Advances in Bioresearch
Adv. Biores., Vol 9 (1) January 2018: 21-26
©2018 Society of Education, India
Print ISSN 0976-4585; Online ISSN 2277-1573
Journal's URL:http://www.soeagra.com/abr.html
CODEN: ABRDC3
DOI: 10.15515/abr.0976-4585.9.1.2126

Advances in Bioresearch

REVIEW ARTICLE

Sweet Sorghum: An Emerging Smart Biofuel Crop

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ABSTRACT
Self-sufficiency in energy requirements is critical to the success of any emerging economy. Renewable sources of energy are considered to be one of the major pillars of energy security that reduces dependence on fossil fuels besides negating the negative effects on the environment. Agriculture has always been a source of fuels for energy production such as feed for draught animals and more recently juice for biofuels, e.g., bioethanol (blended with fossil fuels) or biodiesel. Production of fuels, especially bio-ethanol from lignocellulosic biomass, holds remarkable potential to meet the current energy demand as well as to mitigate greenhouse gas emissions for a sustainable clean environment. Sweet sorghum is a widely adapted sugar crop with high potential for bioenergy and ethanol production. Sweet sorghum can yield more ethanol per unit area of land than many other crops especially under minimum input production. Sweet sorghum is well-adapted to marginal growing conditions such as water deficits, water logging, salinity, alkalinity, and other constraints. Sweet sorghum potential exists for ethanol yield of 6000 L/ha with more than three units of energy attained per unit invested. Sweet sorghum is genetically diverse and variations exits for characteristics such as Brix % (13-24), juice sucrose concentration (7.2-15.5%), total stalk sugar yield (as high as 12 Mg ha/1), fresh stalk yield (24-120 Mg ha/1), biomass yield (36-140 t/ha) and others indicating potential for improvement. Large-scale commercial cultivation of these crops by industries for biofuel production may be economically viable but lack of knowledge and access to seed material besides marketability of the farm produce would potentially deprive the poor dry land farmers from benefitting from the these emerging opportunities. The latter targets to improve sugar and grain productivity of sweet sorghums cultivars for specific semi-arid tropic regions and aware the farmers about cultivation of sweet sorghum as biofuel crop that may leads to sustainable development of farmers communities. It reviews information about uses, current practices and also suggests future prospects of sweet sorghum in India.
Keywords: *lignocellulosic biomass, Biofuel, sweet sorghum*

Received 24.07.2017 Revised 10.08.2017 Accepted 21.12.2017

How to cite this article:
A.U.Ingle, A.R.Gaikwad, Suvarna Gare and Kusalkar D.V.Sweet Sorghum: An Emerging Smart Biofuel Crop. Adv. Biores., Vol 9 [1] January 2018.21-26.

INTRODUCTION

Global population growth continues to rise at an alarming rate in spite of control measures taken by many countries. Predictions are that the population of the world will reach 9.4 billion by 2050 (US Census Bureau, 2006). The demand for food, fuel and energy resources of both developing and developed nations would increase substantially. According to the Food and Agricultural Organization of the United Nations, fossil fuels are the most important energy source worldwide and also the primary cause for global warming and climate change. In 2008, the volatility of global crude oil prices was unprecedented. On 21 January 2008, the price of crude oil per barrel in the international market was $88.92. Crude oil price rise is now a crude reality. In June 2008, it touched a historic high of $147 per barrel, and hit rock bottom at $33 per barrel in December 2008, owing to global economic recession; subsequently, it increased to $80 in November 2009.

The climate is changing and there is now scientific, social and political recognition that this is very likely a consequence of increasing anthropogenic greenhouse gas (GHG) emissions. Transport now accounts for about 20% of global anthropogenic carbon dioxide emissions and these figures are growing faster than for any other sector. However, access to energy underpins our current way of life and the hopes of people around the world for improved livelihoods. Mobility is a core component of these aspirations. Transport

