries. As a result, and given a strong global demand, international sugar prices may well remain relatively high and volatile in the coming years[1]. This is attributed to low cane availability and increased sugar intake in several emerging and developing countries. Hence, the need for suitable sugar alternatives. Sweet sorghum juice, obtained from low water consuming, drought resistant, short duration and seed propagated sweet sorghum, is thus a suitable source to obtain syrup. This syrup can replace sugar in food and pharmaceutical industry applications, thereby reducing its dependence on sugar.

Sweet sorghum is a plant with C_4 photosynthetic pathway, so its photosynthetic rate and dry matter production in g/m^2 per day per unit of inputs are more than those of other sugar producing crops like sugarcane and sugar beet. These characteristics make sweet sorghum an ideal crop for syrup and jaggery production. Sweet sorghum is a special purpose sorghum with a sugar-rich stalk like sugarcane. Besides having rapid growth, high sugar accumulation and biomass production potential, sweet sorghum has wider adaptability. The sugar content in the juice extracted from sweet sorghum varies from 16-23% Brix. It is a good source of energy, protein, vitamins and minerals. The syrup obtained from sweet sorghum contains biologically active substances and micronutrients. The sweet sorghum syrup is a rich source of calcium, potassium and iron. It is also a rich source of natural antioxidants (ascorbic acid and other carotenoids). Sweet sorghum syrup cannot be easily crystallized into sugar because of its relatively higher content of reducing

[1] FAO (2010). Sugar Market analysis, Food Outlook. November 2010; http://www.fao.org/docrep/013/al969e/al969e00.pdf (accessed on 06.01.2011)

sugars as compared to cane sugar. Thus, there is an opportunity for product developers to explore the use of sweet sorghum syrup in applications where crystallization is not an issue.

Sweet sorghum syrup can be used in the preparation of food products without compromising on their sensory quality. The syrup is thus a natural source for effective sugar replacement in bakery items, energy bars, breakfast cereals, sugar confectionery, fruit and vegetable based products etc. Beverages can also be formulated using sweet sorghum syrup. Sweet sorghum cultivation and further value addition through conversion of the juice to syrup and beverages and its use as sugar alternative, offers farmers an excellent opportunity to improve farm income and productivity in semi-arid tropics of the world.

II. Innovative use of sweet sorghum syrup in the food industry

1. Food grade sweet sorghum syrup production

The NutriPlus Knowledge (NPK) Program of the Agribusiness and Innovation Platform (AIP), ICRISAT, developed an innovative method of clarification and processing of the sweet sorghum juice in order to produce food grade quality syrup. It involves the following steps:

A) Clarification of sweet sorghum juice

The freshly harvested sweet sorghum stalks were crushed in roller mill to extract the juice from the stalks. The collected juice was pre-heated for about 20 min at 70°C. The juice was then cooled down to 40°C. Further, the cooled juice was clarified using vacuum filtration. Vacuum filtration was carried out on a uniform bed of Celite® (filter aid), prepared on filter cloth. A filter press may be used for filtration during scale up of the process. The clarified juice thus obtained, was either used directly for preparing beverages or it can be converted into shelf-stable sweet sorghum syrup for use in different food product formulations as detailed in Section 3.

B) Preparation of sweet sorghum syrup

Clarified sweet sorghum juice was used to prepare syrup. The juice was heated and evaporated slowly. Concentration was carried out under uniform heating conditions with continuous stirring. As concentration increases, the boiling point also increases. It was thus important that heating is carried out under a low flame to avoid charring. During the concentration process frothing and scum formation occurs as a result of coagulation of remaining suspended particles, starch geletinization and protein denaturation. The scum was continuously removed.

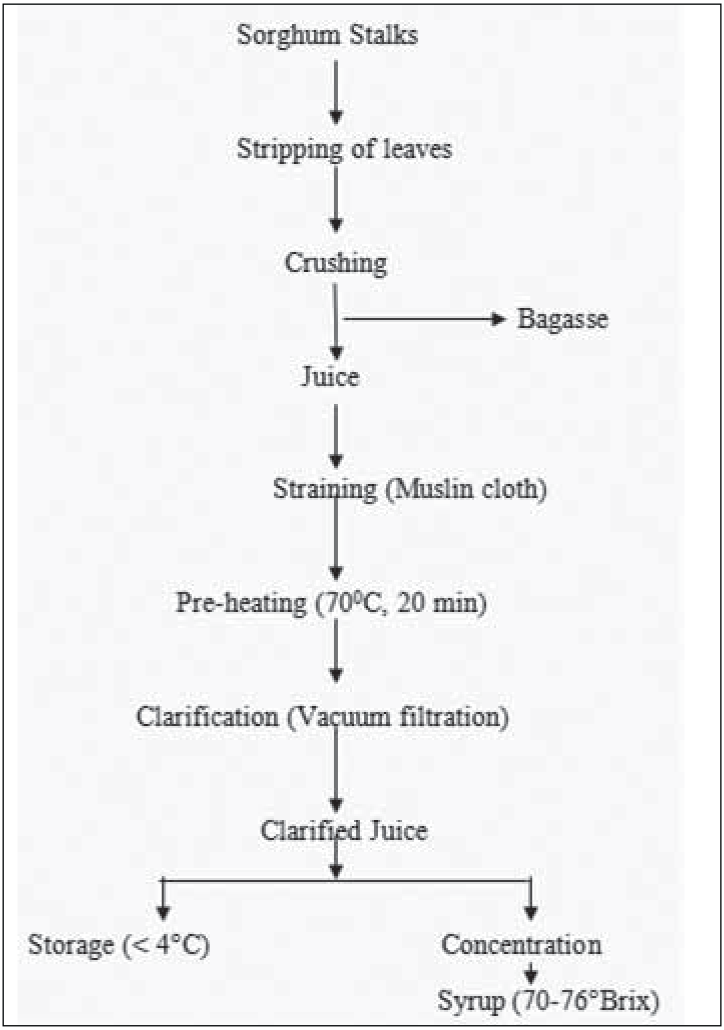


Fig. 1. Sweet sorghum juice extraction, clarification and concentration to syrup.

When the final Brix of concentrated juice (syrup) was 72 to 76% Brix, heating was completely stopped. The syrup was then cooled and stored in food grade containers under ambient conditions. The detailed steps involved in the sweet sorghum juice extraction, clarification and concentrating into syrup are presented in Fig. 1.

2. Shelf-life of sweet sorghum syrup

The physical and chemical composition of food helps determine the type of process required for its preservation. Factors that influence a choice of preservation method are the desired end product, type of packaging, cost and distribution methods. The two most important factors that affect how a food is preserved are water activity and acidity (pH).

Water content in any food sample includes moisture level, and what is even more important is the measurement of water activity. Water activity (a_w) refers to the level of available water in the food. Available water is water that is not bound chemically and is thus free for microorganisms to use. The water activity of pure water is 1.0 (or 100% relative humidity), a dry cracker has a water activity of about 0.2, and jam has a water activity of about 0.85. A low level a_w indicates less free water in the food and hence inhibits microbial growth. The sweet sorghum syrup produced in the range of 73 to 75% Brix had a_w varying between 0.60 to 0.75. Thus sweet sorghum syrup is an intermediate moisture food, similar to honey and can be stored at room temperature in air tight containers. Sweet sorghum juice has a_w of approximately 0.99 and hence susceptible to rapid microbiological spoilage.

The pH of food grade sweet sorghum syrup was in the typical range of 5.0-5.5. Thus given a combination of low a_w and acidic pH, it is possible to store sweet sorghum syrup under ambient conditions. However, it is important to ensure that no moisture ingress occurs into the product during storage.

3. Potential applications

Sweet sorghum syrup may partially substitute or completely replace sugar in the food and pharmaceutical industry. The sweet sorghum syrup can be used as an ingredient in the following food and pharmaceutical applications:

- Confectionary and ice-cream
- Fruit and vegetable products
- Beverages, syrup concentrates
- Bakery items
- Traditional sweets
- Extruded products and snacks
- Energy bars, energy drinks and sports drinks
- Nutraceutical formulations
- Medicated sweets
- Blended powders
- Syrups, elixirs
- Tablets, lozenges
- Capsules

4. Sweet sorghum-based food products developed by NutriPlus Knowledge Programme (NPK), ICRISAT

A number of food products were successfully formulated using the food grade sweet sorghum syrup (Fig. 2).

A) Ready-To-Serve (RTS) sweet sorghum-based beverage

A sweet sorghum-based, ready-to-serve (RTS) beverage was prepared using sweet sorghum syrup. Approximately, 6.0% of the syrup was used in formulating the product. Different flavored variants of the product were prepared (apple, peach, etc.). No artificial colors were added. The product is meant to be consumed directly as a refreshing drink and should be served chilled.

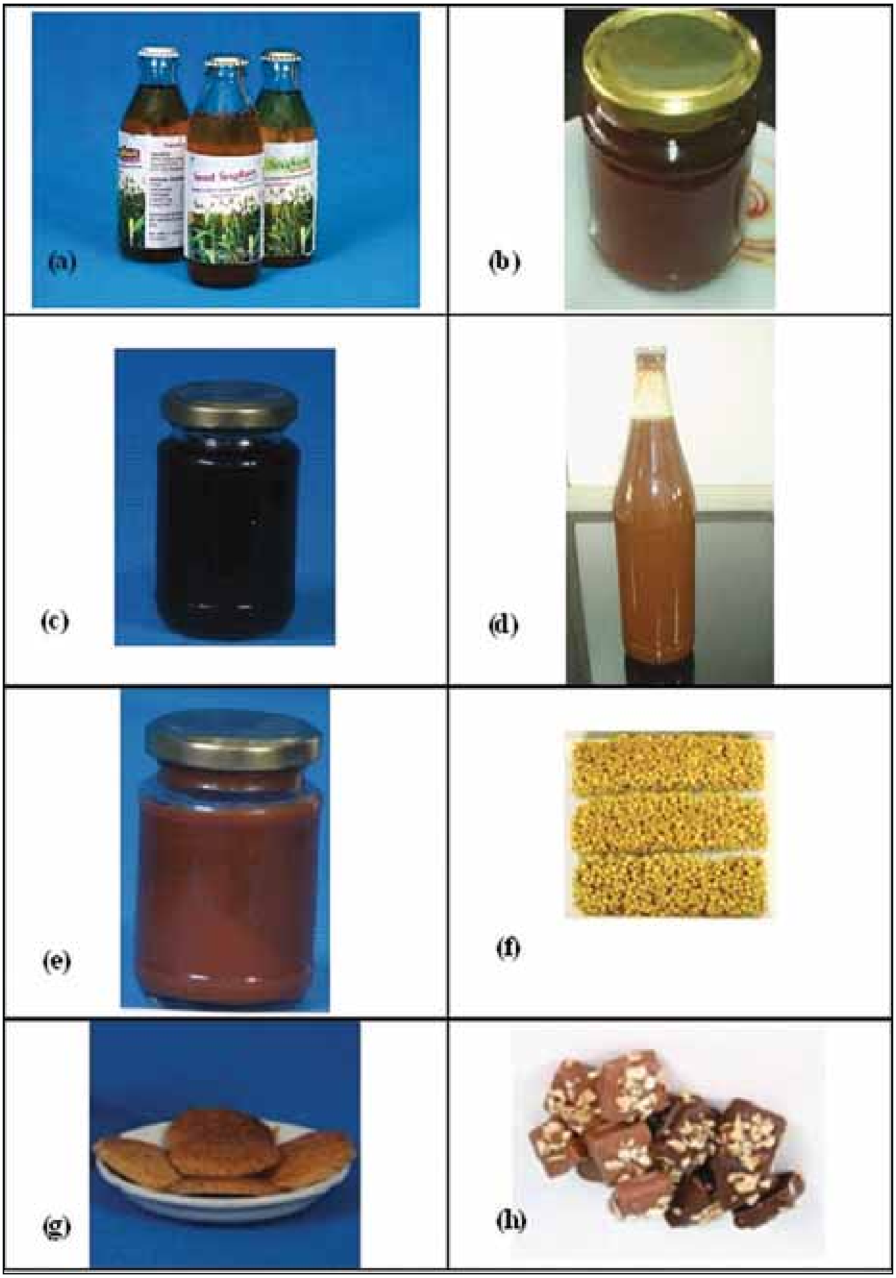


Fig. 2. Sweet sorghum-based food products: (a) Ready-To-Serve (RTS) Sweet sorghum-based beverage (b) Sweet sorghum-based mixed fruit jam (c) Sweet sorghum-based waffle syrup (d) Tamarind - Sweet Sorghum Sauce (e) Sweet sorghum-based tomato sauce (f) Sweet sorghum-based energy bar (g) Multi-grain cookies with sweet sorghum syrup (h) Sweet sorghum-based toffee.

B) Sweet sorghum-based mixed fruit jam

Sweet sorghum-based mixed fruit jam was prepared using a combination of sweet sorghum syrup and mixed fruit pulp (apple, banana, guava, papaya, grapes etc.). Approximately 18.0% of the syrup was used in the product formulation. The product can be consumed with bread, cakes, biscuits etc.

C) Sweet sorghum-based waffle syrup

Sweet sorghum-based waffle syrup was prepared using a combination of sweet sorghum syrup and apple extract. Approximately 15% of the syrup was used in the product formulation. The product can be consumed as a topping along with waffles. It can also be used as toppings in cakes, desserts, ice creams etc.

D) Tamarind–sweet sorghum sauce

Tamarind–sweet sorghum sauce was prepared using a combination of tamarind pulp and sweet sorghum syrup. The sweet sorghum syrup in the product also acts as an alternative sweetener and hence no sugar was required. Approximately 33% of the syrup was used in formulating the product. The product can be consumed as a tangy sauce along with different snack and savory products (samosa, sandwich, burgers etc.).

E) Sweet sorghum-based tomato sauce

Sweet sorghum-based tomato sauce was prepared using a combination of tomato pulp and sweet sorghum syrup. Approximately 8% of the syrup was used in the product formulation. The product can be consumed as a sauce along with different snack and savory products (samosa, sandwich, pizza, noodles, pasta, burgers etc.).

F) Sweet sorghum-based energy bar

A sweet sorghum based energy bar was prepared using low fat sweet sorghum crispies as one of the ingredients. The crispies were prepared from sweet sorghum grains using extrusion technology. In addition, sweet sorghum syrup was used as a binder and sweetener in formulating the product. Approximately 12% of sweet sorghum syrup was used in the binder formulation. The product is a healthy and ready source of energy and can be used as part of normal diet or as a source of energy in emergency and disaster management.

G) Multi-grain cookies with sweet sorghum syrup

The multigrain cookies were prepared using sweet sorghum flour, wheat flour and other cereal grains. Sweet sorghum syrup used in the product acts as an alternative sweetener, replacing sugar in the product. The syrup also imparts a typical flavor to the product. Approximately 18% of syrup was used in formulating the product. The product can be consumed directly as a snack product and has a good potential to be sold in coffee parlors etc.

H) Sweet sorghum-based toffee

Sweet sorghum-based toffee was prepared using sweet sorghum syrup along with milk solids and other ingredients. The product formulation used approximately 16% of the syrup.

