SWEET SORGHUM: A Smart Crop to Meet the Demands of Food, Fodder, Fuel and Feed

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BACKGROUND

At present, energy demand for transport in India is primarily met through non-renewable energy sources like fossil fuels. Being short in domestic production, India mainly depends on crude oil imports. In the near future oil imports are slated to rise further with no major breakthrough in domestic oil production. A compounding factor is the rise in the number of vehicles on the road, which has grown by 10 % each year between 2001 and 2006,[1] and is expected to rise further. Against this backdrop, there is a renewed interest in energy augmentation through biofuel crops to meet the energy demand in the country. One such promising biofuel crop is sweet sorghum, whose sugar-rich stocks can be crushed to produce juice, then fermented into bio-ethanol, and used to make a blended fuel replacing conventional gasoline (Reddy et al. 2005).

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 rain-fed conditions (Reddy, et al., 2005). One advantage of sweet sorghum compared to other crops is that using sweet sorghum for fuel does not reduce its contribution as food because the grain can be harvested for food, and the bagasse (the fiber left over after extraction of juice from sweet sorghum) that remains after the extraction of juice used for biofuel may be used for fodder (Nalini Kumari et al. 2011). Hence, sweet sorghum is a "smart" crop, which meets the triple requirements of food, fuel and fodder

To assess the potential benefits of sweet sorghum as a feed stock for bioethanol production, a new pilot program is being tested in the state of Andhra Pradesh, under the partnership of ICRISAT, the Indian Council of Agricultural Research (ICAR), National Agricultural Innovation Project (NAIP) (www.ssvc-icar-naip.icrisat.org). The project promotes a value-chain approach to augment incomes of farmers, while promoting a sustainable sweet sorghum–ethanol value-chain. The overall objective of the project is to provide greater employment and income opportunities for farmers and other stakeholders in the value chain, at the same time supplying an environmentally friendly energy source. Through the example of a successful sweet sorghum value-chain for ethanol production, this paper explores the opportunities for agro-enterprise development from sweet sorghum.

Sweet Sorghum Syrup for Bioethanol

Working with a Centralized Distillery

The value-chain model called "Seed to Tank" (ICRISAT, 2008) was adopted for the project, which encompasses sweet sorghum production, processing, value addition and marketing. Sweet sorghum is processed into ethanol in a distillery established by a private sector partner M/s Rusni Distilleries Pvt. Ltd, located in Medak district of Andhra Pradesh. The distiller has the capacity to produce 40 kilo liters of ethanol per day. The distillery was incubated in ICRISAT's Agri-business and Innovation Platform.

Sweet sorghum stalks have to be crushed shortly after harvest to avoid loss of juice due to drying. Hence the harvesting and crushing of stalk to process into ethanol have to go hand-in-hand and the cultivation area of the crop ideally should be no more than 50 km from the distillery.

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[1] Authors own estimate based on Road Transport Year Book 2006-07, MoRTH, Government of India

The distillery is a ‘centralized unit’, meaning that farmers are linked to the distillery through a partnership with a local non-governmental organization (NGO), whose role is to deliver the stalks to the distillery and to process payments to farmers. The NGO also liaises with research organizations to promote the program in general and to provide technological assistance. A schematic presentation of value chain under a centralized unit is presented below (figure 1).

*********Place figure 1 here*************

- Using a centralized distillery, a typical ethanol yield of 40 kilo liters per day (KLPD) requires raw material from 8000 ha of crop area per year spread over two seasons – 3500 ha in the rainy season (rain-fed) and 4500 ha in the post-rainy season (irrigated), which requires the mobilization of a large number of farmers (on an average 1 farmer would cultivate an hectare under sweet sorghum) preferably within a 50 km radius of the distillery. This presented significant limitations, namely: Finding 4500 ha with irrigation facilities during the post-rainy season is a daunting task in the semi-arid tropics due to limited irrigation.
- Organizing such a large number of farmers (3000) to undertake sweet sorghum cultivation within the specified area (<50km) is also difficult.
- Farmers located more than 50 km from the distillery will be burdened by high transportation costs owing to the bulkiness of stalks.
- 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 economic loss to the grower and the processor.

Given these limitations, the project coordinators decided to establish ***decentralized crushing units*** (DCU) at the village level, which also had the added benefit of being a small-scale agro-enterprise.

