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Sweet Sorghum Utilization for Dual-Purpose: Feed-Fodder and Fuel Production (A review)

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ABSTRACT

Sweet sorghum (*Sorghum bicolor* L. Moench) is a versatile crop with a growing reputation for its multifaceted applications in the agriculture and energy sectors. The potential of sweet sorghum as a dual-purpose crop for both feed fodder and fuel production, shedding light on its economic and environmental advantages. In recent years, the livestock industry has recognized sweet sorghum's nutritional value as feed fodder, owing to its high fibre, sugar, and protein content. Sweet sorghum's resilience to adverse weather conditions and its ability to thrive in diverse agroecological zones makes it an attractive choice for livestock farmers seeking sustainable and cost-effective feed alternatives. Beyond its role in livestock nutrition, sweet sorghum presents a compelling case as a feedstock for biofuel and bioenergy production. The plant's high sugar content, coupled with its relatively low input requirements, positions it as a promising source for bioethanol and biogas production. Its potential to sequester carbon and reduce greenhouse gas emissions further aligns sweet sorghum with sustainability goals in the bioenergy sector. Additionally, the potential environmental benefits, such as reduced greenhouse gas emissions and improved soil health, are discussed. This study underscores the importance of further research, policy support, and investment in sweet sorghum to unlock its full potential in dual-purpose agriculture and renewable energy production.

Key words: *Cultivation, Energy production, Feed fodder, Sweet sorghum and Utilization*

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. Sweet sorghums have also been widely used for the production of forage and silage for animal feed.The oil crisis noticed so that's why interest in the commercial production of sweet sorghum for biological transformation into ethanol for use as fuel or fuel additive. Sweet sorghum, similar to grain sorghum except for its juice-rich sweet stalk, is being grown in the USA (for syrup) Africa (for fodder), and India (feed and fodder) for many centuries and is considered to be a potential bio-ethanol feedstock, expected tomeet food, feed, fodder, fuel and fiber demands. Some sweet sorghum lines attain juice yields of 78 % of totalplant biomass, containing 15–23 % soluble fermentable sugar (Srinivasarao *et al.*, 2010). Energy

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sorghum is specifically bred for high lignocellulosic biomass that can be converted to biofuels, whereas sweet sorghum, also known as sweet stalk sorghum, refers specifically to genotypes that accumulate soluble sugars in the stalk (Codesido *et al.,* 2013). Sweet sorghum may grow up to twenty feet tall and produce significantly higher biomass yields compared to grain sorghum. Stems of sweet sorghum are thicker and fleshier than the grain varieties, though the seed yield is relatively low (Whitfield *et al.,* 2012). It is often stated that sweet sorghum cultivars do not produce grain yield or the grain yield is very less *vis a vis* that of grain sorghum. Studies at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) showed that sweet sorghum hybrids had higher stem sugar yield (11 %) and higher grain yield (5 %) compared to grain sorghum types, while sweet sorghum varieties had 54 % higher sugar yield and 9 % lower grain yield compared to non-sweet stalk varieties in the rainy season. There is a little trade-off between grain and stalk sugar yields in the sweet sorghum hybrids in the rainy season while the trade-off is less in varieties in the postrainy season (Srinivasarao *et al.,* 2010; Kumar *et al.,* 2009). Biofuels are a sustainable and renewable source of energy derived from organic matter in the form of biomass. Biofuels can be derived from the plant as well as animal biomass. Studies showed that plants grown for biofuel purposes have the potential to reduce the net greenhouse gas emissions. Schmer, (2014) reported that usage of corn and switch grass as a source of biofuels reduced greenhouse gas emissions by -29 to -396 g of CO_2 equivalent per megajoule of ethanol per year. Currently, about 2.5% of the world's transportation fuels are produced from crop plants including sorghum, maize, sugarcane, and vegetable oils. Sweet sorghum accessions from Chad were found to be of the caudatum and bicolor races, with most having loose panicles with red seeds, according to the current study. In sweet sorghum brix levels were found to range from 5.5 to 16.67 percent with these varieties "Balnda" and "Chian Woua," were identified as having a high brix value of 16.67 percent and could be used as sugar sources to improve grain sorghum in Chad. The potential yields and theoretical values for sugar and ethanol ranged from 0.45 to 5.3 Mg ha^{-1} and 279.5 to 3101.2 L ha^{-1} respectively (Naoura *et al.,* 2020).

