Sweet sorghum syrup R&D in India

Anil K. Rajvanshi, Shivam Patange and Nandini Nimbkar*

Sweet sorghum (SS) is one of the varieties of sorghum having stalks with high sugar content and is grown primarily for forage, silage and syrup production. SS syrup is a high antioxidant food material produced by concentrating its sugary juice. SS has been mostly used in India for ethanol production, but demand for its syrup is growing. This article discusses R&D on SS syrup in India and highlights the challenges that need to be overcome to meet the growing demand. The challenges in improving crop productivity and syrup processing are also outlined. A simple economic analysis of small-scale SS syrup plant shows that producing syrup is economical both for farmers and syrup-producing units.

Keywords: Ethanol, fodder, sweet sorghum, syrup production.

SWEET sorghum (SS; *Sorghum bicolor* (L.) Moench) is a sugar-producing multi-purpose crop which is used for simultaneous production of grain (from earhead), sugary juice (from stem) and fodder (leaves and bagasse) for livestock[1–3]. It is a short-duration crop of 110–130 days and shows great tolerance to a wide range of climatic and soil conditions[2–4]. Due to the juicy sweet stalk, SS is an excellent source of ethanol and syrup production. However in the food versus fuel debate, importance should always be given to food. Besides, SS syrup has shown good antioxidant properties and is found to be useful in food, beverage and pharmaceutical industries. Hence it is considered suitable for syrup production[4,5]. It has also been suggested that the syrup is a good substitute for honey in nutraceutical formulations. Decrease in natural honey has led to greater demand for SS syrup in the last decade[6,7].

Syrup from sugary SS juice is made by boiling it to about 75 brix (Table 1), which results in honey-like consistency and appearance. Because of the chemical composition of the syrup, its shelf life is also good.

Since the late 1970s till recently SS was thought a good alternative to sugarcane for the production of ethanol, but increased demand for syrup partly due to decline in honey production has made it more attractive now. This study discusses the research and development (R&D) status of SS syrup in India.

History of sweet sorghum syrup R&D

USA is the pioneer in producing syrup from SS, which was introduced into the country probably from China in the 1850s, and for the next three decades it was extensively cultivated for syrup production. By the late 1880s the annual production peaked to about 30 million gallons. However, with the advent of cheaper corn and maple syrups, SS production declined steeply in the next three decades[8]. From the 1930s to 1970s, its production continued on family farms and homesteads on a non-commercial basis[8]. Currently in the USA less than 1 million gallons is produced annually by family-owned small syrup-producing units, and production is mostly restricted to the states of Alabama, Arkansas, Georgia, Iowa, Kentucky, Mississippi, North Carolina and Tennessee[8].

SS was introduced in India in the early 1970s by the Nimbkar Agricultural Research Institute (NARI), Phaltan by bringing cultivars from various US breeding stations and crossing them with Indian grain sorghum varieties[1]. The major aim of breeding work was to develop a SS hybrid for sugar production when sugarcane was not available[9]. The NARI hybrids and varieties contain maximum sucrose at grain maturity. The brix and purity in the juice of some of these varieties are nearly equal to those of sugarcane[9]. Some attempts were made by NARI in the late 1970s to produce crystalline sugar from SS jaggery. They were unsuccessful because of the difficulty in crystallization[10]. Therefore, in the early 1980s it was decided to use SS as a feedstock for ethanol and syrup production.

In 1980, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, also began research on the development of SS cultivars with high sugar content and biomass, but it was discontinued[11]. Research at ICRISAT was renewed in 2002 to develop new seed parents and restorer lines for hybrid SS development to meet the increased demand for ethanol for blending with petrol[11].

