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Sweet Sorghum for Biofuel Production in Sub-Tropical India

A. V. Umakanth [a], Seema Paroha [b], Ashok Kumar [b], Ananthalakshmi Ranganathan [b*] and D. Swain [b]

[a] ICAR-Indian Institute of Millets Research, Rajendranagar, Hyderabad, Telangana, India.
[b] National Sugar Institute, Kanpur, Uttar Pradesh, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Short Communication

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ABSTRACT

Sweet sorghum (*Sorghum bicolo*r L. Moench), a sugar crop with wider adaptation and high potential for bioenergy and ethanol production is expected to meet food, feed, fodder, fuel and fibre demands. It produces high biomass (50-80 t/ha) and alcohol (1500-2800 l/ha) and multiple income opportunities exist with this crop. Some sweet sorghum lines attain juice yields of about 78% of total plant biomass, containing from 15 to 23% soluble fermentable sugars which are composed mainly of sucrose (70–80%), fructose and glucose. Due to its short growing period (3-4 months), it 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. The major advantage with this crop is that no CAPEX is required when used in a sugar mill system as same machinery can be used for crushing and fermentation. It will help farmers to fetch additional income and provide an opportunity for better utilization of industrial facilities during sugarcane off-season. Promising sweet sorghum genotypes developed by ICAR-IIMR, Hyderabad are being tested for their suitability to sub-tropical conditions in February and June-July plantings at the NSI, Kanpur to establish a sustainable cropping system. Five sweet sorghum genotypes were tested during kharif 2021 for sweet sorghum productivity traits. The fresh stalk yield ranged from 45-60 t/ha and based

**Corresponding author: E-mail: ananthuknocks@gmail.com;*

on TRS, maximum alcohol percentage in wash was observed in three varieties, i.e., Phule Vasundhara, CSH 22SS and SSV 74 which was 8.4%, 8.38% and 7.8% respectively. Maximum ethanol yield of 53.05 L/T was recorded in CSH 22 SS followed by SSV 74 (50.93 L/T). Phule Vasundhara, with a highest stalk yield of 60 t/ha recorded highest ethanol content of 2837 L/ha followed by CSH 22SS (2780 L/ha) and SSV 74 (2411 L/ha).

Keywords: Sweet sorghum; sweet sorghum juice; alcoholic fermentation; ethanol; economics.

1. INTRODUCTION

India has achieved more than 11.7% blending of petrol with ethanol recently and the next target is 20% blending by 2025. 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. There is every need for exploiting alternate feedstocks for biofuel production. Sweet sorghum (*Sorghum bicolor* L. Moench), a widely adapted sugar crop with high potential for bioenergy and ethanol production and which produces higher biomass yield with less inputs is listed as a candidate crop for biofuel production in our National Policy on Biofuels. Sweet sorghum is an attractive crop for biofuel production and in the era of climate change, it is good renewable feedstock suitable for cultivation under arid regions. This crop can be considered as a potential crop for ethanol production in northern India as it is a warm-season crop that needs high temperatures and short days and can also fit into the sugarcane based cropping systems. It tolerates drought and high-temperature stress better than many other crops.

"Nowadays this crop is gaining attention as a potential alternative feedstock for energy and industry, because of its high biomass yield and particularly, fermentable sugars. Sweet sorghum has rich soluble sugar in the stalk which can be converted into number products such as ethanol, syrup, fodder, jaggery and paper" [1]. "Sweet sorghum is similar to grain sorghum except for its juice-rich sweet stalk and is considered to be a potential bioethanol feedstock which is expected to meet food, feed, fodder, fuel and fibre demands (5 Fs). Some sweet sorghum lines attain juice yields of about 78% of total plant biomass, containing from 15 to 23% soluble fermentable sugar. The sugar is composed mainly of sucrose (70–80%), fructose and glucose. It also contains bioactive compounds, and therefore can be applied to produce various desired chemicals" [2]. It is a C_4 crop, with a fibrous root system that branches profusely. The roots can be extended to a distance of up to 1 m and a depth of 1.8 m. Its wider adaptation and tolerance to various abiotic stresses like drought, salinity [3], water logging etc [4,5] along with higher water, nitrogen and radiation-use efficiencies make it a preferred biofuel feedstock over other crops like corn, sugarcane and sugar beet. "Around 50-60 % of sweet sorghum bagasse can be obtained after the extraction of juice can also be used as a potential feedstock for bioethanol production" [6]. "But the removal of inhibitory compounds like lignocellulose from bagasse increases the price of second generation bioethanol production" [7].