5. Product packaging and storage

All bottled products can be packed in glass or PET bottles and should be stored in a cool and dry place. The products are shelf-stable at ambient conditions and should be refrigerated (4-10°C) after opening. The energy bar and cookies can be packed in laminated aluminum foil or other similar packaging materials. High molecular weight high density poly ethylene (HM-HDPE) or poly propylene (HM-HDPP) or other similar compatible laminates can be used for packaging of toffees.

III. Regulatory status of sweet sorghum

Sweet sorghum (Codex Code No. 0658) is classified under Group 021, Grasses for sugar or syrup production along with sugar cane[2]. In addition sweet sorghum molasses finds mention in the Codex, under "Miscellaneous derived edible products of plant origin" (Group 069) along with other similar edible products[3]. Hence the juice and syrup obtained from sweet sorghum can be used as a GRAS (Generally Recognized as Safe) substance.

Source: Codex classification of foods and animal feeds (http://www.codexalimentarius.net/download/standards/41/CXA_004_1993e.pdf).

Source: Codex classification of foods and animal feeds (http://www.codexalimentarius.net/download/standards/41/CXA_004_1993e.pdf).

IV. The way forward

ICRISAT's efforts are presently focused on the establishment and promotion of small-scale decentralized sweet sorghum crushing and syrup making enterprises in rural areas, with the aim of reducing poverty and improving the livelihoods of the smallholder farmers of the semi-arid tropics. As discussed, the NutriPlus Knowledge Program of the Agribusiness and Innovation Platform at ICRISAT has successfully developed sweet sorghum-based food products with complete or partial replacement of sugar with sweet sorghum syrup. In addition, ICRISAT conducts workshops and entrepreneur development programs on establishing and managing commercial sweet sorghum syrup enterprises. Further, it is now proposed to scale up the food grade syrup production process and commercialize the food grade sweet sorghum syrup and syrup-based products, in order to establish new market opportunities and linkages for developing a sweet sorghum food value chain.

Chapter XIII: Assessing sweet sorghum juice and syrup quality and fermentation efficiency

C Ganesh Kumar, R Nageswara Rao, P Srinivasa Rao, Ahmed Kamal, A Ashok Kumar, Ch Ravinder Reddy and Belum VS Reddy

I. Introduction

Sweet sorghum is a C4 crop with high photosynthetic efficiency with a unique ability of high carbon assimilation (50 g m^{-2} day^{-1}) and accumulates high concentrations of easily fermentable sugars (glucose, fructose and sucrose) in the stalks. Hence, it is widely believed that it is an alternate energy source that is renewable, sustainable, efficient, cost-effective, convenient and safe to use. Sucrose is the major sugar in sweet sorghum juice which constitutes up to 85% of the total sugars (Woods 2000). The sugar yields ranged between 1.6 to 13.2 Mg ha^{-1}, with significant variations observed between years and regions (Jackson et al. 1980; Reddy et al. 2007; Zhao et al. 2009). The juice sugar content is dependent on the crop stage, because fructose is more abundant at the early development stage, whereas sucrose tends to be dominant after heading (Sipos et al. 2009). The sweet sorghum juice sugar content ranged from 10 to 25 Brix% at maturity (Reddy et al. 2007; Ritter et al. 2004). Research at the International Crops Research Institute for the Semi-Arid-Tropics (ICRISAT) showed that sweet sorghum juice yield ranges between 16.8 to 27.2 m^3 ha^{-1} (Reddy et al. 2007) and accrues about 23% additional returns vis-à-vis grain sorghum (Rao et al. 2009).

II. Postharvest losses

Postharvest deterioration of sweet sorghum stalk, both qualitatively and quantitatively is a problem limiting the sustainability of the sweet sorghum value chain. If the time lag between harvesting to milling of the sorghum stalk is between 2 to 4 days, then it leads to huge losses in the recoverable sugars due to deterioration and souring of the harvested stalk. Weather conditions such as high temperatures and humidity also have a great impact on the stalk deterioration in tropics. In sweet sorghum, it has been observed that quality losses in stalk is primarily due to chemical (acid) and enzymatic inversion where the sucrose could be hydrolyzed to the respective reducing sugars (glucose and fructose) by the acid invertase enzyme (acid inversion of sucrose) which is secreted by few yeast species like Saccharomyces (Rao et al. 2012). As the stalk deteriorates the stalk deterioration products such as invert sugars, polysaccharides (eg, dextran, levan) and microbial contaminants (eg, ethanol and lactic acid formation) increase, all of which has a negative effect on processing. The primary disadvantage of the sweet sorghum value chain is the short shelf life of the juice due to its high sugar content which favors contamination by the spoilage microbes. Thus, the preservation and storage of sweet sorghum juice is needed for its further utilization in ethanol production (Wyman and Goodman 1993; Rao et al. 2012). Therefore, this chapter discusses the critical areas of sustainability of sweet sorghum value chain such as genetic variability of sugar yield vis-a-vis phenology, juice and syrup preservation, fermentation efficiency etc. The chemical analysis of the juice and syrup were determined using standard methods and procedures (Dubois et al. 1956, Miller 1959; Kumar et al. 2010).

III. Dynamics of sugar yield vis-a-vis phenology

The analysis of variance (ANOVA) revealed that the mean sum of squares of juice yield, Brix%, sugar yield, sucrose, glucose and fructose contents, and pH were significantly ($P \leq 0.05$) different at all the three different phenological stages, ie, dough, physiological maturity and post-physiological maturity (Table 1) across 19 improved cultivars indicating quantitative and qualitative changes in sugar yield and allied traits vis-a-vis crop phenology. The genotypes evaluated also exhibited highly significant ($P \leq 0.01$) differences for sugar related traits. However, there is significant genotype x stage interaction for juice yield, Brix% and glucose content, at $P \leq 0.05$ level, while highly significant genotype x stage interaction was observed for sugar yield, sucrose and fructose levels besides pH ($P \leq 0.01$). This data suggests that there is high degree of variability among the genotypes for the sugar yield and its components and offers opportunity to harness high sugar yield owing to genotypic differences, stage-wise differences and also from the significant interaction of genotype with phenological stage for sucrose content.

Table 1. Analysis of variance (ANOVA) for metric traits and biochemical parameters at three phenological stages.

Source	DF[+]	MS[++] for juice yield (t ha^{-1})	MS for Brix%	MS for sugar yield (t ha^{-1})	MS for sucrose (%)	MS for glucose (%)	MS for fructose (%)	MS for pH
Stage	2	546.45**	108.28**	13.24**	159.79**	8.99**	2.49**	0.95**
Replication	6	17.51*	1.12	0.15	0.87	0.28	0.12	0.29**
Genotype	18	25.22**	25.14**	1.08**	5.46**	0.52**	0.19	0.55**
Genotype x Stage	36	6.38*	3.97*	0.39**	4.27**	0.33*	0.28**	0.14**
LSD		3.34	2.59	0.36	0.52	0.15	0.13	0.09

[+]DF: Degrees of freedom; [++]MS: Mean squares

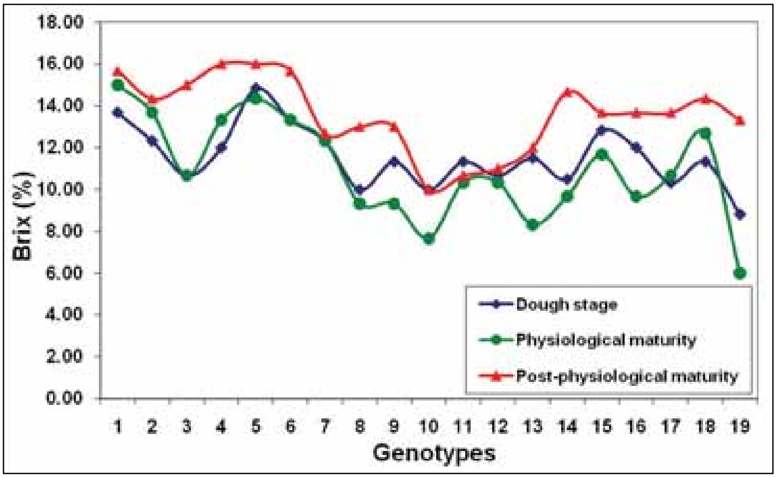
The juice yield at dough stage was highest and its variation among the 19 genotypes ranged between 3.03 (SP 4511-2) and 9.03 t ha^{-1} (ICSA 38 x ICSV 700); while the Brix (%), in the juice varied between 8.83 (JK Recova) and 14.83 (SP 4495) (Fig. 1a); sugar yield ranged between 0.37 (ICSA 84 x E 36-1) and 1.02 (ICSA 38 x ICSV 700) (Fig. 1b). The sucrose content (%), a major disaccharide in sweet sorghum juice that contributes to the bulk of non-reducing sugars, ranged between 2.58 (ICSA 702 x SSV 74) and 5.48% (SP 4495) at dough stage (Fig. 1c); The glucose content (%), a major monosaccharide in sweet sorghum juice which has a significant bearing on the ethanol yield, showed variation in a narrow range of 1.12 (ICSA 702 x SSV 74) and 2.94 (CSH 22SS) at dough stage (Fig. 1d). Another prominent monosaccharide in the juice, fructose (Fig. 1e) ranged between 1.05 (ICSA 702 x SSV 74) and 2.39% (CSH 22SS), while the pH was in a range of 4.97 (ICSA 38 x ICSV 700) and 5.6 (ICSA 475 x SSV 74) (data not shown).

The juice yield at physiological maturity among the 19 genotypes ranged between 12.08 (SS 2016) to 18.41 t ha^{-1} (SP 4487-3) with a mean of 14.64 t ha^{-1}; while the Brix (%) varied between 6.0 (JK Recova) and 15.0 (SP 4495) (Fig. 1a); sugar yield ranged between 0.89 (JK Recova) and 1.99 (ICSA 38 x ICSV 700) (Fig. 1b). The sucrose content (%) varied between 3.34 (ICSA 475 x NTJ 2) and 6.07 (ICSA 474 x SSV 74) at physiological maturity (Fig. 1c); The glucose content (%) showed variation in a narrow range of 0.83 (SP 4511-2) and 1.73 (JK Recova) with a mean of 1.53 showing a sharp decline of over

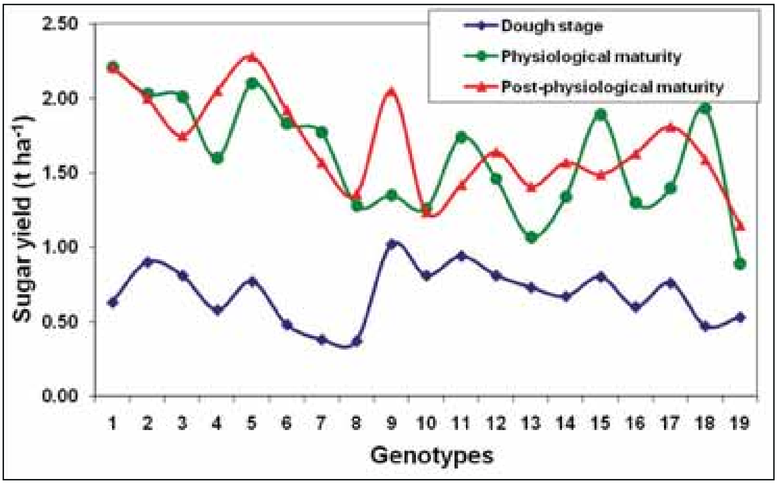
36.1% compared to that of dough stage (Fig. 1d). Fructose (Fig. 1e) ranged between 1.05 (ICSA 702 x SSV 74) and 2.39 % (CSH 22SS) with a mean of 1.59% showing a moderate increase of 16.1%, while the pH was in a range of 4.22 JK Recova) and 5.73 (SP 4511-3).

At post-physiological stage, the Brix (%) varied between 10.67 (ICSA 675 x ICSV 700) and 15.67 (SP 4511-3 and SP 4511-2) with a mean of 13.60% (Fig. 1a); sugar yield ranged between 1.15 (JK Recova) and 2.28 t ha^{-1} (SP 4495) with a mean of 1.69 tha^{-1} showing an increase of 146% over that of dough stage and 5.5% over that of physiological maturity (Fig. 1b). The sucrose content (%) varied between 4.73 (ICSA 38 x ICSV 700) and 11.15% (ICSA 475 x SSV 74) at post-physiological maturity (Fig. 1c) while the glucose content (%) showed variation in a narrow range of 1.07 (ICSA 475 x SSV 74) and 2.26 (ICSV 93046) (Fig. 1d). Another monosaccharide in sweet sorghum juice, fructose (Fig. 1e), ranged between 0.95 (JK Recova) and 1.67% (ICSA 675 x ICSV 700) while the pH was in a range of 4.97 (ICSA 38 x ICSV 700) and 5.6 (ICSA 475 x SSV 74) (data not shown).

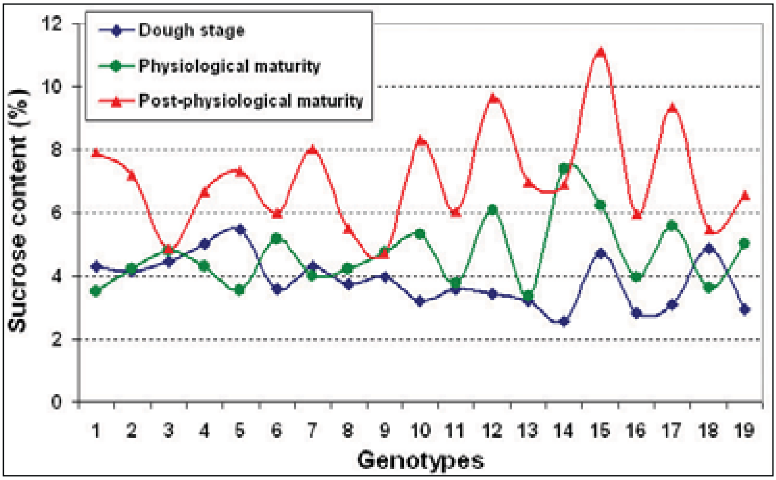
The overall mean of total soluble solids ie., Brix% was marginally high at dough stage, 11.57% vis-a-vis 10.96% at physiological maturity, but majority of the genotypes recorded the highest Brix% at post-physiological maturity as vindicated by the highest mean Brix% value of 13.6 owing to rapid accumulation of sucrose from dough stage (3.86%) to physiological maturity (4.67%) and also to post-physiological maturity (7.08%). It is reported in the literature that sucrose begins to accumulate after heading and shows maximum accumulation after the soft dough (McBee and Miller 1982) because the developing panicle represents a less competitive sink than elongating internodes (Lingle 1987). It was observed that there was about a two-fold increase of sucrose component in all the genotypes at post-physiological maturity ranging from 4.74% (ICSA 38 x ICSV 700) to 11.15 % (ICSA 475 x ICSA 74). A perusal of experimental data revealed that the reducing sugars, ie., glucose and fructose, did not increase significantly ($P \leq 0.05$) from dough stage to either physiological or post-physiological maturity in the 19 improved sweet sorghum varieties and hybrids. The mean glucose levels fluctuated between 1.35% at physiological maturity, 1.9% at post-physiological maturity, but peaking at dough stage (2.12%). However, the fructose level is highest at physiological maturity, 1.6% followed by dough stage 1.37% and post-physiological maturity, 1.18%. A bird's eye view of the overall data supports the observation that the relative percentages of each sugar present in the juice were approximately 70%, 20%