has become the main driver for increasing global primary oil demand, which is predicted to grow by 1.3% per year up to 2030, reaching 116 million barrels per day (up from 84 million barrels per day in 2005).
The continued escalation in crude oil prices will have serious repercussions at the global level, crippling the economies of developing and under developed countries, thus necessitating the monitoring of oil prices on a continuous basis by UN agencies and other world bodies. Many countries, including large economies like USA, China and India are importing huge amounts of petroleum products. Research on renewable sources of energy was initiated in many countries a few decades back especially after the oil shock in 1973. However, success was limited to Brazil, where ethanol distillation from sugarcane has been economically sustainable. Ethanol is blended with petrol for use in flexi-fuel vehicles in Brazil, reducing the dependence on 100% petrol.
The vast majority of today's ethanol is derived from starch- and sugar-based feedstocks. The sugars in these feedstocks are relatively easy to extract and ferment using widely available biochemical conversion technologies, making large-scale ethanol production affordable. Starch-based feedstocks include cereals such as corn, wheat and milo. Sugar-based feedstocks, such as sugarcane, sweet sorghum and sugar beets, contain simple sugars that can be extracted and fermented readily. Corn grain is the feedstock for more than 90% of current US ethanol production. High sugar yielding sweet sorghum is being utilized in India, the USA, the Philippines and other countries owing to the pioneering work at ICRISAT-Patancheru, Directorate of Sorghum Research (DSR), and All India Coordinated Sorghum Improvement Project (AICSIP) under the Indian Council of Agricultural Research (ICAR), India; Texas A&M University, Rutgers University and University of California (all in the USA); Mariano Marcos State University, the Philippines; CSIRO Plant Industry, University of Queensland and University of Melbourne (all in Australia).
This study covers the significance, research status in several areas, potential, food-fuel trade off and environmental implications of using sweet sorghum as feedstock for production of ethanol in the context of present food crisis and also global food vs fuel debate. It also briefly addresses the prospects of using sorghum stover/biomass/ bagasse for ethanol production through second-generation lignocellulosic technology.

- Now a day's the world's present economy is highly dependent on various fossil energy sources such as oil, coal, gasoline, natural gas, etc. These are being used for the production of fuel, electricity and other goods.
- Due to excessive use of fossil fuels, mainly in urban areas, has resulted in depletion of their resources. The level of greenhouse gasses in the earth's atmosphere has drastically increased.
- In the present demand for renewable, sustainable sources of energy to overcome the burden on world energy crisis, bioethanol have presented exciting options.
- Bio-ethanol is one of the important alternatives being considered due to the easy adaptability of this fuel to existing engines, less greenhouse gas emissions.
- Sweet sorghum is similar to grain sorghum but accumulates sugary juice in its stalk. Traditionally used as livestock fodder, the stalks can now be crushed to extract juice as raw material for ethanol production.
- Because of its short growing period, high biomass and bio-product potential, tolerance to drought, water-logging, salinity and acidity, low water requirement and greater income opportunities, sweet sorghum is the preferred crop for cultivation on dry lands in the semi-arid tropics.
- Sweet sorghum is recognized as an alternate feedstock for bioethanol production by the Government of India [1].

The sweet sorghum ethanol value chain shows a positive net energy balance of 7.5 and a reduction of greenhouse gas emissions by 86%, compared to fossil fuels.

Need For Alternate Raw Material:

The Supreme Court of India informed the Government of India (GOI) to use Compressed Natural Gas (CNG) as an alternative to petrol and diesel for fuelling automobiles to reduce environmental pollution. However, considering the reduced output by the Oil and Natural Gas Corporation (ONGC), and thereby likely shortage of CNG in future , the GOI has made it mandatory to blend petrol and diesel with ethanol (to reduce carbon monoxide emission in automobiles) initially up to 5% and gradually hiking it to 10% in the second phase. There are two objectives in this strategy, reducing both the environmental pollution and the fuel-import bill for the country. According to the Federation of Indian Chambers of Commerce and Industry (FICCI), India could save nearly 80 million L of petrol annually if petrol is blended with alcohol by 10%. Burning quality of alcohol-blended petrol is more eco-friendly than that of CNG [6]. These environment and cost considerations have triggered a debate on the availability of adequate raw material to meet the possible increased demand for ethanol production.