The complete technology of ethanol production from SS was developed by NARI in the late 1980s. It consisted of producing higher yielding SS varieties, better fermentation technologies and distillation of ethanol using solar energy[12]. The ethanol produced was used in specially

Anil K. Rajvanshi, Shivam Patange and Nandini Nimbkar are in the Nimbkar Agricultural Research Institute, Phaltan 415 523, India.
*For correspondence. (e-mail: anilrajvanshi50@gmail.com)

Table 1. Different properties of sweet sorghum cultivars developed by NARI for syrup production

Parameters	Madhura-1 (hybrid)	Madhura-2 (variety)	Madhura-3 (variety)
Biomass (tonne/ha-season)	10–40	20–40	20–40
Stripped stalk (tonne /ha-season)	5–20	10–25	10–30
Extraction (kg juice/100 kg of stripped stalk)	15–35	15–25	25–35
Juice yield (kg/ha-season)	750–7000	1500-6250	2500–10500
Juice brix[a]	15–20	16-18	16–20
Stem borer damage (kg/100 kg of stripped stalk)	5–35	10–20	0–5
Syrup recovery (kg/100 kg of stripped stalk)	3–6	2–7	5–7
Syrup yield (tonne/ha-season)	0.15–1.2	0.2–1.5	0.5–2.1
Best sowing season	May–June	May–June and October–November	May–June
Crop duration (months)	4	4	4

Note: This table is based on past six years' sweet sorghum syrup production data at NARI. Stripped stalk includes damaged stalk too.
[a]Brix (measured in degrees), is the sugar content of an aqueous solution. One degree brix corresponds to 1 g of sucrose in 100 g of solution.

Table 2. Comparison of the nutritional content of Madhura sweet sorghum syrup with honey and sugarcane syrup

Nutrient	Madhura syrup (mg/100 g)[4,5]	Honey (mg/100 g)[29]	Sugarcane syrup (mg/100 g)[32]
Potassium	1810.00[a], 133.20–145[b]	40–3500	662
Calcium	160.00[a], 190.87–272.33[b]	3–31	18.4
Sodium	84.25–153.13[b]	1.6–17	21.5
Phosphorus	11.00[a]	2–15	61
Iron	0.86[a], 15.43–19.74[b]	0.03–4	0.16
Nicotinic acid (vitamin B_3)	153.00[a]	0.10–0.20	–
Vitamin C	11.50[a]	2.2–2.5	–
Riboflavin (vitamin B_2)	10.00[a]	0.01–0.02	–
Total phenolic content (antioxidants)	184.70–261.31[b]	7.37–46.57 (refs 30, 31)	29–98 (ref. 33)
Total flavonoid content (antioxidants)	75.62–197.50[b]	0.53–11.67 (refs 30, 31)	109–135 (ref. 33)
Shelf life	1–2 years[d] (without refrigeration)	Long	6 months[c]

[a]Analysis of samples of 'Madhura' syrup by CFTRI, Mysore and ITALAB Pvt Ltd, Mumbai[4].
[b]Analysis of samples of syrup made from 'Madhura' hybrid cultivated at different locations in Kenya[5].
[c]This is the recommended shelf life of sugarcane syrup manufactured by companies in India. To improve shelf life of sugarcane syrup, various chemicals are added[34]. Also, storage in a refrigerator after opening the sealed container can increase shelf life up to two years[35].
[d]The pH of food-grade sweet sorghum syrup was in the typical range 5.0–5.5. Thus given a combination of low a_w and acidic pH, it is possible to store sweet sorghum syrup under ambient conditions. However, it is important to ensure that no moisture ingress occurs into the product during storage[36].

designed lighting and cooking devices such as lanterns and stoves[13,14]. Presumably, due to the secondary products such as aconitic acid and polyphenols in the SS syrup, it was found that it had a good keeping quality and could be used year round as a raw material for ethanol production[15].

However ethanol from SS was costly in the early 1990s and there were no buyers for it since the national policy on biofuels had not been formulated. Only in 2003 with pressure from the sugar lobby to take care of the surplus sugar, a programme for ethanol blending in petrol was formulated by the government of India[16]. This also spurred ethanol production from SS. With environmental issues taking centre stage, there is renewed interest worldwide in the use of sugary crops like SS for ethanol production.