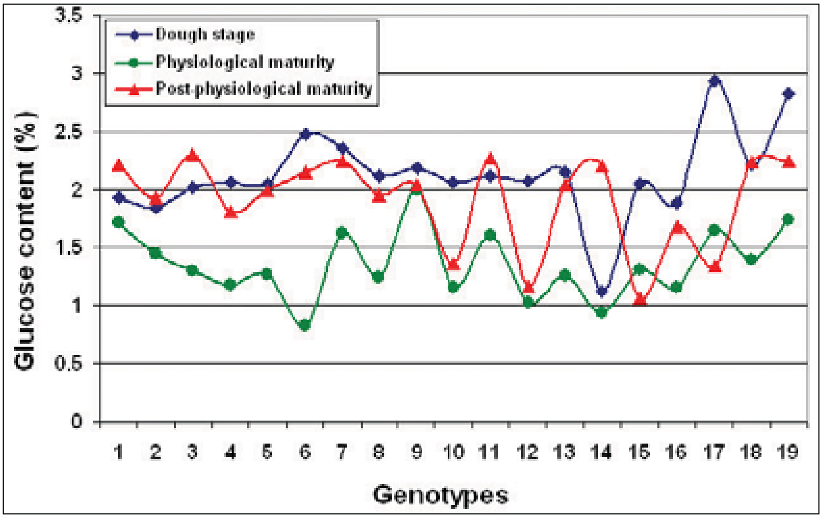
Brix (%)
Genotypes
Dough stage
Physiological maturity
Post-physiological maturity



Sugar yield (t ha-1)
Genotypes
Dough stage
Physiological maturity
Post-physiological maturity



Sucrose content (%)
Genotypes
Dough stage
Physiological maturity
Post-physiological maturity



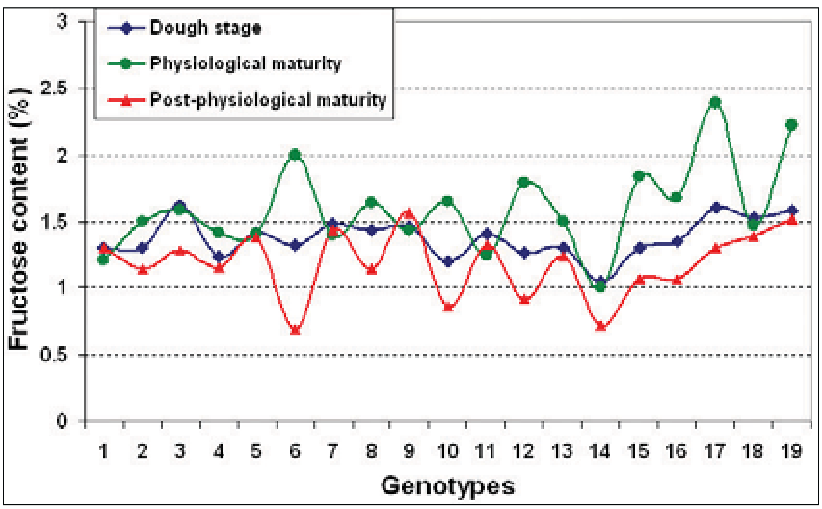


Fig. 1. Performance of sweet sorghum genotypes for (a) Brix (%) (b) sugar yield (t ha^{-1}) (c) sucrose content (%), (d)fructose content (%) and (e) glucose content (%) in three phenological stages (dough stage, physiological maturity and post-physiological maturity.

and 10% for sucrose, glucose and fructose, respectively. The incremental rise in sugar content during the physiological maturity stage has been attributed to decrease in the activity of amylases due to the aging processes and increase in temperatures during the maturation of the crop (Ikegaya et al. 1994; Channappagoudar et al. 2007). These observations shed light on the extent of variability for different sugars at three phenological stages and provide new window of opportunity in hybrids like ICSA 475 x SSV 74, ICSA 38 x ICSV 700 and varieties such as SP 4495 and SP 4511-3.

IV. Standardizing the storage conditions

Fresh sweet sorghum juice samples of two different cultivars, ICSV 93046 and CSH 22SS, stored at 4 and 15°C did not show any sugar losses, while marginal sugar losses were observed in juice samples stored at room temperature even after 24 hours of storage for both un-stripped and stripped juice samples, in case of both cultivars, ICSV 93046 and CSH 22SS (Table 2). It is concluded that temperature of 15-18°C would be ideal for storage of fresh sweet sorghum juice after crushing.

Table 2. Storage conditions of fresh sweet sorghum juice of two different cultivars, ICSV 93046 and CSH 22SS, at different time and temperature intervals.

S. No.	Cultivar	Temp. (°C)	Brix (%)	pH	Glucose (%)	Fructose (%)	Sucrose (%)
After 4 h							
1	ICSV 93046 (Unstripped)	4	14	5.71	2.36	2.49	5.47
		15	14	5.72	2.39	2.52	5.52
		RT	13.8	5.70	2.37	2.49	5.47
2	ICSV 93046 (UnStripped)		13	5.62	2.57	2.69	5.76
		15	13	5.72	2.62	2.71	5.77
		RT	12.9	5.61	2.58	2.67	5.74
3	CSH 22SS (Unstripped)	4	12	5.48	2.21	2.24	4.61
		15	12	5.63	2.24	2.26	4.62
		RT	11.8	5.46	2.23	2.27	4.59
4	CSH 22SS (Unstripped)	4	11.5	5.37	2.34	2.36	4.82
		15	11.5	5.49	2.36	2.37	4.83
		RT	11.4	5.35	2.32	2.36	4.81

Continued

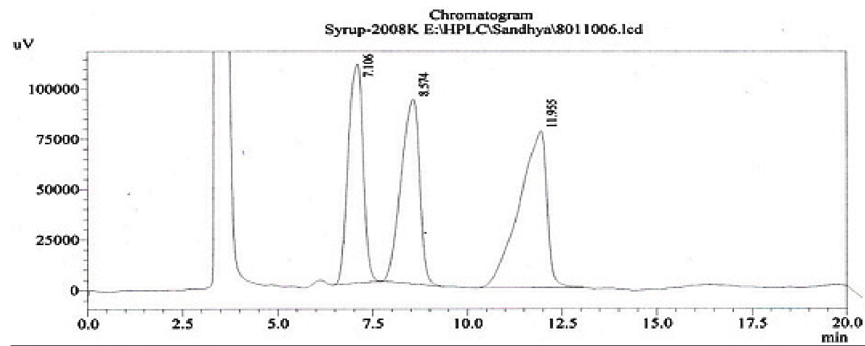
Continued

Table 2. Storage conditions of fresh sweet sorghum juice of two different cultivars, ICSV 93046 and CSH 22SS, at different time and temperature intervals.

S. No.	Cultivar	Temp. (°C)	Brix (%)	pH	Glucose (%)	Fructose (%)	Sucrose (%)
After 8 h							
5	ICSV 93046 (Unstripped)	4	14	5.72	2.34	2.46	5.46
		15	14	5.73	2.38	2.51	5.52
		RT	13.6	5.70	2.27	2.38	5.39
6	ICSV 93046 (Unstripped)	4	13	5.64	2.54	2.67	5.74
		15	13	5.65	2.59	2.70	5.76
		RT	12.8	5.60	2.46	2.57	5.67
7	CSH 22SS (Unstripped)	4	12	5.49	2.19	2.22	4.60
		15	12	5.50	2.23	2.24	4.61
		RT	11.7	5.46	2.17	2.19	4.47
8	CSH 22SS (Unstripped)	4	11.5	5.37	2.32	2.33	4.81
		15	11.5	5.40	2.34	2.36	4.82
		RT	11.3	5.33	2.24	2.25	4.73
After 24 h							
9	ICSV 93046 (Unstripped)	4	14	5.74	2.32	2.43	5.44
		15	14	5.74	2.38	2.51	5.47
		RT	13.5	5.7	2.19	2.24	5.27
10	ICSV 93046 (Stripped)	4	13	5.65	2.52	2.64	5.72
		15	13	5.67	2.57	2.69	5.74
		RT	12.8	5.6	2.37	2.46	5.54
11	CSH 22SS (Unstripped)	4	12	5.49	2.17	2.21	4.57
		15	12	5.52	2.21	2.23	4.58
		RT	11.7	5.41	2.06	2.08	4.31
12	CSH 22SS (Unstripped)	4	11.5	5.38	2.31	2.31	4.79
		15	11.5	5.41	2.32	2.34	4.81
		RT	11.1	5.3	2.18	2.17	4.64

Studies on syrup quality at different Brix% levels: Syrup samples of different Brix% values were collected from decentralized crushing unit (DCU) located at Ibrahimabad, Medak, Andhra Pradesh, India for storage studies: 4 samples with 40, 50, 60 and 70% Brix and 3 samples with 50, 60 and 65% Brix. Based on these results, it was observed that the syrup of different

Brix% values could be stored for one year; however, a slight deterioration was observed in total soluble sugars (%) and reducing sugars (%) values on storage of these samples. The chromatograms of syrup of 2008K are shown in Fig. 2. The chemical analysis of different syrup samples of Kharif (K) seasons for the years 2008, 2009, 2010 and 2011 were analyzed and shown in Table 3.



Detector A Ch1

Peak	Name	Ret Time	Area	Area%
1		7.106	3001132	29.809
2		8.574	3126643	31.055
3		11.955	3940251	39.136
Total			10068025	100.000

Fig. 2. Chromatogram of syrup of 2008K (1 year stored).

Table 3. Chemical analysis of syrup samples of kharif crop seasons for the years 2008, 2009, 2010 and 2011.

			2008K					
S. No.	Parameters	Analysis Method	(Fresh)	(1 year stored)	(2 years stored)	2009K (fresh)	2010K (fresh)	2011K (fresh)
1	Brix	Brixmeter	85	80.2	80	10	67	75
2	Calorific value	CA[a]	3730	2830	2940	2360	2772	ND
3	TSS (% wt)	UV[b]	75.3	73.2	94.98	42.8	95.12	78.98
4	Total reducing sugars (% wt)	UV	31.3	29.7	32.0	20.4	32.4	ND
5	Ash (% wt)	CA	3.6	3.6	3.05	0.12	2.64	2.84
6	Riboflavin	HPLC[c]	5791	2642	11	1243	10	84
7	Vitamin C (% wt)	IC[d]/HPLC	23	0.7	85	34	33	34

Continued

Continued

Table 3. Chemical analysis of syrup samples of kharif crop seasons for the years 2008, 2009, 2010 and 2011.

S. No.	Parameters	Analysis Method	2008K (Fresh)	2008K (1 year stored)	2008K (2 years stored)	2009K (fresh)	2010K (fresh)	2011K (fresh)
8	Nicotinic acid	HPLC	4	4	9	2	2	16
9	Benzoic acid (ppm)	HPLC	38	7	25	2	6	27
10	Iron (ppm)	AAS[e]	76.4	69.6	65.2	45.9	75.1	224.1
11	Calcium (ppm)	AAS	2455	2100	1909	400	770	759
12	Sodium (ppm)	AAS	1945	8400	1515	1300	662	442.9
13	Potassium (ppm)	AAS	11603	17500	9763.5	9300	9870.5	8100
14	Phosphorus (% wt)	CA	0.1	0.005	ND[g]	0.024	ND	ND
15	Sulphur (% wt)	CA	0.0	0.89	ND	0.68	ND	ND
16	Glucose (% wt)	HPLC	16.2	20.62	17.07	18.89	17.50	19.8
17	Fructose (% wt)	HPLC	5.6	17.79	14.93	14.87	14.92	15.3
18	Sucrose (% wt)	HPLC	45.0	20.63	23.62	10.25	16.28	23.4
19	Maltose (% wt)	HPLC	Nil	Nil	Nil	Nil	Nil	Nil
20	Other sugars (% wt)[f]	HPLC	Nil	Nil	Nil	Nil	Nil	Nil
20	Free acids (% wt)	Volumetric	0.5	0.52	ND	0.56	ND	ND
21	pH	pH meter	5.6	5.49	5.1	5.47	5.0	5.22

[a]CA – Chemical analysis

[b]UV – UV Spectroscopy

[c]HPLC – High Performance Liquid Chromatography

[d]IC – Ion Chromatography

[e]AAS – Atomic absorption spectroscopy

[f]Sugars analyzed: Xylose, Ribose, Galactose, Mannose, Arabinose

[g]ND – Not determined

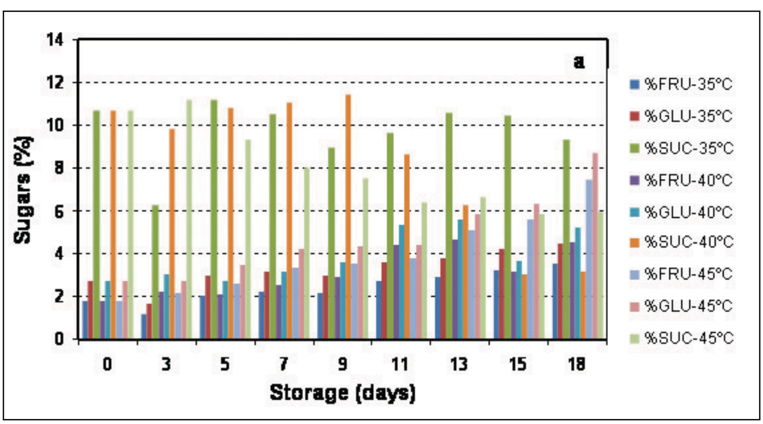
K- Kharif

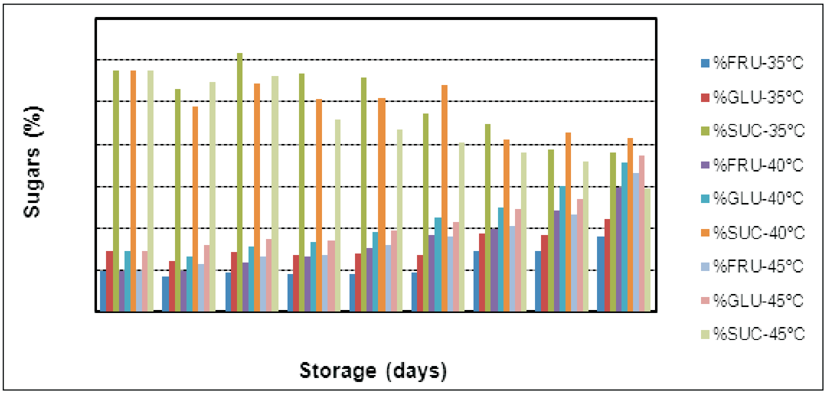
2. Effect of pasteurization treatment on the shelf life of juice

The percentages of the individual sugars like glucose, fructose and sucrose as a function of time did not reveal much variations in the sugar levels on storage for 10 days (Fig. 3 a-c). The experimental data suggests that pasteurization at 80°C for 10 min and storage of juice at a temperature of 35°C was recommended as a good treatment method for enhancing the storage shelf life of the juice.