Life cycle and growth conditions

Sweet sorghum is an annual plant with a short life cycle of about 4 months. It allows two crops per year though the optimal planting date varies with the place of cultivation and the variety. It is a warm-season crop with the highest productivity in the rainy and summer seasons. Sweet sorghum is mainly adapted to arid and semi-arid regions, with a temperature range of 12-37°C, the optimum range being 32-34 °C. The yield of sweet sorghum is directly affected by the planting time. In the semi-arid tropical climate, the ideal time for planting sweet sorghum is early June to early July (Rao *et al.,* 2013). Loam and sandy loam soils with soil temperature above 18°C and pH around 5.8 are considered best for the optimum growth and maximum stem juice yield. Although increased seeding rate compromises the size of individual plants and total yields, it has a positive impact on the total biomass and sugar yields. Tillage and use of fertilizers can also significantly affect the total yields. Pittelkow *et al.,* (2015) evaluated several environmental and agronomic factors on no-till yields. Their results showed that under water limiting conditions, the no-till system increases overall yield as compared to conventional tillage systems in arid regions. It has also been reported that sweet sorghum requires approx 36% of nitrogen fertilizer that is needed for similar ethanol yields from corn. However, the use of a moderate amount of nitrogen fertilizers enhances sweet sorghum growth rate and ethanol yields. Although moisture availability is critical for plant growth, sweet sorghum is relatively drought-tolerant and can be adapted to grow on marginal lands with low water availability (Somegowda *et al.,* 2021). The well-developed root structure that can extend up to 2 m below ground aids to obtain moisture from the soil. Under adverse conditions or in the absence of sufficient moisture, sweet sorghum plants become dormant but can resume growth as soon as favorable conditions are available, whereas excessive moisture usually results in the reduction of overall biomass as well as quality and yield of stalk juice (Zhang *et al.,* 2016). The life cycle of sorghum has been divided into three distinct growth phases with ten morphologically distinguishable growth stages. The first phase involves germination to panicle initiation, the second phase starts with panicle initiation and ends with the anthesis, and the third phase starts from anthesis until maturity. Morphologically distinguishable growth stages include emergence, 3-leaf stage, 5-leaf stage, panicle initiation, flag leaf stage, booting, half bloom, soft dough, hard dough, and physiological maturity. Duration from emergence to flowering in tropical sweet sorghum varieties usually ranges from about 55 to 70 days; however, this phase is quite variable in different varieties. Especially, in the varieties adapted to temperate climate zones, this phase can be further extended by 20-30 days beyond what is reported for tropical varieties. Flowering is directly influenced by photoperiod through sensitivity to photoperiod varies among different varieties of sweet sorghum (Rao *et al.,* 2015). Due to variation in photoperiod sensitivity and temperature, the time of maturity varies in different varieties and hybrids and usually ranges from 90 to 150 days. Accumulation of soluble sugars in sweet sorghum stems are reported to surge after the internode elongation stops at the time of anthesis. Therefore, sweet sorghum stems are usually harvested about 30 days after anthesis. However, the stage of maximum sugar accumulation varies in different varieties with some genotypes mainly accumulating sugars between dough stage and physiological maturity, whereas others accumulate sugars up to 15 days post-physiological maturity. Sweet sorghum bioethanol production and suggested 100-110 days after planting as the appropriate time for harvesting sweet sorghum canes (Kumar *et al.,* 2013).

Use of sweet sorghum feed and fodder production

Traditionally sorghum for forage is grown under both rainfed and irrigated conditions. It is estimated that about 60–70 % of forage demand in the rainy season is met from sorghum. In the majority of areas of sorghum cultivation in India sweet sorghum is cultivated in small pockets across different regions since time immemorial. For example the sweet sorghum variety ''Amrutha'' is grown in the villages around Rahuri, Ahmednagar district of Maharashtra. Similarly farmers in the Nandyal region of Andhra Pradesh where magi sorghum cultivation is predominant local sweet stalked sorghum landraces were cultivated in large tracks a few decades earlier until sorghum area declined due to competition from cotton and corn (Munirathnam *et al.,* 2013). Sorghum is suitable for silage and haymaking and thus supplements the nutritious supply in the lean season. However, there is a lot of demand for high biomass-producing sorghums as a source of green fodder for dairy industries. Sweet sorghum is similar to other sorghum types having fast growth, wider adaptability and high biomass-producing ability with sugar-rich stalks (Rao *et al.*, 2013; Mishra *et al.*, 2015). Sweet sorghum cultivars grown during the rainy season produce higher biomass as compared to grain and forage sorghums (Channappagoudar *et al.* 2007). Because of its high fodder yielding ability coupled with sweet and juicy stalks, it is more often used as a fodder crop in India than for its intended use as a sugar or bioenergy

Table 1. Comparative performance of sweet sorghum, sugarcane and maize

Parameter	Sweet sorghum	Sugarcane	Maize
Crop duration	4 months	12 months	4 months
Water required	4000 m^3	36000 m^3	8000 m^3
Grain yield (t/ha)	2.0	N.A.	3.5
Ethanol from grain (liters/ha)	760	N.A.	1400
Green stalk/cane yield (t/ha)	35	75	45
Ethanol from stalk (liters/ha)	1400	5600	0
Stover (t/ha)	4	13.3	8
Ethanol from residue (liters/ha)	1000	3325	1816
Total ethanol production (liters/ha)	3160	8925	3216
Cost of cultivation (US$/ha)	238.00	995.00	287.00
Ethanol cost per 1000 liters (US$/ha) (ICRISAT, Hyderabad)	75.30	111.50	89.20

crop. It contains high water-soluble carbohydrates, which may improve the ensiling quality of forage by accelerating lactic acid production (Nimbkar *et al.*, 2010). Because of its inefficient starch digestion and low energy use by broiler hens, sorghum is not as popular as maize as a feed. Sorghum replaced corn in the diets of lambs affected with *Haemonchus contortus*, improving infection resistance and meat colour (Zhong *et al.*, 2016). The main attribute to modify through breeding to multiply the market value of sorghum as feed is the reduction in concentrations of kafirin and "nontannin" phenolic chemicals (Selle *et al.*, 2017).

