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Suitability of Pearl Millet as an Alternate Lignocellulosic Feedstock for Biofuel Production in India

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Abstract Due to the depletion of the world petroleum energy reserves and the increased public concern about global warming are strongly attracting worldwide interest in alternative fuels. In 2011, India collaborated with United States Partnership to Advance Clean Energy (PACE) for production of biofuel with low carbon emission. For this reason, both the countries were issued a funding opportunity to establish a JCER&DC (Joint Clean Energy Research and Development Centre. National Renewable Energy laboratory (NREL) had executed various ethanol research projects for cellulosic ethanol production for commercial scale production from various sources. Cellulose (41.6 %) and hemicellulose (22.32 %) are the principal component for cellulosic biofuel production. These carbohydrates (Cellulose and hemicellulose) are present in the bajra biomass. The feasibility of a new energy crop will be largely depends on its production costs, availability, conversion efficiency and cost of existing fuels. These characters are present in the bajra crop which makes the crop suitable as a bioenergy crop.

Keywords: *bajra, carbohydrates, feasibility, bioenergy crop*

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1. Introduction

The countries namely USA, China and India are the major importers of bulk quantity of petroleum and crude oil products. The growing demand for energy from foreign fuel [1], depletion of fossil fuels and environmental impact have forced the development of alternative biomass resources with clean energy in India [2]. The energy demand will increase from 750 million tons of oil equivalent (Mtoe) to 1258-1647 Mtoe between 2011 and 2035. The demand of biofuel range is defined by WEO (world energy outlook) 450 Scenario and Current Policies Scenarios. It is most likely to be doubled over these 25 years [3]. In this context, India has an indicative target of 20 % blending of bioethanol with petrol by 2017. India is initiating the use of ethanol as an automotive fuel for reducing the fuel energy demand. Biofuel can be produced from three different kinds of biomass feedstock which are rich in reducing sugars (sugarcane, sugar beet, molasses and fruit) starch (grains, potatoes and root crops) and cellulosic biomass (municipal solid waste, paper waste, forest and agricultural crop residues). Cellulosic biomass could be converted into 3 major products such as electrical heat energy, transport fuel and chemical feed stock.

India's biofuel program is a benchmark for alternative and renewable fuel energy sources. The main barriers to achieve the target ethanol production are the feedstock demand and higher production cost. Ethanol production can be increased in two ways [4]. One kind of approach is to use the existing and easily available lignocellulosic biomass feedstock [5]. Another kind of approach is altering the composition of the biomass through molecular or genetic engineering [6]. Moreover, an integrated systematic approach requires the assessment of biomass availability with altering the composition of biomass for staple supply of feedstock.

Pearl millet [*Pennisetum glaucum* (L.) R.Br.] is an annual C_4 crop, locally known as bajra and is a nutritious coarse grain cereal. Pearl millet is the fourth most important grain crop in India which can be predominantly grown as stable food, feed and fodder [7]. In the world, it ranks sixth after rice, wheat, maize, barley and sorghum in terms of area under cultivation. In India, pearl millet crop occupies 7.12 mha and ranks third in area after rice and wheat among the cereals. In India, Rajasthan, central Maharashtra, northern Karnataka, Gujarat, Uttar Pradesh, Haryana and Tamil Nadu are the major bajra growing states in the rainy season. Bajra hybrid varieties for food grains (ICM 4 -155, VBH, NBH-4, NBH-149, MH-306, NH-338, MP-204) and forage crop with single cut (Giant bajra, PCB 15, PCB 141, Raj Bajra Chari 2, AFB 2, CO 8, FMH 3, GHB 235) and multi cut varieties (DFB1).

Pearl millet can be cultivated both in *kharif* as well as *rabi* season. Its grain is a rich source of protein and amino acid that can be utilized as human food. The remaining part is used as animal feed, seed, potable alcohol and processed food. The biomass is a valuable livestock feed in India and Africa. It can be fed whole or ground to poultry feed but grain milling is required for cattle and swine feed [8]. In addition to grain and forage uses, pearl millet crop residues are used as fodder, building material and fuel for cooking, particularly in dry land areas. In countries like the United States of America pearl millet is grown as a summer forage crop and seed for the bird feed industry and wildlife [9]. The remaining part (10 to 20 %) of the dry fodder is sold in the market. The fodder demand was estimated based on the livestock population. In the year 2020, the demand for fodder is expected for green fodder (825 Mt), dry fodder (494 Mt) and (54 Mt) of concentrate feed.