3. Effect of chemical preservatives on the shelf life of juice

Storage studies were carried out on sweet sorghum juice samples spiked with different chemical preservatives like benzoic acid, sodium benzoate, sorbic acid, citric acid, sodium citrate and ascorbic acid at 1000 parts per million (ppm). The results on the analysis of the amount of total soluble sugars and the percentages of the individual sugars like glucose, fructose and sucrose as a function of time decreased significantly in the juice samples spiked with citric acid (Fig. 4a), sodium citrate (Fig. 4b), ascorbic acid (Fig. 4c) and benzoic acid (Fig. 4d), as compared to the juice samples spiked with sodium benzoate (Fig. 4e) and sorbic acid (Fig. 4f). It was also observed that the amount of reducing sugars increased, while the amount of non-reducing sugars decreased with increase in the storage time. The fructose and glucose content increased from 1.69% to 3.42% and 3.07% to 5.41%, respectively, while sucrose content decreased from 8.27% to 0.87% in sodium benzoate-spiked samples as depicted in (Fig. 4e). The sorbic acid-spiked samples showed an increase in fructose and glucose content from 1.47% to 3.3% and





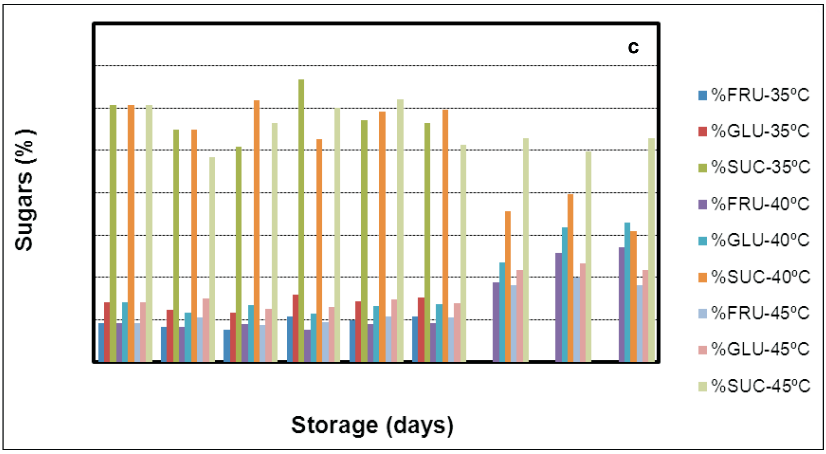
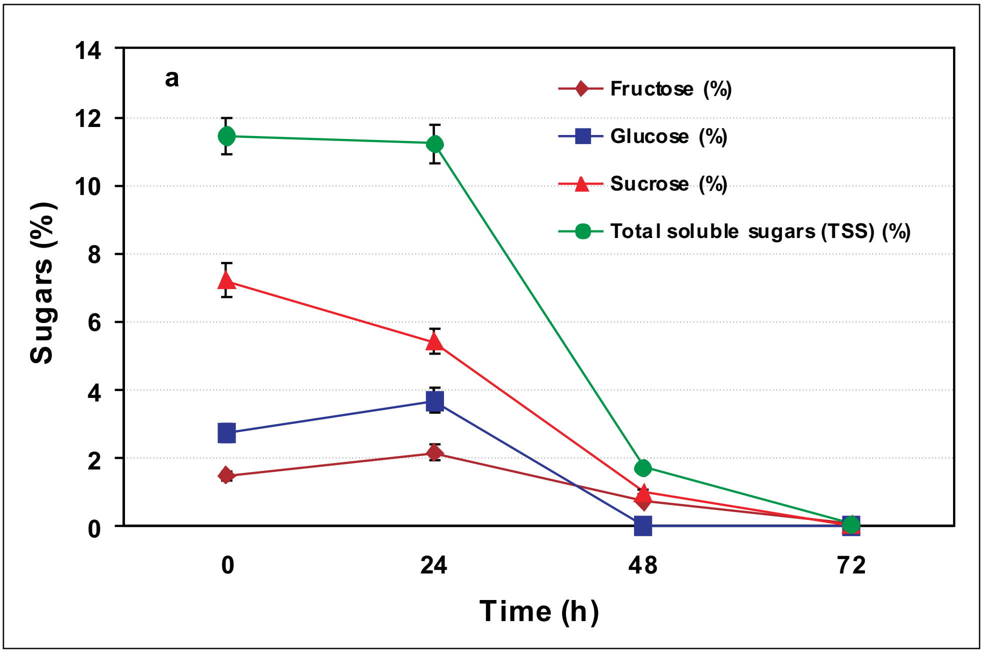


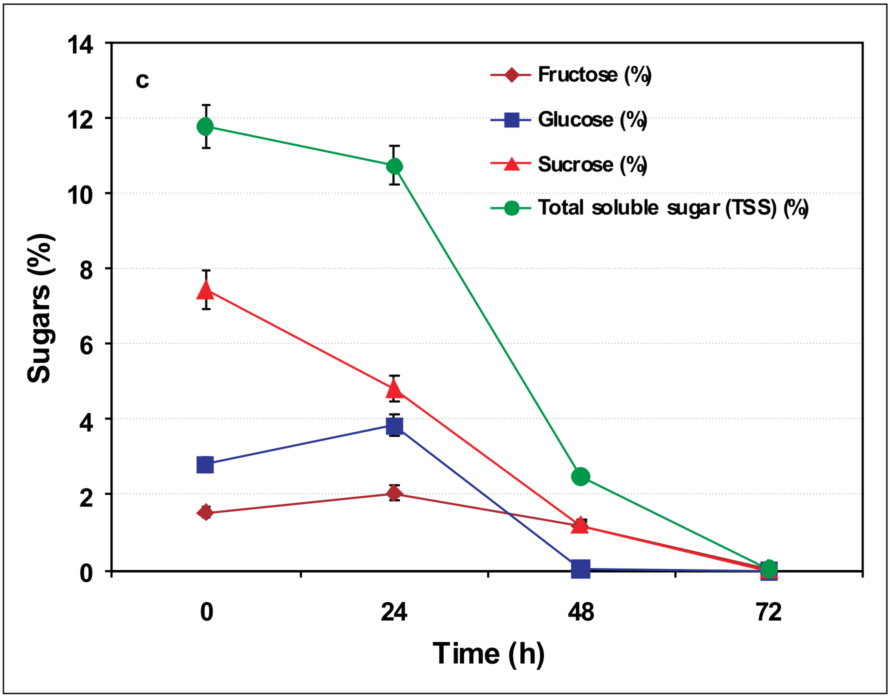
Fig. 3. Effect of pasteurization: (a) 70°C for 15 min, (b) 80°C for 10 min, and (c) 90°C for 5 min, as a function of time on the storage shelf life of sweet sorghum juice.

2.7% to 5.84%, respectively, whereas sucrose content decreased from 7.18 to 1.02% as evident from Fig. 4f. The total soluble sugar content decreased from 13.03% to 9.7% and 11.35% to 10.16% for sodium benzoate and sorbic acid-spiked samples, respectively. Based on these results, sodium benzoate and sorbic acid were identified as most suitable preservatives to enhance the storage shelf life of the sweet sorghum juice for 72 h.



a
Fructose (%)
Glucose (%)
Sucrose (%)
Total soluble sugars (TSS) (%)
Sugars (%)
Time (h)
0
24
48
72
0
2
4
6
8
10
12
14

Fig. 4a.



c
Fructose (%)
Glucose (%)
Sucrose (%)
Total soluble sugar (TSS) (%)
Sugars (%)
Time (h)
0
24
48
72
0
2
4
6
8
10
12
14

Fig. 4b.

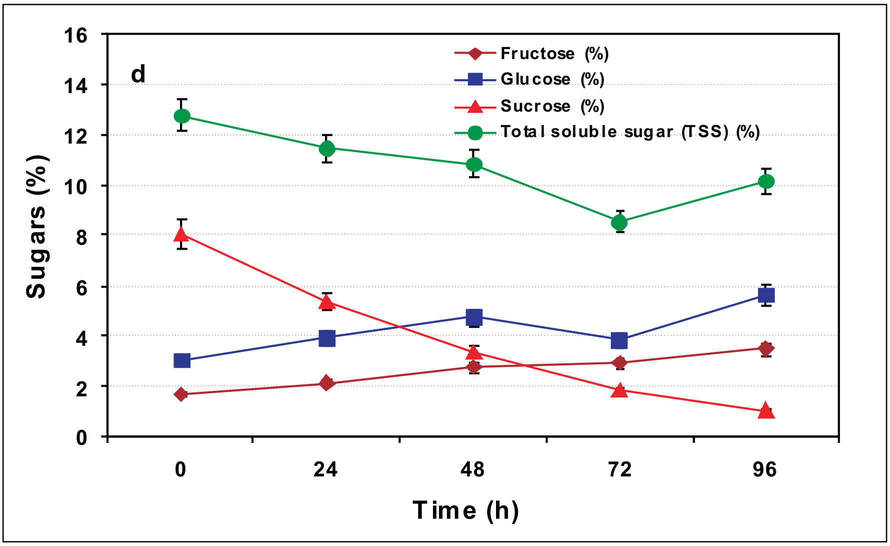

d
Fructose (%)
Glucose (%)
Sucrose (%)
Total soluble sugar (TSS) (%)
Sugars (%)
Time (h)
0
24
48
72
96
0
2
4
6
8
10
12
14
16

Fig. 4c.

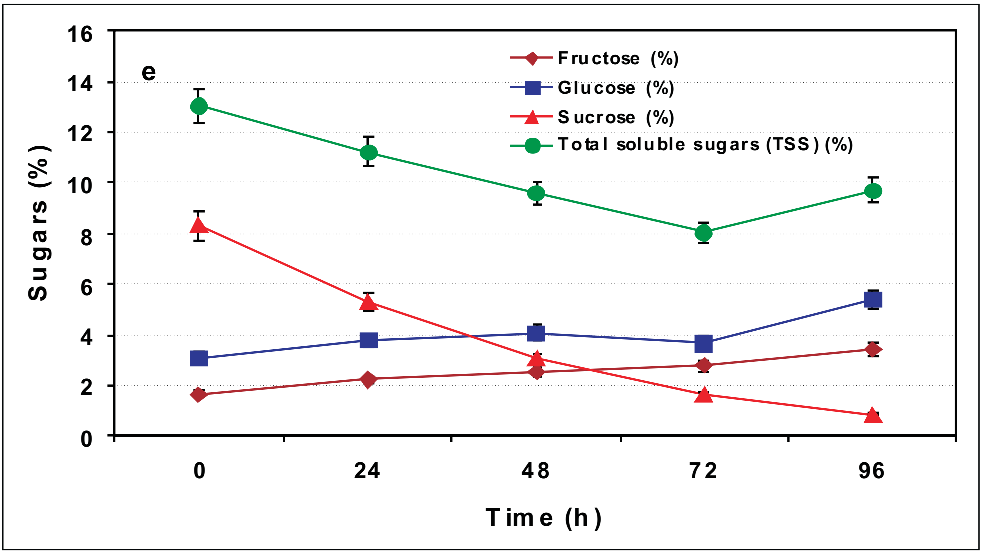

e
Fructose (%)
Glucose (%)
Sucrose (%)
Total soluble sugars (TSS) (%)
Sugars (%)
Time (h)
0
24
48
72
96
0
2
4
6
8
10
12
14
16

Fig. 4d.

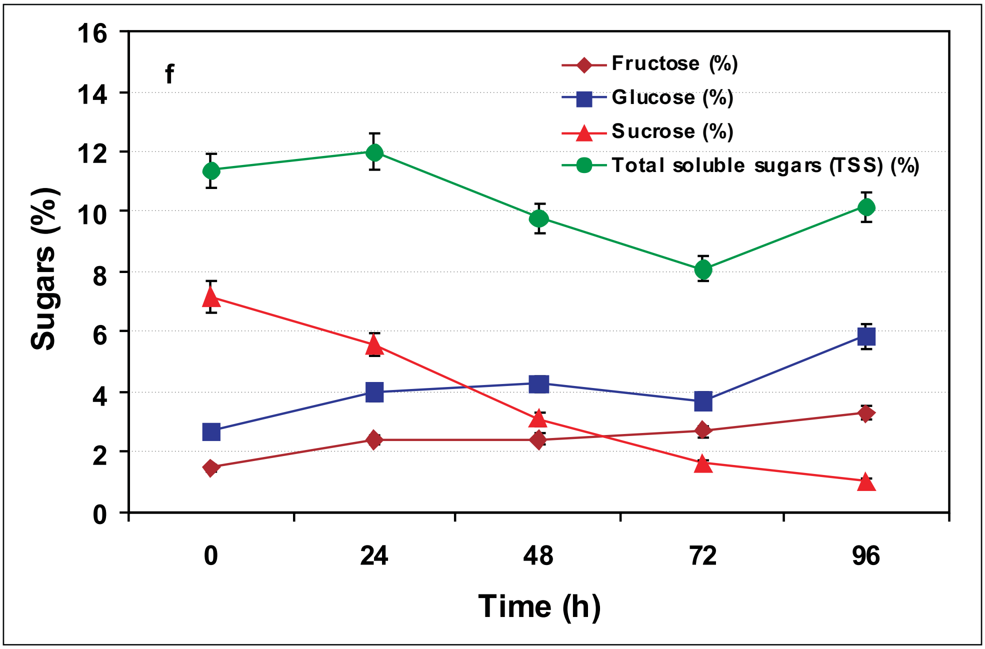


Fig. 4e.

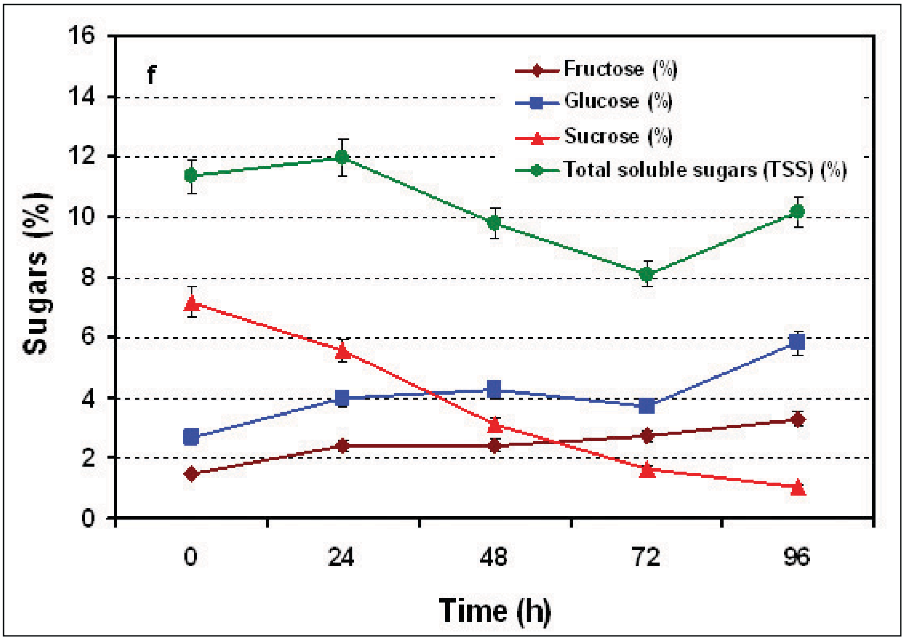


Fig. 4f.

Fig. 4. Sugar analysis as a function of time of juice sample spiked with (a) citric acid, (b) sodium citrate, (c) ascorbic acid, (d) benzoic acid, (e) sodium benzoate, and (f) sorbic acid.

