Sweet Sorghum Stalk Supply Chain Management: Decentralized Crushing-cum-Syrup Making Unit

Information Bulletin No. 90

ICRISAT
Science with a human face
International Crops Research Institute for the Semi-Arid Tropics

Citation: Ravinder Reddy Ch, Basavaraj G, Belum VS Reddy, Ambekar SS, Ashok Kumar A, Parthasarathy Rao P, Michael Blümmel, Ramana Reddy Y, Srinivas I, Rao SS, Wani SP, Umakanth AV, Ganesh Kumar C, Srinivasa Rao P, Mazumdar SD and Karupan Chetty SM. 2012. Sweet sorghum stalk supply chain management: Decentralized Crushing-cum-Syrup Making Unit. Information Bulletin No.90, Patancheru, 502 324, Andhra Pradesh, India. International Crops Research Institute for Semi Arid Tropics. 52 pp. ISB No: 978-92-9066-545-8 Order code: IBE 090.

Acknowledgments

We gratefully acknowledge the funding support for this publication from the ICAR-NAIP project. We also acknowledge the external reviewers, Dr Vilas A Tonapi and R Ratnakar, for their valuable comments and suggestions.

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Patancheru 502 324, Andhra Pradesh, India

2012

Abstract

In the climate of environmental concerns associated with fossil fuel use and the increased demand for energy in different counties, biofuel research and development has come to center stage. Sweet sorghum is a SMART crop with triple product benefits - food, feed and fuel. It is a good candidate for commercial ethanol production with potential opportunities for benefiting the poor dryland farmers through the emerging biofuel markets. Commercial ethanol production from sweet sorghum requires feedstock supplies for the long period of a year. ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) with Rusni distillery Pvt. Ltd. and other partners are working on supply chain management and addressing other issues in the sweet sorghum ethanol value chain. Principally, the sweet sorghum supply chain involves centralized and decentralized models. Under the centralized model, farmers supply the sweet sorghum stalks directly to the distillery, whereas in the decentralized model, farmers supply stalks to the Decentralized Crushing-Syrup Making Unit (DCU) located within the village where the crop is grown. The stalks are crushed at the DCU and the sweet juice is boiled to produce concentrated syrup that can be stored for more than 2 years at room temperature, and which is used for ethanol production, particularly in the off-season. This serves to augment the feedstock supply to the distillery. Use of the DCU for crushing and syrup production at the village level is a new idea and there is as yet no publication available on the requirements for establishment of a DCU and its management. In this bulletin, an attempt is made to briefly describe the experiences of ICRISAT and partners in the establishment and maintenance of a DCU, covering all the aspects from selection of site for its establishment, logistical requirements, plant and machinery, operation and management, economics of crushing sweet sorghum and its role in sweet sorghum supply chain management.

Contents

Foreword

Food, fodder and energy security are most critical for the sustenance of modern civilization.

Considering the volatility in the availability of fossil fuels, their costs and the associated environmental pollution, there is renewed global interest in biofuels. Sweet sorghum is a unique biofuel feedstock that gives food, feed, fodder, fiber and fuel. Off late, there has been a growing global interest in the use of sweet sorghum for ethanol production. Sweet sorghum juice-based (first generation) ethanol production is a commercial reality, and efforts are underway to use it as a feedstock for second generation (Ligno-cellulosic) ethanol production. However, there are certain critical issues that need to be addressed before taking sweet sorghum ethanol production to a higher level of commercialization, so that its socio-economic benefits can reach a large number of smallholder farmers in the semi-arid tropics (SAT). Enhancing crop productivity in farmers' fields, developing sweet sorghum genotypes and technologies that help in year-round scheduling of feedstocks, supply chain management, and increasing the shelf-life of the juice are some of the issues that need immediate attention. While addressing these issues, ICRISAT and its partners have been working on both centralized and decentralized models to ensure year-round supply of feedstock to distilleries for ethanol production.

The centralized model involves farmers supplying sweet sorghum stalks directly to the distillery, whereas the decentralized model involves farmers supplying stalks to the Decentralized Crushing Unit (DCU) located close to the village. The stalks are crushed at the DCU and the sweet juice is boiled to produce concentrated syrup that can be stored for more than 2 years. The syrup can then be used for ethanol production, particularly in the off-season, thereby augmenting feedstock supply to the distillery. In addition, the DCU helps in reducing the bulkiness of feedstocks and pumps the bagasse back to farmers for use as animal feed or for composting. This ensures direct employment to about 20-25 people in the village during this operation. ICRISAT and its partners are working on the economic viability of syrup production at the DCU to make it a sustainable unit that serves as a low-cost micro-enterprise. This bulletin on Sweet sorghum stalk supply chain management: Decentralized Crushing-cum-Syrup Making Unit comprehensively covers all aspects of setting up a DCU and it's management

The publication will serve as a useful guide for micro-entrepreneurs and farmer groups to establish a decentralized crushing unit as a rural agro-enterprise in order to take sweet sorghum ethanol production to a higher level of commercialization.

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1. 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 just the simple passive copying of technologies from others, but an active and creative process of adaptation that recognizes indigenous capabilities. Establishment of small-scale industries in rural areas will help to reduce poverty and unemployment. At the same time, it is an efficient way of preventing migration from rural to urban areas by creating new employment opportunities in the villages. The majority of rural populations in developing countries and least developed countries lack the agro-based small-scale enterprises that provide income to farmers through value addition to their agricultural 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 a 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. Therefore, a business model for small-scale farmers that helps them add value to their produce will result in improved livelihoods, besides helping to protect the environment at the same time.

2. Background and Rationale

Food and energy security are critical for the sustenance of modern civilization. Considering the volatility in 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 dry land farmers an opportunity to increase their incomes while protecting the environment without sacrificing food and fodder security. Sweet sorghum is a C4 plant with high photosynthetic efficiency. It produces a high biomass (up to 40-50 t ha^{-1}) in a short time (4 months) under rainfed conditions. It is a SMART crop that produces food, feed and fuel (grain for food, sweet juice for ethanol after fermentation and bagasse for animal feed/compost). ICRISAT is working on sweet sorghum improvement and, through its Agri-Business Incubator, has incubated the sweet sorghum ethanol production technology with Rusni distilleries. 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 the private sector (distillery) for crushing and processing of the juice for ethanol production; and decentralized stalk crushing and syrup making at the village level together with the supply of syrup to various end-users. A consortium of partners including ICRISAT, ILRI, National Agricultural Research Services (NARS), the private sector, NGOs and farmers associations actively contributed to the development of this value chain.

An assured supply of raw materials is critical for the success of any industry. Sweet sorghum being a season-bound crop, can produce stalks for crushing only for a limited period (3-4 months) during 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 the industry (Fig. A). A combination of the two models, centralized and decentralized, helps in supply chain management. While centralized distilleries crush the stalks in bulk quantities and produce ethanol, the

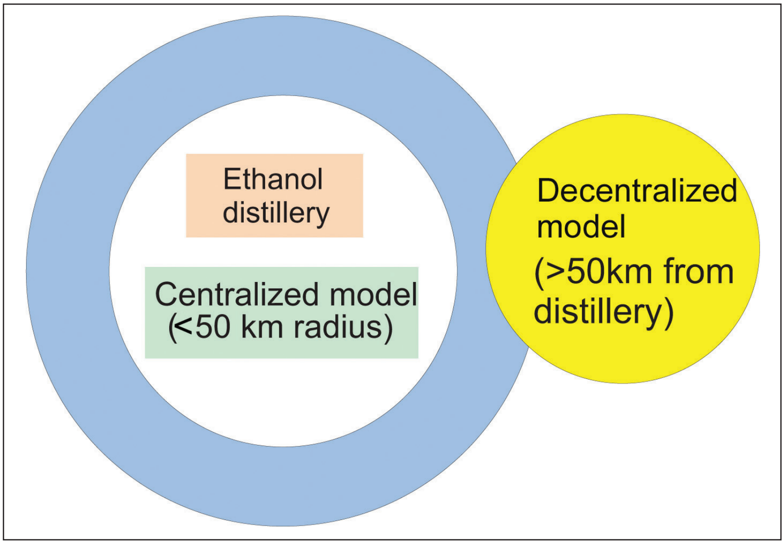


Figure A. Project design depicting centralized and decentralized models.

decentralized units crush the stalks at the village level and convert the sweet juice into syrup. The syrup can be stored for up to 2 years at room temperature thereby increasing the period of raw material (syrup for ethanol production) availability to the industry. Decentralized crushing reduces the legwork in dealing with high volumes of stalk and the costs of transportation associated with the centralized model.