Sweet Sorghum as Feedstock For First Generation Ethanol Production

Sorghum [*Sorghum bicolor* (L) Moench] is considered to be one of the most important food and fodder crops in arid and semi-arid regions of the world. Globally, it occupies about 45 million hectares with Africa and India accounting for about 80% of the global acreage. Although sorghum is best known as a grain crop, sweet sorghum is similar to the grain sorghum, besides possessing sweet juice in the stalk tissues that is traditionally has been used as livestock fodder due to its ability to form excellent silage (Table 1); the stalk juice is fermented and distilled to produce ethanol. Therefore the juice, grain and bagasse (the fibrous residue that remains after juice extraction) can be used to produce food, fodder, ethanol and electricity. The ability of sweet sorghum to resist drought, saline and alkaline soils, and water logging has been proven by its wide prevalence in various regions of the world. The per day ethanol productivity of sweet sorghum is higher when compared to sugarcane besides a shorter growing period of four months and low water requirements of 8000 cubic meter (over two crops) that are about four times lower than that for sugarcane (12–16 month growing season and 36000 cubic meters of water) [7]. Its lower cost of cultivation and familiarity with cultivation of sorghum, the ability and willingness of farmers to adopt sweet sorghum is much easier. Sweet sorghum has some inherently pro-poor characteristics compared to other major feedstocks (sugarcane, maize) for ethanol production. Moreover, sweet sorghum-based distilleries require quality feedstock at a predetermined price and in high volumes on continuous basis while small-scale farmers need a fair price for their produce, and technical and credit assistance.

Other positive aspects of sweet sorghum include its higher profitability (23% higher)) than the grain sorghum under rainfed conditions in India. Sweet sorghum juice is better suited for ethanol production because of its higher content of reducing sugars as compared to other sources including sugarcane juice. These important characteristics, along with its suitability for seed propagation, mechanized crop production, and comparable ethanol production capacity *vis a vis* sugarcane molasses and sugarcane juice makes sweet sorghum a viable alternative source for ethanol production (Table 2). Additionally, the pollution levels in sweet sorghum-based ethanol production has 25% of the biological oxygen dissolved (BOD), i.e., 19500 mg liter^{-1} and lower chemical oxygen dissolved (COD), i.e., 38640 mg liter^{-1} compared to molasses-based ethanol production [as per pilot study conducted by Vasantdada Sugar Institute (VSI), Pune, India].

Table 1. Characteristics of sweet sorghum that makes it a viable source for ethanol production.

As crop	As ethanol source	As stillage/bagasse
• Shorter gestation period (3–4 months) • Dryland crop • Greater resilience • Farmer friendly • Meets fodder/food needs • Non-invasive/least invasive species • Low soil NO_2/CO_2 emission • Seed propagated	• Eco-friendly process • Superior quality • Less sulphur • High octane • Automobile friendly (up to 25% of ethanol petrol mixture)	• Higher biological value • Rich in micronutrients • Use as feed/for power cogeneration/ biocompost

Why Sweet Sorghum?

Sweet Sorghum is an extraordinarily promising multifunctional crop for several reasons:

- It requires common soil even with high % of sand and it is also adapted to salty areas;
- It requires low water inputs (~200m3/ton), 1/3 of sugarcane requirements, 1/2 of corn;
- It has a shorter growing cycle (4/5 months), 1/3 of that sugar cane;
- A high productivity of several components (grains, sugars, lignocellulose);
- It can be grown in all continents, in tropical, sub-tropical and temperate regions (covering sugar-cane and most sugar-beet areas);
- Sweet-Sorghum is not a food crop but a multi-functional (energy) crop, thus not a competitor crop for the food market!
- Sweet Sorghum absorbs large amounts of CO2(~50 t CO2/hax cycle);
  ~10 t/ha/y, within the tolerance level (11 t/ha/y);
- Biofertiliser production (compost) from Sweet Sorghum residues can improves the sustainability of cropping;

Comparison with Sugarcane:

Sweet sorghum has less water and fertilizer requirements and hence lower cost of cultivation than sugarcane (Table 3). Sweet sorghum can be an additional or an alternative raw material to sugarcane. In most situations, it will be a supplement rather than a substitute for sugarcane.