In India, besides ICRISAT, efforts were mounted by various organizations, including ICAR-Indian Institute of Millets Research (IIMR), Hyderabad, various centres of the All India Coordinated Sorghum Improvement Project (AICSIP) and Indian Institute of Sugarcane Research (IISR), Lucknow for developing high-yielding SS hybrids and varieties for ethanol production[2,3,17]. A SS-based ethanol unit was established near Hyderabad in cooperation with the agribusiness incubator of ICRISAT, but it failed to take-off[2]. These organizations were also involved in R&D in syrup production, but there were no sustained efforts.

Realizing the importance of food over fuel, since the 1990s NARI has focused its efforts on producing syrup from SS. Today it is the only organization in India producing and selling SS syrup. In the past NARI had mostly used its own hybrid Madhura-1 for syrup production. Recently, two new varieties, viz. Madhura-2 and Madhura-3 have been successfully used for syrup-making.

Table 1 lists the properties of these cultivars and because of its good performance, Madhura-3 is presently being used for syrup production.

A small pilot plant producing syrup from SS has been running for the last two decades at the NARI campus, and till today more than 5 tonnes of syrup has been sold in bulk[4]. This has helped in creating a market for SS syrup

Table 3. Comparison between sweet sorghum and sugarcane

Factor	Sweet sorghum (Madhura-3)	Sugarcane
Juice brix at the time of harvest (%)	16–20	15–23[38]
Stripped stalk yield (tonne/season-ha)	10–30	70–100[39]
Potential sugar yield (tonne/season-ha)	1.6–6	11.2–12.6
Crop duration (days)	110–130[4]	300–540[40]
Potential sugar yield per 14 months (tonne/ha)	4.8–18	11.2–12.6
Growth-period water requirement (mm)	400–450[37]	1500–2500[41]
Average water requirement (litre/kg sugar)	1119	1681
Net profit to a farmer (Rs lakh/ha-year)	0.50–1.00[a] (from Figure 4)	0.60–1.66[b]

[a]The selling price of sweet sorghum for syrup production is assumed to be Rs 2000–4000/tonne.
[b]The selling price of sugarcane from sugar factories is Rs 2300–2850/tonne (ref. 42).

in India. Recently, NARI has also tested SS fodder hybrids and varieties, developed elsewhere, like Sugargraze, Honey Pot and SSV-84 for making syrup. The data collected from them so far is limited and efforts are underway to generate more data for facilitating comparison with NARI cultivars.

Why sweet sorghum syrup?

In India maple and other exotic syrups as sweeteners are now available. The current demand for these syrups is met by importing them. Last year, sugary syrups and sweeteners worth Rs 600 crores were imported into India to cater to the growing demand[18]. Traditionally honey and sugarcane syrup have been used as liquid sweeteners. With the shortage of good-quality honey, the focus is now shifting to other liquid sweeteners of equivalent nature, and SS syrup may fit the bill. Table 2 shows a comparison of SS and sugarcane syrups with honey.

With high antioxidant properties of SS syrup, it is being preferred over others for nutraceuticals and other food items like breakfast bars and sweet snacks. In terms of its yield per unit of water and profitability to the farmer, it is even better than sugarcane syrup (Table 3). From Table 3 it is evident that SS is a much more water-efficient crop than sugarcane and this makes it more climate-resilient.

Globally, the dietary products/supplements (for vitamins, minerals, natural antioxidants) market is estimated to reach US$ 230.73 billion by 2027 (ref. 19). Since syrup from SS is one of the natural products with wholesome nutrition, it has a tremendous potential for capturing this large market segment. In India discussions with nutraceutical and wholesome foods companies show the estimated demand for SS syrup to be 1000 tonnes/year (Sreejith, M., pers. commun.).

Issues in sweet sorghum syrup production

In order to increase the production of syrup and cater to the potential demand, issues regarding increased crop yield and improved syrup processing need to be addressed.

Crop issues

Since SS is a multipurpose crop, NARI has always attempted to maximize the grain and stalk yield in the cultivars developed. This in addition to solving the food versus fuel problem also gives extra income to the farmers and makes economics of products from SS more favourable.

