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Sweet Sorghum

A novel opportunity for biofuel production

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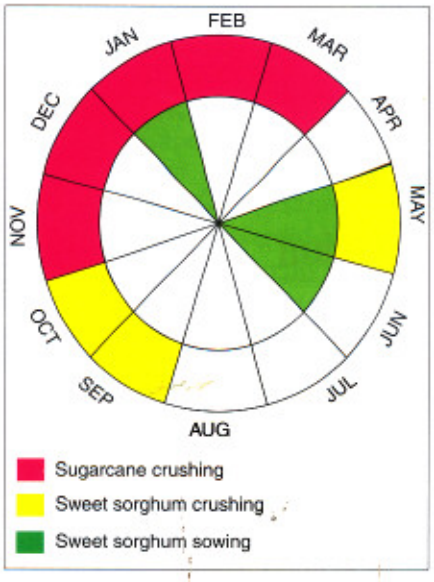
IN view of the rapid increase in the global population (7.39 billion) and the consequent increase in energy requirement, depletion of natural energy sources is rapid with atmospheric pollution reaching highest levels. Therefore, worldwide, the demand for renewable energy sources is continuously on the rise to cater to the needs of increased population and to reduce carbon dioxide emissions along with associated risks of climate change, and global warming. In India, of the total primary energy consumption basket, crude oil and natural gas constitute 45% share in the total energy basket mix and more than 75% of the energy requirements are met through imports from the international markets which are causing a huge burden on the exchequer in the form of fuel import bills. The supplies through imports though unhindered at present, are more vulnerable in the current context of increased threat associated with geo-political uncertainty. Coupled to this, the increasing environmental concerns due to the usage of fossil fuels necessitates the need for alternate energy sources for ensuring environmental sustainability and energy security.

Among several alternative renewable energy sources viz., wind, solar and hydro etc, energy derived from plant biomass is found to be more promising and sustainable towards reduction in greenhouse gas emissions. Ethanol is the most common form of plant based biofuels.

In India, ethanol is produced from sugarcane molasses which is a by-product of sugar industry and used as a biofuel for blending with petrol. In January 2003, Government of India (GOI) mandated 5% blending of ethanol with gasoline through its ambitious Ethanol Blending Program (EBP). Ever since the blending program has been initiated, the trade balance for ethanol has been generally negative as the need for ethanol is greater from industrial sector (chemical industry, potable alcohol industry, etc.) and less quantity is available for blending programme. To promote biofuels as an alternative energy source, the GOI in December 2009 announced a comprehensive National Policy on Biofuels formulated by the Ministry of New and Renewable Energy (MNRE), calling for blending at least 20% of biofuels with diesel (bio-diesel) and petrol (bio-ethanol) by 2017. The policies are designed to facilitate and bring about optimal development and utilization of indigenous biomass feedstock for biofuel production. In the last few years, the country could achieve only closer to 2% blending of petrol with ethanol against the envisaged 5% blending. The fact remains that ethanol production from sugarcane molasses alone does not ensure optimum supply levels needed to meet the demand at any given time owing to reasons such as cyclical nature of sugarcane cultivation, difficulty in increasing sugarcane area due to high water intensiveness of the crop, erratic monsoon and power supply. Increasing the area under sugarcane at the cost of diverting land from other staple food crops is undesirable.

Sorghum as a dryland crop offers a sustainable solution to the above problems as it can be grown for feed, feed, fodder, fuel and fibre. First generation bio-ethanol production from sorghum grain through saccharification and fermentation of the readily convertible carbohydrates (i.e. starch) and from stem juice (i.e. free sugars including sucrose, glucose and fructose) has been well understood and put into commercial use. Sweet sorghum based ethanol

The National Policy on Biofuels identified sweet sorghum as one of the candidate crops for augmenting biofuel production in the country. Sugar industries are exploring the possibilities of complementing their existing molasses-based ethanol production with alternative raw material to fill-in the lean period of sugarcane crushing for year-round operations. Sweet sorghum could be cultivated and supplied during the lean period of sugarcane crushing thus extending the crushing period before and after sugarcane crushing and stretch the sugar mill operation.



Scheduling the sweet sorghum feedstock availability during lean period of sugarcane crushing

production distilleries have been established in India and elsewhere.

First generation biofuel production from sweet sorghum

Sweet sorghum *Sorghum bicolor* L. Moench is a new generation bioenergy crop that has the potential to accumulate sugars in the stalk similar to sugarcane but within a short growing period of four months and yields grain on par with grain sorghum. Further, it has a low water requirement which is about half the quantity of water required by sugar beet and a third of the requirement for sugarcane (4,000 m^3 vs. 36,000 m^3) and produces high biomass (50-80 tonnes/ha) and alcohol (1,500-2,000 l/ha). Its wider adaptation and tolerance to various abiotic stresses like drought, salinity along with higher water, nitrogen and radiation-use efficiencies make it a preferred biofuel feedstock over other crops like corn, sugarcane and sugar beet. Some sweet sorghum lines yield juice volume of about 78% of total plant biomass and contain soluble fermentable sugars from 15 to 23% in comparison to sugarcane which has 14–16% sugars.