It has a low water requirement of 8000 m^3/ha (over two crops annually) that is only 25 percent of that required for sugarcane and about half the quantity of water required by sugar beet. It is seed propagated unlike sugarcane which is propagated through setts. Given that water availability is poised to become major constraint to agricultural production in coming years, high input requiring cultivation of sugarcane becomes difficult and sweet sorghum offers a sustainable choice as it requires minimal water and purchased inputs.

"Sweet sorghum could be cultivated and supplied during the lean period of sugarcane crushing (Fig 1) thus extending the crushing period before and after sugarcane crushing and stretch the sugar mill operation" [8].

2. FIRST GENERATION BIOETHANOL FROM SWEET SORGHUM

Sweet sorghum 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. It can be grown across the length and breadth of the country in

kharif (rain-fed) and summer seasons (under irrigation). It produces high biomass (50-80 t/ha) and alcohol (1500-2800 l/ha) and multiple income opportunities exist with this crop. Availability of cultivars with variable maturities ensure for dedicated supply chain. The major advantage with this crop is that no CAPEX is required when used in a sugar mill system as same machinery can be used for crushing and fermentation.

3. AGRICULTURAL AND INDUSTRIAL YIELDS FROM SWEET SORGHUM

The sweet sorghum productivity traits are listed in Table 1.

4. RELEASED AND NOTIFIED SWEET SORGHUM CULTIVARS AVAILABLE FOR COMMERCIAL CULTIVATION

The available sweet sorghum varieties and hybrids are SSV 84, CSV 19SS, CSV 24SS, CSV 49SS, CSV52SS, CSH 22SS, PhuleVasundhara and RVICSSH 28.

5. PILOT SCALE TRIALS WITH SUGAR INDUSTRIES

In the last two decades, ICAR-IIMR and ICRISAT along with other partners had organized pilot-studies (Table 2) in collaboration with sugar industries like Renuka Sugars, Rusni distilleries, Tata Chemicals Limited, Madhucon Sugars, Eid Parry India Pvt Ltd, Sagar Sugars, Nav Bharat Ventures,Shree Ganesh Khandsari Sahkari Udyog Mandali Ltd etc. The yields realized in various pilot studies include ethanol recovery (9-11% of juice), unit ethanol yield (40-50 L per one tonne of stalks crushed), and total ethanol yields (1500-2500 L/ha /one crop cycle, bagasse yield (5-7 t/ha). Power from bagasse cogeneration process can be produced to the extent of 3.5 MW/ha of crop. Though many big mill tests were conducted, sweet sorghum couldn`t take off in earlier years due to several reasons like:

- Primarily, the ethanol procurement price (EPP)received was not sufficient to make the industry viable
- Feedstock supply was not continuous –so limited period of operations of industry
- Non-compliance for ethanol blending targets and hence low market demand for ethanol

6. COLLABORATIVE TRIALS OF ICAR-INDIAN INSTITUTE OF MILLETS RESEARCH (ICAR-IIMR), HYDERABAD WITH NATIONAL SUGAR INSTITUTE (NSI), KANPUR

In order to promote bioethanol production from alternate feedstocks so as to cope up with the mandatory blending of ethanol in petrol, NSI, Kanpur and ICAR-IIMR, Hyderabad joined hands for working together to promote Sweet Sorghum for bioethanol production over a five-year period (2020-2025). As per the understanding, promising sweet sorghum genotypes developed

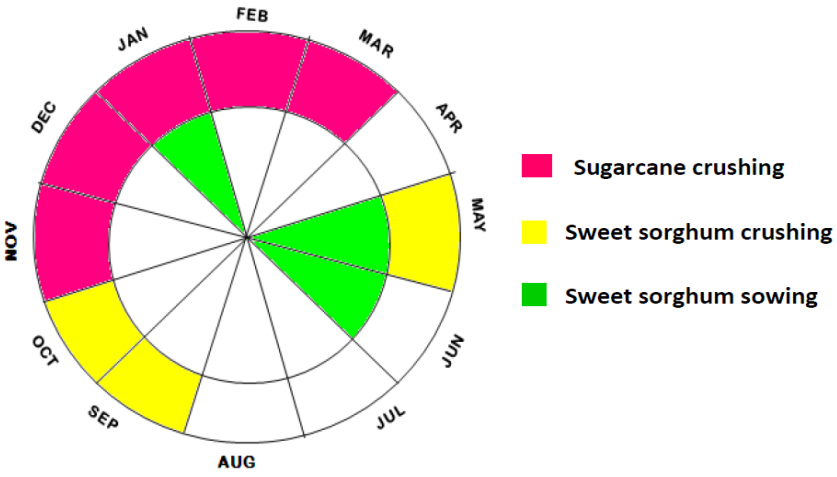

Fig. 1. Scheduling the sweet sorghum feedstock availability during lean period of sugarcane crushing