High-energy SS types which are sweet-stalked and also have relatively high grain yields have been developed[20]. Similar to NARI's Madhura-1, these hybrids utilize a grain-type female and a sweet-type male. Some researchers have suggested that after anthesis, production of assimilate in SS is more than that required for seed development[21]. This excess of non-structural carbohydrates produced therefore accumulates in the upper stems. Mechanisms beyond sink strength and enzymatic activity are necessary to explain the higher rates of sucrose accumulation in SS compared to grain sorghum, and need to be studied[22].

Yearly (two seasons) SS grain yields are typically 3–7 tonnes/ha and stalk yields are typically 50–100 tonnes/ha (refs 23–25). Achieving yields at the higher end of the ranges depends on the many biotic and abiotic stresses faced by the SS crop.

(a) Abiotic stresses include those related to environmental factors such as temperature, precipitation, day length and soil quality. These adversely affect productivity of SS crop. At NARI attempts have been made to develop cultivars which do well year-round under conditions at Phaltan. Therefore, they grow well under temperatures ranging from a minimum of 12°C to a maximum of 42°C. The crop is grown under irrigated conditions, and so drought stress is generally not an issue. Similarly, flooding is rarely encountered. Lodging during stormy weather (heavy rainfall accompanied with high wind) was observed in hybrid Madhura-1. Lodging markedly reduces fresh weight and sugar content in the stalks of SS mainly due to decline in the rate of photosynthesis[26]. However, Madhura-3 is tolerant to lodging.

It is desirable to have photoperiod and thermo-insensitive varieties which can be grown during any time of the year. Most SS cultivars reach a peak sugar content about 30 days after flowering, which then declines. This decline varies with cultivars and also from one year to another depending on climatic conditions. The harvesting period has to be managed by either using cultivars with different maturities or by sowing the same cultivar on different dates. Further research is needed on the development of cultivars tolerant to changeable climatic conditions.

(b) Biotic stresses include various pests, diseases and weeds which in addition to reducing the stalk and grain yield also affect juice quality. The most serious pests are the lepidopteran stem borer (*Chilo partellus*), the dipterans midge (*Stenodiplosis sorghicola*), and shoot fly (*Atherigona soccata*). Madhura-3 is tolerant to stem borer and shoot fly. Attack by fungal and bacterial diseases is found to be more during the rainy season, but again Madhura-3 has been seen to be fairly tolerant to them. SS cultivars were found to sustain less damage from aphids (sucking pests), when higher concentration of aconitic acid and polyphenols accumulated in the stem. These secondary products therefore may serve as a defence against aphids[15].

Processing issues

Presently, syrup processing is done manually. Figure 1 shows the schematic of the process. The main steps are as follows: (a) leaf stripping. (b) Crushing of cane for juice extraction. (c) Clarification of juice to remove suspended and dissolved impurities by settling it. (d) Boiling of juice to evaporate water and remove scum.

Leaf stripping: SS when harvested has green leaves attached to the stalk. If the stalk is crushed with the leaves, the resulting syrup has an off-taste and becomes dark in colour. Thus in order to improve the taste and colour of syrup leaf removal is necessary. Also the damage to the stalk due to pests like stem borer or diseases becomes visible only when the leaves are removed. If the damaged part of the stalk is not removed before crushing, it can give a bad taste to the syrup. Since syrup recovery is calculated based on total stripped stalk weight (stripped stalk weight + damaged stalk weight), the syrup recovery decreases with increasing percentage of damaged stalk (Figure 2).

Leaves are strongly attached to the stem, unlike those of sugarcane which are dry and easily removed from the stalk when it is harvested. Leaf stripping of SS is done manually and is a labour-intensive process. For example, around 10–12 labourers working for 4–6 h are required to remove leaves from 1 tonne of SS biomass. This increases the cost of syrup production. An automatic leaf-stripping machine for small-scale syrup production will go a long way in speeding up the syrup production rate and also reduce labour cost.