Sweet sorghum comes up well in drylands where the annual rainfall ranges from 550-800 mm under a variety of soil and climatic conditions. The best regions to raise this crop during *kharif* and summer are central, south India and subtropical areas in Indo-Gangetic belt. Itcan be grown from 15 to 45° C and the optimum temperature for growth and expression ranges between 25 to 40°C and the day length requirement is 10 to 14 h.Sweet sorghum can thrive under moderate water stress conditions, on marginal lands with little or no external inputs. It is an ideal crop with thick stems and juicy internodes maintaining stem juiciness until maturity that can begrown in sugarcane growing areas to complement ethanol production from molasses. It can also be benefited with the managerial expertise and the existing sugarcane machinery during the off season of sugarcane crushing. The juice can be fermented to bio-ethanol while the harvested grain can be used for food. The stillage or the bagasse can also be used as livestock feed and for co-generation of power. The bagasse from sweet sorghum has a higher biological value than the bagasse from sugarcane when used as feed for animals, as it is rich in micronutrients and minerals and can also serve as a raw material for paper and pulp industry. Sweet sorghum offers a solution to the ongoing food versus fuel debate as the diversion of crop land for cultivation of bioethanol crops (food vs. fuel conflict) does not arise with sweet sorghum as it meets food, fuel and fodder requirement. Wider adaptability of sweet sorghum and its amenability for ethanol production using the existing sugar mills infrastructure without any extra investment makes it an attractive feedstock for the industry.

A techno-economic feasibility study undertaken by Indian Institute of Millets Research (Formerly Directorate of Sorghum Research (DSR), and National Research Center for Sorghum (NRCS), Hyderabad) during 2004, indicated that the per litre cost of production of ethanol from sweet sorghum (Rs 13.11) was lower than that from sugarcane molasses (₹ 14.98) based on the then prevailing prices for molasses, sweet sorghum cane etc. Besides this, the ethanol produced from sweet sorghum is of superior quality with low or negligible spent wash and with high octane rating due to low sulphates and aldehydes.

These virtues along with the availability of hybrid seed production technology allow sweet sorghum to be raised in different seasons to schedule the cane supply to the industry on a regular basis. The various yield parameters which make sweet sorghum as an ideal biofuel feedstock are given in Table 1.

Available sweet sorghum technology

Concerted research efforts utilising the wide variability in the germplasm during last two decades at IIMR and its cooperating centres in different State Agricultural Universities and at ICRISAT have resulted in development and commercialization of excellent sweet sorghum genotypes for use in ethanol production by the sugar industries/alcohol distilleries and for use as green/dry fodder. Promising nationally released varieties/hybrids are SSV 84 (high brix), CSV 19SS (High stalk yield, shoot fly tolerance), CSV 24SS (High stalk and sugar yields) and hybrid CSH 22 SS (High stalk and sugar yields). The yields of these genotypes may vary according to the

Table 1. Yield parameters in sweet sorghum

Character	Average yields
Green cane yield or stripped stalk yield (tonnes/ha)	40-55 *kharif* and summer (with protective irrigations)
Juice yields (litres/ha)	12000-14000
Brix (%)	16-19 (*kharif* and summer)10-14 (*rabi*)
Reducing sugars (%)	2-4
Pol (sucrose %)	8-12
Juice extraction (%)	40-45 (small mill)>60% (big mill)
Bagasse yield (tonnes/ha)	5-8 (dry wt basis)
Ethanol yields (litres/tonnes of cane)	40-50
Power from bagasse (MW/ha)	2-2.5
Grain yields (tonnes/ha)	2-4

Brown midrib sorghum with brown colouration of leaf midrib and stalk

location, date of planting, soil type, season (*kharif* or *rabi*), rainfall distribution etc. Stalk yields obtainable during *rabi* will be 30-35% less with reduced sugar content than *kharif* and summer grown crops because of prevailing low night temperatures and shorter day lengths and their interaction with planting time.

Second generation biofuel development from sweet sorghum

Currently, biofuels are mainly generated from starch and sugarcane sucrose; however, the bulk of plant biomass is in the form of cell walls, which promise to be the most abundant renewable source of biofuels. In recent years, utmost priority is being given to the production of ethanol from agricultural wastes/residues which contain the carbohydrates, viz. cellulose and hemicelluloses that can be converted to ethanol by fermentation considering the long term economic, environmental and social benefits.