In the centralized model, a typical 40 kilo liters 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 a 30-50 km radius of a distillery so that the time for and cost of transportation of stalks is kept at a minimum. However, the centralized model has the following limitations:

- Farmers located more than 50 km from the distillery will be burdened by high transportation costs owing to the bulkiness of stalks.
- Delay in crushing stalks beyond 24 hours of harvest causes >6% reduction in juice yield.
- A 24 hour delay in transportation of stalks to distilleries after harvest leads to reduction in stalk weight up to 20%, depending on climatic conditions, causing a financial loss to the grower as well as to the DCU.
- 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 such as vegetables, soybean, maize, rice, and wheat may be more economical than growing sweet sorghum under irrigated conditions.

The decentralized model overcomes some of these difficulties.

3. Decentralized Crushing Unit Model

The purpose of setting up decentralized crushing units (DCU) at the village level is to crush sweet sorghum stalks and extract the juice, which 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 units and by increasing the period of feedstock availability (supply of syrup) to industry to make sweet sorghum ethanol a commercial reality.

The by-product, bagasse (crushed stalk) is retained in the village and is 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. The DCU also serves as a model for farmer-centric, farmer-driven rural industry towards improving the livelihoods of small-scale sorghum farmers (Fig. 1).

Under the decentralized model, villages located at more than 50 km distance from the distilleries will be served by decentralized crushing units managed by farmers group/micro-entrepreneurs of the same village.

The model strengthens the farmers through capacity building, and links 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 costs from the farmers after crop harvest and supply of stalks to the DCU. The model also envisages the linking of the DCU with a distillery, with buy-back agreement for supply of syrup at a pre-agreed price.

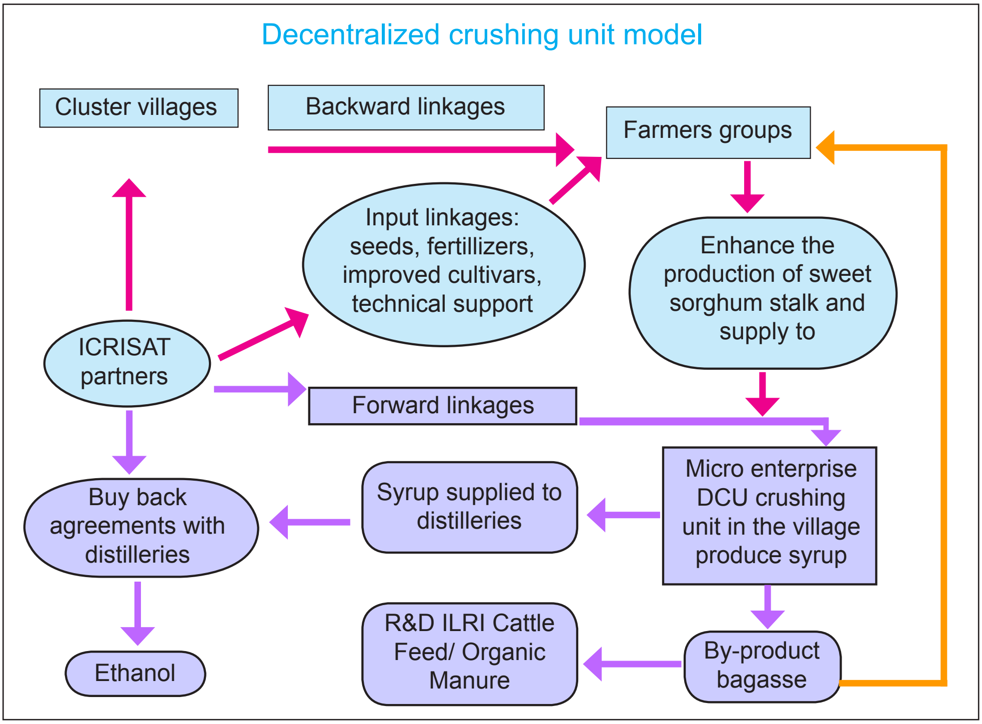


Figure 1. Decentralized crusing unit model.

Issues in decentralized crushing units

- Initial high investment for establishment of DCU
- Assurance by distillery for procurement of small quantities of syrup 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.

4. Establishment of Decentralized Crushing Unit

i) Selection of villages and site for DCU

An exhaustive survey needs to be conducted to select appropriate villages for growing sweet sorghum and to establish DCUs for syrup production. 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 of 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 surveys in different villages of the project areas, tentative cluster villages were identified for further study. 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 panchayath land (community land) to set up the DCU (Fig. 2).

After analyzing the merits and demerits of the different clusters, it was found that some cluster villages were suitable for large-scale sweet sorghum cultivation and for the establishment of a pilot DCU. Subsequently, five to seven villages were identified in this cluster within a 5−7 km radius from the nucleus village.

Figure 2. Meeting with village administration and local leaders.

As there was no panchayat land available in the village, a couple of farmers offered their land on lease for the 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 @ ₹ 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 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 village located alongside a main road that connects the cluster village and to the Mandal headquarters. It has a 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).

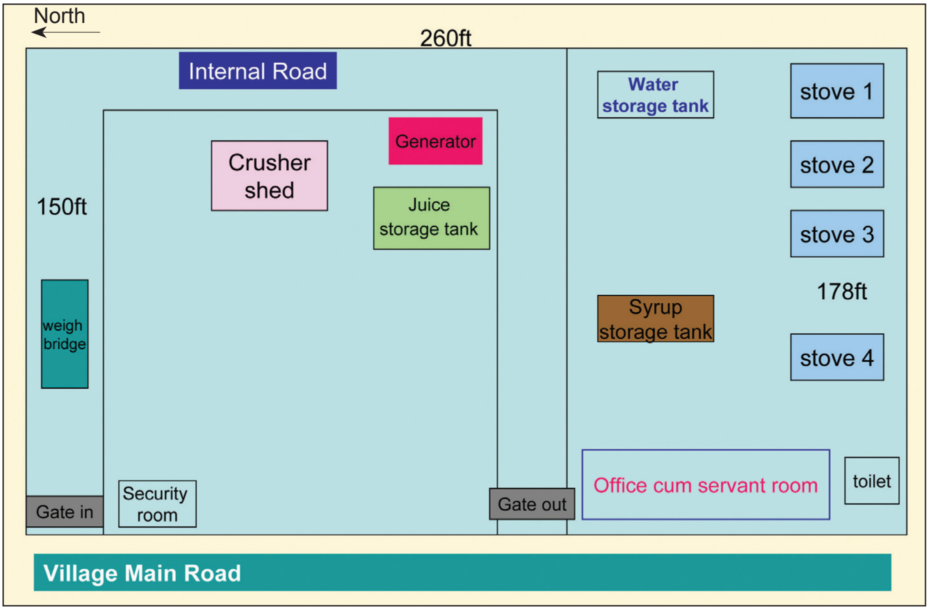


Figure 3. Layout of the decentralized crushing unit at Ibrahimbad village.

iii) Plant and machinery

In order to procure reliable and efficient machinery for the decentralized crushing unit, enquiries were made with local jaggery-making farmers and industry personnel. The following equipment and machinery was 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

a) Crusher: The crusher is the most 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 per hour 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 and 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 lapse between harvesting and crushing. The modified crusher efficiency was 350 liters per ton of stalk compared to the sugarcane crusher, which was around 260 liters per ton. As the crusher is critical in the DCU, it should have a low maintenance cost and fewer mechanical problems, and spare parts and repairing facilities should be easily available. The specifications of the crusher are presented in Annexure 2.