Crushing of stalk: One of the most important processes in syrup production is juice extraction. We use a three-roller crusher with a 7.5 kW motor. As can be seen from Table 1, the present juice extraction is only 15–35 kg/100 kg of stalk. This is very low and the sugar which remains in the bagasse is wasted. As shown in Figure 3, syrup recovery is directly related to extraction percentage. Therefore, we need to develop improved crushers which can nearly double the juice extraction. This requires extensive R&D.

Clarification of juice: SS juice contains starch, proteins and other dissolved materials. Removal of these materials helps in improving the colour and taste of the syrup. Normally extracts of okra fruits or plants and other mucilaginous substances are used as flocculent, and the floating scum is removed manually. This is generally done during the heating of the juice. If a suitable filter which can remove starch at room temperature is developed, then the energy cost of syrup production can be reduced since it can be boiled under vacuum at lower temperature.

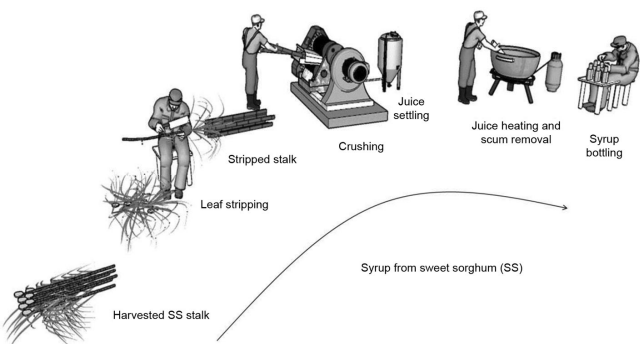

Figure 1. Schematic of the sweet sorghum syrup production process.

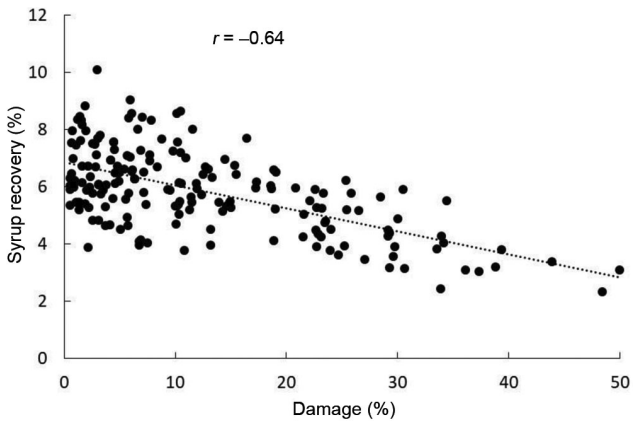

Figure 2. Effect of pest damage to stalk on syrup recovery for Madhura-3.