Table 1. Sweet sorghum productivity traits

S No	Trait	Range
1	Fresh stalk yields	40-50 t/ha (Kharif& summer)
2	Juice brix	16-19% (Kharif and summer)
3	Reducing sugars (RS)	2-4%
4	Sucrose (%)	8-11%
5	Juice extraction	40-60%; 70-90% in big mills
6	Juice yield/ha	16-18 KL
7	Bagasse (residue) Yield	5-7 t /ha (dry wt basis)
8	Ethanol recovery	6-9 % of juice
9	Ethanol Yield	1500-2800 Lit/ha/season
10	Power from residue (bagasse)	2.5-3.0 MW /ha of crop

Table 2. Mean Performance of five promising varieties of Sweet sorghum during Kharif 2021

S No	Variety/ Hybrid	Millable cane yield (t/ha)	Juice (L)	pH	TRS %	Initial Gravity	Final Gravity	Alco (%)	Ethanol yield L/T	Ethanol yield L/ha
1.	SSV84	46.8	60	5.9	13.67	1.745	1.215	7.14	43.55	2040
2.	SSV74	47.3	60	5.9	13.99	1.775	1.13	7.8	50.93	2411
3.	CSH 22 SS	52.4	60	5.9	13.92	1.725	1.075	8.38	53.05	2780
4.	ICSSH 28	53.59	60	5.8	12.48	1.71	0.65	6.39	40.06	2147
5.	Phule Vasundhara	60	60	5.8	14.62	1.785	0.95	8.4	47.29	2837

by ICAR-IIMR, Hyderabad are being tested for their suitability to sub-tropical conditions in February and June-July plantings at the NSI to establish a sustainable cropping system. Initially the trial started with testing of nine sweet sorghum genotypes in different seasons at NSI and based on the performance in different seasons, five best entries were shortlisted and further studies up to ethanol production were taken up. The leads obtained in Kharif 2021 trials at NSI, Kanpur with sweet sorghum as a sole crop are furnished below (Table 2).

TRS of Phule Vasundhara was highest i.e 14.62 % followed by SSV 74 (13.99%) and CSH22SS (13.92%). Similarly based on TRS, maximum alcohol percentage in wash was observed in three varieties, i.e., Phule Vasundhara, CSH22SS and SSV74 which was 8.4%, 8.38% and 7.8% respectively. Maximum ethanol yield of 53.05 L/T was recorded in CSH 22 SS followed by SSV 74 (50.93 L/T). Phule Vasundhara, with a highest stalk yield of 60 t/ha performed better for juice % extraction while the brix was low as compared to other selected varieties. ICSSH 28 was the second promising hybrid with a stalk yield of 53.6 t/ha while CSH 22SS was third promising with a stalk yield 52.4 t/ha. The ethanol production from sweet sorghum juice was carried out in the same way as that of molasses based ethanol production. Phule Vasundhara yielded highest ethanol content of 2837 L/ha followed by CSH22SS (2780L/ha) and SSV 74 (2411 L/ha). In the preceding year studies too, CSH 22SS was identified as the best performer for sweet sorghum productivity traits

7. ECONOMICS OF ETHANOL PRODUCTION FROM SWEET SORGHUM

7.1 Feedstock

Sweet Sorghum (Stem) - Sugary feed stock
Varieties analysed : ICSSH28, CHS22SS, SSV74, SSV84, Phule Vasundhara
Sugar content is 13 to 18 %
Yield (stem) in tons per hectare to 45 to 50
Yield (seed) in tons per hectare 2.5 to 3.5

7.2 Farmer

Price of seed in Rs. per ton 29900/-
Price of stem in Rs. per ton 2000/-
Revenue earning in Rs per hectare 187400/-
Crop duration 100 to 110 days
Cost of production in Rs. Per hectare 35000/-
Net income per month in Rs. per hectare 43543/-

7.3 Industry

Can be crushed in the existing sugar mill increasing duration of season
Cost of raw material in Rs/ton. 2000/-
Ethanol Yield in liters/ton 50
Cost of production in Rs/liter62.53
Revenue in Rs/liter 76.06
Earning in Rs/liter 13.52
Fuel availability is from the raw material itself with additional power gen.