The biochemical conversion of high biomass lines of sorghum including sweet sorghum to bioethanol is distinctive as the sweet and forage sorghums are good sources of cellulose and hemicelluloses. Besides this, they have a high yield potential of 20-45 tonnes/ha of dry biomass and close to 100 t/ha of fresh biomass. The bagasse of sweet sorghum after extraction of juice contains similar levels of cellulose as sugarcane bagasse which makes it a suitable raw material for lignocellulosic biofuel.

Brown midrib (*bmr*) sorghum as feedstock for biofuels

An advantageous feature of sorghum for bioenergy is the presence of brown midrib (bmr) mutations in sorghum that can reduce lignin content. Beyond the use of brown midrib mutants to increase forage digestibility, there has been significant interest in the impact potential these mutants may have on lignocellulosic bioenergy production. Lignocellulosic bioenergy conversion requires decomposition of the cell wall polysaccharides cellulose and hemicellulose into monomeric sugars prior to their conversion into ethanol or alternative biofuels. Lignin negatively impacts lignocellulosic conversion because it can block the enzymatic liberation of sugars from cell wall polysaccharide moieties, releases aromatic compounds that can inhibit microbes used for fermenting sugars to fuels, and adheres to hydrolytic enzymes. Therefore brown midrib feedstocks, which have reduced lignin content, are known to result in increased yields of fermentable sugars upon enzymatic saccharification thus improving the overall biomass conversion efficiency. The introduction of the bmr trait into high biomass sorghums would result in a dual-purpose bioenergy crop that supplies fodder and fermentable sugars from the lignocellulosic biomass. Indian Institute of Millets Research is the first institute in India to develop brown midrib genotypes and has registered the low lignin line SPV 2018 with NBPGR. Efforts are underway to transfer the browm midrib trait in to elite high biomass lines for use as feedstocks in bioenergy production

Way forward

In order to meet the increased demand for energy, there is a need to develop renewable energy sources such as sweet and high biomass sorghums which produce high stalk yield per unit time, input energy, photo-and thermo-insensitivity with inbuilt desired levels of resistance/ tolerance to various stresses. These genotypes have to be with different maturities so as to ensure a continuous sup-ply of feedstock to the biofuel industry.

Commercialization of sweet sorghum cultivation is possible if the required policy support in the form of incentives from Government for both producer and processor are

extended and genetically enhanced cultivars for high sugar, cane yields and important biotic and abiotic stresses are made available. Genetically improved brown midrib (bmr) sweet sorghums having reduced lignin content will pave a better path to increase cellulosic ethanol production as compared with other sorghum cultivars and improve process economics targeting higher conversion efficiency.

The efforts by the government to implement the Ethanol Blending Programme (EBP) by way of conversion of surplus sugarcane into ethanol instead of producing surplus sugar would improve cash flow of sugar mills which in turn, will help in timely payment of fair and remunerative cane price to the farmers. Government is contemplating the introduction of flexi-fuel vehicles into India shortly and is also calling upon the sugar industry to ramp up the ethanol production as demand for it is likely to go up once these vehicles are introduced into the country. The EBP which was at 5% and which is to be increased to 10% would still be falling short of the required quantities of ethanol which is to be routed from sugarcane industry. Given the fact that the sugarcane area can't be increased due to several reasons and the fact that sweet sorghum cultivation can complement the ethanol production from sugarcane molasses due to several advantages including wider adaptability, ease of cultivation with less inputs and more importantly its availability during the lean period of sugarcane crushing would certainly give a fillip to the ethanol blending program. A three year (2015-18) project funded by Department of Biotechnology, Government of India on "Commercialization of sweet sorghum as a complimentary feedstock for ethanol production in the sugar mills of Maharashtra, Tamil Nadu and Gujarat" has come at the opportune time for research institutes working on sweet sorghum and currently, Indian Institute of Millets Research is collaborating with ICRISAT, Sugar industries and National Federation of Cooperative Sugar Factories Limited, New Delhi to promote sweet sorghum as a promising biofuel feedstock for complementing ethanol production from sugarcane molasses.

SUMMARY

Sweet sorghum being a promising alternative feedstock for sustainable ethanol production can also provide a wide range of environmental, economic and employment benefits under rainfed conditions. There is an urgent need to address important issues in sweet sorghum cultivation such as *rabi* season adaptation, biotic stress tolerance, mechanical harvesting, post-harvest juice quality deterioration etc. In view of the current remunerative price for ethanol which is between ₹ 48.50-49.50 per litre, the use of sweet sorghum as biofuel feedstock in existing sugar mills is going to be a win-win situation for both industry and resource poor, dryland sweet sorghum farmer while improving the environment and reducing the oil import bill for country.

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