Sweet sorghum R&D at the Nimbkar Agricultural Research Institute (NARI)

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ABSTRACT

The research work on sweet sorghum carried out at the Nimbkar Agricultural Research Institute (NARI) during last twenty-five years has been summarized. American lines were crossed with a local Indian fodder/grain variety to produce varieties with a juicy stalk and good quality grain. Further breeding was carried out to produce varieties and hybrids giving high yield of good quality grain while retaining the characteristic of juicy stalks high in sugar. Complete development of indigenous technology for fermentation of sweet sorghum juice, solar distillation of ethanol and finally its use as a cooking and lighting fuel in new and improved stoves and lanterns was carried out. The technology of producing jaggery (unrefined sugar) and syrup from sweet sorghum was also developed. Consumer response to these products was assessed by marketing them in limited quantities. A completely automated multifuel gasification system capable of producing thermal output between 120-500 kW was developed for direct heat applications such as those in jaggery and syrup making units. Sweet sorghum bagasse was also tested in an existing paper mill to assess its suitability for paper manufacture. Areas of possible research for better exploitation of sweet sorghum have been suggested.

INTRODUCTION

Sweet sorghum [*Sorghum bicolor* (L.) Moench] is the only crop that provides grain and stem that can be used for sugar, alcohol, syrup, jaggery, fodder, fuel, bedding, roofing, fencing, paper and chewing. It has been used for nearly 150 years to produce concentrated syrup with a distinctive flavour [7]. Sweet sorghums have also been widely used for the production of forage and silage for animal feed. The oil crisis of 1973 and 1976 renewed interest in the commercial production of sweet sorghum for biological transformation into ethyl alcohol for use as fuel or fuel additive [1].

Nimbkar Agricultural Research Institute (NARI), a non-profit, private organization started work on sweet sorghum R&D in the early 1970s. This institute is situated in western Indian State of

Maharashtra about 300 km southeast of Mumbai (formerly Bombay). It has been one of the pioneers who initiated sweet sorghum research in India, and has made a substantial contribution to the development and utilization of sweet sorghum for mainly food and fuel. This paper summarizes the research carried out at NARI in five major areas.

Breeding high yielding varieties and hybrids for grain and sugar production

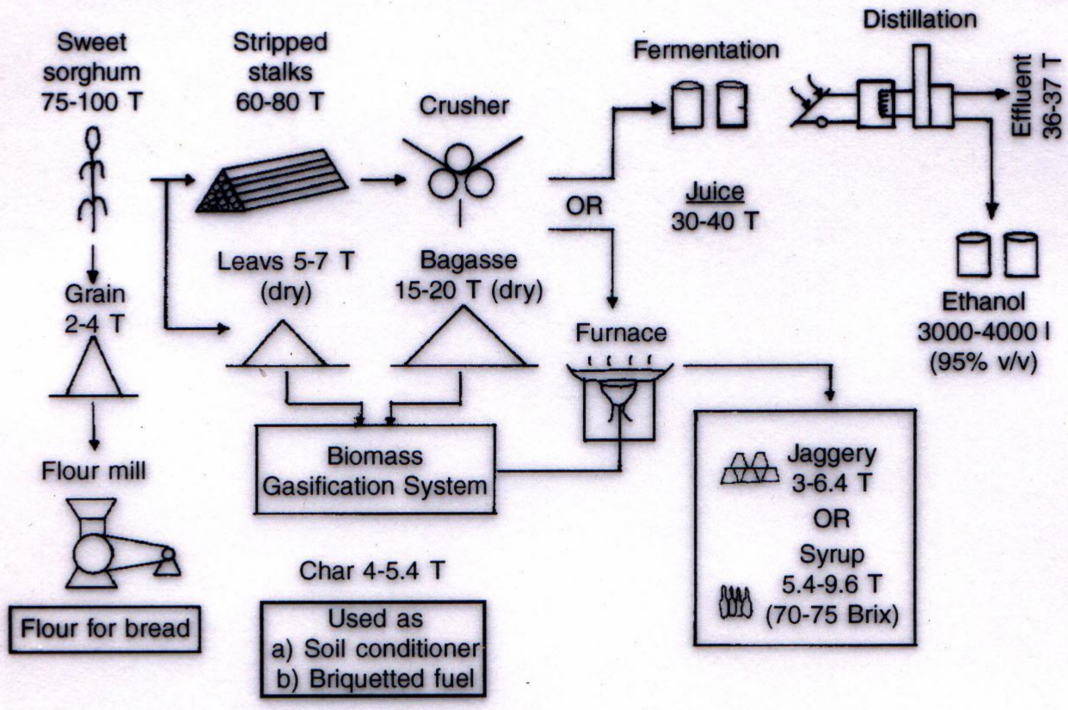
Cultivars developed by the U.S. Sugar Crops Field Station at Meridian, Mississippi, Texas Agricultural Experiment Station, Weslaco and Georgia Agricultural Experiment Station, Griffin were brought to the Nimbkar Agricultural Research Institute during the early 1970's. Their major drawbacks were felt to be: (1) Greater susceptibility to pests and diseases than the normally cultivated grain/fodder sorghums in India (2) Photothermosensitivity (3) Poor seed quality for human consumption as well as low seed yield and (4) Late maturity. Keeping these shortcomings in mind, a breeding program was carried out to minimize them. As a result we were successful in producing relatively early lines yielding about 50 tons of stripped stalks per hectare per season throughout the year. The lines were photothermoinsensitive and produced medium to bold-sized grain with pearly white color [3]. This was basically achieved by crossing the American lines with M 35-1 or Maldandi as the pollinator. Maldandi is planted locally on a large scale as a fodder/grain variety and has a juicy stalk as well as good quality grain.