The crusher is operated with a 25 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 lit. capacity) placed beneath the ground level 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 the sugarcane stalks by tractor, bullock carts and sometimes by truck. It is important to weigh the stalks brought to the DCU for crushing, as the payments to farmers will be made based on the quantity of fresh stalks they supply. In this project, we installed a surface mounted weigh bridge with a 50 ton load capacity. If a weigh bridge facility is available within the village limits or near the DCU, such an investment can be avoided. The weight of the stalks are recorded with a computer attached to the weigh bridge. A stalk weight slips with the farmer's name and contact details are provided to the farmer.

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

d) Chulas: These are earthen stoves for boiling the juice. They are made of bricks and cemented with pressed mud. Each chulha measures 6.6 ft in diameter, and is embedded 3.0 ft. deep into the soil. A 10 ft. high exhaust outlet (tower) erected 7.0 ft. from the chulha, was also made of bricks and pressed mud. Each chulha has a 9.0 ft long air passage channel below the soil surface connecting the chulla and exhaust tower. The opening for feeding the bagasse (fuel for the chula) is 1. 6 ft long and is located in the rim of the chula.

e) Boiling pans: standard sugarcane juice boiling pans were used to boil the juice. They are made of 18 gauge thick galvanized mild steel sheets, with a diameter of 7.0 ft. and a depth/height of 1 ft 6 inches. Each pan can hold 700−750 liters of juice per cycle (Fig. 4). The boiling pan has to be put aside for cooling of syrup before filling syrup into plastic cans for storage. An additional set of boiling pans would facilitate continuous operations.

f) Juice boiling accessories: Several small tools are needed for syrup production. Metallic sieves are required to remove unwanted contaminants

Figure 4. Boiling juice in the pan and feeding bagasse into the chulha.

floating on the surface of the boiling juice and to remove the froth or scum that 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 (Fig 5). All these accessories are custom made locally.

Figure 5. Juice boiling accessories, metal sieves and wooden dragger.

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 hose pipe. The juice collection tank is placed near the crusher (in a pit) connected with an outlet pipeline from the crusher delivery channel. Wide-mouthed plastic cans are used for storing syrup (Fig. 6). Steel baskets (3 ft × 3 ft) are used to shift the bagasse from the crushing site to the drying yard.


Figure 6. Syrup from pans are poured into wide-mouthed syrup storage cans.

iv) Other facilities

- 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 an important requirement. For this project, we used the water from the farmer's bore well.
- Technician: Trained local technicians must be engaged for maintenance of the plant and machinery, and for troubleshooting. We made arrangements with local technicians to render their services as and when required.
- Sheds: It is recommended that a shed with tin or asbestos sheet roofing should be erected, which will enhance labor efficiency.

5. Command Area Development

Sweet sorghum command areas need to be developed to meet the raw material requirements of a DCU. In the present project, there was a limited area available under irrigation, therefore, major emphasis was placed on sweet sorghum cultivation in the rainy season. Inputs like seeds, 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 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, an NGO and the famers' association complemented the project team particularly for 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, top dressing, etc), activities that would enhance production and help develop harvesting schedules for the supply of sweet sorghum stalks to the DCU. The objective of including these partners in project activities from the beginning is to strengthen these community based organizations in operation and management of DCU, so that these stakeholders will continue the project activities even after completion of the project period, and thus sustain project interventions.

6. Crushing and Syrup Production

i) Procurement of raw materials

This is critical to the success of the model as it involves winning the confidence of farmers through timely harvest, stalk procurement and prompt payment. Under the project, the farmers association assisted in linking the farmers to the DCU. This involved community mobilization for various activities of the project including scheduling the harvesting process to facilitate steady supply of stalks for crushing at the DCU (Box-1). Payments for stalks were made on pre-agreed price (buy-back agreement) per ton of stalk.

Box-1

Stalk supply chain management

Issues: During the first year of project implementation some difficulties were observed in the 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 coincide 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 1 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 timely and transport cart by cart to the DCU will help to retain the original weight of the stalks.

Innovation: Looking into the economics of syrup production, the timely harvesting and stalk supply and 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 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 ₹ 220 per ton of stalk for the entire task. It is being run smoothly.

Benefits:

- Timely harvest of the sweet sorghum crop
- No time lag between harvesting of stalks and their transportation to DCU
- Timely crushing of stalks at DCU leading to increased juice recovery
- Enabled the farmers to attend other works (most farmers are working at DCU during this period)
- Gainful employment to a group of laborers through sweet sorghum harvesting and transportation
- Increased efficiency of DCU in terms of timeliness of operations like crushing stalks and producing syrup.

ii) Crushing

Sweet sorghum stalks should be crushed on the same day as harvesting (Fig.11). Delay in crushing results in low juice recovery and eventually low syrup yield. The DCU established at Ibrahimbad village has the capacity to crush 2 tons per hour, and can crush stalk from a 25 - 30 ha area during the rainy season (Kharif) within 30 days of operation, working one shift of 8 hours per day. The starting time for crushing usually depends upon sowing date, as generally the 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 modified sugarcane crusher was used for crushing sweet sorghum (Box-2).

Box-2

Improved Efficiency of crusher

Development of high juice recovery 3-roller crusher with 25 hp motor was developed with the help of a private sector company “Adarsh engineering company” Nagpur, Maharashtra. The rollers of the crusher were designed in such a way that it crushes the stems of sweet sorghum completely. The stems of sweet sorghum are softer than the sugarcane stems. The grooves on the rollers were modified and were 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 crushed 24 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 $l\ t^{-1}$, the percentage increase in juice recovery when compared to the sugarcane crusher was found to be increased by 37%. With this increased efficiency the average productivity of syrup has increased by 25% and overall syrup production cost decreased by 22%. This will have a positive effect on viability of DCU operations and economics.

Sugarcane crusher with modifed rollers.

iii) Bagasse

The solid bagasse that remains after crushing sweet sorghum stalks is a byproduct from DCU and has several potential uses. Bagasse is used as fuel in chullas at the DCU for boiling juice to make syrup. Other potential uses are as a source of animal feed, directly after chopping or after ensiling, and as a source of pulp for the paper industry. At the DCU, 50% of the bagasse is consumed as fuel for making syrup and balance 50% as fodder/ feed for livestock supplied to farmers and fodder agents.

Sweet sorghum bagasse as livestock feed

- Sweet sorghum is one of the most efficient dry land crops and well adapted to the semi- arid tropics.
- It is similar to grain sorghum crop but rich in sugars. The juice extracted from stalks is used for ethanol production.
- The stalks after extraction of juice from the stalks is called sweet sorghum bagasse.
- The sweet sorghum bagasse (SSB) fresh or dried, is suitable for feeding animals.
- The dried bagasse can be utilized for feeding of livestock as a source of roughage, and animals relish it.