Decentralized Crushing Unit - An Innovative Approach Of Syrup Production From Sweet Sorghum

A crushing unit at the village level was established (Ravinder Reddy et al. 2009) in the close vicinity of the farmers’ fields at Ibrahimbad village, Medak district of Andhra Pradesh. The site of the unit was established in consultation with the local NGO, village leaders, and farmers and was based on several socio-economic criteria, namely, the existing natural resource base, social harmony, agro-ecology and the feasibility of cultivating sweet sorghum. A total of 514 households spread across 7 villages of Ibrahimbad cluster were selected to cultivate sweet sorghum. Having a decentralized crushing unit meant that the harvested sweet sorghum stalks could be crushed and juiced on the same day, after which the juice was boiled into syrup (figure 2). The brix content of syrup (between 70-80%) allows storage for a longer time period than the juice - over 24 months- without loss in fermentable sugars, and can be processed to produce ethanol at the distillery. The decentralized approach makes the supply-chain more efficient by reducing the volume of feedstock to be supplied to centralized crushing units and by increasing the period of feedstock availability (supply of syrup) to industry. Further, the establishment of decentralized crushing units benefits the farmers further away from the distillery as long as they have a crushing unit relatively close to them.

*********Place figure 2 here*************

The crushing of sweet sorghum into syrup continued for 4 years under this project, and was carried out using a modified sugarcane crusher. (A crusher customized for sweet sorghum had not been designed.) The crushing capacity was 2 tons per hour and the crushing efficiency depended on the sweet sorghum genotype, crushing season, time lapse between harvesting and crushing, and temperature. During the rainy season (sweet sorghum is presently grown only in rainy season), in 30 days, working 8 hours a day, the crushing unit could crush sweet sorghum cultivated on 25-30 hectares. The initial cost of the unit for the pilot phase was jointly financed by ICAR and NAIP (Ravinder Reddy et al. 2009).

*********Place figure 3 here*************

To meet the raw material requirements of the decentralized crushing unit, forward and backward linkages had to be established (figure 4). The linkage established between the Farmers' Association, a local NGO, and the crushing unit facilitated the mobilization of farmers, the distribution of seed, and helped avail technical advice related to production and harvesting schedules to supply sweet sorghum stalks to the unit. Inputs such as fertilizer and herbicides were supplied on credit to farmers, payment for which was later deducted from the payment made to the farmers. Other forward linkages included the technical advice on crushing the stalk to produce juice and syrup, assistance with contract agreements between farmers and the distillery, and information on value-addition of the bagasse being provided by consortium partners.

*********Place figure 4 here*************

The Economics of Syrup Production

Under the pilot project, the crushing unit produced sweet sorghum syrup between 2008 and 2012. Below, we provide an overview of the economics of syrup production for the years 2008-2010. Our discussion is in two parts: the cost of sweet sorghum cultivation and cost of processing sweet sorghum to syrup.

The economics of sweet sorghum cultivation: Data on cost of cultivation was collected from farmers who were part of the project and analyzed for various costs, gross and net returns, and input-output ratios of the crop. The cost of cultivation included both paid out costs and imputed costs. In 2008, total cost of cultivating sweet sorghum was Rs[2]. 15,804 (USD 316)/ ha with an average stalk yield of 15 t /ha during 2008.

The economics of syrup production: Data for syrup production was analyzed for the stalks supplied to the crushing unit by 102 households in 2008-09 and 94 households during 2009-10. A total of 600 tons of sweet sorghum was crushed in 2009 with an average crushing capacity of 22 tons per day (table 1). The average labor requirement was 54 person days, with an average production of 5,897 liters of juice per day. The total quantity of juice extracted from crushing 600 tons of sweet sorghum was 161,565 liters with a total quantity of 28.8 tons of syrup.

*************Place table 1 here**********

The total cost of production of 28.8 tons of sweet sorghum syrup was Rs 739,528 (USD 14, 790) and on an average, the cost incurred in processing 1 kg of syrup was Rs 25.65 (USD 0.50) during 2009. The cost of syrup progressively decreased to Rs. 22 (USD 0.44.) per kilogram during 2011. Table 2 shows that raw material (sorghum stalks) accounted for 57% of the total costs of production, followed by labor costs (29%), and fuel (6%) (Table 2, Figure 5). Currently the crushing unit is managed by farmers; there is still significant scope for reducing the cost of syrup production with the proper protocols in place.