Since sorghum grain is the staple food grain in our part of India, further improvement in grain yield was attempted to get a dual-purpose crop giving high yields of grain and stem biomass. To achieve this, crossing was carried out between lines having high stalk yields, high brix of juice, property of retention of juiciness of stalk after grain maturity and lines giving high yield of pearly white grain as pollinators [8]. This resulted in production of sweet sorghum varieties capable of giving high yields of grain of acceptable quality and possessing juicy stalks high in sugar.

A total of 22 sweet sorghum accessions were tested for three years to identify the most promising ones for ethanol production. S 21-3-1 and S 23-1-1 were found to be the most promising in terms of stalk and grain yields, juice quality and total energy production per unit land area [12].

Hybridization was carried out with both non-sweet, dwarf and sweet, tall female lines successfully. Hybrids were generally found to possess greater uniformity and were felt to be more desirable than varieties from commercialization point of view.

Thus as can be seen from Figure 1, sweet sorghum planted in 1 ha area has been found to yield different products viz. grain, leaves, bagasse, jaggery, syrup or alcohol in given quantities. Attempts are underway to achieve further increase in the total quantities of these products obtained as well as qualitative improvement, so that it becomes more remunerative for the farmers to plant this crop. Our hybrid "Madhura" is now one of the major crop in India for ethanol production from sweet sorghum. It has been taken up by large number of distilleries both in India and abroad.



Yearly production of different products from 1 ha of Sweet Sorghum

Development of ethanol production technology including fermentation, distillation using solar energy and development of stoves and lanterns running on ethanol

Sweet sorghum has been noted for its potential as an energy crop. Unlike sugarcane, which is a tropical plant, sweet sorghum can be cultivated in nearly all temperate and tropical climatic areas. At NARI, technology of alcohol production from sweet sorghum and its use as a cooking and lighting fuel for rural India has been developed.

The fermentation studies conducted at the Institute have shown that out of the 16 strains tested, the strain NCIM 3319 of yeast, *Saccharomyces cerevisiae* gave good results in batchwise fermentation of unsterilized juice to produce ethanol. Fermented juice containing 10-11% (w/w) total fermentable sugars yielded about 6% (v/v) ethanol after 48 to 72 hours. The batch size was 200 l and no nutrient supplementation of juice was carried out [2].

A pilot solar distillation plant consisting of 38 m^2 of flat plate solar collectors coupled to a hot water storage tank of 2150-l capacity was set up at NARI campus (Fig. 2) in early 1990s. Distillation column of this completely instrumented facility was of packed bed type and was specifically designed to run at distillation temperatures of 50-70^{0}C. These temperatures are easily obtainable from solar collectors.

This plant logged about 4000 hours of operation proudcing 30-40 l.day^{-1} of 95% (v/v) ethanol [4]. About 70% of total yearly distillation heat load came from solar energy, while the rest had to be provided by electric heaters or a biomass-powered producer gas unit. Technoeconomic analysis for setting up a 10,000 lpd distillery was carried out. Calculations showed that for 95% (v/v) ethanol, the cost will be Rs. 14.5/l ($ 0.40/l) for sweet sorghum stripped stalk cost of Rs. 300/ton ($ 8.60/ton).

Fig 2. Solar powered Ethanol distillation plant

An improved, multifuel lantern called “Noorie” was developed. It is a pressurised mantle lantern producing light output of 1250-1300 lumens (equivalent to that from a 100 W light bulb). Compared to existing pressurised kerosene lanterns, this lantern consumes only 60% of the kerosene and operates at one-third the pressure. It can run on kerosene, ethanol or diesel. Ethanol concentrations of a minimum of 80% (v/v) are required [5]. A pressurised alcohol stove has also been developed. It requires a minimum ethanol concentration of 50% (w/w) and above to run. Its heating capacity is 2.5 kW (thermal) for 50% (w/w) ethanol concentration and its thermal efficiency is between 40-55%. Fig 3. Shows the stove.


