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Review Article

ETHANOL PRODUCTION POTENTIAL IN MILLETS

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Abstract: Recently in February 2023 the "Roadmap for Ethanol Blending in India 2020-25" laid out an annual plan to increase domestic ethanol production in line with target of the amended National Policy on Biofuels (2018) as well as with its Ethanol Blended Petrol (EBP) Programme to reach a blending of 20% of ethanol in petrol (E20) by 2025/26. In addition to this Government of India (GOI) has planned to introduce Ethanol operated vehicle till the end of August 2023. So, there is indeed a need of finding different ways of ethanol production. At the same time GOI is celebrating 2023 as International Millet Year by implicating different GOI, policies to promote millets. Moreover, after COVID-19 humanity is in search of gluten-free diet. So, in this context, millets a group of single seed plants particularly belonging to the *Poaceae* or *Gramineae* family emerged as best nutritious crops and an excellent bio-ethanol producers. Different studies in last decades specified that millets can be effectively utilized for ethanol production with limited supply of input in water scarcity areas. Studies reveal that few types of millet such as Sorghum (*Sweet Sorghum, Grain Sorghum, Fodder Sorghum*), Pearl millet, Finger millet, Proso millet, foxtail millet, Barnyard millet and Little millet and husk of millets have good potential to become a component crop for high ethanol production. In present study ethanol production capacity from different millet are reviewed. It can be concluded that there is need of more research and development in all millet groups along with capacity building for development of processing distilleries. This will ensure income as well as nutrition of farmers leading to sustainability.

Keywords: *Millets, Biofuel, Nutrition, Millet Husk*

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Introduction

Recently in February 2023 the "Roadmap for Ethanol Blending in India 2020-25" [1] laid out an annual plan to increase domestic ethanol production in line with target of the amended National Policy on Biofuels (2018) as well as with its Ethanol Blended Petrol (EBP) Programme to reach a blending of 20 per cent of ethanol in petrol (E20) by 2025/26. The Ministry of GOI highlighted that the blending of ethanol with petrol has increased to 10 per cent in 2021-22 which was just 1.53 per cent in 2013-14 through the back of efforts made by farmers and industry, aided by favorable government policies. It was also added that supply of ethanol to oil marketing companies (OMCs) increased to 408 cr litre in 2021-22 from 38 Cr litres in 2013-14 [1]. Moreover, due to the superior nutritional quality of millets, Millets are declared as a “Shree Annam” in India. These single seed grass family members can be grown with 1-2 irrigations. After COVID-19 humanity is in search of gluten free diet. Different studies in the last decades specified that millets can be effectively utilized for ethanol production with limited supply of input in water scarcity areas. Studies reveal that a few types of millet such as *Sweet Sorghum, Grain Sorghum, Fodder Sorghum*, Pearl Millet, Finger Millet, Proso Millet, Foxtail Millet, Barnyard Millet and Little Millet or their husk has good potential to become a component crop for high ethanol production. In present study ethanol production capacity from different millets are reviewed. It can be concluded that there is need of more research and development in all millets along with capacity building for development of processing distilleries. This will ensure potential for income as well as nutrition stability of farmers leading to sustainability. All three type of Millets (i.e. Positive, Negative & Neutral) are very water use efficient plants as compared to other crops. The cost of production of Millets is also very less as compared to other crops.

Material and Methods

For capacity building of millet farmers, Agricultural Development Trust’s, Krishi Vigyan Kendra (KVK), Baramati has been demonstrating millet plots on its instructional farm, since 2018. During the voyage of promoting millets KVK noticed that one should find new market opportunities for millet growers. Simultaneously, the occasion of International Millet Year 2023 and KVK is trying to find out new possible opportunities for millet growers. In this context KVK had searched for possibilities of Ethanol production from millets. It was found that bio-ethanol can be produced from different Plants such as Sugarcane, *Sweet sorghum*, Corn, Cassava, Wheat, feed stock, starch containing feed stock, Syngas fermentation [2,3]. So, to expand the boundaries of income from millet crops present investigation was undertaken to finding possibilities & scope of ethanol production from millets. In this quest various approaches of ethanol production from millets by numerous scientists are appraised to get absolute conclusion.

Results and Discussion

Ethanol production from millets can be possible by either evolving elite strains of millet crops through different advance breeding technologies/strategies that will have moderately superior traits for ethanol production or use of millet by-products such as husk, damaged grain etc., as an admirable substrate for fermentation through various microorganisms.