7.4 Government

No Extra Govt. Revenue involved, so no burden on the Govt. Exchequer

7.5 Economy

The net profit of the plant as a whole varies with varieties. It remains positive till the price of raw material reaches Rs. 325 per quintal in case of ICSSH28 (Fig-2), Rs 265 per quintal for CSH22SS (Fig-3), Rs 285 per quintal for SSV74 (Fig-4), Rs 265 per quintal for SSV 84 (Fig-5) & Rs 275 per quintal for Phule Vasundhara (Fig-6). The economy goes negative in case of Sweet Sorghum when the price exceeds the given price of individual varieties.

8. ENVIRONMENTAL ADVANTAGE OF SWEET SORGHUM

As discussed earlier, water required for cultivation of sweet sorghum is low as compared to that of other ethanol producing crops like sugarcane, Rice, etc., It is estimated that sweet sorghum cultivation requires 1.79 ton of water per liter production of ethanol whereas for Rice it is estimated 5.56 ton/liter of alcohol and for maize it is estimated as 3.81 ton/liter of alcohol. As there is no need of burning trash sweet sorghum is not going to be hazardous to the environment especially to the air (Parali burning).

8.1 Intercropping Studies

Intercropping studies of sugarcane ratoon with spring sown sweet sorghum are underway at two different sugar mills in Uttar Pradesh. Preliminary data suggests that March sowing doesn`t

promote sucrose accumulation as was evident by more vegetative growth and absence of grain formation. Since Sorghum is a short day plant, it appears that the critical (night) temperatures required for the plants to enter into reproductive stage (Flowering) were not available with March sowing. The corresponding longer day lengths and higher temperatures during crop growth stages promoted more of vegetative growth and increased the duration of the crop. In sweet sorghum, sucrose accumulation starts from flowering and reaches its maximum at the time of physiological maturity of the grains which is at the most 120-130 days. There is a need to test early January sowing of sweet sorghum with sugarcane ratoon which might allow the crop to enter into reproductive stage (flowering) at the right time thus favouring sucrose accumulation.

8.2 Constraints in Promotion of Sweet Sorghum for Biofuel Production

- Though the crop has been listed in the National Policy on Biofuels, there is no clear cut road map for commercialization of sweet sorghum in the absence of policy support for its industrial scale plantation
- Lack of awareness among the sugar industries of the country about the complementarity of sweet sorghum with sugarcane for ethanol production
- Lack of mechanization in sweet sorghum cultivation especially harvesting which is highly labour intensive
- Biotic stresses especially shoot pests and abiotic stresses which include cold.
- Storage losses