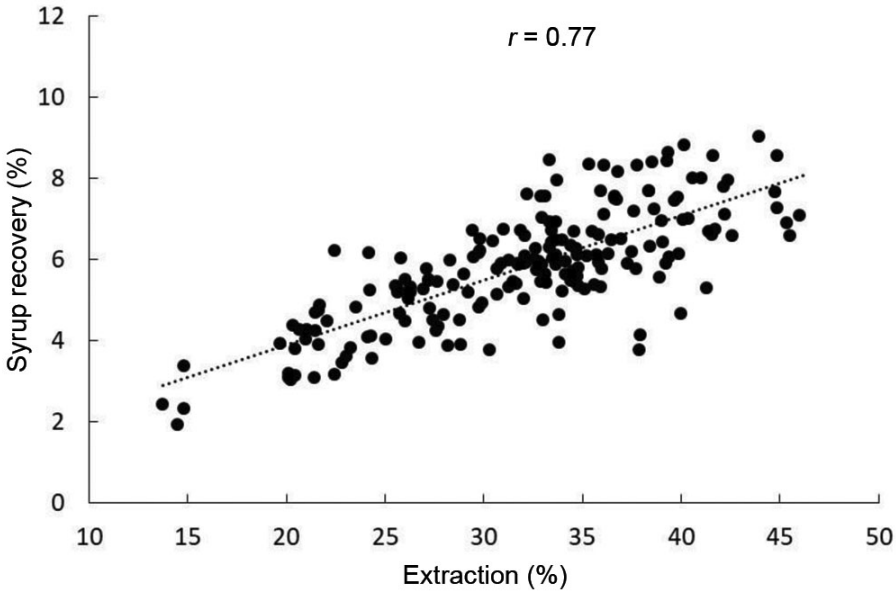

Figure 3. Effect of juice extraction efficiency on syrup recovery for Madhura-3.

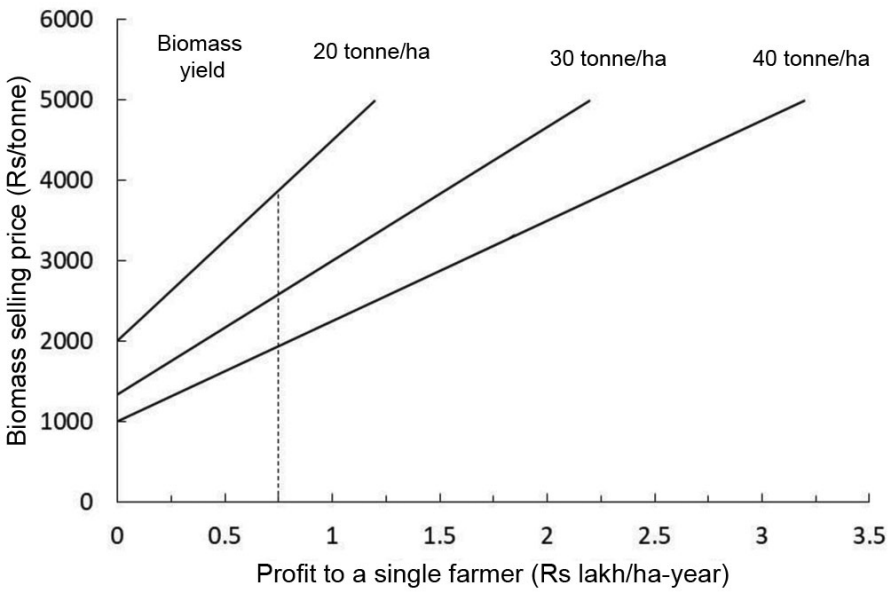

Figure 4. Farmer's profit versus biomass cost of Madhura-3.

Boiling of juice: Around 95% of total energy used in syrup-making is used in heating of the juice. Thus the use of an efficient juice evaporator is a necessary component in increasing the efficiency of syrup production and reducing its cost.

Since scum removal is done manually during the boiling process, open pans are preferred since they allow easy access for skimming the juice surface for scum removal. The syrup is taken out when the temperature reaches about 105°C, corresponding to 74–76 degrees brix.

Presently, SS bagasse is used as fuel in the furnace, but with its alternative use as fodder for animals there is need to develop an efficient multi-biomass furnace which can take other agricultural residues as fuel. In the early 1990s, NARI had developed an efficient loose leafy biomass gasification technology which could run on SS bagasse and other loose biomass fuels[27]. However, its use in the proposed syrup production rate of 50–150 kg/day is quite costly and uneconomical. Thus an efficient, small-scale, direct biomass-fired boiler/furnace of 300–500 kW (thermal) capacity running on various biomass residues will be a great boon for small-scale syrup production. Such a furnace is presently not easily available in the market.