Nutrient composition (%) of dried sweet sorghum bagasse	
Organic matter	90.75
Protein	3.94
Fat	1.89
Fiber	37.58
Nitrogen free extract	47.34
Ash	9.25
Calcium	0.82
Phosphorus	0.47

The nutritive value (%) of sweet sorghum bagasse

	Buffalo	Sheep
Energy (TDN)	51.59	50.59
Protein	1.58	1.86

- Sweet sorghum bagasse is comparable to other crop residues such as sorghum stover and maize stover in protein, energy and fiber.
- It is superior compared to paddy straw.
- The SSB can be fed either in chopped form or in ground form
- Ground SSB can be incorporated in complete rations at 60% level for growing sheep.
- SSB based complete diet can also be processed into expander extruded pellets
- Such SSB based complete diets can meet the nutrient requirements of buffaloes to support the milk production of 5-7 litres and growth rate of 100 g in lambs and 500 g daily in calves (Fig 7).

Chopping bagasse.

Sheep eating chopped bagasse.

Bagasse heap ofter crushing.

Chopped bagasse for feeding of buffalos.

Figure 7. Chopping of bagasse for feeding livestock.

SSB based complete diets for dairy and growing animals		
Ingredient (kg/100kg)	Ration 1	Ration 2
SSB	60.00	50.00
Maize	12.40	15.50
Groundnut cake	6.60	8.25
Sunflower cake	8.00	10.00
De-oiled rice bran	9.20	11.5
Molasses	2.00	2.50
Urea	0.60	0.75
Mineral mixture	0.80	1.00
Salt	0.40	0.50
Vitamin mixture (g)	10.00	10.00

SSB Silage

- The fresh SSB can also be made into silage and fed to the animals.
- It can be made into silage as whole and chopped without any further addition of moisture or additives to make it cost effective.
- Feeding silage with 225 g concentrate supplementation can support 50 g average daily gain in growing lambs.

Box-3

Bagasse as fodder

Issues: During the first year of project implementation some difficulties were observed in sweet sorghum bagasse utilization. Large amounts 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 were apprehensive about whether the animals would like bagasse, so did not use it. We have conducted on-farm experiments with farmers' participation wherein the bagasse was fed to their milch cattle, and demonstrated that higher intake by the animals resulted in increased body weight, milk output and marginal increase in fat content of the milk.

Educating farmers and fodder agents: We started sensitizing the farmers about the advantages of using sweet sorghum bagasse as animal feed from the beginning of the rainy season. Simultaneously, we also sensitized the fodder agents who supply the sorghum stover to the dairy industry on the utility and market opportunities of sweet sorghum bagasse as animal feed.

Innovation: Our partners SVVU and ILRI took a lead role in facilitating fodder value chain development. We 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 were supplied with the samples of fresh and chopped bagasse. The fodder agents arranged to lift the fresh bagasse from the DCU immediately after crushing 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 bagasse went up and agents offered Rs 1.2 kg^{-1}. The demand for bagasse provides a clear indication that private dairy farms prefer sweet sorghum bagasse over other feeds. Therefore, there is a great scope for promoting sweet sorghum bagasse as animal feed through innovative linkages and value chain development.

Benefits of bagasse value chain

- The sweet sorghum bagasse augments the fodder requirements of the farmers
- A new fodder variant available in the fodder market
- Opportunity for additional income to farmers through sale of bagasse
- Opportunities for use of sweet sorghum stover for animal feed
- Increased availability of fodder to the fodder market.
- Safe disposal of sweet sorghum bagasse generated at DCU

iv) Syrup making

The syrup making process involves collection of juice from the crushing point and boiling it to 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 (Fig. 8) (Box-3).

The juice in the pan is constantly stirred, and the undesirable coagulate is skimmed off frequently (Fig. 4) The skimmings are generally rich in protein and starch as well as some sugar, and can be used in the preparation of animal feed. As the syrup density increases, the boiling temperature is gradually increased. The boiling pans are removed from the burners (chulas) when the temperatures 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 is stored in plastic containers at room temperature (Fig. 6).

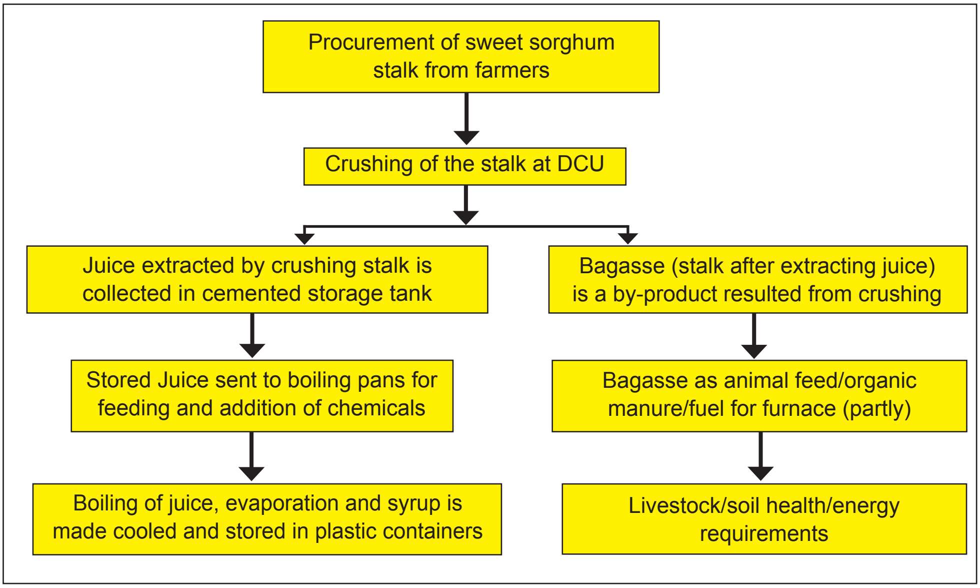


Figure 8. Steps in syrup making process.

Box-4

Producing syrup from sweet sorghum juice

1. Extraction of juice

The earheads are harvested at physiological maturity followed by stalks harvested and transported to DCU for crushing and extraction of juice. The percentage of juice extracted depends on the time lapse between harvesting and crushing. Delay in crushing over 24 to 48 hours will result in reduction of juice output by 20-30% depending on relative humidity and temperature and crusher type. Generally, sugarcane crushers yield 260 L t^{-1} of stalk. A modified crusher developed for crushing sweet sorghum stalks yields 350-425 L t^{-1} stalk.

Filtration of juice:

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

2. Boiling of Juice

The juice extracted is transferred to juice boiling pans with a capacity of 700 L. The following precautions are taken for boiling juice.

- Steady evaporation is the most important process of making syrup.
- Evaporation should be done with uniform heating to obtain 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
- Syrup quality improves with continuous removal of scum from the surface of the boiling juice in the pan.

3. Clarificants (chemicals) for removal of impurities from the juice 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.

Cont...

Box-4 Continued

- Above two chemicals are used at time placed into the pan before filling juice and juice is filled in the pan by stirring the chemicals. These chemicals will clear the juice by removing dirt.
- Hibiscus (ladies finger powder)- 10 gr. Placed after filling the juice in the pan
- Caustic Soda (Sodium Hydroxide) - ½ kg. – will be applied during boiling juice
- Castor oil – 100 gr (to get froth on the boiling juice, which collects all the dirt in the juice, and is later decanted)

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

sodium Hydrosulphite-50 gr, (is applied at the end after getting brix 70%, chemical is placed into the syrup just before removing syrup from the pan and stirred well) this also restores color of the syrup.

4. Evaporation process

- The density of juic (Brix%) increases as the boiling temperature rises.
- When the temperature of the juice reaches 1050^{O}C to 1070^{O}C, the Brix of the syrup should be 65-70%.
- The Brix and temperature of the boilling juice has to be monitored at regular intervals.

5. Cooling of syrup

- Cooling of syrup should be done immediately to avoid burning.
- The temperature of 1050^{O}C to 1070^{O}C, should be brought down to 850^{O}C to 800^{O}C within 10-15 minutes
- The syrup should be free from burnt taste and smell.

6. Syrup yield

- Syrup yield: 50-55 kg/ton of stalk (15-18% of juice v/w) at 70-75^{O} Brix
- Syrup yield depends on intial Brix% of juice
- The color of the syrup varies with the genotype and season of growth.