Fig 3. Low concentration Ethanol Stove

Development of protocols for jaggery and syrup production

Industry for producing jaggery (traditional unrefined sugar) and khandsari (partially refined sugar) from sugarcane is a Rs. 30,000 million ($ 860 million) rural industry in India. About 40% of sugarcane produced in India is diverted for these purposes. Considering this, it was felt that sweet sorghum could become an attractive alternative feedstock to sugarcane for jaggery and syrup production [10]. Thus research efforts at NARI were aimed at developing technologies to produce jaggery and syrup from sweet sorghum using an efficient gasifier-powered furnace running on low-density biomass residues.

Jaggery of excellent quality was prepared whenever the brix of sweet sorghum juice was at least 15 degrees and when the ratio of sucrose to reducing sugars was at least nine. In contrast to the normally manufactured sugarcane jaggery, no chemical additives were utilized in the production of either of these products. Stalk yield and juice quality data for hybrid "Madhura" have been collected from year-round plantings carried out every month. It was possible to produce good quality jaggery from crops planted either during April-May or mid-November to mid-January.

Excellent quality syrup could be made when the brix of raw juice was at least 14 degrees, which was more or less throughout the year. The prepared syrup generally has a final brix of 70-75 degrees (corresponding to syrup temperatures of approximately 106^{0}C) and a minimum shelf-life of 6 to 9 months. Lower brix was encountered only in the winter season plantings (October-November), as these planting dates gave high grain yields. Most farmers in this area plant grain sorghum in winter, so this is the only time when grain becomes available. All other seasons show a heavy bird predation. It was possible to increase the brix of juice in winter season by harvesting the stalks 10-15 days after grain maturity.

Till todate, about 400-kg jaggery and 1500 kg syrup has been test marketed. The consumer response has been encouraging. The syrup was found to be especially rich in calcium, vitamin C, proteins, riboflavin and nicotinic acid and was free of sulphur or any pesticide residues. The syrup in addition to being a table syrup to be eaten with bread or pancakes, can be used in salad dressing, as a sweetener in baked goods or as ice-cream topping [11]. It could also provide a syrupy base for pharmaceutical formulations. Recently it has been shown to have excellent antioxidant properties thereby increasing its medicinal value. The Table below shows the constituents of Madhura syrup and its comparison with honey.

Constituents of Madhura Syrup and its comparison with Honey

(Analysis of a sample of Madhura by CFTRI, Mysore and ITALAB Pvt. Ltd., Mumbai)

	Madhura	Honey (Average)
Calorific value, Cal/g	2.60	3.26
Total solution solids, % wt	77.00	81.00
Total reducing sugars, % wt	70.30	70.40
Proteins (N x 6.25), % wt	1.65	-
Ash, % wt	3.69	0.59
	mg/100g	
Calcium	160.00	5.00
Phosphorus	11.00	4.10
Riboflavin (Vitamin B_2),	10.00	0.06
Vitamin C	11.50	5.00
Nicotinic Acid	153.00	32.00
Iron	0.86	0.59
Sodium	86.00	4.70
Potassium	1810.00	90.00
Sulphur	Not detected	8.00
Benzoic acid	Not detected	
Added coloring matter	None	
Pesticide residues	Not detected	

* Date for Honey is from Literature

Development of an efficient biomass gasifier which can run on sweet sorghum bagasse and can be used as a source of heat in the furnace for jaggery and syrup manufacture

One of the major improvements in jaggery or syrup making can be affected by improving the furnace efficiency. Existing furnaces normally have only 10-15% overall efficiency. A completely automated multifuel gasification system capable of producing thermal output between 120-500 kW was developed. In addition to sugarcane leaves and bagasse from sweet sorghum, or sugarcane, it can also use other low-density biomass like wheat and safflower residues and grasses like Cenchrus and hybrid Napier (Table 1).

The modern jaggery and syrup-making unit set up at NARI includes this gasifier, an efficient gas combustion unit and a furnace. The system is controlled by a programmable logic controller (PLC)-based unit and includes automatic biomass feeding and diagnostic controls for the gas system [9]. Unlike conventional units, there is no smoke pollution from this unit. The cold gas efficiency of the gasifier for direct heat applications is about 45% resulting in great savings of biomass.