V. Isolation of new yeasts for increased fermentation efficiency

Saccharomyces cerevisiae, the conventional baker's yeast is a Generally Regarded As Safe (GRAS) microorganism that is more tolerant to ethanol than other microorganisms and thus is commonly employed in industrial wine making, brewing and baking processes for the production of ethanol and CO2 from fermentable sugars like glucose. It is reported that the possible ethanol yield can be 600-650 gallons/acre if all the fermentable sugars in sweet sorghum are converted to ethanol (Imam and Capareda 2010). Different types of yeasts were isolated from the surfaces of different spoiled fruits like mango, apple, grapes etc. (for epiphytic yeasts), toddy juice and sweet sorghum juice. Further, the short-listed isolates were subjected to secondary screening in shake-flasks through submerged fermentation. These isolates were subjected to secondary screening in the basal medium to determine the fermentation efficiency and ethanol yields. Based on this secondary screening, 15 yeast strains were shortlisted as good isolates based on the ethanol yield and fermentation efficiency. The results suggested that two strains (ICTY 417 and ICTY 685) exhibited maximum fermentation efficiency of 93% and 88% with ethanol yield of 0.47 and 0.45 g g-1, respectively, after a fermentation period of 48 h.

The yeast strain, ICTY 417 was further used to ferment sweet sorghum juice of two cultivars (CSH 22SS and ICSV 93046). These studies suggested that undiluted juice (15% Brix) supplemented with mineral salts showed better ethanol yields after a fermentation period of 48 h as compared to the undiluted juice without mineral salts supplementation, diluted juice (1:1) supplemented with mineral salts and diluted juice (1:1) without mineral salts supplementation.

1. Effect of chemical preservatives on ethanol yield and fermentation efficiency

Since sodium benzoate and sorbic acid exhibited more stability as compared to the other tested preservatives further studies were carried out to evaluate their effect in the fermentation process. The fermentation efficiency of the yeast strain, ICTY 414 was further evaluated in presence of two preservatives (sodium benzoate and sorbic acid) on the storage of sweet sorghum juice. The storage studies indicated that there was not much difference in the efficiency and yield of the fermentation till 96 h as compared to the samples without the addition of preservatives. The ethanol yield remained in the range of 0.425-0.475 g g^{-1} in sodium benzoate-spiked samples (Fig. 5), which showed an optimal efficiency of 93%, while in case of sorbic acid-spiked samples (Fig. 6) the ethanol yield was in the range of 0.405-0.445 g g^{-1} which corresponded toan optimal efficiency of 92%. In case of control (without preservatives), the ethanol yield was 0.36 g g-1 which declined to 0.26 g g-1 after 96 h of storage and the optimal efficiency reduced to 57%. The initial sugar levels determined in fresh juice was 150 mg ml^{-1} and the left over sugars in the juice after fermentation ranged between 28-33 mg ml^{-1}. Overall the sodium benzoate-spiked samples showed comparatively better results than sorbic acid-spiked samples. Therefore, it is recommended that the addition of sodium benzoate as chemical preservative is necessary to prevent the spoilage by microbial contamination and thus extend the shelf life of the sweet sorghum juice under ambient temperature conditions.

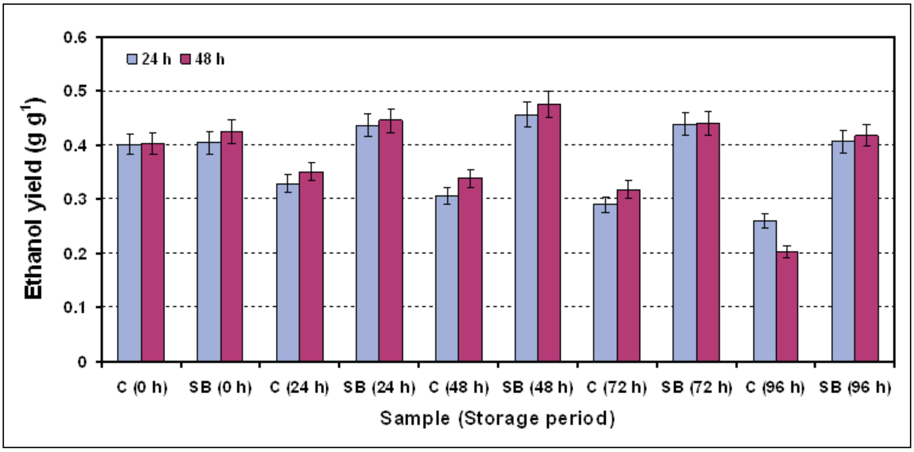


Fig. 5. Ethanol yield as a function of fermentation time with and without sodium benzoate-spiked juice samples.

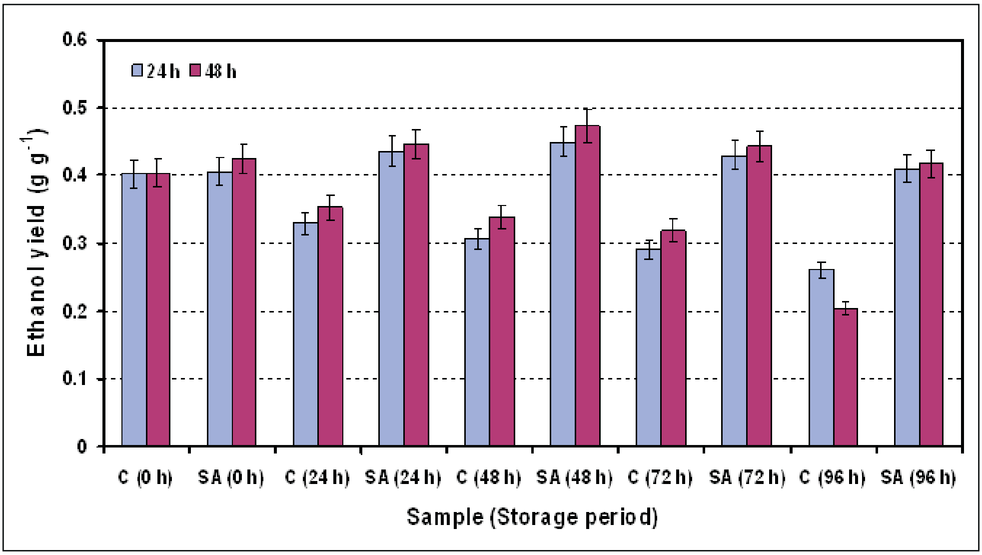


Fig. 6. Ethanol yield as a function of fermentation time with and without sorbic acid-spiked juice samples.

VI. Conclusions

In sweet sorghum, there is a significant genotype x stage interaction for juice yield, Brix%, sugar yield, glucose content, sucrose content and glucose content that can be exploited favorably by a centralized sweet sorghum ethanol distillery. A temperature of 15-18°C would be ideal for storage of fresh sweet sorghum juice. The sweet sorghum syrup with > 65% Brix is better for storage under ambient conditions without deterioration in quality. Two yeast strains (ICTY 417 and ICTY 685) exhibited maximum fermentation efficiency of 93% and 88% with ethanol yield of 0.47 and 0.45 g g^{-1}, respectively, after a fermentation period of 48 h. Based on the experimental results, sodium benzoate and sorbic acid at 1000 ppm were identified as most suitable preservatives to enhance the storage shelf life of the sweet sorghum juice for 72 h.

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al salts and diluted juice (1:1) without mineral salts supplementation.

Chapter XIV: Business models for viability of sweet sorghum decentralized crushing unit

SM Karuppanchetty and Aravazhi Selvaraj

I. Introduction

The Agri-Business Incubation (ABI) program of ICRISAT was established in 2003 with the support of the National Science and Technology Entrepreneurship Development Board (NSTDEB) of the Department of Science and Technology (DST), Government of India, to promote public-private partnerships in the agricultural sector. With well equipped infrastructure, technical and scientific backstopping, and a full-fledged management team to support the entrepreneur, ABI-ICRISAT has been able to commercialize more than 60 technologies from the Indian NARS and nurture 300-odd startups.

ABI-ICRISAT partnered with the ICRISAT-NAIP (National Agricultural Innovation Project) Sweet Sorghum Ethanol Value Chain Project and handled the decentralized crushing unit (DCU) operations since 2008. With the experience gathered over the past years, ABI-ICRISAT has considered various business models to make the DCU a viable business proposition. While a full-fledged business model will not be documented here, here is the model's considered look at achieving the viability of the unit either as a standalone unit or a franchisee business entity.

The major cost component for the unit lies in establishing the crushing unit for which we have developed various models that can be considered for offsetting such investments, like operating it as a simple crushing unit and selling of the syrup or outsourcing the crushing to other kadharis/gur units, while the distillery carries out the fermentation and distillation process to produce ethanol. Comparisons of the various models have been carried out in this chapter.

The five business models are as follows:

- Model 1: DCU as a standalone unit.
- Model 2: DCU established and managed by the distillery.
- Model 3: DCU as an alternative for crushing unit of distillery outsourced to kadharis/gur units.
- Model 4: DCU as a franchising mini ethanol manufacturing unit.
- Model 5: DCU supplying syrup to alternative markets (food, RTS, confectionery, vinegar).

The five business models

Parameters	**DCU as stand-alone unit**	**DCU with syrup making unit and run by distillery (40 KLPD)**	**DCU as alternative crushing unit of distillery outsourced to khadars/gur units**	**DCU as franchising mini ethanol manufacturing unit**	**DCU supplying syrup to alternative markets (food, RTS, vinegar, confectionary)**
Approach to Business model	Operated by individuals or group as a standalone unit	DCU is established and managed by the distillery (40 KLPD). As the distillery cannot be run beyond 90-120 days, it may establish 93 DCUs to store the syrup for rest of the year	Crushing and syrup making is outsourced to local Kandasaris and procured from them. The 40 KLPD distillery may outsource its crushing operations	The sweet sorghum growers were organized into an association that functions as a united entity for crop cultivation, marketing, management of DCU	Setting up of processing units in micro, small and medium levels for food, RTS, vinegar, confectionary production
Investments (Rs lakhs)	50.30	4590	Outsourced to 133 DCUs (investment cost would be reduced) Operational cost is Rs. 7,50,000	Not applicable	Not applicable
Syrup production (MT)	45	3255	4655	Not available	Not applicable
Sales revenue per annum (Rs lakhs)	7.49	3300	3300	Not available	Not applicable
Net Profit/Net Loss (Rs In Lakhs)	-15.95 per Kg	-5.00 per unit	1.3 per liter	Not available	Not applicable

Continued

Continued

The five business models

Parameters	**DCU as stand-alone unit**	**DCU with syrup making unit and run by distillery (40 KLPD)**	**DCU as alternative crushing unit of distillery outsourced to khadars/gur units**	**DCU as franchising mini ethanol manufacturing unit**	**DCU supplying syrup to alternative markets (food, RTS, vinegar, confectionary)**
Price per kg of syrup	13	13	13	Not available	Not applicable
Inference	This model is incurring Rs 15.95 loss per kg of syrup produced. If the syrup is sold at Rs 28.95, it will be no profit - no loss situation	This model will incur investments for distilleries for establishing 93 DCUs which is huge and makes the proposition unviable	In this model the distillery investment and cooperative investment is reduced, it can benefit the sweet sorghum growers locally which can create business opportunity for gur/ kandasari units	In this model, the farmers are linked to DCU but due to excise regulations in India, the operations become difficult	This model is technically viable, and the financials needs to be assessed
Assumptions	This model is not sustainable as the total current loss is Rs 3.86 lakhs per season and return of investment is (-7.9%)	It is assumed that all the DCUs will produce consistent syrup to feed the distillery	This model is one of the viable options for the success of the DCU and distillery	This model of DCU is useful at the village level with the mini processing plant. Easy management for the distillery and enhanced benefits to entrepreneurs making this model as most viable for the DCU	In this model micro, small and medium level entrepreneurs will benefit by manufacturing of food, RTS, vinegar and confectionary

Chapter XV: SWOT analysis of sweet sorghum ethanol value chain

G Basavaraj, Parthasarathy Rao and Ch Ravinder Reddy

I. Introduction

In recent years there is considerable debate on alternative feedstocks for bioethanol production to meet the mandated blending requirements with fossil fuels (petrol). Worldwide, a number of feedstocks ranging from cereal grains to sugarcane juice to molasses (obtained from conversion of cane juice to sugar) are commonly being used. However, these feedstocks are being critically examined for their role in increasing food costs and compromising on food security. Sweet sorghum has emerged as an alternative crop whose stalks are converted into juice for ethanol production. Two models for conversion of sweet sorghum into ethanol have been pilot tested, ie., a centralized model (stalks supplied directly to the distillery for ethanol production) and a decentralized model where the syrup produced at village level is supplied to distillery for ethanol production. A number issues and strengths in using sweet sorghum as an alternative feedstock have emerged.

To get a better handle on the conversion of sweet sorghum to syrup and subsequently to ethanol at the distillery, a SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis is carried out for Sweet Sorghum to Ethanol Value Chain under the Decentralized Crushing Unit (DCU) model established at Ibrahimbad village, Medak district, Andhra Pradesh, India in 2008. Such an analysis will be useful for researchers, policymakers and also all the stakeholders in the value chain. A summary of the major strengths, weaknesses, threats and opportunities of the DCU pertaining to the function of the entire sweet sorghum bioethanol value chain is provided in this chapter.

II. The SWOT analysis

A SWOT analysis is a strategic planning tool used to evaluate the Strengths, Weaknesses, Opportunities and Threats involved in a project or business venture. It involves specifying the objective of the project, analyzing the advantages and disadvantages of the project and identifying the internal and external factors that help to achieve the project objective.

The general matrix used for SWOT analysis is

Strengths	Weaknesses
Opportunities	Threats

The schematic view of the DCU has already been presented in the earlier chapters. The SWOT is elaborated in terms of brief statements on the strengths, weaknesses, opportunities and threats of the decentralized production system of ethanol production. These statements shall give a quick overview about advantages and disadvantages of DCU for ethanol production from syrup.

Strengths	• Reduces the volume of feedstock transport over a long distance. • Reduces the delay in crushing of sweet sorghum stalks as a 24-hour delay in crushing will reduce juice yield by 6%. • Crushing of sweet sorghum at DCU provides bagasse as by-products can be used for livestock feed by the farmers. • Additional employment generation due to syrup making during lean periods of agricultural operations. • Additional employment generated provides additional income for the participating households. • Provides opportunities for smallholder farmers to become micro-level entrepreneurs. • The linkages/partnerships established under DCU are mutually beneficial to Farmers, DCU and the Industry. • Farmers' collective action in processing sweet sorghum to syrup strengthens the community as a whole. • Provides scope for value addition for various products (bagasse for livestock feed, for vermicomposting and for paper making etc). The syrup is also in demand by the food industry as a sweetener. • Processing of sweet sorghum to syrup is environment-friendly as it does not produce any pollutants. • The grain can be harvested and used as food before supplying the stalks to DCU. • Syrup can be stored for 24 months or more before conversion into ethanol.