7. 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 airtight containers leaving a gap at the top of the container.

v) Food grade syrup production and its use in food industry

A study was undertaken to explore and demonstrate the innovative usage of sweet sorghum juice in the food industry, which focused both on improving the processing of juice to food-grade syrup and the development of value-added sweet sorghum syrup-based food products. This innovative study describes a new method to produce clarified sweet sorghum juice using filter-aid and a vacuum filtration system. The juice is clarified and processed into syrup. The syrup is innovatively used as a sugar replacement or ingredient in developing value-added food products (Fig. 9), developed as per the Indian food regulations.

Processing

- Harvest crop at physiological maturity.
- Remove the leaves and leaf sheath from the stalks before crushing.
- The juice extracted from the stalks is pre-heated for about 20 minutes to 70^{O}C, then cooled down to 40^{O}C.
- The juice is clarified using vacuum filtration – A filter cloth is cut to size and placed on the Buchner funnel.
- A uniform bed of Celite® is prepared on the filter cloth,
- The juice is poured on the Celite® bed and filtered under vacuum. This process results in clarified sweet sorghum juice.
- The juice is concentrated to syrup by heating and slow evaporation. This is carried out under uniform heating conditions with continuous stirring.
- As concentration proceeds, the boiling point increases. Hence, it is important to heat under a low flame to avoid charring.
- Scum formed is continuously removed.
- Heating should be stopped when the concentrated juice (syrup) is 72^{O} to 76^{O} Brix.

Physico chemical characteristics

- Total soluble solids (^{O}Brix) and pH of juice, syrup and the developed beverages are measured with a digital pocket refractometer and pH meter, respectively (Annexure 3).
- Acidity is calculated by titrating against 0.1 N NaOH and is expressed as percentage of citric acid. Water activity (a_w) is measured using a water activity meter.

Advantages in product development

- The syrup obtained from sweet sorghum juice contains biologically active substances and micro-nutrients.
- It is a rich source of calcium, potassium and iron, and of natural antioxidants (ascorbic acid and other carotenoids).
- It does not easily crystallize into sugar because of its relatively high content of reducing sugars as compared to cane sugar.
- Product developers can therefore explore the use of sweet sorghum syrup in applications where crystallization is an issue.
- The study proves that sweet sorghum syrup can be used in the preparation of a number of food products without compromising on their sensory quality.

Syrup is shelf-stable

- As the syrup contains 70% or more sugar, it is shelf-stable and does not ferment. The sugars present in the syrup bind most of the available free water thus reducing the water activity (a_w), leaving very little water for microbial growth.
- It is also an acidic food (pH<4.6). Thus sweet sorghum syrup with a_w between 0.6 to 0.65 and pH 3.75-4.00, is a shelf-stable product without need for preservatives or refrigeration.

Syrup for the pharmaceutical and food industry

- Sweet sorghum syrup can be used as an ingredient in Neutraceutical formulations, Medicated sweets, Blended powders, Syrups, Elixirs, Tablets, Lozenges and Capsules. Evaluation of food products (RTS) showed that the samples were acceptable to the consumers and rated at par with commercially available samples. These products are ready for commercialization. (Fig. 9).

Sweet sorghum syrup based products

Figure 9. L to R: Ready-To-Serve (RTS) Sweet sorghum-based beverage, Tamarind - Sweet Sorghum Sauce, Sweet sorghum-based tomato sauce, Sweet sorghum crispies.

7. Training stakeholders in DCU operation

Under the ICRISAT-NAIP 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 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 as care should be taken while the DCU is in operation particularly with regard to handling the crushers and chulhas. Training programs were conducted to enhance capacities of farmers' group like farmers' association, local community-based organization (CBOs) partner institutions staff and NGOs. The training programs included hands-on-training in overall maintenance and repairs, trouble shooting, stalk supply chain management and assessing quality parameters of juice and bagasse output, and 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.

8. Economics of Syrup Production

Over the past two decades India's economy has grown at the rate of 5-6% per annum. Energy consumption is one of the major indicators of a country's economic progress and is one of the major universally recognized inputs for economic growth and development. India ranks sixth in terms of energy demand accounting for 3.6% of the total global energy demand (Prasad et al. 2007) and its energy demand is expected to increase by 4.8% in the next few years (Joseph B Gonsalves 2006). India's energy demand is primarily met through non-renewable energy sources such as fossil fuel (coal, natural gas and oil). About 70% of the oil demand is met through import of crude oil (Ministry of Oil and Natural Gas 2009) with a high import bill putting pressure on the scarce foreign exchange resources.

Growth in economy coupled with growing energy demand on the one hand and the rapid depletion of energy resources on the other, is forcing the identification of alternative sources of energy. The shortage of energy supply from non-renewable sources has been further exacerbated with the growing concern over environmental pollution due to indiscriminant usage of fossil fuels.

Due to these growing concerns, global focus has shifted to resource augmentation through renewable alternative energy sources to meet the energy demand. Among several alternative renewable energy sources such as wind, solar and hydro-power, energy derived from biomass is gaining importance worldwide. Bioenergy derived from biofuels has been the major thrust across countries as an alternative to ensure energy security.

Biofuels are liquid fuels derived from renewable biomass such as plants and organic waste. The fuels derived from agricultural feedstock, vegetable oils and animal fats using conventional technology are referred to as *first generation biofuels*. Bioethanol and biodiesel are the two most common biofuels that are commercially exploited.

Palm, edible oil, Jatropha and switch grass are some of the feedstocks that are used for production of biodiesel, while sugarcane, corn and sugar beet are common commercially exploited feedstocks for bioethanol. India is the world's fourth largest producer of ethanol after Brazil, the United States and China (Joseph B Gonsalves 2006). Ethanol in India is primarily produced from the fermentation of sugarcane molasses, a byproduct from conversion of cane juice into sugar. Current production of ethanol from sugarcane molasses will just be able to meet the requirement of blending 5% ethanol in automotive fuel mandated by the Government of India by 2011-2012 (Table 1). Since it will not be feasible to increase the area under sugarcane due to resource constraints, alternative sources of raw materials for bioethanol production that are economically viable and sustainable have to be explored. One such promising feedstock for bioethanol production for commercial exploitation is sweet sorghum.

Table 1. Projected demand and supply of ethanol for 5% blending in petrol.

Year	Petrol demand (M tons)	Ethanol demand (M liters)	Molasses production (M tons)	Ethanol production (M liters)	Ethanol utilization (M liters)			
					Potable alcohol	Industrial alcohol	Fuel blending	Surplus/ Deficit
2006-07	10.07	592.72	13.09	2100	990	1010	120	(20)
2011-12	12.85	1090	11.36	2400	1550	1100	1090	(1190)
2016-17*	16.40	1389	11.36	2400	2175	1411	1389	(2575)

Source: Planning Commission (2003) & Indian Chemical Council

* Projections based on growth rates of 7% for potable alcohol, 5% for industrial and 5% for fuel blending.

i) Sweet sorghum as a source for bioethanol

Sweet sorghum can be grown under dry land conditions with a minimum annual rainfall of 700 mm. Sorghum being a C4 tropical grass is adapted to latitudes ranging from 40°N to 40°S of the equator. Like grain sorghum, sweet sorghum is a drought resistant crop and can be cultivated by poor farmers in the rainfed areas of the semi-arid tropics. The crop can be grown successfully on clay, clayloam or sandy loam soils, and can tolerate salinity and alkalinity considerably. The crop is also considered to be a natural replacement for less water efficient crops. The cultivation practices of sweet sorghum are similar to those of grain sorghum, and the only dissimilarity between grain and sweet sorghum is the accumulation of sugars in the stalks of sweet sorghum. The current yield of sweet sorghum stalks is in the range of 18-20 tons per hectare. Apart from stalk harvested for its juice content to produce bioethanol, additional benefits are in the form of grain harvested for food, and bagasse, which is an excellent feed for livestock.