************Place table 2 here*************

************Place figure 5 here*************

The gross returns realized per hectare and per ton of sweet sorghum stalk produced for syrup were Rs 9,670 (USD 193) and Rs 480 (USD 10), respectively. Currently, the purchase price of syrup by the distillery for ethanol conversion is at Rs 10 (USD 0.02) /kg. The pricing is based on ethanol recovery from syrup, processing costs of syrup to ethanol, and the selling price of ethanol (based on discussions held with the distillery). The distillery requires about 3 kg of syrup to convert to a liter of ethanol. The ethanol prices for blending with gasoline are regulated by the government of India and the 2012 administered price of ethanol is Rs 27 (USD 0.5)/ l. It is not feasible for the distillery to pay more for the syrup unless and until the government revises the ethanol price.

************Place table 3 here*************

Several other alternatives were also explored to reduce the operating cost of syrup production, namely:

- Reducing labor costs (labor efficiency);
- Further mechanization of production (improving crushing efficiency and extraction efficiency);

[2] Rs. is the abbreviation for India currency rupees. 1 USD is 50 rupees at 2012 exchange rate.

- Increasing the brix (sugar content) of the stalks through improved genotypes.

The above mentioned efforts resulted in increasing the syrup extracted by 50% and reducing the labor costs by 28%

Benefits of the decentralized crushing unit as an agro-enterprise

The long range goal of establishing a village-level small-scale agro-enterprise is to reduce poverty and unemployment. Achieving this was envisioned through producing value-added agricultural produce and creating new employment opportunities in the villages to enhance the livelihoods of the rural population. The establishment of a decentralized crushing unit in Ibrahimbad village had both tangible and intangible benefits. The tangible benefits included increased employment opportunities, especially during the post-rainy season, which tends to be a lean period for agricultural activities in drylands. On average, the project generated about 40 additional person days of employment per household. The monetary value of the additional employment generated was about Rs 6400 (USD 128) per household annually (the wage rate prevailing during 2012 was Rs 160 (USD 3) per day). Some of the intangible benefits were improvement in farmers' ability to manage a small-scale village level agro-enterprise and enhanced food security due to increased incomes.

Besides developing sweet sorghum syrup as a fuel source, two more alternatives for agro-enterprise development have been explored to make the DCU viable and provide alternative opportunities to smallholders from sweet sorghum:

- Sweet sorghum syrup for use in food industry and,
- Value addition for bagasse.

ALTERNATIVE OPTIONS FOR AGRO-ENTERPRISE DEVELOPMENT FROM SWEET SORGHUM

Syrup for use in the food industry

An alternative use for sweet sorghum syrup is in the food industry, provided the product is food-grade. Food-grade syrup can be used as a sugar replacement in certain value-added food products. In addition, the syrup, which is rich in iron, calcium and potassium, also has potential pharmaceutical applications.

If sweet sorghum syrup were to compete with sugar cane, it could claim a share of the country's sugar industry, which in 2011 produced 24 million ton of sugar (Indian Sugar Mills Association, 2012) valued at 144 million USD (at current prices of Rs 27 (USD 0.5) per kilogram of sugar).

Assuming that even if just 1% of sugar market value is tapped, the market potential for sweet sorghum would be USD 1.44 million.

The processing of sweet sorghum juice for food--grade syrup involves the removal of leaves and leaf sheath from the stalks before crushing. The juice is then pre-heated and clarified. The clarified juice is then further concentrated to syrup by heating and slow evaporation ensuring the taste profile is not compromised. Some of the products developed using food--grade sweet sorghum syrup by the NutriPlus Knowledge Program of the Agri-business and Innovation Platform (AIP), ICRISAT include: Ready-To-Serve (RTS) beverage, Tamarind-Sweet Sorghum Sauce, sweetened tomato sauce, and energy bars (Figure 6).

************Place figure 6 here*************

When it comes to making value-added food products from sweet sorghum, opportunities exist for the entrepreneur to establish an agro-enterprise that integrates production and processing at the village level. However, strict regulations and stringent quality requirements of the food industry need to be observed, which are likely to increase the costs of production.

The economics of syrup for food industry

The entrepreneur has the option to either cultivate sweet sorghum and produce syrup or purchase stalks from the farmer and convert it to syrup. The economics of syrup production presented below is for a stand-alone agro-enterprise producing only syrup and only the returns realized from by-product (bagasse) value addition is included in the economic analysis.