Weaknesses	• Extensive co-ordination and planning requirements in operations and management of DCU/supply chain management . (For example, there is a strict time frame to be followed for staggered sowing, harvesting at the right time, transportation of stalks etc.). • Knowledge dissemination (by way of initial training and extension) is expensive. • Non-availability of specific crushing equipment to crush sweet sorghum stalks. • Lack of management skills to handle DCU operations without assistance of partners such as ICRISAT, NGO or ABI. • High cost of establishment of DCU; high processing and operational costs. • Inability of the DCU to supply large quantity of syrup as feedstock to process into ethanol. • Appropriate policy support not in place to support production and processing of sweet sorghum to syrup and ethanol. • Low bargaining power of the farmers in pricing of syrup.
Opportunities	• Provides opportunity to mechanize and standardize most of the processing activities. • Provides opportunity for value addition for various by-products available for alternate markets. • Scope for promoting the DCU as an small-scale agro-enterprise in rural areas. • Valuation of environmental benefits from economic and sustainability perspective. • Provides opportunities for smallholder farmers at village to become micro-level entrepreneurs through establishment and management of decentralized unit. • Meet the mandated blending requirement of the government. • Research activities for development for genotypes with high Brix content stalk yield.

Threats	• High dependence of DCU on distillery leading to uncertain market and uneconomic price. • High cost of syrup production acts as threat to the viability of DCU. • Sustainability of DCU is an issue without support from ICRISAT/partners. • There has to be continuous technical backstopping to ensure sustainability of the DCU. • As majority of the processing activities are labor-oriented, labor scarcity might affect syrup production. • Non-monetary benefits of the elected members of the farmers' association may impact the functioning of the association per se. • Lack of government policy support for establishment of DCU.

Chapter XVI: Tweaking national biofuel policy for promotion of sweet sorghum as alternate feedstock

G Basavaraj, P Parthasarathy Rao, Ch Ravinder Reddy, A Ashok Kumar, P Srinivasa Rao and Belum VS Reddy

I. Introduction

Energy is a critical input for economic growth and sustainable development in both developed and developing countries. Globally, the energy requirement for the transportation sector is met from fossil fuels that are non-renewable and contribute to atmospheric pollution. However, the sharp rise in crude oil prices from US$20 a barrel in 2002 to almost US$100 (even touching $140 before stabilizing at around $80) forced nations to seriously look for alternative energy sources that are renewable and non-polluting. This trend of rising oil prices is expected to continue in the face of their shrinking supplies and rising demand. Secondly, growing concerns over human-induced climate change, as evidenced by rising temperatures and environmental pollution is further driving the impetus for non-polluting energy sources. One such source is seed ethanol from plant biomass/grain and biodiesel from processing edible and non-edible vegetable oils.

The mandatory blending has triggered a rapid growth in the biofuel sector in the last decade. By 2007-08, world biofuel production had touched 62.2 billion tons (t), of which around 88% was in the form of ethanol. The two largest ethanol producers, Brazil and the United States, account for almost 87% of its total production. Biodiesel production that accounts for a smaller proportion of liquid biofuels increased from 0.01 million t in 1991 to 9.0 million t by 2008. The European Union (EU) produces over 60% of the global share with a significantly smaller contribution coming from USA (17%).

II. Energy demand in India

India's energy demand is primarily met through non-renewable energy sources such as coal, natural gas and oil that will continue to play a dominant role in the country's energy scenario in the next few decades. The highest demand for energy comes from industry followed by transportation sector, which consumed about 16.9% (36.5 m of oil equivalent) of the total energy (217 million t) in 2005-06 (TERI 2007). Within the transportation sector, the consumption of motor spirit (gasoline) grew by 6.64%, from 7.01 million t in 2001-02 to 11.26 million t in 2008-09 and that of high speed diesel (HSD) by 4.1%, from 36.55 million t to 51.67 million t, respectively (GOI 2009). This growth will only escalate over the next several years since India's vehicular population is expected to grow by 10-12% per annum. Hence securing a long-term supply of energy sources and prioritizing development will ensure the country's future energy requirement. Currently, the country is looking for alternative energy options from biofuels to meet the energy demand for the transportation sector. To promote biofuels as an alternative energy source, Government of India stipulated mandatory blending requirements of gasoline with biofuels by 5-10% along with various other policy incentives. The policies are designed to facilitate and bring about optimal development and utilization of indigenous biomass feedstocks for biofuel production.

The policy chapter is organized as follows. Section III and IV present the biofuel policy in India since late 1940s and outline the salient features of the National Policy on Biofuels of India, 2009. Section V and VI describe the challenges and distortions affecting the biofuels development. Sections VII and VIII discuss sweet sorghum as a potential feedstock to augment ethanol production to meet blending targets and the possibilities of tweaking policies to support ethanol production from sweet sorghum. This is followed by Section IX which concludes with recommendations.

III. Biofuel policy in India

In 1948, the Power Alcohol Act heralded India's recognition of blending petrol with ethanol. The main objective was to utilize ethanol from molasses to blend with petrol with the aim of bringing down the price of sugar, trim wastage of molasses and reduce dependence on petrol imports. Subsequently, the Act was repealed in 2000, and in January 2003, the Government of India launched the Ethanol Blended Petrol Programme (EBPP) in nine States and four Union Territories promoting the use of ethanol for blending with gasoline and the use of biodiesel derived from non-edible oils for blending with diesel (5% blending). In April 2003, the National Mission on Biodiesel launched by the Government of India identified Jatropha curcas as the most suitable tree-borne oilseed for biodiesel production.

Due to shortage in ethanol production[1] during 2004-05, the blending mandate was made optional in October 2004, and resumed in October 2006 in 20 States and 7 Union territories in the second phase of EBPP. These ad-hoc policy changes continued until 2009 when the Government of India came out with a comprehensive biofuel policy. This comprehensive National Policy on Biofuels was formulated by the Ministry of New and Renewable Energy (MNRE) and cleared by the Government of India in December 2009, calling for blending at least 20% biofuels with diesel and petrol by 2017.

1. Salient features

- An indicative target of 20% blending of biofuels both for biodiesel and bioethanol by 2017.
- Biodiesel production to be encouraged from non-edible oilseeds on waste, degraded and marginal lands.
- A Minimum Support Price (MSP) to be announced for farmers producing non-edible oilseeds used to produce biodiesel.
- Financial incentives for new and second generation biofuels, including a National Biofuel Fund.
- Biodiesel and bioethanol likely to be brought under the ambit of 'declared goods' by the Government to ensure the unrestricted movement of biofuels within and outside the states.
- Setting up a National Biofuel Coordination Committee under the Prime Minister for a broader policy perspective.
- Setting up a Biofuel Steering Committee under the Cabinet Secretary to oversee policy implementation.
- Several ministries are currently involved in the promotion, developing and policy making for the biofuel sector.
- The Ministry of New and Renewable Energy (MNRE) is the overall policymaker, promoting the development of biofuels and research and technology development for its production.
- The Ministry of Petroleum and Natural Gas has the responsibility of marketing biofuels, and developing and implementing a pricing and procurement policy.

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[1] Shortage in ethanol production was mainly caused by a shortage in molasses production which was in turn driven by shortages in cane production.

- The Ministry of Agriculture's role is that of promoting research and development for the production of biofuel feedstock crops.
- The Ministry of Rural Development is specially tasked to do the promotion, especially of Jatropha plantations in wastelands.
- The Ministry of Science & Technology supports research in biofuel crops, specifically in the area of biotechnology.

In view of the multiple departments and agencies involved, a National Biofuel Coordination Committee (NBCC) headed by the Prime Minister has been set up to provide high-level co-ordination and policy guidance/review on different aspects of biofuel development, promotion and utilization.

IV. Policy challenges affecting biofuel development

Biofuel policies have important implications for the development of the energy sector. The profitability of biofuel production is significantly influenced by biofuel policies affecting multiple sectors which include agriculture, research, industry and trade.

For example, subsidies can affect the sector at different stages (Steenblik 2007). The various points in the biofuel supply chain where direct and indirect policy measures can support the sector are interrelated, and assigning policies to one category or another may be somewhat artificial in practice (FAO 2008).

The distortions of the biofuel policy of India at various stages of the biofuel supply chain in production, commercialization and sustenance in promotion of biofuel sector are discussed below.

1. Blending mandates

Imposing quantitative targets in the form of blending mandates is the key driver in the development and growth of the biofuel industry. The blending mandate of 5% ethanol with gasoline in 9 states of India in 2003 was enhanced to include 20 states in 2006. In 2010, the National Policy on Biofuels (NPB) approved a target 20% blending with biofuels (both biodiesel and bioethanol) by 2017.

In India, the main raw material for ethanol production is molasses, a by-product derived during sugar production. Supply of sugarcane and the production of molasses are dependent on sugar cycles. During 2006 and 2007, due to excess supply of cane and molasses, prices were depressed. The mandated blending targets were probably based on the surplus ethanol available during a good sugarcane production year. The price of molasses has been fluctuating considerably over the years from Rs 50 t^{-1} to Rs 6000 t^{-1} (US \$1.1 to \$133.3[2]) between 2003-2008. Additionally, there is competition from the potable and chemical industries for the alcohol from molasses. During a normal year, cane converted into sugar generates enough molasses to produce alcohol that can meet the needs of potable and chemical sectors (30-40% each) with another 20-30% surplus alcohol available for conversion into ethanol and related products. During 2009, the total supply of ethanol was 2.4 million tons that was sufficient to meet total demanded of 1.80 million tons from all three sectors (@5% blending target for ethanol). Despite this, the ethanol blending target could not be met due to inability of the OMCs to procure the required amount of fuel ethanol at prevailing market prices that are lower than alcohol prices for different uses. Another estimate by the Indian Chemical Council finds that even at 5% blending there would be a deficit of 1140 million liters in 2010-11 which would grow to 2400 million liters by 2014-15 assuming constant production of molasses and alcohol (Table 1). A study by Shijoj et al. (2011) finds that as per the 20% blending target set by the government by 2016–17, the fuel ethanol demand would be 1.93 million tons and total demand (ethanol + alcohol) would be as high as 3.52 million tons.

Table 1. Projected demand and supply of alcohol in India (Million leters).

Alcohol requirement (million liters)	2010-11	2011-12	2012-13	2013-14	2014-15
Potable sector	1450	1550	1660	1780	1900
Industrial sector	1050	1100	1160	1210	1280
5 % blending	1040	1090	1150	1200	1260
Total alcohol required	3540	3740	3970	4190	4440
Highest expected alcohol availability (million liters)	2400	2400	2400	2400	2400
Deficit (million liters)	(1140)	(1340)	(1570)	(1790)	(2040)

Source: Indian Chemical Council, 2010

Note: On the basis of past trends, the growth rates are assumed to be 5% for the industrial sector, 7% for the potable sector and 5% for blending.

[2] One USD = Rs 45.

2. Input support (subsidies)

The justification for providing policy support to any new sector is based on its ability to overcome the initial costs of technological innovation and market development required to make the sector competitive. This is the ‘infant industry’ argument for providing subsidies.

Most inputs like fertilizer, pesticides and electricity to pump irrigation water for crop production are subsidized in India. The quantum of subsidy for a crop varies based on the inputs utilized for its production. Currently, molasses, a by-product of sugarcane is the chief raw material for ethanol production. The inputs utilized in cane production are highly subsidized through seed subsidy, purchase of implements and tools and electricity to pump irrigation water apart from fertilizer and pesticides subsidy. The subsidies provided for cane production indirectly accrue to molasses used in production of ethanol.

3. Output support

Besides production support, output support for the purchase of biofuels is also critical. The National Biofuels Policy proposes a Minimum Support Price (MSP) mechanism for Jatropha whose seed is used to produce biodiesel. For sugarcane, the existing statutory minimum price provides effective protection to growers. In the case of biodiesel, the policy proposes that the Minimum Purchase Price (MPP) be delinked to the prevailing retail price of diesel while for bioethanol it is based on the actual cost of production and import price of bioethanol.

4. Processing, distribution and marketing support

OMCs in twenty states and four Union Territories have been assigned the task of blending 5% ethanol with gasoline. The sugar industry has been permitted to produce and process ethanol from sugarcane juice to augment production to meet blending requirements. Other than molasses and sugarcane, the policy does not specify in concrete terms processing of alternative feedstocks for bioethanol. Alternative feedstocks like sweet sorghum and sugar beet are mentioned in the policy but there is no concrete road map suggested for their promotion.

OMCs have been responsible for the storage, distribution and marketing of biofuels in India. India's biofuel policy exempts the biofuel sector from central taxes and duties. While biodiesel is exempt from excise duty, bioethanol enjoys a concessional excise duty of 16%. Custom and excise duty concessions are also provided on plant and machinery for the production of biodiesel and bioethanol. While these policies do promote the biofuel sector, those promoting production of feedstock to fully realize the benefits provided on the processing front need to be looked at, since production and processing are interdependent. Though the policy mentions about exemption of central taxes and duties on biofuels, various forms of taxes like sales tax, license fee, permit fee and import taxes still exist hindering the growth and development of the biofuel industry. The policy provides no additional incentives for blenders and retailers of biofuel unlike in several other countries.

5. Financial and fiscal incentives

Apex financial institutions like the National Bank for Agriculture and Rural Development (NABARD), Indian Renewable Energy Development Agency (IREDA), and Small Scale Industries Development of India (SIDBI) have refinancing provisions to set up biodiesel plantations, oil expelling/extraction units, and infrastructure for storage and distribution. The lending towards these sectors would be classified as priority sector lending. The policy states consideration of subsidies and grants upon merit for new and second generation feedstocks; advanced technologies and conversion processes; and production units based on new and second generation feedstocks. Similar emphasis is not explicitly mentioned for bioethanol.

6. Consumption support

The biofuel policy's thrust is primarily on the supply side even though demand side factors also play a major role in promoting biofuels. For example, many countries actively promote flex-fuel vehicles designed to use a higher percentage blend of ethanol with petrol than ordinary vehicles through reduced registration fees and road tax exemptions. Similarly, support is provided for the purchase of biofuels, co-products and flex-fuel vehicles.

Under Section 52 of the Motor Vehicles Act in India, an existing vehicle engine can be converted to use biofuels and accordingly, engine manufacturers need to suitably modify the engines to ensure compatibility with biofuels. Demand for such vehicles and consequently biofuels can be stimulated by providing exemption of road tax and reduced registration fee for vehicles running on blended fuels. Incentives similar to the ones approved by MNRE for the dissemination and promotion of battery operated vehicles (BOV) will also help in augmenting the biofuel industry.

7. Research & development

The policy's major thrust is innovation, research and development (R&D) and demonstration. It focuses on R&D efforts in processing and production technologies and maximizing efficiencies and utilization of by-products along the biofuel value chain. Demonstration projects are to be set up for biodiesel and bioethanol production, focusing on conversion technologies through Public–Private Partnerships (PPP). Grants are to be provided to academic institutions, research organizations, specialized centers and industry for promising R&D and demonstration projects.

8. Institutional mechanisms

Among the institutional policies that promote the biofuel industry are international cooperation through technical cooperation in production, conversion and utilization; trade in biofuels; state participation in planning and implementing biofuel programs, and capacity building for dissemination and creating awareness.

Though a policy on biofuels is in place to promote biofuels at various stages of the supply chain, the government's initiatives on their production and commercialization have not taken off as anticipated to meet the energy demand both for ethanol and biodiesel.