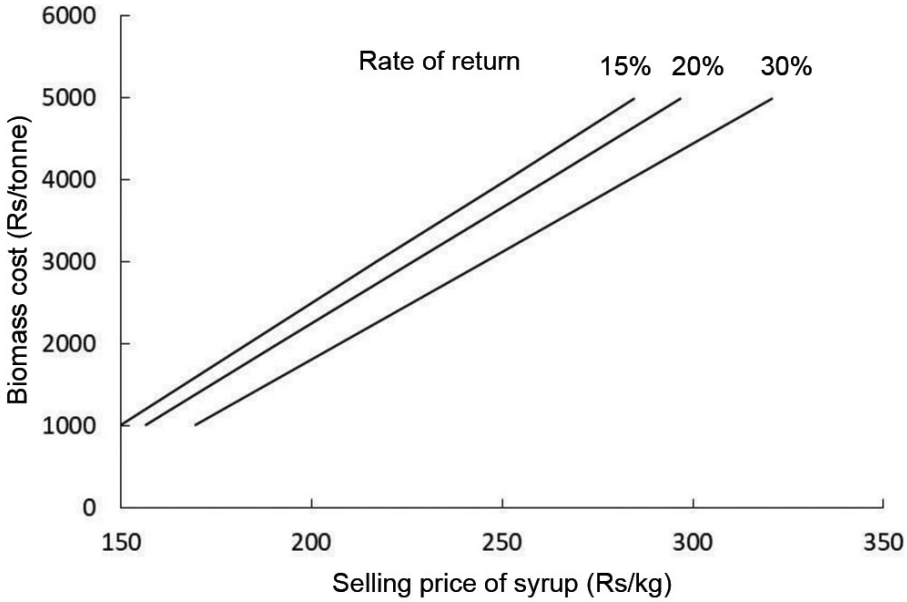

Figure 5. Biomass cost versus syrup selling price.

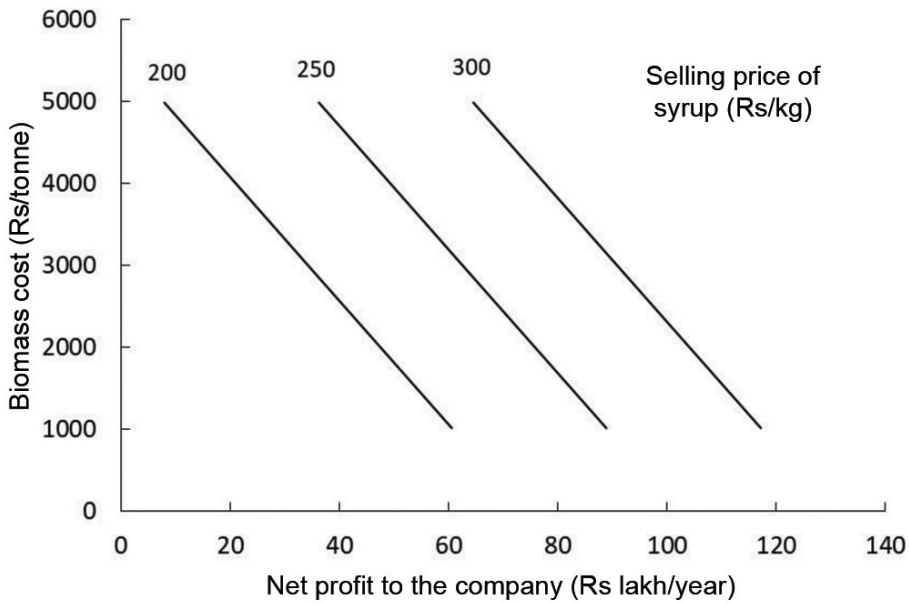

Figure 6. Biomass cost versus net profit to the syrup unit.

Economics of syrup production

Any food-processing unit becomes economically viable when it provides adequate compensation to the farmers for the growing of crops and good rate of return to the processing unit.

(1) Data collected over the last six years at NARI on Madhura-3 show that the cost of cultivation of SS is Rs 40,000–45,000/ha-season and biomass yield is 20–40 tonne/ha-season. Data from sorghum-growing farms show the cost of cultivation to be Rs 30,000–35,000/ha-season[28]. The cost of growing SS is similar to that for grain sorghum. For the economic analysis in this study, the average cost of cultivation has been assumed as Rs 40,000/ha-season, which translates into SS biomass cost of Rs 1000–2000/tonne.