***********Place table 4 here************

Value addition to bagasse

Bagasse (fibrous matter that remains after extraction of juice from sweet sorghum) a by-product is obtained under both the options of producing syrup for ethanol and syrup as a substitute in food industry. Bagasse is a good livestock feed and value addition to bagasse in the form of chopping, feed blocks or pellets provides additional income opportunities for farmers. The processing of bagasse can also be integrated into facilities that produce syrup for ethanol or for the food industry. The additional returns generated from the value-addition of this by-product can enhance the attractiveness of the business proposition for entrepreneurs.

The economics of bagasse processing

The current rate of conversion of a ton of stalk to juice is 27 to 30% (269-350 liters), leaving 650-700 kg of wet bagasse. The wet bagasse is dried and used as a source of fuel during the process of syrup production. However, even after using the bagasse for fuel, about 55% of it remains as surplus, which can serve as a good livestock feed. Research on the quality and composition of bagasse fodder was conducted by the International Livestock Research Institute (ILRI), a consortium partner and is described in Blummel *et al*. 2009.

During 2009, the surplus bagasse was sold directly to fodder traders by an arrrangement faciliated by ILRI and partners in the project. During 2010, the fodder traders chopped the bagasse and transported it by lorry to their customers in Hyderabad, 70 km away. This type of value-addition resulted in selling the bagasse at higher prices (Rs. 0.70 per kg (USD 0.014) during the start of season and increased to Rs. 1.2 per kg (USD 0.24) at the end of season), which was remarkable, given that the whole (i.e., unextracted) sweet sorghum stalks were valued only slightly higher at Rs 0.80 per kg. The scope for further value addition to different end products (feedblock, pellets, mashed and chopped) was demonstrated by ILRI under the project. The economics of value addition is presented only for two end products: feedblocks and chopped fodder (Table 5).

************Place table 5 here************

The small-scale entrepreneur may set up a stand-alone small-scale stover and bagasse processing agro-enterprise, which will suit prevailing labor and infrastructural conditions or integrate with the syrup-based decentralized crushing unit. In case of stand-alone stover and bagasse based agro-enterprise the returns realized per ton of stalk will be in the range of Rs 2,440 - 9,840 (USD 49- USD 197) dependng on the end-products. The bagasse based agro-enterprise has to be integrated with either syrup production for ethanol or through production of food grade syrup.

Conclusions: Viable sweet sorghum agro-enterprise options

This paper has discussed three different options for agro-enterprises from sweet sorghum. The benefit cost ratios (BCR) for each of the option are presented in table 6. Though simple value addtion in the form of chopping sweet sorghum stover provides the highest BCR of 2.56, the sustenance of the agro-enterprise depends on the avaliability of multiple feedstocks like maize and sorghum stover for optimum capacity utilization and profitability. Syrup production from sweet sorghum for the food industry as an agro-enterprise integrated with chopping of surplus bagasse with a small-scale processing unit will provide a BCR of 1.40. The bagasse can be stored and processed to chopped form after completion of syrup production operations. This will aid in increasing the operating window and optimum capacity utilization of the agro-enterprise. However, since setting up of an agro-enterpise for processing sweet sorghum to food--grade sryup would require strict regulations, there would be escalation in cost of syrup production to meet the quality standards and cost of establishment. The benefit cost ratio of producing and processing syrup was the least at 0.38 relative to other options explored.

************Place table 6 here************

The decentralized crushing unit was established to overcome some of the shortfalls of the centralized unit. The establishment of the crushing unit on a pilot basis to aid in supply chain managment for the centralized unit led to alternative options for syrup utilization and establishment of alternate agro-enterprises. The direct benefits of DCU establishment as an agro-enterprise for supply of syrup to ethanol industry provided 40 person days of employment with monetary benefits of Rs 6,400 during the lean season of agriculture.

The results of crushing sweet sorghum over a four year period has shown a gradual decline in costs of syrup production by 31%. The existing costs of syrup production still are on the higher side for converting it to ethanol and there is signifcant scope for reducing the cost through mechnization of the DCU. Policy options and enabling environment also play a signifcant role in promoting the DCU as a village level agro enterprise complementing ethanol production from the centralized unit. Capital assistance for establishment of the DCU and increase in procurment price of ethanol will help in sustainability and economic viability of the DCU.