Strengthening ethanol production through genetic improvement of millets

Sorghum

Amongst positive millets, Sorghum crop exhibits tremendous variability. There are about thirty species of sorghum. *S. bicolor* is cultivated for grain and forage while *S. halepense* (Johnson grass) and *S. propinquum* are cultivated only as forage crop. Broadly sorghum can be classified into Grain Sorghum and Forage Sorghum. All types of sorghum are suitable for ethanol production in different ways but mostly *Sweet sorghum* is considered as most suitable for ethanol production as sugarcane and maize.

Table-1 Performance of ethanol producing traits in Sweet sorghum

Source	d.f.	B60	B50	BM	JE	RS	NRS	GCY
Replication	2	0.0684	0.0948	0.289	2.3977	0.004	0.394	0.0001
Genotypes	45	4.7466**	15.117**	26.5615**	286.253**	1.589**	24.063**	0.028**
Error	90	0.098	0.174	0.344	2.796	0.003	0.119	0.0008

For higher and quality ethanol production, there must be a strong association/correlation among ethanol producing traits and ethanol production. One study conducted by Shinde and Jadhav (2016) [4] indicates that Juice extracted from the stems of Sweet Sorghum [*Sorghum bicolor* (L.) Moench] can be used for syrup, jaggery and sugar production and can be fermented to produce ethanol. The use of ethanol extracted from sweet sorghum in automobiles holds great promise for reducing air pollution from CO_2 and SO_2. Thus, ethanol from sweet sorghum may be used as a non-conventional energy source. Further they estimated the magnitude of genetic variability in a selected base population of 46 varieties among important ethanol enhancing traits. They had observed [Table-1] a wide range of phenotypic variation for brix percentage (%) at 60 DAS, brix percentage (%) at physiological maturity, brix percentage (%) at 50 per cent flowering, reducing sugars (%) at physiological maturity, non-reducing sugars (%) at physiological maturity, juice extraction per cent at physiological maturity, green cane yield at physiological maturity on an average of five plants (kg) indicates the feasibility of effective selection for these traits for ethanol production. Corresponding results were also found by Reddy, *et al.*, (2007) [5], Pallavi, *et al.,* (2023) [6], Ratanavathi, *et al.,* (2004) [7] and Seetharama and Prasad Rao (1987) [20] in this Millet.

Further, high heritability estimates as per [Fig-1] specifies that all characters associated for ethanol production are highly heritable. Similar outcomes were observed for high heritability result for green stalk yield was obtained by [6] and [8] in this millet. The characters juice extraction percentage, reducing sugars, cane yield and grain yield showed high genetic advance as per cent of mean pointing out that selection for these traits would be effective for ethanol production. They also found that Genetic advance was moderate for non-reducing sugars indicating both additive and non-additive gene action. Hence, they suggested that hybridization followed by selection would be proficient for developing new genotypes which will have enhanced ethanol production capacity. High heritability coupled with high genetic advance were observed in juice extraction percentage, reducing sugars, cane yield and grain yield indicating selection for these traits would be effective and excellent verities can be developed with aim of high ethanol producing varieties in these traits [9]. Similar results were observed by Sankarapandian*, et al.,* (1996) [8] for dry green stalk yield per plant, [10] for grain yield; For grain yield and green cane yield by Pallavi, *et al.,* (2023) [6] One can predict that there is strong association among the ethanol producing characters and ethanol production [11], selection for such characters among the genotypes will ultimately results in to strengthening of ethanol production capabilities in millets like Sweet Sorghum.