Use of sweet sorghum in ethanol production

Sweet sorghum is becoming a popular biofuel crop, making it a one-of-a-kind crop that may be used for food, feed, fodder, fuel, and fibre. Sorghum stems are high in soluble sugars (glucose, sucrose, and fructose) and insoluble carbohydrates (cellulose and hemicellulose), making them an excellent source of energy for biofuels, bioenergy, biogas, and bioethanol production. Similar to sugarcane, sweet sorghum with sugary liquid in the stem is used for ethanol and bagasse. Brix units, which indicate the percent soluble sugars in sweet sorghum stalks, are used to assess sugar content. 1 g of sugar per 100 g of juice is equal to one degree Brix. Brix content varies by variety and is also influenced by environmental factors like internode location, season, and harvesting stage (Quazi *et al.*, 2012). Sweet sorghum may store up to 78 percent of its total biomass as juice, while its Brix level is believed to be between 14 and 23 percent (Vinutha *et al.*, 2014). Sucrose accounts for 75% of the sugars in sweet sorghum stalks, with a small proportion of fructose and glucose (2.6%). Although annual ethanol generation from sweet sorghum is dependent on a variety of parameters such as genetic background, season, soil quality, and other environmental conditions, sweet sorghum crops are projected to yield up to 8000 l/ ha/year of ethanol (Rutto *et al.*, 2013). The stem's sweet juice is fermented to make ethanol, which is then used, as the residue left after crushing the cane, has a variety of uses, including in wood composites (Mathur *et al., 2017*; Wright *et al.*, 2017). Furthermore, through lignocellulosic processing, sorghum can be used to produce second-generation biofuels. Based on the lignocellulosic content of the plant biomass, low-lignin sorghums, primarily the brown midrib, are used as second-generation biofuels. Maintenance and recovery of internode elongation during and after water deficit conditions contribute to stem biomass output in drought-prone regions. Internode soluble sugar and lignocellulose concentrations in sorghum responded to drought in the opposite direction. These biochemical traits should be examined in biomass sorghum phenotyping and breeding because they are critical in defining biomass quality for end-users (Mathur *et al., 2017*). ICRISAT-ICAR (NAIP) starteda sweet sorghum value chain project and shared the sweet sorghum ethanol production technology with Rusni Distilleries. Sweet sorghum is a season-bound crop that can produce stalks for crushing only for a limited period (3-4 months) during the year. The stalks have to be crushed within a short period after harvest to avoid loss of juice due to drying up of stalks. Hence harvesting and crushing of stalk to process into ethanol haveto go hand in hand for an effective source-sink mechanism.

Conclusion

Sweet sorghum can play a significant role in ad-

Table 2. Cultivars of sweet sorghum

Crop	Varieties
Sorghum	SSV 84 (High Brix: 18 %), CSV 19SS (RSSV 9), CSH 22 SS (NSSH 104), CSV 24SS (SPSSV 6), CSH 13, IS 27206, ICSSH 28, CSH 24MF
Sweet sorghum varieties used for industrial purpose	
Madhucon sugar and power industries, Telangana	ICSV 25308, ICSV 25306, ICSSH 28, Phule Vasundhra and ICSV 12012
Shree Ganesh Khand Udyog Sahakari Mandli Limited, Gujarat	ICSSH 28, PhuleVasundhra, ICSV 25306, CSH 22 SS
Kisan Sahkari Chini Mills Ltd, Uttar Pradesh	PhuleVasundharaand ICSV 25306
Salem Co-operative Sugar Mills Limited, Tamil Nadu	ICSV 25308, ICSV 12012, ICSSH 28, CSH 22 SS
Core green sugars, Yadagiri, Karnataka	ICSSH 28, ICSV 12012, ICSV 25308 and ICSV 25306

dressing the growing need for renewable energy to displace fossilfuel-based energy resources. Secondly, instead of competing with food crops for arable land, it will rather help in the conservation of marginal lands by converting them to agricultural land. However, Sorghum exhibits huge genetic diversity and resources towards region-specific climatic conditions or changing climatic conditions, andthe number of fermentable sugars and grain yields vary considerably in different sweet sorghum cultivars. Therefore, screening and selection of appropriate varieties for each region are critical for optimum results. Furthermore, there are several unexplored areas of research, which can have a huge impact on sorghum cultivation. Efforts to develop multipurpose sweet sorghum cultivars with high sugar as well as grain yields have been initiated using both classical and biotechnological approaches to make it economically more attractive. In-depth sequencing of the whole genome of a sweet sorghum cultivar is highly awaited to assist in gene discovery and to initiate genome-wide association studies.

Conflict to Interest- None

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