Alternative options explored for establishing an agro-enterprise producing food grade syrup integrated with bagasse value addition has also shown to be a promising avenue. However, setting up an agro-enterprise producing food--grade syrup requires strict regulations to meet the quality requirments of the industry. Hence, these parameters and its cost implication needs to be taken into consideraton before establishment of the unit.

Given the scarcity for fodder and the growth of livestock economy at the rate of 4 % in India, alternate options of sweet sorghum stover based and bagasse based agro-enterprise are very promising. Hence, establishing a small scale agro-enterprise for sweet sorghum stover value addtion might be an economically viable proposition taking into condsideration the avaliability of multiple feedstocks for processing (enabling utilization of capacity from more than 6 months in a year), prevailing labor supply and infrastructural conditions.

The DCU options explored, will pave the way for micro-entrepreneurship development at village level that will increase income and employment opportunities and thus reduce rural poverty. At the same time, this would prevent migration of population from rural to urban areas, there-by preventing the growth of urban slums.

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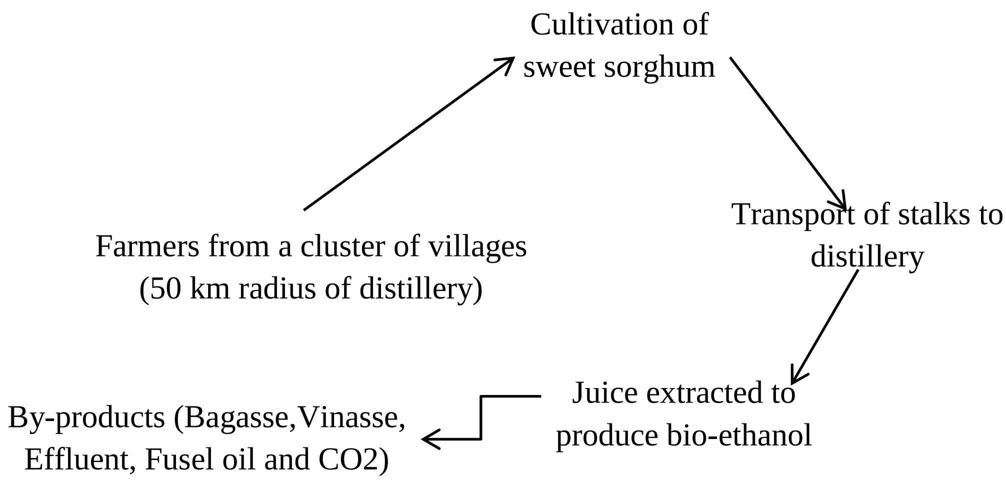

Figure 1: Schematic sweet sorghum value chain for ethanol production - Centralized Unit