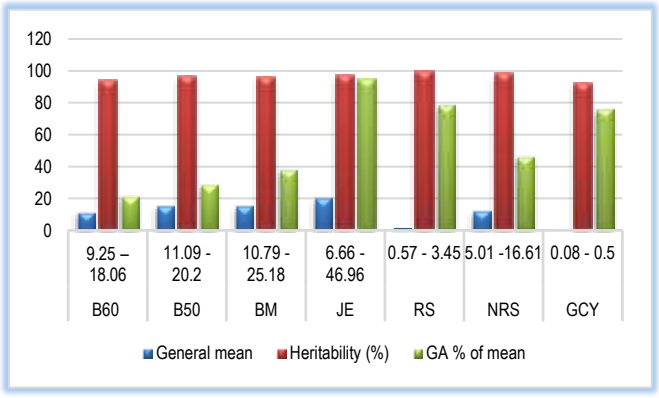

Fig-1 Study of association of ethanol producing traits in Sweet sorghum

Proso millet

In Proso millet (*Panicum miliaceum* L.) Devin and Dipak (2013) [12] investigated with the objective of determining the conversion efficiency of Proso millet to ethanol compared to corn in a bench-scale dry-grind procedure. They conducted the study on seven Proso millet cultivars and six advanced breeding lines containing waxy starch and fermented with Saccharomyces cerevisiae for ethanol production and compared with normal corn and "highly fermentable" corn. They found that amongst Proso millet cultivars under investigation highest fermentation efficiencies was of Huntsman (85.9 ± 0.6%), 172-2-9 (90.8 ± 0.2%), 172-2-13 (85.1 ± 2.5%), and 182-4-24 (84.7 ± 2.1). So, they also concluded that Waxy Proso millet cultivars were good fermenters than the non-waxy having normal starch. Proso millet distiller's dried grains with soluble (DDGS) contained more protein (26.6–33.4%) than the DDGS from corn (17.2–23.4%). This pointed out that Proso millet can be an outstanding ethanol producer millet crop more over much emphasized on development of "highly fermentable" lines.

Such type of research indicates that millets like sweet sorghum, Proso millet etc has tremendous capabilities to become a component crop for ethanol production but there must be more research for genetic improvement in all type of millets. In same way more research and study in all types of millet groups are needed.

Strengthening ethanol production through use of millets by product

Use of millet byproducts such as husk, damaged grain is proved as admirable substrate for fermentation through various microorganisms. All millets husk can be used as substrate for ethanol production by employing suitable bacteria. Some of the studies are discussed here.

Pearl Millet

On same aspect Wu *et.al.* (2006) [13] analyzed the ethanol production from Pearl Millet Using Saccharomyces cerevisiae. They observed that ethanol fermentation resulted from shaking-flask tests showed that ethanol yields from pearl millet mashes containing 20, 25, 30, and 35% dry mass were ≈9, 11, 13–14, and 16–17% (v/v), respectively. Further they found that their corresponding fermentation efficiencies were between 90.0 and 95.6%. There is no significant difference between fermentation efficiencies of mashes made from different pearl millet samples at the same dry mass content at $P < 0.05$. As, weight loss from CO_2 evolution during fermentation is a useful parameter in monitoring fermentation rate and predicting ethanol yield, hence they concluded that as pearl millets fermentation efficiency is equivalent to that of corn, It could be used as an alternative feedstock for fuel ethanol production. Results were also coinciding with results of Andrews, *et.al* [14].

Finger millet

Finger millet biomass straw was analyzed for ethanol production possibilities by Teshager, *et al.,* (2015) [15]. The results revealed that trough hydrolysis of 10 % biomass concentration at two per cent sulfuric acid at 35°C reaction temperature within four days of hydrolysis time, a maximum sugar content of 79.04 and 82.01 %w/w was achieved. They also found that maximum of 7.28 %w/v of ethanol content was obtained using Pycnometer measurement. So, they concluded that bioethanol achieved from Finger millet biomass straw at optimized conditions were highly promising and it can be used for bioethanol production.

Positive Millet husks and Negative Millet

Rice and Wheat are referred as Negative millets. Ethanol production is also possible from these crops. Even though positive millets or byproducts of are proved as excellent source of ethanol production than negative millets. Gwandu, *et.al.* (2021) [16] conducted a study on the bioethanol production from Rice and millet husks. Through Proximate, elemental and thermo gravimetric analysis (TGA) estimates they found that millet husk had the highest moisture content of 26.67±0.58% as compared to rice husk 8.17±0.29%. The TGA of rice husk had a high End set temperature of 355.51°C and a weight loss of -48.23%, millet husk had low end set temperature of 349.21°C and a weight loss of -44.25%.

Rice husk indicated low yield after seven days of fermentation period but showed a significantly high yield in the volume of ethanol produced *i.e*., 68.67±17.69g/l. While, ethanol production yield in millet husk was found to be 79.80±0.93g/l. through this analysis they concluded that both Millet husks and Rice have the capacity to become a component crops for bioethanol production amongst them millet husk will have the highest yield. Oyeleke, and Jibrin (2009) [17] found similar results while evaluating Guinea Corn husk and millet husk for alternative and cost-effective feed stock to produce bioethanol and reported that *A. niger* and *Z. mobilis* may be better organisms for ethanol production from Guinea corn husk and millet husk.