Additionally, bioethanol produced from sweet sorghum is more eco-friendly compared to ethanol produced from molasses due to:

- Impacts of climate change having adverse effects on irrigated crops like sugarcane due to scarcity of water
- Environmental certifications required by sugarcane distilleries to process molasses to ethanol as the effluents have high Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

ii) Economic assessment of syrup production from sweet sorghum for bioethanol

As part of the ICRISAT-ICAR (NAIP) sweet sorghum value chain project linking sweet sorghum farmers to the ethanol industry, a decentralized crushing unit was set up at Ibrahimbad village, Medak district, on a pilot basis. This model was being pilot tested to overcome some of the shortcomings of the centralized unit. In the centralized model, it was found that delay in transporting stalk to the industry resulted in loss of juice yield, and hence stalk can only be procured from farmers close to the industry. The main advantage of the DCU model is that the syrup can be stored for 24 months before it is converted into ethanol, thus allowing flexibility in transportation and conversion into ethanol. The experience of operating the DCU on a pilot scale are presented here.

This chapter provides an overview of the economics of the decentralized crushing unit and options to increase its economic viability/returns during the 2009 crop season. The results are also compared with data for 2008.

iii) Operations of decentralized unit

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

From the sweet sorghum harvested area a total of 599.9 tons of sweet sorghum stalk was produced in kharif 2009 with an average yield of 20 ton/hectare. There was however considerable variation in the yield levels, varying between 3 tons to 31 tons/hectare[1]. Relative to the kharif 2008 season, average stalk yield per hectare was higher by 34% increasing from

[1] Variations in yields were mainly due to poor agronomic practices (no intercultural operations, no top dressing fertilizer), wild boar damage and poor germination.

15 to 20 ton/hectare. The entire stalk of 599.9 tons was crushed in 27 days with an average crushing capacity of 22 tons per day. The average labor requirement was 54 man days with an average production of 5,897 liters of juice per day (Table 2).

Table 2: 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 (ton/ha)	15	20	33
Average stalk crushed (ton/day)	13	22	69
Crushing days	43	27	(37)
Average labor/day	NA	54	-
Juice extracted/ton of stalk	261	269	3
Syrup yield/100 liters of juice	15	18	20
Average syrup/ton of stalk	40	48	20

The total quantity of juice extracted from crushing 599.9 tons of sweet sorghum was 161,565 liters and fresh bagasse weighed 419 tons. 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 liters was 28.8 tons. The average syrup production per ton of stalk is 48 kg, which is 20% higher compared to syrup production of 40 kg in 2008. Syrup yield per 100 liters of juice is 18 kg, which was 20% higher compared to 2008 (Table 2).

iv) Cost of processing stalk to syrup

The total cost of production of 28.8 tons of sweet sorghum syrup is ₹ 739,528 and the net return realized in rupees is ₹ 384,248. The break-up of cost presented in Table 3 indicates 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 (Table 3, Figure 10). On an average, the cost incurred in processing 1 kg of syrup is ₹ 25.65. The cost per kg of syrup production has declined from ₹ 31.4 per kg in 2008 to ₹ 25.6 per kg in 2009. The decline in cost of production is Rs 6 per kg, which is an 18% decline relative to 2008.

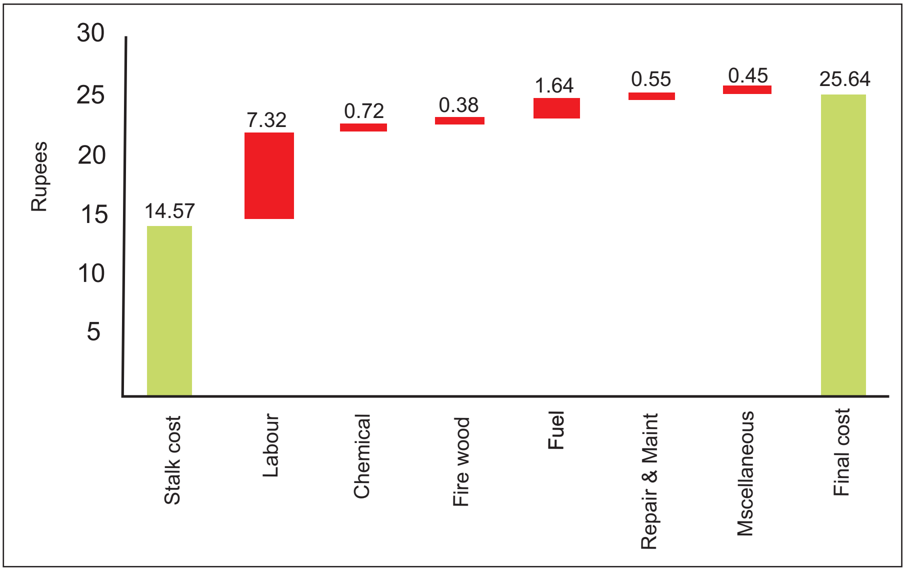


Figure 10. Item-wise break-up of costs of processing sweet sorghum to syrup production.

Table 3. Cost of syrup production in decentralized unit, kharif 2009, Ibrahimbad, Andhra Pradesh.

Cost Item	Total costs (rupees)	Cost/kg of syrup	Percent to total costs
Cost of raw material			
Stalk yield (tons)	600		
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 reveals that the cost incurred for drying the bagasse after crushing the stalk accounts for 39% of the total labor costs/ ton 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 (Table 4). On an average, about 52 man days of labor are required to convert one ton of stalk to syrup, which at current wage rates amounts to Rs 8,800.

Table 4. Labor utilization for crushing stalk and syrup processing, Ibrahimbad, 2009.

Activity	Labor days	Percent of total labor days	Labor cost/ton of stalk	Percent labor cost /ton of stalk
Crushing	490	33	2,722	31
Drying	694	46	3,414	39
Boiling	262	17	2,060	23
Syrup supervisors	58	4	604	7
Total Labor	1,504	100	8,800	100

v) 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 5). The gross returns and total costs per hectare realized from sweet sorghum for syrup production works out to Rs 9,670 and Rs 24,783, respectively, with a net deficit of Rs 15,113.

Table 5. Costs and return from sweet sorghum for syrup production (Rupees).

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)

vi) Options for Increasing Returns

Currently, the pricing of syrup for ethanol is at Rs 10/kg. 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 by the food industry 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.

Breakeven 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. Breakeven scenarios of syrup production per ton of stalk and per hectare of sweet sorghum are presented below (Table 6 and Table 7). In both tables the figures in bold indicate the breakeven scenario pertaining to syrup production.

Sensitivity analysis for the breakeven 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 to make the unit viable.

Table 6. Breakeven scenarios for syrup production from sweet sorghum (per ton of stalk).

Indicator	Current scenario	Breakeven scenario/ton of stalk		
		Juice & Syrup Yield Increase	Price Increase	Cost Decrease
Syrup yield/ton of stalk	48	**124**	26	48
Total cost/ton of stalk (Rs)	1,232	1,232	1,232	**480**
Gross returns/ton of stalk (@ Rs10/kg)	480	1,240	**1,248**	480
Net returns/ton of stalk	-752	8	16	0

The other alternative to break even is to reduce the cost of processing as there is scope for improving labor efficiency and crushing efficiency. Sensitivity analysis done to reduce cost reveals that a decline in cost to the extent of 120% makes the unit viable for crushing.

Table 7. Breakeven scenarios for syrup production from sweet sorghum (per hectare).