Multiple Uses of Sweet Sorghum Crop:

As indicated above, in addition to sweet stalks, average grain yield of 2−2.5 t h^{-1} can be obtained from sweet sorghum for use as food or feed. The bagasse (stalks after crushing) remaining afterthe extraction of juice has higher biological value than the bagasse from sugarcane when used as cattle feed, as it is rich in micronutrients and minerals which is also as good as stover in terms of its digestibility.

Animal feeding experiments using the sweet sorghum bagasse and stripped leaves-based feed block (BRSLB) by International Livestock Research Institute (ILRI) and ICRISAT showed that no significant differences between BRSLB and commercial sorghum stover-based feed block (CFB) for neutral detergent fiber % (NDF), daily intake (kg d^{-1}) and weight gain per day in animals (Table 3). However for significant differences were observed between BRSLB and CFB for nitrogen content, *in vitro* digestibility and metabolizable energy (ME) contents. As expected, the laboratory quality indices were lowest in the sorghum stover. An important aspect of the present work was to investigate the palatability of feed blocks when sorghum stover was entirely replaced by BRSLB. There was no (statistical) difference in feed intake between the CFB and the BRSLB.

In summary, sweet sorghum is more accessible to poor farmers because of its low cost of cultivation and its ability to grow in areas that receive a minimum of 700 mm annual rainfall. Secondly, sweet sorghum has a high net energy balance, 3.63 compared to grain sorghum (1.50) and corn (1.53) [4, 5]. Even though the ethanol yield per unit weight of feedstock is lower for sweet sorghum compared to sugarcane, the much lower production costs and water requirement for this crop more than compensates for the difference, and hence, it still returns a competitive cost advantage in the production of ethanol in India [2,3]. It produces three valuable products: food, fuel and feed, raising smallholder incomes by about 23% in central India [3], while probably reducing net greenhouse gas emissions compared to fossil fuels.

Table : 2

Comparison With Sugarcane:

Crop	**Sugarcane**	**Sweet sorghum**
Duration (days)	Seasonal - 360 Pre-seasonal - 420 Adsali - 480	110-150
Fertilizer requirement N: P: K (Kg/ha)	Seasonal - 250:115:115 Preseasonal - 340:170:170 Adsali - 360:170:170	100:50:50
Amount of water required (mm)	Seasonal - 2000-2200 Preseasonal - 2500 Adsali - 3000-3500	400-450
Commercial cane sugar produced (T/ha-season)	9.4	2.4
Cost of cultivation of stalks (Rs./ha - season)	46,355	23,245

Table 3 : Sweet sorghum vis-à-vis sugarcane and sugarcane molasses.

Crop	**Cost of cultivation (USD ha^{-1})**	**Crop duration (months)**	**Fertilizer require-ment (N-P-K kg ha^{-1})**	**Water require-ment (m^3)**	**Ethanol produc-tivity (lit. ha^{-1})**	**Av. stalk yield (t ha^{-1})**	**Per day produ-ctivity (kg ha^{-1})**	**Cost of ethanol produc-tion (USD lit^{-1})**
Sweet sorghum	435 over two crops	4	80 - 50 - 40	8000 over two crops	4000 $year^{-1}$ over two crops(a)	50	416.67	0.32(d)
Sugarcane	1079 $crop^{-1}$	12–16	250 to 400 - 125 -125	36000 $crop^{-1}$	6500 $crop^{-1}$(b)	75	205.47	
Sugarcane molasses	-	-	-	-	850 $year^{-1}$(c)	-	-	0.37(e)

(a) . 50 t ha^{-1} millable stalk per crop @ 40 l t^{-1} (b) 85–90 t ha^{-1} millable cane per crop @ 75 l t^{-1} (c) 3.4 t ha^{-1} @ 250 l t^{-1}
(d) Sweet sorghum stalk @ US$ 12.2 t^{-1} (e) Sugarcane molasses @ US$ 39 t^{-1} Source(d,e): Dayakar Rao et al. 2004.