In Haryana state, 8 ethanol distilleries were established. Among these, 6 plants are using broken rice or pearl millet grain. In each plant, the demand for feedstock is 48,000 t/ annum of grain. In India, broken rice is used as a viable feedstock for alcohol industry followed by pearl millet grain (lower grade grain quality) and sorghum. The feedstock like pearl millet grain (lower grade grain quality) and broken rice are used in whisky preparation. The lignocellulosic biomass namely oats, barley, wheat, pearl millet grains have also been tested for saccharification and fermentation by many authors [10]. The choice of the plant species has the capacity to grow marginal land, short period of crop rotation, well adapted to poor soils, requires low inputs for establishment, high biomass yield per unit area, non-food crop, readily available, cheap, renewable, desirable chemical composition of the biomass and energy yield potential. These characters are present in the bajra crop that can be considered as a bioenergy crop. Therefore, pearl millet could be a potential feedstock for fuel production in areas that are too dry or too hot to where other cereal crops do not grow. Application of pear millet biomass for energy crops is not reported.

2. Materials and Methods

2.1. Current Fuel Statistics

The global annual target of ethanol production will increase to 120 billion litre by 2020 [11]. In the world US, Brazil, and Sweden are major biofuel producing countries which is approximately 110 million tons. Canada also promotes ethanol use as a fuel. Brazil is the world's largest producer of sugarcane approximately 7.5 Mha. Out of this half of the sugarcane is used for sugar production and the remaining part is used to produce 25 billion liters of ethanol. Considerable quantities of biofuel is being produced from countries *viz*., USA (55.64 billion litres), Brazil (26.85 billion litres), European Union (52.50 billion litres), China (3.08 billion litres), Canada (1.65 billion litres), other countries (1.48 billion litres), Thailand (1.26 billion litres), Argentina (0.80 billion litres) and India (0.80 billion litres) [12]. In the year 2019, ethanol production will be expected from various countries namely Brazil, US, EU, India, Indonesia, China (8.34 billion litres) and Malaysia in much quantities.

2.2. Supply and Demand

Ethanol is used as chemical and pharmaceutical industries, automotive fuel, and potable liquor. India's biofuel program mainly depends on the availability of molasses (by-product of sugarcane) and partially from grains. The shortage of sugarcane ultimately leads to affect the availability of feedstock. Production of ethanol from various sources is still in research and development stage and also global level policies are mandatory for the target blending as well marketing of fuels. The ethanol producing countries have set targets to meet their ethanol demand [13]. India established an ambitious National Mission policy on biofuels in 2009, but the infancy of the ethanol industry and difficulty in meeting current targets constrains future demand growth in the projections. The Renewable Fuels Standard (RFS) recommendation is to produce 36 billion gallons of biofuels by the year 2022 [14]. The Demand and supply of ethanol in India (2015) is shown in Table 1.

Table 1. Demand and supply of ethanol in India (2015)

Alcohol	Demand (M ltrs)
Portable sector	1900
Industrial sector	1280
Blending (5 %)	1260
Demand all over the country	4440
Existing production	2400
Total demand	2040

[15]

In the world, Brazil and Sweden are the producers of large quantity of ethanol as a fuel. Canada promotes ethanol is used as a fuel. India is initiating the use of ethanol as an automotive fuel. The shifting of fossil fuel to alcohol made the distilleries in India to use surplus alcohol as a blending agent. India should start working on the road map of 10 % blending followed by 20 %. The tenders 2010 -11 of ethanol blending by Oil Corporation are full swing. India has already blended ethanol to the tune of 30 crore litters in April 2011, out of the 71 crore litters that was expected on October 2011. All the sugar companies having ethanol facility are on the verge of expansions. Since the blending took off smoothly.

In 2012, the ethanol requirement was deducted 720 million liters and only 610 million litters had been supplied. The domestic production of surplus molasses was exported to Europe and used as cattle feed. In 2013, the demand for oil is 3.7 million barrels per day (bbl/day). The demand for agricultural commodities and volatile oil prices about continues oil supplies have led to search for substituting petroleum products. The target 10 % blending of ethanol was successful in few states like Goa, Uttar Pradesh, Haryana, Delhi, Punjab and Karnataka. But, the all over the country should reach 5 % level of ethanol blending target by the end of June 30, 2012. The fuel ethanol cost as Rs.38 to 54 per liter has been quoted by suppliers.