		Breakeven Scenario /ha		
Indicator	Current Scenario Actual	Juice & syrup yield increase	Price increase	Cost decrease
Syrup yield/ha (kg)	967	2,480	967	967
Total cost/ha (Rs)	24,783	24,783	24,783	9,670
Gross returns/ha (@ Rs 10/kg)	9,670	24,800	24,794	9,670
Net returns/ha	-15,113	17	11	0

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 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 developed.

vii) 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 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.

viii) Importance of syrup recovery and quality

Present recovery of juice per ton of stalk is 26.9% (269 liters of juice per ton of stalk). If the juice recovery increases to 32% (320 liters per ton of stalk) with cost of processing remaining the same at Rs 25.65, the total yield of syrup will be 57 kg per ton of stalk, instead of the present 48 kg. Hence, the cost per ton of syrup will be reduced by ₹ 4.00, which is a 15% decline, or the increase in gross returns will be to the extent of ₹ 4kg 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 ₹ 1.44 from the current level (₹ 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 (Figure 11).

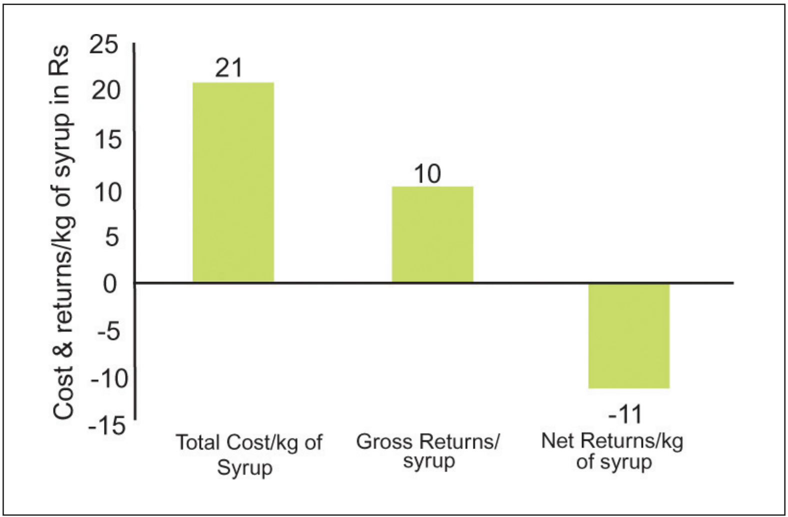


Figure 11. Reduction in unit cost of syrup due to improvement in juice yield.

ix) Importance of selling bagasse as fodder for additional returns/reducing costs of syrup production

Presently, the price received for bagasse sold to the fodder industry is Re 1/kg. 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 liters) 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 ₹ 115.5. With better utilization of bagasse, the cost of processing a ton of stalk (₹ 1,231 for both raw material and processing) will reduce by ₹ 115.5 (1,231−115.5=1,115.5), and hence the unit cost of syrup production will reduce from ₹ 25.65 to ₹ 23.23, a decline of ₹ 2.40 kg^{-1} or 9% decline in cost.

In other words the gross returns will increase by ₹ 2.4/kg of syrup due to additional returns from selling bagasse. Figure 12 below presents a graphical representation of reduction in unit cost of syrup/increased returns because of additional returns from bagasse.

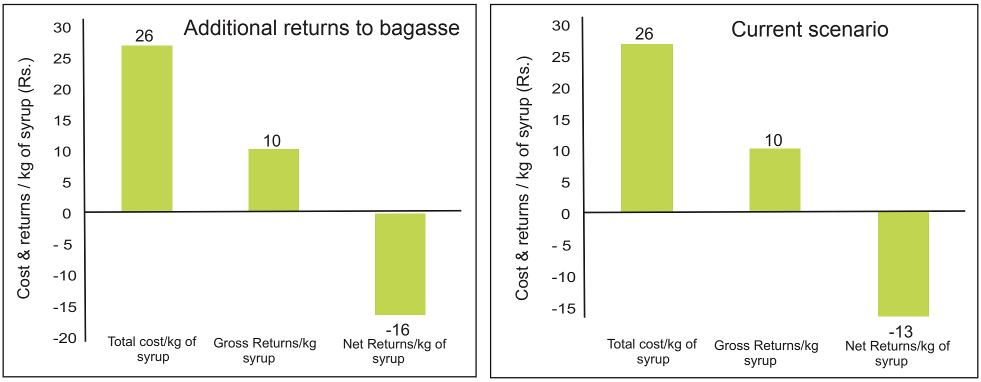


Figure 12. Additional returns to syrup from value addition to bagasse.

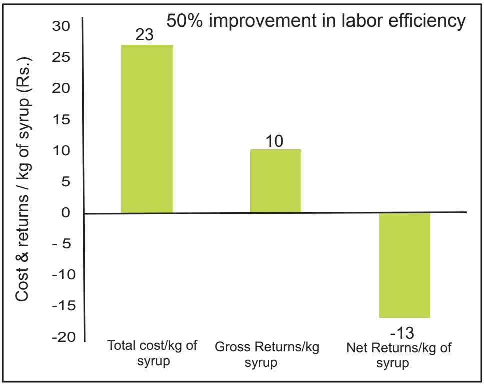
x) Importance of labor efficiency for cost reduction

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%.

Figure 13 shows reduction in per unit cost of syrup through improvement in labor efficiency to the extent of 30 to 50%. Of the total cost of processing one kg of syrup ₹ 11.07 (excluding raw material cost), the labor cost is

₹ 7.32. If the labor efficiency improves by 30%, the reduction in cost of labor will be ₹ 2.19. The labor cost will thus be reduced from ₹ 7.32 to ₹ 5.12 and the reduction in cost of syrup because of labor efficiency alone would be by 8%, ie, from ₹ 25.65 to ₹ 23.45. If the labor efficiency improves by 40%, the reduction in cost of syrup will be by ₹ 2.92, ie, to ₹ 22.72 from ₹ 25.65, and 50% improvement in labor efficiency will reduce the cost by ₹ 3.66.

To optimize returns from syrup production and reduce the cost of syrup production, sensitivity analysis was carried out with various scenarios. Figure 14 shows the overall efficiency gains in labor, juice and syrup recovery and



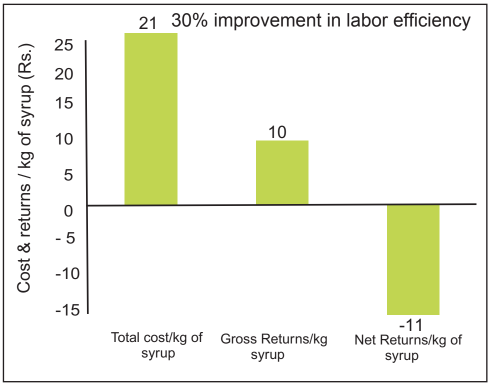


Figure 13. Reduction in unit cost of syrup due to labor efficiency.

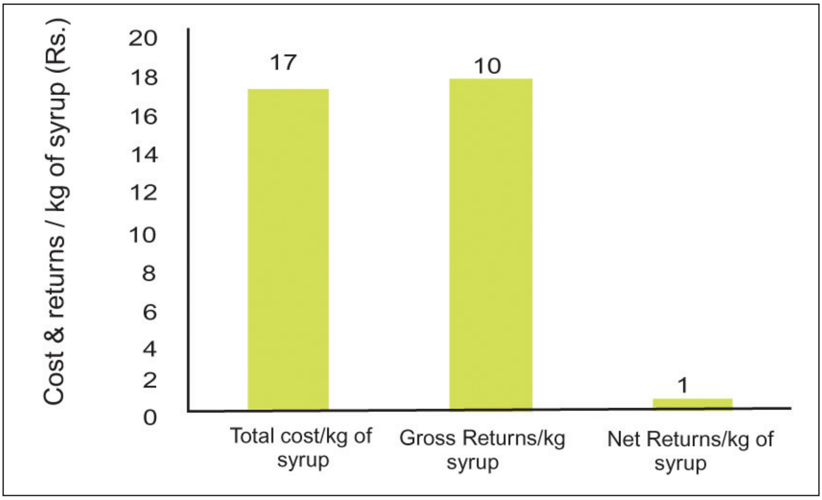


Figure 14. Optimum scenario through efficiency gains in syrup production.