A farmer should get much more than this amount to make growing SS attractive. The farmer should get similar profits as those from growing sugarcane (one of the most profitable crops). As shown in Table 3, a sugarcane farmer gets an average profit of Rs 0.60–1.66 lakhs/ha-year. For the economic analysis, we have therefore taken the

Table 4. Assumptions for economic analysis of 150 kg/day syrup plant

Parameters	Value
Capital cost (Rs lakhs)	60[a]
Interest on capital cost (%)	15
Loan repayment period (years)	10
Raw material cost (Rs/tonne of biomass)	2000–4000
Operating cost (Rs lakhs/year)	29.35[b]
Average inflation/year (%)	5[c]
Rate of return	15–30%
Land needed for growing sweet sorghum (ha/year)	35[d]
Syrup production capacity of the plant	150 (kg/day) or 45 tonne/year
Plant operation period (days/year)	300

[a]It includes plant cost (Rs 30 lakhs) and land cost (Rs 30 lakhs).
[b]Operating cost:
- Total labour charge for stripping and syrup making for 45 tonnes of syrup in a year is Rs 20.76 lakhs.
- Electricity cost is Rs 1.71 lakhs/year.
- Miscellaneous (salary, logistics, inventory, cleaning) is Rs 3.6 lakhs/year.
- Maintenance cost (5% of capital cost) is Rs 3 lakhs/year.
- Total operating cost is 29.35 lakhs/year.

[c]Inflation is assumed for raw materials, operating cost and price of the syrup.
[d]For 150 kg/day syrup production for 300 days in a year, total land needed to grow sweet sorghum will be 35 ha (1300 kg syrup/ha with production of 45 tonnes syrup/year.)

average profit for SS farmer to be Rs 0.75 lakhs/ha-year. With this profit margin, there will be no dearth of farmers growing SS.

Figure 4 shows the farmers' profit as a function of biomass cost for three biomass yield scenarios. With a profit of Rs 0.75 lakhs/year, the SS biomass selling price will vary from Rs 2000 to 4000/tonne for different biomass yields.

The keeping quality of SS stalk is poor compared to that of sugarcane. There is a high chance of sugar inversion and fermentation of the invert sugars (glucose and fructose) if the crop is kept for more than 48 h after cutting. This may impact the quality of the syrup. The cost of transporting SS biomass to the syrup plant should be minimized as well. Thus it is necessary that the syrup plant should be small and situated within a kilometre of the SS growing area. This has necessitated the choice of 50–150 kg/day mini syrup-producing plants for which economic analysis has been done.

For any syrup-producing unit, the profit is dependent on biomass cost and selling price of the syrup. Figure 5 shows the relationship between biomass purchase price and the syrup selling price for varying rates of return. Figure 6 shows the relationship between biomass purchase price and net profit to the entrepreneur for varying syrup-selling prices. Table 4 lists the assumptions in Figures 5 and 6.

From the economic analysis, it appears that with the present demand for SS syrup, producing it on a small scale by a large number of mini plants should be viable. This is in line with the 'self-reliant India' mission (Atmanirbhar Bharat Abhiyan) promoted by the Government.

Moving forward

This study details the status of SS syrup R&D in India. The demand for SS syrup in the country has picked up, and a part of the credit must go to the work done at NARI. SS syrup is an excellent sweetener which is high in antioxidants; it is finding use in nutraceutical and food industries. The challenges faced in meeting the increasing demand have been detailed in the article.

To move forward, we need to take the following steps: (1) Develop a semi-automatic continuous syrup-producing plant of 50–150 kg/day capacity. Such small plants situated in rural areas can supply good-quality syrup to a bigger company for quality control and marketing. The marketing and selling of syrup should be based on the Amul Dairy model of successful milk collection, processing and sale.

(2) Develop better varieties of SS which are high in sugar and less susceptible to pests like stem borer and pathogens. This can help increase the productivity and income of the syrup-manufacturing units.

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