V. Sustaining bioethanol production to meet blending mandates

The NPB states that a level playing field is necessary for accelerated development and utilization of biofuels vis-a-vis direct and indirect subsidies to fossil fuels and distortions in energy pricing. To augment availability of ethanol and reduce the oversupply of sugar, the NPB permits sugar industry to produce ethanol directly from sugarcane juice. The policy implies further concessions to sugarcane growers and processors who are already benefitting from the input subsidy. Sugarcane has the advantage of having massive infrastructure already established for it, and favorable government policy support since earlier years. This has led to policymakers tailoring policies favoring ethanol production from sugarcane and molasses. However this is counter intuitive to the policy recommendation of using degraded and less fertile land for biofuel production. This lopsided policy that implies concessions for ethanol production through sugarcane could have a detrimental effect on resource allocation in the agriculture sector.

However, considering the demand for sugar in India, it is highly unlikely that sugarcane juice will be used for ethanol production in India. The analysis conducted by Shinoj et al (2011) has shown that it is highly unsustainable to extend the sugarcane area beyond a limit, given the fact that sugarcane is a crop that is highly water intensive with a water requirement of 20,000–30,000 m^3 per ha per crop.

Due to the lopsided policy along with non-availability, economic viability and sustainability of ethanol from molasses the viability of blending mandates the EBPP has not been successfully implemented. This necessitates options to augment bioethanol production to meet the blending mandates through policy support for alternative feedstocks. One such alternative feedstock that has been pilot tested in recent years is sweet sorghum. Though the policy document mentions feedstocks like sweet sorghum, sugarbeet etc, for ethanol production, neither have these crops been given due prominence in the policy nor has a clear roadmap been specified for their commercialization and utilization. Policy support mechanism to promote alternative feedstocks will benefit all the stakeholders of the bioethanol supply chain in the long run while meeting the mandated requirements.

VI. Sweet sorghum as an alternate source of bioethanol production

Sweet sorghum stalk has been found to be a potential source of raw material for commercial ethanol production. Sweet sorghum does not compromise on food, feed or fodder production when used for energy production, thereby meeting the biofuel program's vision without compromising on food security[3].

Cultivation of sweet sorghum involves the judicious use of scarce resources like irrigation water and other inputs (sweet sorghum uses less than a third of the inputs used by sugarcane, such as water, electricity and fertilizers) making it a promising alternative feedstock (Reddy et al. 2008; Srinivasa Rao et al. 2009; Table 2). Sweet sorghum scores favorably on all the parameters compared to alternative feedstocks. Additionally, the pollution levels in sweet sorghum-based ethanol production has 25% of the biological oxygen dissolved (BOD), ie, 19500 mg liter^{-1} and lower chemical oxygen dissolved (COD), ie, 38640 mg liter^{-1} compared to molasses-based ethanol production (as per a pilot study conducted by Vasantdada Sugar Institute, Pune, India). Hence, besides molasses there is a need for clear guidelines to promote alternative feedstocks like sweet sorghum for bioethanol production.

Field surveys conducted by ICRISAT in Ibrahimbad, Medak district, Andhra Pradesh, in 2008 under the National Agricultural Innovation Project (NAIP) revealed that the cost of inputs (fertilizer and imputed cost of irrigation) in the cultivation of sugarcane was Rs 6691 ha^{-1} compared to Rs 1948 ha^{-1} for sweet sorghum. The cultivation of sugarcane requires higher amounts of scarce resources such as irrigation water and fertilizers which are highly subsidized. Sugarcane requires nearly 160-180 ha cm of irrigation water while sweet sorghum is cultivated under rainfed conditions. Additionally, crop-wise estimates of input subsidies during 2001-2002 (Table 3) show that sugarcane had the highest input subsidy of Rs 6099 ha^{-1} while sorghum had the lowest. The difference in irrigation subsidy alone provided to sugarcane was Rs 1444 ha^{-1} relative to sorghum.

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[3] The grain can be harvested for food, and bagasse left after extraction of juice from the stalk is an excellent feed for livestock.

Table 3. Crop-wise distribution of input subsidies per hectare in India (2000-2001).

Crop	% Fertilizer subsidy to total subsidy	% Electricity & canal subsidy to total subsidy	Subsidy/ha of crop area (Rs)
Paddy	31.43	31.01	3587
Sugarcane	5.51	4.95	6099
Sorghum	3.55	1.01	839
Maize	2.64	1.87	1634
Total (billion rupees)	138.0	366.40	

Source: *Acharya* and Jogi 2004.

VII. Tweaking policies to support alternate feedstocks

1. Economics of sweet sorghum cultivation and processing

As mentioned earlier, the justification for providing policy support to any new sector is based on its ability to overcome the initial costs of technological innovation and market development required to make the sector competitive.

Data on cost of cultivation for sweet sorghum collected over a period of three years by ICRISAT across various locations under the project on value chain model for bioethanol production in India, funded by NAIP, ICAR, Government of India, shows that sweet sorghum stalk yields have varied between 14 to 18 t ha^{-1}. With the buy-back price of sweet sorghum stalk at Rs 700-1000 t^{-1} sweet sorghum cultivation is competitive with other dryland crops in Medak district of Andhra Pradesh (Table 4). Across clusters in western Maharashtra also, sweet sorghum was found to be profitable with competing crops like sorghum intercropped with pigeonpea and sole sorghum. However, it becomes less competitive when compared to commercial crops like cotton and soybean in Maharashtra clusters. The high opportunity cost of land for cultivation forces the distillery to pay higher prices for sweet sorghum cultivation (if fertile lands used for cultivation of cotton and soybean has to be replaced to cultivate sweet sorghum).

Table 4. Benefit cost ratio of sweet sorghum cultivation with competing crops in Ibrahimbad, Medak, Andhra Pradesh.

	Benefit-Cost ratio		
Crop name	2008	2009*	2010**
Sweet sorghum	1.55	0.96	0.81
Maize–Pigeonpea	1.30	NA	0.97
Sorghum–Pigeonpea	1.37	0.97	0.59

Note: *, ** Low returns from crops during 2009 and 2010 was due to adverse climatic conditions.

Sweet sorghum is economically the next best alternative for ethanol production after molasses (Table 5) when the feedstock is priced at Rs 800 per ton of stalk. However, feedstock and ethanol pricing have a bearing on the viability of ethanol production from all available feedstocks.

Table 5. Relative economics of ethanol production from different feedstocks in India.

Parameter	Sweet sorghum	Sugarcane molasses	Sugarcane juice	Grains (pearl millet & broken rice)
Cost of raw material (Rs t^{-1})	700*	3000-5000**	1200+	8000+
Cost of processing (Rs t^{-1})	384	1890	490	2800
Total cost of ethanol production (Rs t^{-1})	1084	4890-6890	1690	10800
Output of ethanol (l)	45	270	70	400
Value of ethanol (Rs t^{-1})	1215	7290	1890	10800
Net Returns (Rs t^{-1})	131	2400 to 400	200	0
Cost of feedstock (Rs l^{-1})	15.56	11.11-18.51	17.14	20.0
Cost of ethanol (Rs l^{-1})	24.08	18.11-25.51	24.14	27
Profit from ethanol (Rs l^{-1})	2.91	8.88-1.48	2.85	0

Note: The information on the parameters is collected from Rusni distilleries for sweet sorghum, Nizam Deccan Sugars Pvt. Ltd. for molasses and AGRO Bio-tech, Ajitgarh, Rajasthan, for grains.

* The value of by-products is not considered in the analysis. Even when the feedstock is priced at Rs 800, it becomes profitable to produce ethanol from sweet sorghum without accounting for capital costs. However, the cost of feedstock has varied between Rs 700 and 1200 t^{-1}.

** The molasses prices have ranged between Rs 3000 and 5000 t^{-1} during the last few years and hence the profitability of molasses ethanol production is highly sensitive to fluctuating molasses prices.

+ The data on all the other feedstocks cost is for the year 2009. The prices of feedstock (sugarcane and grains) have increased in the recent years.

On the processing side, economic viability assessment was carried out by the authors using the data from a distillery crushing sweet sorghum for ethanol production. The distillery which had a buy-back arrangement with farmers for cultivation of sweet sorghum was paying Rs 1200-1300 t^{-1} of stalk to farmers since they had to be compensated for loss in returns for cultivation of crops like cotton and soybean. With feedstock price fixed at Rs 1200-1300 t^{-1} of stalk and subsequent processing costs incurred by the distillery, ethanol has to be priced at Rs 36 per liter from the existing administered Rs 27 per liter to make the distillery viable.

Several scenarios were developed by varying feedstock price, ethanol price and ethanol recovery rate by performing sensitivity analysis. The sensitivity analysis performed helped to estimate the break-even points and ethanol pricing scenarios for sweet sorghum value chain.

2. Policy support for sweet sorghum

The area under cultivation of alternative feedstocks for ethanol production is low due the reasons mentioned (higher feedstock prices, assured buy-back arrangement for farmers and low ethanol prices).

In the current market context, policy support for the production of a biofuel crop primarily depends on mutual/simultaneous co-existence of producers and processors to promote alternate feedstocks. For growers it's the relative profitability of bioethanol crops vis-a–vis competing crops and assured buyback at pre-determined prices are important factors determining allocation of land for these crops. While for industry, the raw material's conversion efficiency, its continuous supply for at least 5-6 months in a year, the economics of establishing multi-feedstock production units and the purchase price of ethanol by oil companies are critical factors. For industries producing ethanol from alternative feedstock, policy support should be in the form of a minimum purchase price to ensure at least a break-even price of ethanol production.

Policies favoring ethanol production from feedstock such as sweet sorghum by capping a third of the 5-10% requirements in the initial years will serve as an incentive to tap alternative sources.

Additionally, conversion of any form of sugars to alcohol requires special permissions and licensing (opinions based on the visits to industries by ICRISAT scientists). Barriers to licensing and permissions for conversion of multiple feedstocks to ethanol deters industry from processing as the industry cannot sustain on single feedstock to run on optimal capacity and profitability. Licensing has to be made easy for establishment and operationalization of multi-feedstock units that can operate for longer periods in a year to augment the ethanol production using different feedstock.

Options can be explored with sugar industry to integrate crushing of sweet sorghum during lean periods of sugarcane crushing.

Viability gap funding as undertaken for infrastructure projects in PPP mode can also be explored for financial assistance for private sector for production of ethanol from alternate feedstocks like sweet sorghum.

Policy support for the industries established to crush alternate feedstocks in the form of ‘infant industry sops’ during the initial years has to be provided by the Government until the industry achieves technological and efficiency breakthrough.

Sweet sorghum is a newly introduced promising crop for the production of bioethanol. Research is on to develop promising cultivars for higher stalk and support yield and juice content. So are pilot projects linking farmers to the bioethanol industry. Hence, funding support for ongoing research on sweet sorghum and its promotion are critical. Identifying institutional mechanisms through PPP and funding support by national and international funding agencies to promote such biofuel crops will go a long way in promoting alternative feedstocks.

3. Economic viability and cost of subsidy from policy perspective

Various studies across countries have calculated the point at which ethanol from various feedstocks would be competitive with fossil fuels and policy incentives and interventions to be provided for promotion of bioethanol. In the Indian context, there are arguments in favor of bioethanol that it would become economical in a scenario of higher crude oil prices, high to the tune of USD 147/barrel (July 2008). The analysis conducted by Shinoj et al. 2011 on the sustainability of sugarcane based ethanol has shown that even in such a scenario, it would be difficult to meet the mandated ethanol blending requirement.

To determine the break-even points of production of ethanol from sweet sorghum in the Indian context, the Tyner and Taheripour (2007) framework of determining break-even points of ethanol production from maize as feedstock relative to crude oil is replicated by the authors. The analysis is done taking into account current prices and conversion technology of the feedstock that could form the basis for price and policy incentives to promote biofuels from alternative feedstocks.

The break-even price analysis shows that with a conversion rate at 4.5% of ethanol from sweet sorghum, the feedstock price should be Rs 1200 t^{-1} of stalk when the price of crude is at $85 per barrel.

A) Cost of subsidy

An estimate is made by the authors on the magnitude of support required if alternate feedstocks like sweet sorghum are prioritized and promoted with enabling environment in India and taking into consideration the land required for its cultivation and ethanol production for blending mandates. Based on projections by the Planning Commission, 1.97 billion liters of bioethanol at the rate of 10% blending would be required by 2017. Currently, the entire blending requirement by OMCs has to come from sugarcane molasses. Given the unsustainable scenario of ethanol production from molasses (shortage of molasses due to cyclical nature of sugarcane production, fluctuating prices of molasses, inability of OMCs to procure ethanol at the prevailing market rate and better price and assured demand for potable and industrial uses) ethanol could be produced from alternate feedstocks like sweet sorghum.

Since, in the short run it would not be possible to bring a larger area under its cultivation and also because of the research and extension efforts required to make it a viable option for blending, it is assumed that only 5% of the total ethanol required for blending would come from sweet sorghum during 2012 and this would go up to 20% by 2020. Based on these assumptions, annual requirement of bioethanol from sweet sorghum, and land requirement for sweet sorghum during 2012-2014, 2015-2019 and 2020 have been projected at 5, 10 and 20% of the total ethanol requirement respectively.

Based on these annual projections, the cumulative area that would need to be brought under sweet sorghum cultivation by 2020 would be 0.5 million ha, a small proportion of the total area presently under cultivation in kharif (rainy season) sorghum alone (around 3.5 million ha). The area under kharif sorghum in the state of Maharashtra is close to 1.2 million ha. Here we assume that initially sweet sorghum would replace kharif sorghum since both crops grow under similar conditions and the grain from sweet sorghum crop would compensate for the loss in sorghum grain.

It is expected that the on-farm sweet sorghum stalk productivity of 20 t ha^{-1} increase to 30 t ha^{-1} between now and 2020 with improved cultivars, better management practices and increased awareness of farmers on sweet sorghum cultivation. With increased productivity, a larger area could be brought under sweet sorghum cultivation, and hence ethanol available for blending from sweet sorghum stalk as raw material would also increase.

The estimated break-even price of sweet sorghum for ethanol production is Rs 1200 t^{-1} (including the cost of processing) at 4.5% recovery when crude is priced at $85 a barrel. Based on the estimated break-even, if a support of Rs1200 ha^{-1} (one third of what is provided for crops like paddy and sugarcane) is provided for processors, the total economic cost of subsidies for sweet sorghum production would amount to Rs 105 million to Rs 605 million ($2.33 to 13.35 million) by 2020 based on area required for sweet sorghum cultivation. Comparing the amount of subsidies provided to water-intensive crops like sugarcane and paddy in India which account for an average of Rs 3000-4000 ha^{-1} and the subsidies provided in the United States and EU for biofuel production the estimated quantum of support for sweet sorghum is modest.

VIII. Conclusion

While the policy framework to promote the biofuel sector in India is very encouraging, experience has shown that the Government's initiatives have not translated into results on the production and commercialization fronts to meet the country's energy demand, calling for a re-examination of the policy from various stages of the biofuel supply chain. This chapter highlighted the key features of the biofuel program in India, and critically examined them to meet the mandated ethanol blending program stipulated by the Government of India.