The global level fuel ethanol suppliers had quoted as Rs.69 to 92 per litre and supplied it around 620 million litres. Hence, the global level tender was disapproved. This tender was valid up to November, 2014 for supply of ethanol. But, OMC (Oil Marketing Companies) got validity up to May, 2015. The successful blending rate was 1.6 %. The fuel ethanol (from molasses) cost was Rs. 33 to 46 per litre. The OMCs were providing a ceiling price of Rs.44 per litre at various depots. The mandatory 10 % blending of ethanol with petrol required 2.65 billion litters in 2016. Indian government had set up an indicative target of 20 % blending with petrol by 2017. Hence, this program required more than seven million liters of ethanol for 20% successful blending of ethanol with petrol.

India is initiating the production and use of ethanol as an alternative fuel from various industries and various sources. The sugar industry has been permitted to produce ethanol directly from sugarcane juice. The shifting of fossil fuel to alcohol made the distilleries in India to use surplus alcohol as a blending agent. The sugar industries and distilleries will be encouraged to increase the production of ethanol to meet out the target of the mandatory blending of ethanol with petrol. Support will be provided for creation of awareness, capacity building, training and development of biofuel production. India has 330 distillers which can produce more than 4 billion liters of rectified spirit (alcohol) per year with 1.5 billion liters of fuel ethanol. Ethanol production facilities are still in infancy stage in all the sugar industries. Out of this, 162 distilleries have the facility to produce ethanol from molasses to 2 billion liters per year. It could be meet the demand for only 5 % blending with gasoline. Domestic production of biofuel can meet the demand only 1 % level of global production whereas it consumes about 3.1 % of global consumption. India should start working on the road map of 10 % blending followed by 20 %.

The demand for oil reached up to more than 8 million barrels per day in 2013 as per Energy Information Administration [3]. The government of India (GOI) has started several schemes for promoting the biofuels production from renewable sources and planned to provide incentives for second generation biofuel production by National Biofuel Fund (NBF) in India, USA and China. In India, centre for biofuels had established at CSIR-NIST. This is the pilot plant demonstration center for biofuel production from lignocellulosic biomass and the conversion efficiency was found to be 70 %. This technique is comes from TIFAC (Technology Information Forecasting Assessment Council) and DST (Department of Science and Technology). The biofuel program is used to provide technical support by demonstration, training with R & D.

The Indian government and a number of private organization namely D1 oil PLC, Emami group, Aatmiya biofuels Pvt. Ltd., Reliance industries ltd., Godrej Agrovet, Jain Irrigation system, Gujarat Oelo Chem. Ltd., Nova biofuels Pvt. Ltd., Sagar Jatropha oil extractions Pvt. Ltd., Tata industries Pvt. Ltd., Pune, Reliance Bioenergy Ltd., Mumbai, Dupont Pvt. Ltd., Hyderabad, Danisco India Pvt. Ltd., Hyderabad /Ahemdabad, Jay Biozyme technologies Pvt. Ltd., Pune, Indian oil corporation Ltd., Faridabad are mainly involved in the research for 20 % target biofuel blending program. Ethanol plants in India are shown in Table 2.