Foxtail millet, Barnyard millet and Little millet

As per as other small millets are concerned, husks obtained from all millets can be successfully used for bioethanol production, but the concentration of bioethanol was observed higher in barnyard millet husk. Similar results are observed by Ashwini (2009) [18] when carried out the experiment to study the possibilities of Bioethanol production from husks of different small millets. In this experiment she used the husk of foxtail millet, Barnyard millet and Little millet. Husks were subjected to Six pre-treatments (*i.e*., Acid, Alikali, Microwave Acid, Microwave Akali, Steam Exploson, Lime, Control) of enzymatic hydrolysis and fermentation. In enzymatic hydrolysis the total sugars were higher at 12 hours in autoclaved alkali barnyard millet husk (*i.e*., 20905.36 mg/50g of feedstock) and total soluble solids were higher at 72 hours in autoclaved alkali pretreatment. Higher ethanol content during fermentation was recorded in autoclaved alkali barnyard millet husk (T17) pre-treatment at 120 hours (4018.26mg/50g feedstock). It was confirmed that autoclaved alkaline pre-treatment was the best among all the other pre-treatments. This suggests that use of small millets have a great potential for ethanol production too. Similar results were found by Rabah, *et al.,* (2011) [19] who worked on aspect of utilization of millet and guinea corn husks for bioethanol production. So, from the present review, it is clear these millets as whole crop or byproduct of crop can be used for ethanol production Rabah, *et al*., (2011) [21].

Conclusion

It can be concluded that being climate resilient millet crops can be grown in vary limited amounts of inputs and investment by farmers. Numerous studies shows that millets *viz*., Sorghum (*Sweet Sorghum, Grain Sorghum, Fodder Sorghum*), Pearl millet, Finger millet, Proso millet, foxtail millet, Barnyard millet and Little millet are potent crops for biofuel ethanol production but there is need of more extensive research and refinement of technologies. Also, there is need of capacity building of millet growing farmers through different governmental promotional policies. Millet is the plant that has ability to provide food grains & biofuel simultaneously.

From present study it can be concluded that:

1. Bio-ethanol production is possible from millets.
2. Bio-ethanol can be produced from Sorghum varieties by extracting juice from malleable sorghum canes. Among types of sorghum, Sweet sorghum is emerging as ethanol producing crop.
3. Proso millet can be an outstanding ethanol producer millet crop more over much emphasized to be made on development of “highly fermentable” lines.
4. More research & genetic improvement of millets in term of ethanol producing traits coupled with higher food grain production will open the new market opportunities for millet growers.
5. Millet by-products such as husk, grain, stem, etc. can be productively used for bioethanol production by employing microorganisms.
6. Pearl millets fermentation efficiency is equivalent to that of corn while using Saccharomyces cerevisiae. So, it can be used in ethanol production.
7. Finger millet biomass straws under optimized conditions can be used for bioethanol production.
8. Positive Millet husks and Negative millet husk (Rice & Wheat) have the capacity to become a component crops for bioethanol production amongst them millet husk will yield highest
9. *A. niger* and *Z.mobilis* may be better organisms for ethanol production from Guinea corn husk and millet husk.
10. Husk of all small millets can be productively used for ethanol production but there must be an extensive study on the use of microorganisms on commercial scale and development of processing industry.
11. Government should take initiatives for production of environmentally friendly biofuel and need to plan policies for promotion of millets.

Millet crops are solution to all kinds of issues like Nutritional Security, Environmental Depletion, Climate Change, Ecofriendly biofuel Production and economy of farmers.

Application of research: Study of enhancing the ethanol production capacity from millets

Research Category: Agriculture Technology

Abbreviations: B60 - Brix (%) at 60 DAS
B50 - Brix (%) at 50 per cent flowering
BM - Brix (%) at maturity
JE - Juice extraction per cent
RS - Reducing sugar (%)
NRS - Non Reducing sugar (%)
GCY - Green cane yield per plant (kg)
EBP - Ethanol blended petrol
E20 - Petrol blended with 20% ethanol
COVID-19 - Coronavirus Disease 2019
KVK - Krishi Vigyan Kendra
ICAR - Indian Council of Agricultural Research, New Delhi
ATARI - Agricultural Technology Application Research Institute

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Author statement: All authors read, reviewed, agreed and approved the final manuscript. Note-All authors agreed that- Written informed consent was obtained from all participants prior to publish / enrolment

Study area / Sample Collection: Baramati, Pune

Cultivar / Variety / Breed name: Millets - Sorghum (*Sweet Sorghum, Grain Sorghum, Fodder Sorghum*), Pearl millet, Finger millet, Proso millet, foxtail millet, Barnyard millet and Little millet

Conflict of Interest: None declared

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.
Ethical Committee Approval Number: Nil

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