The focus of the policy is on ethanol production from molasses that is plagued by price volatility combined with demand for molasses-based alcohol from the potable and chemical industries. Its production is dependent on sugar production and hence volatility in sugar production also affects molasses availability. This is already evident as the viability of blending mandates is at stake as the EBPP has not been successfully implemented across the country owing to non-availability of ethanol for blending on a continuous basis.

The policy is thus sugarcane-centric which is counter to the policy recommendation of using degraded and less fertile land for biofuel production. Sugarcane is a big beneficiary of subsidies on fertilizer, pesticides and electricity for pumping irrigation water for crop production in India. The policy document not only favors production of ethanol from sugarcane through molasses but also recommends sugarcane juice as another option. While mention is made of other feedstocks like sweet sorghum, sugar beet etc. in the policy document for ethanol production, due prominence and a clear road map are not given. In view of the above, prioritization of alternative feedstocks to fulfill targeted blending mandates is called for. Policies favoring alternative feedstock such as sweet sorghum by capping a third of the 5-10% requirement will serve as an incentive to promote alternative feedstocks. A small subsidy in the initial years will go a long way in promoting alternative feedstocks which can supplement ethanol production for blending requirements.

The major thrust of the biofuel policy is primarily on supply side. However, the demand side factors like provisions for consumption support also play a significant role in promotion of biofuels. Promotion of flex-fuel vehicles designed to use higher percentage blends of ethanol as in case of Brazil is a classic example. Similarly, reduction in registration fees and road tax exemptions for vehicles running on biofuels are provided by many countries. Policy sops of such kind and incentives similar to the ones announced and approved by the MNRE for dissemination and promotion of battery operated vehicles (BOV) will also help in promoting and sustaining the biofuel industry. Such sops should be provided only in the initial years (5-10) until the industry is able to sustain on its own.

It is hoped that modifications in the existing NBP favoring bioethanol production from alternate feedstocks like sweet sorghum besides molasses will benefit all the stakeholders in the biofuels supply chain and will quicken the pace of biofuel production in the country to meet the blending mandates.

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Chapter XVII: Sweet sorghum ethanol value chain: Issues and the way forward

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I Introduction

The ICRISAT-NAIP-ICAR sub-project on 'Value Chain Model for Bioethanol Production from Sweet Sorghum in Rainfed Areas through Collective Action and Partnership' focused on developing and establishing sustanable bioethanol value chain models by addressing issues involved along the value chain components. The sweet sorghum value chain encompasses sweet sorghum production and transportation of stalks distillery or crushing unit, crushing stalks for juice extraction, syrup production from juice, ethanol production from juice and or syrup, ethanol blending with gasoline and utilization of the by-products, bagasse, vinasse, etc. For successful implementation of the value chain models, based on the core competencies, a consortium of partners involving public sector research and development organizations (ICRISAT, DSR, IICT, CRIDA, ILRI and SVVU) and private sector ethanol distillery (Rusni Distilleries Ltd.) was formed with ICRISAT as consortium lead. Aakruthi Agricultural Associates of India (AAI), an NGO, was engaged to assist in implementation of the project activities that relate to mobilization of farmers and their capacity building in cluster villages. This unique consortium of private-public-people-partnership (PPPP) was in place to help reach the goals by harnessing the synergies of the partners. The information presented in the previous sections is based on the results obtained from implementation of the project work plans from 2008 to 2012. This chapter describes major issues encountered during implementation of the work plans, the issues related to sustaining the sweet sorghum based ethanol value chain in the state of Andhra Pradesh, India, and the way forward.

II. Issues

1. Consortium building and management

The work culture and administrative practices of the public sector are different from the private sector. The public sector is bound by the agreements and procedures and therefore the partnership is more durable. On the other hand, the private sector is more influenced by the financial aspects of the enterprise and also by the nature and composition of its partners, working or otherwise. Therefore, private sector partnership is loosely bounded in consortium by virtue of its objectives and profitability motive. The private sector partner, Rusni Distiller could not sustain its operations through the project period under the centralized model for several reasons. Lack of experience in backward linkages with farmers supplying stalk to the distillery is one of the factors that had a bearing on the success of the value chain. However, factors like inadequate working capital, disharmonious relationships among company partners, and unfavorable government ethanol pricing policy were important ones that determined the economic viability of the distillery leading to its closure. As a result, ethanol production from the juice or syrup in the value chain on a commercial scale was hampered during 3rd and 4th year of the project period.

2. Value chain

Value chain describes the chain of value addition activities from production to final consumption. The chain encompasses inputs-processing-outputs-utilization, and the actors involved in these activities. The innovations in sweet sorghum (SS) based ethanol value chain developed in the project can be successfully commercialized only if all the stakeholders in the value chain are benefitted, ie, the farmers, input suppliers, the Decentralized Crushing Unit (DCU) Cooperative and the industry. We assessed the viability to all stallholders in value chain as given below.

A) Viability for farmers: During the rainy seasons (kharif) of 2008-09, the average net income realized by farmers from sweet sorghum cultivation Rs 6490 ha^{-1} excluding family labor. However, during 2009- 2010 and 2010-2011, the net returns were negative due to adverse climatic conditions that affected all crops in the project sites. The negative net returns from sweet sorghum were the lowest among the rainfed competing crops such as grain sorghum, sole maize and maize and pigeonpea intercrops in Ibrahimbad cluster villages (project location), in the Medak district of Andhra Pradesh. During the project period sweet sorghum average stalk yields with minimum 14.6 t ha^{-1} (centralized area) has increased to maximum of 20 t ha^{-1} (decentralized area) and grain yields ranged from 0.2 to 0.9 t ha^{-1} (Table 1). However, to sustain the farmers' interest in sweet sorghum, the current sweet sorghum productivity should increase from 20 t ha^{-1} to 30 t ha^{-1} and grain from 0.9 t ha^{-1} to 2.0 t ha^{-1} with a higher realization price of Rs 900 t^{-1} for stalk and Rs 12000 t^{-1} for grain. It is not difficult to achieve the proposed yields of stalk and grain as the farmers who adopted fully the improved technologies have realized the set targets.

B) Viability of the Decentralized Crushing Unit (DCU): Sustainability of any rural agro-industry depends on economic and operational feasibility and market linkages and the DCU is no exception. There are several factors that influence the cost of syrup production. These are: juice extraction efficiency (of the machine), sugar content (Brix %) in the juice, conversion of juice in to syrup, and labor and staff employed in managing the crushing unit.

In the course of project implementation, juice recovery increased from 26% in 2008-09 to 30% in 2010-211, reflecting an increase of 15% in juice extraction efficiency. The same sweet sorghum hybrid (CSH 22SS) was used in all the years and it performed well in the farmers' fields, However, there is a need for developing cultivars that give an increased Brix% by at least 6% (from 15% Brix to 16%) that will contribute to increasing the viability of the unit. It is not difficult to achieve the target in the next five years as there is significant variability for Brix% and juice volume in the breeding populations that are being handled.

The labor cost in sweet sorghum syrup production was high (29% of total cost) in 2008-2009 but there is scope for improving labor efficiency through mechanization. There is also scope for improving crushing efficiency by modifying the crushers. Over the three year period, the labor cost has been brought down by 10%. The modifications effected in the crusher helped increase the juice recovery from 260 l to 300 l t^{-1} of stalks (efficiency increased by 15%). Further, the by-product, bagasse feed-chain could contribute to the revenue by the sale of up to 50% of the bagasse to help bring down the operating cost of DCU. The bagasse was sold as fodder at Rs 0.5 kg^{-1} in 2008-2009. In subsequent years, it fetched Rs 1.0 kg^{-1} with minimal processing (chopping). The above factors helped in reducing the cost of syrup production from Rs 32 kg^{-1} (first year of crushing) to Rs 22.5 kg^{-1} in the last year of its operations; the average production cost of syrup during the four year period, 2008-09 to 2010-2012 being Rs 27.2 kg^{-1}. Further, there is a scope for exploring value addition for syrup for use in food industry and demand for bagasse from alternative industries like fuel and paper industry, strengthening the viability of DCU.

During the project period, the distillery offered a maximum of Rs 10 kg^{-1} of syrup on the basis that three kgs of syrup (70% Brix) is required to produce one liter of ethanol (which was then priced at Rs 27 l^{-1}). In such a scenario (selling syrup at Rs 10 kg^{-1} when the production cost is Rs 27.2 kg^{-1}), DCU therefore should look for alternative markets for syrup, such as food/pharmaceutical/ feed industry which give higher price. A part of the syrup produced in the DCU was sold for instance at Rs 22.5 kg^{-1} to the dairy farms.

C) Viability for industry (Centralized area)

i) Productivity: Productivity of ethanol per ton of sweet sorghum stalk was 40 l by Rusni Distilleries, which needs to be improved to 55 l t^{-1} of stalk through 1) efficient crushing to increase juice recovery from the present 300 l t^{-1} to 500 l t^{-1} of stalk; 2) using feedstock with increased Brix% (at least 16%); and 3) increasing the fermentation efficiency by 3% from the present level. Thus, it is hoped that changes if effected as above would help enhance ethanol yield.

ii) Marketing: Ethanol recovery at 55 l t^{-1} at the sale price of Rs 27 l^{-1} will fetch for the industry Rs 1485 t^{-1} of stalk crushed. This leaves Rs 485 towards production cost of ethanol after meeting raw material cost at Rs 1000^{-t} as is the case in the project. However, the present ethanol market price (Rs 27 l^{-1}) needs to be increased to Rs 32 l^{-1} (under the current price structures) to make the industry viable. The industry should also explore the markets for vinasse, the by-product from ethanol production that would further contribute towards the viability of the industry, apart from the bagasse.

iii) Supply chain management: Currently the operating window for industry is only for two months with the available sweet sorghum cultivars which are productive only in the rainy season. Feedstock supply window needs to be increased to at least four months. Further, the industry should be able to utilize other feedstocks, such as broken/molded grain, spoiled potato, cassava tubers, etc., for ethanol production when sweet sorghum is not available. The extension of sweet sorghum feedstock supply is possible provided staggered plantings are possible and also cultivars of different maturities are made available to farmers for cultivation in the rainy season. Thirdly, sweet sorghums that have potentially high stalk sugar yields in postrainy season and in summer (where irrigation is available) should be developed through appropriate breeding methods. Fourthly, adopting and linking DCUs with distilleries will help provide syrup to distillery for use as feedstock at will to run it for several months in an year because syrup can be stored for several months unlike juice which gets fermented within two hours after crushing.

3. Other issues in commercialization

Labor cost is a major factor that contributes to nearly 55% of the cost of production of sweet sorghum, with harvesting operations being the most labor intensive. The sugarcane crushers used initially in the project did not show good recovery of juice. So, crushers need to be specifically designed for sweet sorghum. Attempts made by the project to develop and improve the harvesters and crusher rollers yielded partial success. There is further scope for bringing in further refinements with harvesters and crushers with the prospects for commercialization.

The Government of India has come out with a policy for minimum blending (10%) of ethanol with gasoline but the ground level regulations for implementation are lacking. To augment ethanol production and achieve the mandated blending target, the Government should come up with a clear policy road map to promote alternative feedstocks like sweet sorghum since ethanol from sugarcane molasses alone will not be able to meet the blending requirements as demanded by the policy.

Strong measures are required in terms of capital subsidy for industry on the basis of sops provided for infant industry status. Government should also take measures to strengthen entrepreneurial skills of farmers and recognize DCU as a small-scale agro-industry enhancing business opportunities for local entrepreneurs.

III. The way forward

The bottom line of any enterprise is to ensure economic benefits to all the stakeholders and in this case the farmers, DCU cooperatives and distillery enterprise apart from sustaining the environment where it is targeted. In this value chain, apart from ethanol, there are other by-products like bagasse for animal feed or bio compost both at DCU as well as at the distillery. The efforts should be directed to further enhance the efficiency in all the operational issues raised above in a way to ensure benefits to all the players in both DCU and centralized areas.

1. Crop production

- Emphasizing on strict adoption of recommended cultivation practices by all the farmers so as to achieve the targeted stalk productivity (30 t ha^{-1}).
- Developing improved sweet sorghum harvesters to reduce the cost of cultivation.
- Streamlining further the stalk supply chain innovation to reduce the time lag between harvesting and crushing and reducing the relative cost of harvesting and transportation.

2. Sweet stalk development

- Genetically improving stalk sugar content and resistance to shoot fly to make the cultivars adaptable to different sowing dates and seasons.
- Identifying appropriate staggered sowings and sweet sorghum genotypes with different maturity durations and the genotypes suitable for postrainy season to increase the harvest window and make the feedstock available for longer periods in the given target region.

3. Juice recovery and fermentation efficiency

- Designing a crusher specifically for sweet sorghum to enhance the juice recovery from present level of 32% to 50% both at DCU and distillery.
- Setting up enough crushers to handle the targeted feedstock on a daily basis to enhance juice recovery
- Reducing time lag between juice extraction and conversion in to syrup to enhance syrup recovery.
- Increasing juice storability and fermentation efficiency for higher ethanol recovery by identifying appropriate fermentation inhibitors yeast strains and enzymes to convert starch and sugars in to ethanol.

4. By-product utilization

- Setting up a feed processing plant for studying the economics of different feed processing methods to add value to bagasse.
- Developing value chain for bagasse utilization to enhance the price of bagasse
- Setting up studies to determine vinasse value and marketability

5. Markets for syrup, ethanol and by-products

- Even if the cost of syrup production is reduced to Rs 20 kg^{-1}, it is difficult to sustain the DCU when the syrup is sold at the rate of Rs 10 kg^{-1} to the distillery. So arrangements ought to be made to sell a portion of syrup to food/pharma/feed industries.
- To enhance bagasse value for use as animal feed (after meeting the fuel needs at DCU), working with fodder traders and dairy farmers to get higher price for bagasse is essential for improving the bagasse value chain.
- Attempts should be made at distillery to explore the use of vinasse as fertilizer.
- Also attempts must be made at distillery to utilize bagasse for second generation ethanol production apart from using bagasse for cogeneration.

The Government should take measures to implement strictly the policy of 10% blending of petrol with ethanol. It is likely that if the distilleries get higher support price for ethanol they may offer higher price for syrup as well as stalks.

The distillery should have facility to use multi-feedstocks to enable it to operate for optimum capacity utilization. Capacity utilization would be sub-optimal with a single feedstock that would increase capital costs. Further, the distillery should have good Research and Development support equipped with appropriate technical staff with skills in the production of ethanol from various feedstocks and in input and supply chain management assets.

We are confident that with the leads obtained from implementation of the sub-project and the measures suggested above will render sweet sorghum ethanol value chain sustainable both economically and environmentally. This can be made possible by the collective action of researchers, farmer cooperatives, ethanol industry and policymakers.

About ICRISAT

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) conducts agricultural research for development in Asia and sub-Saharan Africa with a wide array of partners throughout the world. Over 2 billion people, of whom 644 million are the poorest of the poor, live in the semi-arid tropics, which cover 55 countries. ICRISAT (a non-profit non-political organization) and its partners help empower these poor people to overcome poverty, hunger, malnutrition and a degraded environment through better and more resilient agriculture.

ICRISAT is headquartered in Patancheru near Hyderabad, Andhra Pradesh, India, with two regional hubs and five country offices in sub-Saharan Africa.

ICRISAT is a member of the CGIAR Consortium. The CGIAR is a global research partnership for a food secure future.

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