The gasifier is an open top, throatless (cylindrical) type and requires the biomass residues to be chopped into 1-10 cm long particles, which is carried out using a 2.3 kW electric chaff cutter. The gas produced (mainly comprising of 15-25% carbon monoxide, 10-20% hydrogen and 1-5% methane), is combusted in a special burner designed at NARI. It is basically a venturi-type burner with a plate for flame stabilization. It produces a bluish-white flame with temperatures exceeding 1250^0C. Figure 3 shows the gasifier with the flame.

Fig 3. Biomass Gasifier and furnace

The gasifier also produces char [20% w/w) of input biomass feed] as a by-product. It can be mixed with a suitable binder like cowdung (15% w/w) to form briquettes using a hand-operated briquetting machine [9]. These briquettes are smokeless and make an excellent fuel for chulhas (traditional cooking stoves). Experiments were carried out to study the potential of this char as a soil conditioner. Various crops were grown on soils treated with different doses of char, without any adverse effects.

For direct heat applications, in addition to jaggery and syrup making units, potential beneficiaries of this technology can be rural agro-based industries like fruit and food processing plants, bakeries, foundries, brick kilns etc. Gasifiers can also be used for drying of agricultural produce and proudcts, and in crematoriums where substantial wood saving can result. In addition to direct heat applications, this gasification system can also be used for electricity generation by powering a diesel genset [14].

Assessment of possible use of fiber from sweet sorghum bagasse for paper manufacturing

It has been reported that pulps of sweet sorghum lines can be used for the manufacture of fine quality writing and printing paper as well as corrugated and solid particleboard [6].

The most critical issue facing the Indian industry is the availability of cost-effective fibrous raw materials. There has been a chronic shortage of forest-based raw materials, viz. bamboo and pulpwood. The shortage is likely to escalate with dwindling forest cover. The collection and recovery of waste paper in India is largely unstructured and its availability is also limited because of its other varied uses (15% compared to around 40% in developed countries). Creation of paper manufacturing capacity based on straw has remained limited due to the cumbersome and uneconomical task of collection from widely dispersed areas, its storage and its use as cattle feed [13]. Sugarcane bagasse was considered to be a promising alternative to the other raw materials. There was a surplus of bagasse available for paper mills especially from efficient sugar industries. However, recently a massive effort by Government of India to make these factories also produce electricity via cogeneration will create shortage of bagasse for paper manufacturing.

In the light of this situation it was felt that sweet sorghum may be an ideal crop to form the raw material of an alcohol-paper complex. Some samples of bagasse from our sweet sorghum hybrid “Madhura” were given to M/s Shirke Paper Mills Pvt. Ltd., Shirwal for testing. They are one of the few bagasse-based paper manufacturing units in India. They carried out laboratory trials of cooking and bleaching on this material to determine its suitability for paper manufacture. The pulp evaluation showed that good quality pulp could be produced from sweet sorghum bagasse. The only problem envisaged by the paper mill was the handling of bagasse, which is very bulky. This was also expected to reduce the packing density in digesters.

The experience of working with sweet sorghum crop for more than two decades has shown that better exploitation of this promising crop will be possible with the development of the following :

a) a mechanical whole-stalk harvester;
b) a leaf stripping unit which can be used before or after stalk harvest;
c) improved fermentation methodology and extraction technology;
d) improved cultivars, which are photoinsensitive, disease and insect resistant, stress-tolerant, high-yielding and new male-sterile lines, which are sweet and tall.

Thus the total utilization of the sorghum plant in a balanced production of food, feed and selected industrial products will become increasingly important in the developing countries. A total utilization of all components in the sorghum plant for use in the manufacturing and food industries would increase cash flow to the farmer and thereby constitute an incentive for him to increase his production.

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Table 1: Characteristics of Biomass Residues Used in NARI Gasifier

Sr. No.	Biomass Residue	Yield T/ha-yr (oven dry)	Bulk density of chopped material (kg/m^3)	Ash content (%) (w/w, dry)	Suitability for gasification
1.	Sugarcane leaves	4-6	26-40	7-8	Excellent
2.	Sweet sorghum stalks	20-30	70-120	4-5	Excellent
3.	Sweet sorghum bagasse	10-14	70-90	4-5	Very good
4.	Safflower residues	3-8	70-80	2-3	Good; increased tar products
5.	Hybrid napier grass	24-40	42-48	8-12	Fair; problems with bridging of fuel & rapid combustion
6.	Cenchrus grass	5.5-7.0	26-30	11-15	-do-
7.	Wheat husk	4-10	49-53	4.3-11	Good
8.	Sugarcane bagasse	17-20	150-160	1.3-1.5	Very good

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Recently (2015) a high yielding sweet sorghum variety Madhura-2 has been released by NARI. This can be grown both in Rabi (post monsoon) and Karif (monsoon) seasons.