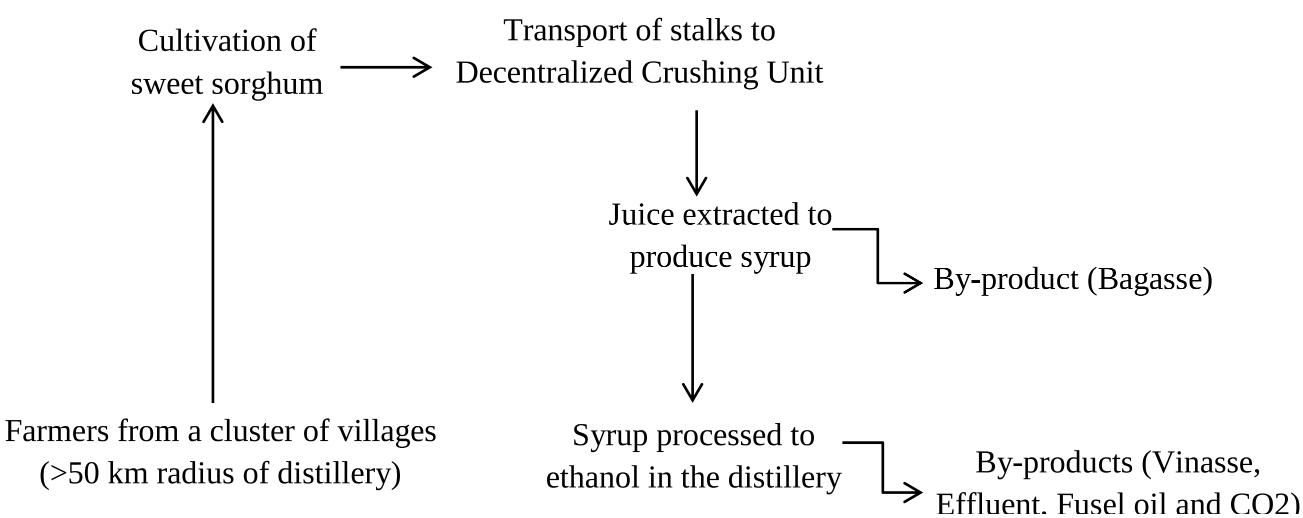

Figure 2: Schematic sweet sorghum value chain for syrup production to ethanol - Decentralized Crushing Unit

Figure 3. Decentralized sweet sorghum crushing unit A) crushing B) bagasse C) boiling the juice to produce syrup

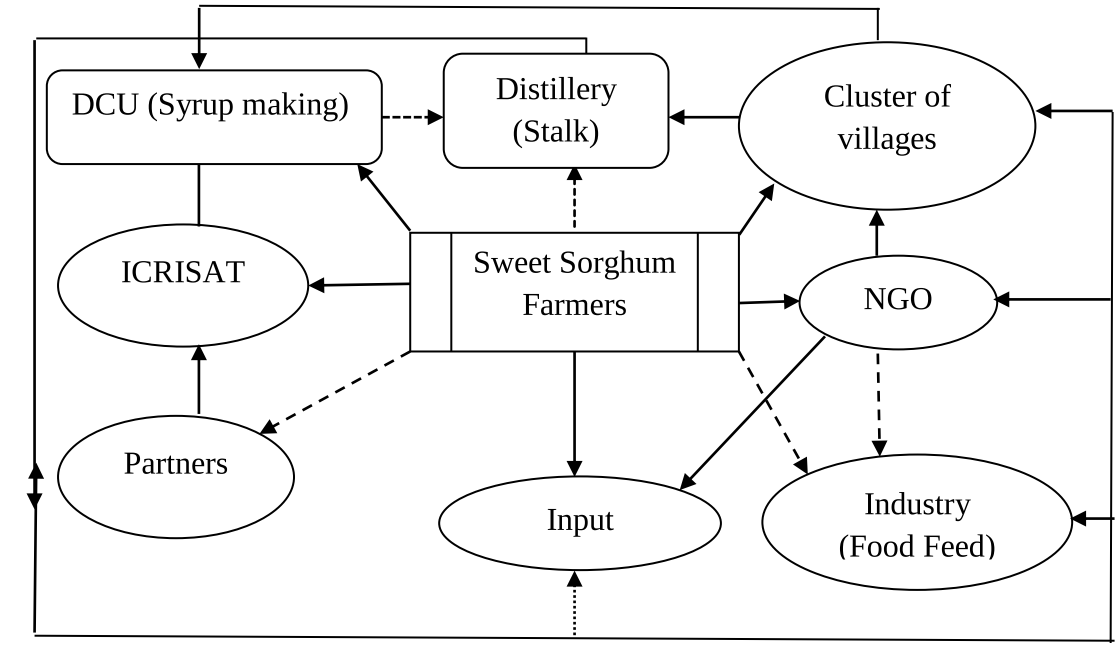

Figure 4: Flow chart of linkages in sweet sorghum value chain[3]

Table 1: Sweet sorghum crushing indicators under DCU, Ibrahimbad, Andhra Pradesh

Indicator	2008	2009
Number of farmers	102	94
Stalks crushed (tons)	557	600
Stalk yield (t/ha)	15	20
Average stalk crushed (t/day)	13	22
Crushing days	43	27
Juice extracted/t of stalk	261	269
Syrup/t stalk	40	48

[3] The solid lines in the figure represents strong linkages while the dotted lines represent weak linkages

Table 2. Cost of syrup production under decentralized crushing unit (2009), Ibrahimbad, Andhra Pradesh.