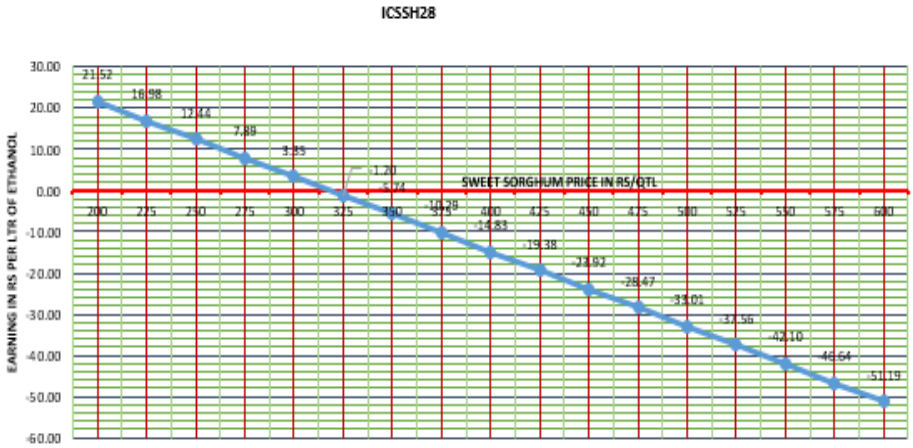

Fig. 2. Economics of ICSSH 28 Sweet sorghum variety for Ethanol Production

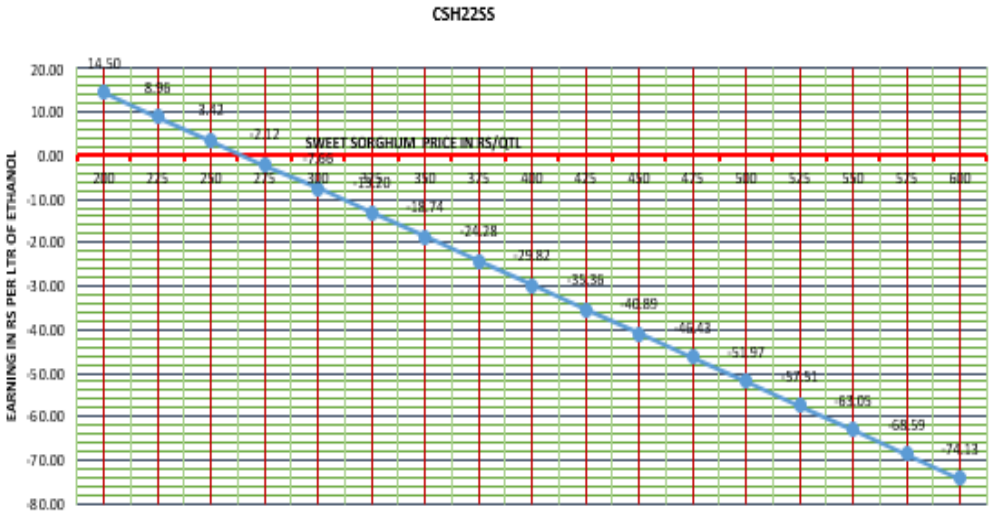

Fig. 3. Economics of CSH22SS Sweet sorghum variety for Ethanol Production

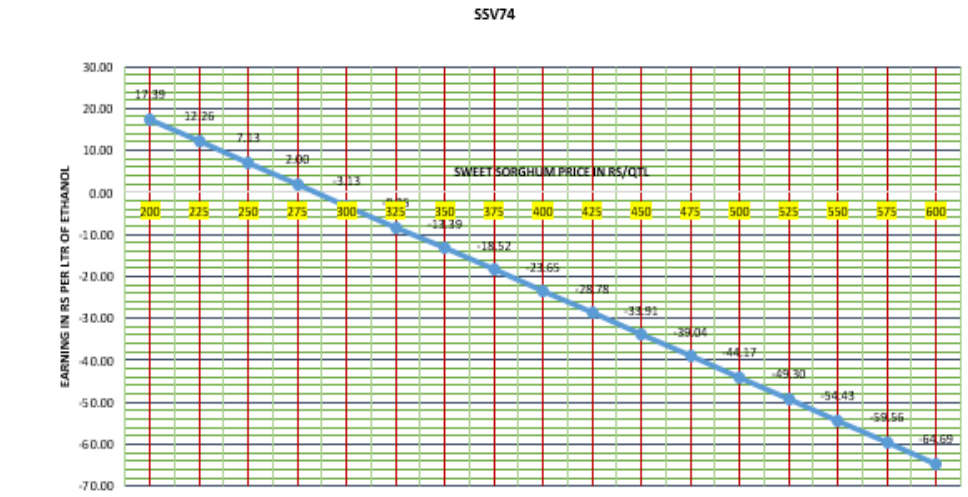

Fig. 4. Economics of SSV74 Sweet sorghum variety for ethanol production

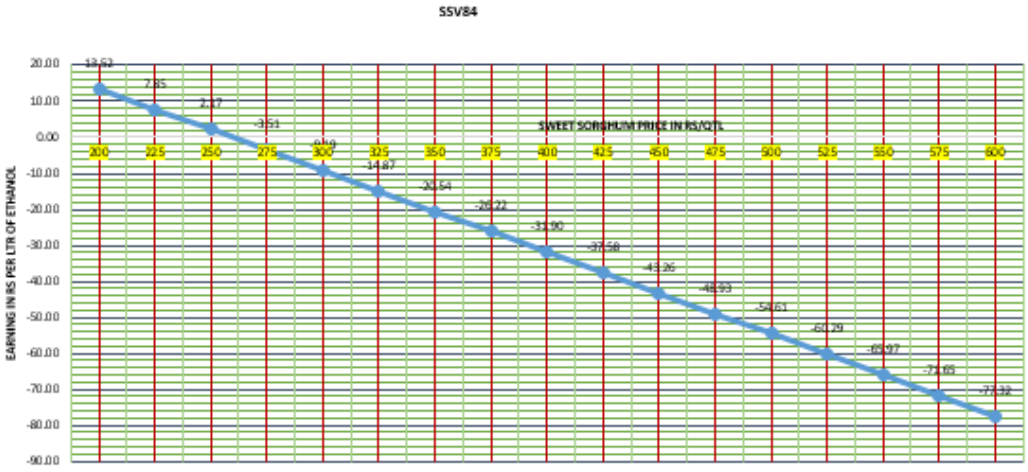

Fig. 5. Economics of SSV 84 sweet sorghum variety for ethanol production

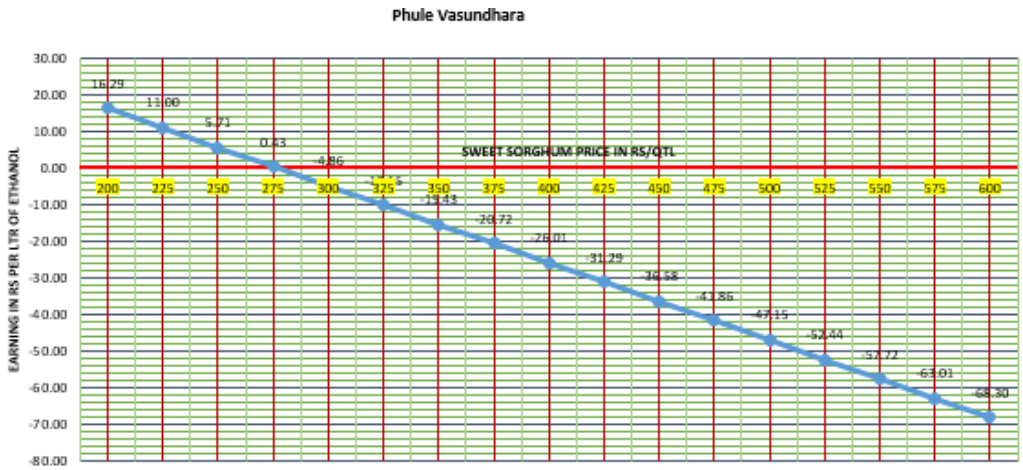

Fig. 6. Economics of phule vasundhara sweet sorghum variety for ethanol production

8.3 Way Forward for Sweet Sorghum Commercialization

More number of trials (Intercrop and Sole crop) under different sowing dates need to be conducted at several sugar mill locations in U.P during Kharif and spring seasons to identify the best sowing window for sub-tropical regions. 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. The apex bodies of sugar industry especially the Indian Sugar Mills Association, U.P Sugar Mills Association and National Federation of Cooperative Sugar Factories need to be sensitized about the complementarity of sweet sorghum with sugarcane molasses for production of ethanol and to meet the huge ethanol requirement of the country. The large-scale crop cultivation is recommended under contract farming with buy-back arrangement between growers and agro-industry or entrepreneurs' as similar to existing sugarcane industry. Stand alone distilleries can also be encouraged to install processing machinery designed to extract sweet sorghum juice and take up cultivation of sweet sorghum or enter into contract with FPOs, SHGs for sweet sorghum production.Owing to the current remunerative price for ethanol, 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 farmers while improving the environment and reducing the oil import bill for country.

9. CONCLUSION

The energy consumption will be increased to 60% by 2030 as predicted by experts and this enormous demand in the energy sector cannot be fulfilled by limited source of fossil-based fuels. Thus the world energy consumption mainly depends on the non- renewable fossil based fuels. Many researchers and industrialist are currently focusing on the bioethanol production using cost-effective substrates, as the employment of petro-chemically derived raw materials leads to environment-related problems. The usage of staple food crops such as jowar, maize, bajra for biofuel production have no doubt, that it will create a long-lasting impact on the food, fodder and nutritional security of human beings and livestock. Thus Sorghum is going to be a big boon for the developing countries like India with more energy intensive than other feedstock due to low grain and fodder yield and as a best alternative feedstock for biofuel production. A study reports that spent wash generated from sweet sorghum juice fermentation is containing high level of plant nutrients and that can be made available to the plants and that result in the better growth and development of the crops like Moong dal, Brown Chena [9]. Thus the effluent generated can also be utilised following the norms of pollution control board.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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