Table 2. Ethanol plants in India

S.No.	Name	Capacity in LPD	Biomass	Remarks	Establish-ment year
1.	Shetimal Sahakari Prakriya Sanastha Ltd., Herwad Fuel ethanol plant MSDH (vapor based technology)	30,000	Corn, beet root, grains (wheat, maize, barley) molasses Current Molasses and sugarcane juice	India's first biofuel plant Praj company has partnership with Delta- T-Corp (USA). active	2002
2.	Patil Alco & Allied Industries Pvt. Ltd., Kolhapur. Ujalaiwadi, Kolhapur, Maharashtra - 416 116.	30,000	Bio- light diesel oil	Wholesale	2013
3.	Precious Alco & Petro India Pvt. Ltd., Wai, Maharashtra – 412803.	30,000	Fermented material	Ethyl alcohol production	2003
4.	Wallams (India) Agro Products & Power Ltd., Islampur, Maharashtra -415409.	30,000	Molasses (Perfumes and biofuel)	Ethanol, Ethyl Acetate, Extra Neutral Alcohol	2001
5.	Vamshi Exports, Uttar Pradesh	60,000	Fine chemicals	Exporter	
6.	XL Telecom and energy Ltd, Apte Road, Pune, Maharashtra.	1,50,000	Sweet sorghum ABI-ICRISAT	Manufacturer /exporter/ wholesale suppliers of ethanol	1985
7.	KMR industries limited	1,50,000		Manufacturer /exporter/ wholesale suppliers	1991
8.	Anantha energy Ltd., Bangalore-560001.	1,00,000	Active	Lubricant and fuel product	1993
9.	AShri Kedarnath Agro and Sugar products Ltd.	1,50,000	-	-	-
10.	Astral Poly 53echnic LTd.	60,000	-	-	-
11.	Om Sai Industries, Kolhapur.	45,000	-	Neutral ethanol production	Pilot scale

2.3. Future Ethanol Production in India

At present, India's first 2G (lignocellulosic) ethanol production plants were established in Punjab (Bathinda) and Uttarakhand (Kashipur). Hindustan Petroleum Corporation Limited (HPCL) has undertaken the Bathinda project. In Punjab, 50 lakh tons of paddy and wheat straw was burned in every year. They were not utilized for livestock feed and thus have been directly diverted into biofuel in the Bathinda Industry. It is having the capacity to produce 100 kilo litters per day or 3.2 crore liters per annum and thereby generating an additional income to rural people up to 4,000 crores. This technology is highly useful for global level indicative target of ethanol production from various sources like bagasse, rice, wheat straw, bamboo, cotton stalk, corn stover and wood chips. In India, surplus alcohol is used as a biofuel (blending agent).

The Kashipur ethanol plant has the capacity to consume 10 tons of feedstock per annum. Biotechnology Research Assistance Council (BIRAC) had undertaken this project. In, 2008, techno-economic feasibility of cellulosic biofuel production technology was established by the DBT - ICT (Department of Science and Technology - Institute of Chemical Technology). The various types of feedstock namely wheat straw, rice straw, bagasse, cotton stalk and bamboo can be used as raw material for biofuel production.

2.4. Existing Potential Resources with Quantity

In India, have shown that there are 328.6million ha of geographical land, of which pearl millet crop occupied 7.12 million ha. The expected future demand and depletion of fossil fuels needs to be augmenting the alternative biomass resources. First generation biofuels (1 G) are derived from food crops like starch (grains of wheat, barley, corn, root crops and potato) sugars (sugar beet, sugar cane, molasses, fruit), animal fat and vegetable oil which can affect the food security that can ultimately increase the price. The recovery of the fermentable sugar is also easy in that feedstock. This approach is also competing with food chain. So, it has given the further better alternative way to second and third generation fuel ethanol production. Second generation (2 G) biofuels are derived from lignocellulosic biomass (non-food crops) like agricultural and horticultural residues, industrial waste (wood chops, skins and pulp from fruit pressing units). This type of biomass can reduce the utilization of food crops. Lignocellulosic feedstock can be grouped into four different kinds of sources namely municipal solid waste, paper industry, agricultural and forestry residues. It is a cheap, renewable abundant and rich in carbon source. Third generation biofuels are derived from algae.

Majority of the National Biofuel Programs have been started to cost effective ethanol production from various resources. There are many promising existing potential feedstock for commercial scale bioethanol production. It includes corn and wheat (USA), sugar cane (Brazil), corn, cassava and rice (China) corn and wheat (Canada) sugarcane and molasses (India), wheat, sugar cane and sugar beet (France), wheat, sugar cane and sugar beet (Germany) and sugar cane (Australia) are the major feedstock in international level biofuel production. Rice straw, wheat straw, corn stover and sugarcane bagasse are the major agricultural wastes in terms of quantity of biomass availability [16]. There are different types of lignocellulosic biomass dry matter production ranging from 7 to 40 t/ ha/yr. Hence, Praj industry had launched a cellulosic waste based bioethanol plant. Switch grass (*Panicum virgatum* L.) is one of the most reference biofuel crops for the comparisons [17]. The buffalo grass (*Bouteloua dactyloides*), aquatic duck weed (*Lemna gibba*) and switch grass (*Panicum virgatum*) have been used as an energy crops and also yield high quantity of dry biomass [18].