Major Challenges in Sweet Sorghum Ethanol Value Chain:

Sweet sorghum ethanol production technology has been steadily gaining momentum in India and elsewhere. However, there is a need to address some core issues to make sweet sorghum a popular choice for biofuel production by entrepreneurs and farmers. Seasonality of the crop, limited harvest window, high labor requirement, quick reduction in stalk sugar content with delay in crushing and supply chain management are some of the major challenges in sweet sorghum to ethanol technology and value chain. Planting the crop in wider geographical areas, staggered sowing, choosing cultivars with different maturity durations, decentralized crushing of stalks, and irrigating the standing crop after harvesting panicles help extending the period of raw material availability to industry. ICRISAT and its partners are working on the development of high sugar and grain yielding sweet sorghum hybrids that are stable across planting dates, mechanization of sowing and weeding operations and overall supply chain management in sweet sorghum. ICRISAT with the help of NAIP-ICAR established the first decentralized crushing-cum-syrup making unit (DCU) at Ibrahimbad village in Medak district of Andhra Pradesh, India, to enable the farmers located away from the industry to participate and gain from sweet sorghum ethanol technology by reducing the volume of raw material for transportation, prevent the losses with delay in crushing and extend the period of raw material availability to industry in the form of syrup. In the 2008 rainy season, a total of 557 tons of green stalks were crushed and to produced 22.5 tons syrup (approx. 80% Brix). The syrup was transported to Rusni Distilleries for ethanol production.

Varieties of Sweet Sorghum

Sweet sorghum stalk are juicy and rich in fermentable sugars as high as 15-18 per cent and has potential for cane yield of 40 t/ha or more. Projected uses of sweet sorghum are production of alcohol, syrup and jaggery from the stalk juice. The recovery of alcohol in the pilot run showed 9 percent of the juice having a brix of 12 0. So far SSV 84 is the only one variety has been released through All India Coordinated Sorghum Improvement Project by the National Research Centre for Sorghum at Hyderabad.

The important sweet sorghum varieties released at international level are Rio, Dale, Brandes, Theis, Roma, Vani, Ramada and Keller. BJ 248, RSSV 9, NSSV 208, NSSV 255 and RSSV 56 are the sweet sorghum cultures identified by the All India Coordinated sorghum improvement project at National level. Hybrid Madhura developed by Nimkar Agricultural Research Institute, Phaltan, Maharashtra is a popular hybrid in Sweet Sorghum. The TNAU has developed a Sweet Sorghum VMS 98003 with a cane yield of 45.7 t/ha and ethanol yield of 3.6 kl/ha as a promising sweet sorghum variety for Tamil Nadu and is being tested under Adaptive Research Trial and will be released soon. Most of these varieties mature in 100-110 days.

CONCLUSIONS

- Sweet-sorghum appears to be a promising viable multi-functional crop for massive production of Bioethanol & Power, worldwide.
- S.S. biorefinieries have the capacity to overcome the major challenging problems existing now in the India:
  - Very high production cost based on the use of expensive food-crops (sugarcane-corn-sugar beets).
  - Low production from cereals, integrated processing not yet adopted.
  - Modest energy Ratio (En. Outputs/ En. Inputs ≤ 2)
- The anticipated production cost of bioethanol from S.S. is ~ 250 €/m3.
- Its C4 photosynthetic system and rapid dry matter accumulation is an excellent bioenergy crop. Therefore, sorghum is expected to gain importance in the coming years in bioenergy farming. Sweet sorghum can be used as a substitute for sugarcane for syrup making.
- Sensitivity analysis showed that higher the stripped stalk yield and syrup recovery, lower would be the syrup cost.
- Comparison of sugarcane with sweet sorghum revealed that sweet sorghum is more economical to grow than sugarcane.

Future Prospective :-

- Demand for renewable energy sources and biofuel which would minimize pollution are expected to rise rapidly in coming years.
- It is need to provide consultancy services on commercialization of sweet sorghum for bio-ethanol production.
- Efforts are on for development of sweet sorghums hybrids and varieties with high juice yield with high sugar content.
- Need to aware the farmers about commercial cultivation and valuable uses of sweet sorghum.
- Sweet sorghum will be most important alternative crop for sugarcane in dry land area.

- Sweet sorghum can overcome against the climate change issue and pollution, hence need to increases area under sweet sorghum and establish bio refineries at village level.
- Make a biofuel policy for sweet sorghum based bioethanol production.

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