Cost Item	Total costs (rupees)	Percent to total costs
Cost of raw material		
Stalk yield (tons)	600	
Cost of stalk (Rs)	419,930	57
Processing costs		
Labor costs	210,830	29
Chemical costs	20,850	3
Firewood	10,825	1
Operating expenses		
Fuel costs	47,359	6
Repair & Maintenance	15,869	2
Miscellaneous	13,265	2
Total costs	739,528	100

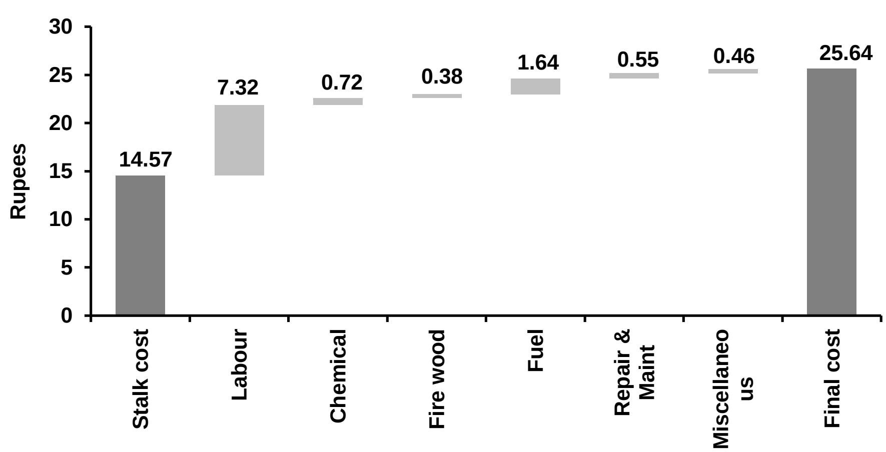

Figure 5. Item-wise break-up of costs of processing sweet sorghum to syrup production.

Table 3. Costs and returns to syrup production for ethanol

Indicator	Per ton of stalk	Per hectare
Cost of syrup production	1,232	24,783
Gross returns (@ 10/kg)	480	9,670
Net returns	(752)	(15,113)
BCR	0.38	

Note: Syrup was sold to the distillery at Rs. 10 kg^{-1}

Figure 6: A. Ready-To-Serve (RTS) Sweet sorghum-based beverage; B-Tamarind- Sweet Sorghum Sauce; C- Sweet sorghum-based tomato sauce; D-Sweet sorghum crispies.

Table 4. Economics of syrup production for food industry

Indicator	Value
Cost of sweet sorghum /t of stalk	800
Processing cost of sweet sorghum to syrup t^{-1} of stalk[1]	531
Total cost of syrup/t of stalk	1331
Returns from syrup/t of stalk[2]	1755
Returns from bagasse/t of stalk[3]	115
Gross returns /t of stalk	1870
Net returns /t of stalk	539
Benefit cost ratio (BCR)	1.40

Source: Author's own estimate.

Note: 1. The cost escalation in producing food grade syrup is not accounted in the analysis

2. The sale price of syrup is assumed to be Rs. 27/ kg which is equivalent to price of sugar at 2012 prices

3. Returns from sale of bagasse is at the rate of 1.2/ kg (the value realized might go upto Rs. 4/kg in distance locations) for surplus bagasse of 115 kg/t of sweet sorghum crushed

Table 5. Economics of bagasse value addition to different end products

Cost / Returns parameters	Bagasse based value added products	
	Feedblock	Chopped Bagasse
Feedstock cost (Rs/t)	800	800
Cost of other raw material[1](Rs/t)	8,840	-
Processing cost (Rs/t)	260	85
Transport cost (Rs/t per 100 km)	260	675
Total cost	10,160	1,560
Gross returns[2] / t	20,000	4,000
Net returns/t	9,840	2,440

Source: Row 3&4 are from Anandan et al (2010) and the rest are author's own estimates
Note: 1. The cost of other raw material includes molasses, bran, husk and cotton seed cake for preparation of feedblock. 2. The selling price of a feedblock is Rs.150 and chopped bagasse is Rs. 4/kg

Table 6. Benefit cost ration of different agro-enterprises from sweet sorghum

Sweet sorghum agro-enterprise[1]	Benefit cost ratio (BCR) of the agro-enterprise	Ranking based on BCR
Syrup for ethanol only	0.38	5
Syrup for ethanol with by-product bagasse valuation	0.98	4
Syrup for food industry only	1.31	3
Syrup for food industry with by-product bagasse valuation	1.40	2
Stover/bagasse value addition only	2.56	1

Source: Authors own estimate. Note: 1. Investment cost of establishing the agro-enterprise is not considered in the calculations.