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 ₹ 17/kg from ₹ 25.65. Assuming 75% of the syrup is sold to the ethanol industry at ₹ 10/kg and the remaining 25% of syrup is sold in alternate markets, we project that the decentralized unit will break even and even earn a small profit.

Thus, by converting stalk to syrup and selling the syrup to the ethanol industry and to alternate markets, farmers can realize additional income through value addition instead of selling the stalk directly to the distillery.

9. Summary and Conclusions

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 for higher recovery of ethanol. The establishment of decentralized crushing units on a pilot basis in the vicinity of sweet sorghum cultivation, helped in processing syrup, which can be stored up to a year (if required) before further processing to ethanol. The results of the economic assessment of crushing sweet sorghum and value addition under a decentralized unit 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 the reason that the management of a crushing unit at farm level would vary significantly leading to high processing cost. The initial technology used for crushing sweet sorghum 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.

The DCU will in general serve as an extended arm of the distillery and will operate as a stand-alone self-sustaining unit. At present, all the syrup produced at the DCU is supplied to Rusni Distilleries, Sangareddy, for ethanol production.

Each decentralized unit provides employment for 20 to 30 people during the crushing season. The major beneficiaries of the DCU are likely to be smallholder 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 empowerment. The success and overall economical viability of the 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, the decentralized model will enable supply of feedstock to the distillery over a longer period of time in a year through the syrup route. Efforts will have to be made to up-and out-scale the unit. This paves the way for micro-entrepreneurship development in villages that increases the income and employment options, and reduces migration to cities. The cost of establishing a DCU with essential plant and machinery can be minimized if a farmer establishes it with his own investment and involving his own family labor as given in Annexure 1.

In view of these benefits, 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 both smallholder farmers of rainfed regions and industry in production of bioethanol.

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Annexure 1. Cost of Establishing a DCU

Essential equipment for establishing a Decentralized Crushing Unit in a village:

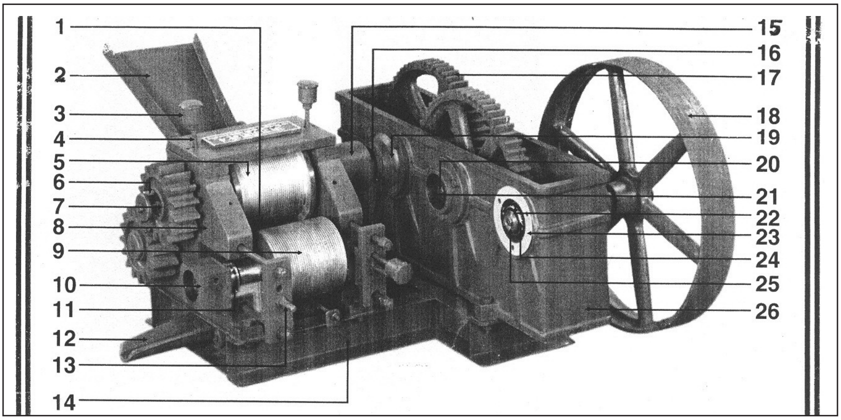
Plant and machinery*

S.No.	Particulars	Cost (₹ '00000)**
a)	Sweet sorghum crusher (2 t/hr): Motor for crusher 20HP, V Belts, gear oil	4.5
b)	Syrup boiling pans (700 lit. capacity) – 2 m dia. and accessories (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, leads and accessories	4.62
d)	Pumps and motors 1 HP, for pumping water to clean the tanks, crushers and pans: 1 no.	0.04
g	Rubber/PVC hose pipe 1" diameter, 200 m length	0.16
h	Syrup storage plastic drums industrial use (50 kg capacity)	0.30
a)	Crusher shed with local available materials (palm tree leaves/ bamboo thatched sheets/ paddy straw covering)	0.2
b)	Chula shed with local materials (palm tree leaves/bamboo thatched sheets/ paddy straw covering)	0.2
b)	Foundation for generator placement	0.10
f)	One utility room construction with asbestos sheet	0.4
g)	Construction of 2 ft height basement for crusher placement 6 x 3 ft with iron channels, nuts and bolts fitting	0.19
h)	Construction of 3 no. chulhas for boiling juice	0.49
a)	Electrical wiring, switches, control panel etc.	0.10
	Total amount (INR)	11.66

* Work and equipment prices quoted by local agents/dealers in Maharashtra state of India.
** Minimum Cost of DCU establishment (if a farmer wants to establish with his own investment).

Annexure 2. Parts of the Crusher

1. A rail scraper
2. Feeder
3. Grease cup
4. Grease pipe
5. A 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. Hosing
19. Pulley
20. Center bolt
21. Counter axel
22. Bearing seal
23. Hosing packing
24. Bearing 32211
25. Main drive
26. Gear box



Annexure 3. Analysis of constituents in sweet sorghum juice and syrup samples

S.No.	Parameter Specifications	Method of Analysis	Juice	Syrup
1.	Brix	Brix meter	10	85
2.	Calorific value [cal/g]	Chemical Analysis	nil	3730
3.	Total Solution Solids [%wt]	Chemical Analysis	7.1	75.29
4.	Total Reducing Sugars [%wt]	Colorimetry	2.1	31.3
5.	Protein [%mass]	Chemical Analysis	nil	nil
6.	Ash [%mass]	Chemical Analysis	0.12	3.6
7.	Calcium [ppm]	AAS	93.5	0.19%
8.	Phosphorous [ppm]	Colorimetry	0.024	0.14
9.	Riboflavin	HPLC	#	#
10.	Vitamin C [%wt]	IC	3.73	0.003
11.	Nicotinic Acid	IC	nil	nil
12.	Iron [ppm]	AAS	4.3	44.5
13.	Sodium [ppm]	AAS	46.9	0.17%
14.	Potassium [ppm]	AAS	926.5	1.97%
15.	Sulphur [%wt]	Chemical Analysis	0.01	0.043
16.	Benzoic Acid	**	**	**
17.	Added Coloring Matter		nil	nil
18.	Pesticide Residues	*	*	*
19.	Fructose [%wt]	HPLC	1.019	1.158
20.	Glucose [%wt]	HPLC	1.03761	0.946
21.	Saccharose [%wt]	HPLC	3.21	3.097
22.	Maltose [%wt]	HPLC	nil	nil
23.	Other Sugars [%wt]***	HPLC	nil	nil
24.	Free Acids [%wt]	Volumetric Analysis	0.71	0.533
25.	Lactones	**	**	**
26.	pH	pH meter	5.02	5.61
27.	Diastase	**	**	**

* Subject to discussion

** Not Determined

*** Sugars analyzed: Xylose, Ribose, Galactose, Mannose, Arabinose

Below detection limits

HPLC – High Performance Liquid Chromatography

IC – Ion Exchange Chromatography

AAS – Atomic Absorption Spectroscopy

About ICRISAT

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a non-profit, non-political organization that conducts agricultural research for development in Asia and sub-Saharan Africa with a wide array of partners throughout the world. Covering 6.5 million square kilometers of land in 55 countries, the semi-arid tropics have over 2 billion people, and 644 million of these are the poorest of the poor. ICRISAT 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 Hyderabad, Andhra Pradesh, India, with two regional hubs and four country offices in sub-Saharan Africa. It belongs to the Consortium of Centers supported by the Consultative Group on International Agricultural Research (CGIAR).

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ISB No: 978-92-9066-545-8 Order code: IBE 090 551-11