Sorghum is a C_4 crop and used as energy crop because of high rate of photosynthesis, high biomass yield per hectare, drought tolerance and cost of cultivation low [19,20]. Sweet sorghum was found to be one of the potential resources of biomass for commercial scale ethanol production [21]. This type of biomass was acting as a limiting factor for conversion of biomass to alcohol. Hence, many countries have been started to develop fuels from available or existing biomass [22].

The researchers mainly focus on the amount of energy or total biomass available. The available biomass potential in India is estimated that 686 MT from 26 types of crop residues. Among these 545 MT of biomass is contributed by cereal, oil seed, pulses sugarcane crop residues, 61 MT of crop residues contributed by horticultural crops like banana, coconut and arecanut and 80 MT of crop residues contributed by cotton and jute. The pearl millet crop biomass availability is based on the area under this crop, yield attributes of the crop, residue production ration (RPR value) of the crop. Pearl millet crop generates 24.3 MT of residual biomass annually. Out of this, 5.1 MT surplus of pearl millet biomass is available in every year. This available (5.1 MT of) biomass can be used for biofuel production.

The ethanol yield from a large production plant is about 1 L of ethanol from 2.69 kg of corn grain [23]. Pearl millet grain gives 0.43 L kg^{-1} of theoretical ethanol yield is comparable to barley and oat [24]. Sweet sorghum is capable of producing up to 13.2 metric tons per hectare of total sugars, which is equivalent to 7682 liters of ethanol per hectare [25]. Ethanol production from sweet sorghum (5,600 liters ha^{-1} from 140 t ha^{-1} per crop @ 40 L t^{-1}) is comparable to ethanol production from sugarcane (6,500 litres ha^{-1} from 85-90 t ha^{-1} per crop @ 75 L t^{-1}). Yield and quality characteristics of sweet sorghum and sugarcane vary with weather conditions. Theoretically, one ton of bagasse could yield up to 300 L of ethanol [26].

3. Result and Discussion

3.1. Chemical Composition of the Selected Biomass

In the present study, comparison of different types of lignocellulosic biomass composition with pearl millet biomass is shown in the Table 3. The chemical composition of the various types of lignocellulosic biomass was analyzed by using National Renewable

Energy Laboratory (NREL) standard protocol. In India, wood, grass, forestry waste, agricultural residues and municipal solid waste are excellent sources of lignocellulosic materials and their chemical composition was studied by many authors .These raw materials are rich in carbon source and abundant in nature. The chemical composition also varies with variety to variety, plant to plant, crop stage, season to season, soil type, method of harvest and storage. However, when grown in different environmental condition significant variation may occur. In addition to that the range in genetics, environmental effects on feedstock composition are also important.

Table 3. Comparison of compositional analysis of selected pearl millet biomass with other lignocellulosic crops for ethanol production

Feedstock	TS	Moisture	Ash	Cellulose	Lignin	Hemicellulose
Pearl millet	92.00±0.38	8.00±0.32	6.27±0.08	41.60±0.01	21.81±0.03	22.32±0.65
Corn dric	88.50±0.12	11.50±0.15	3.00±0.22	40.34±0.18	19.75±0.05	25.01±0.06
Corn shank	88.00±0.13	12.00±0.24	3.00±0.15	33.80±0.24	20.08±0.41	31.12±0.34
Rice husk	87.50±0.33	12.50±0.21	4.00±0.54	35.40±0.22	16.95±0.05	31.15±0.02
Cotton stalk	90.50±0.15	9.50±0.22	16.00±0.11	28.11±0.13	16.20±0.15	30.19±0.22
Arecanut sheath	58.50±0.13	41.5±0.22	10.00±0.12	17.88±0.18	10.43±0.08	20.19±0.02
Arecanut shell	88.00±0.05	12.00±0.13	7.00±0.28	38.38±0.25	17.45±0.12	25.17±0.42
Sorghum	91.00±0.66	9.00±0.66	8.00±0.66	47.00±0.66	26.00±0.66	24.50±0.33
Bamboo	97.40±0.33	2.60±0.33	6.60±0.07	45.70±0.33	26.50±0.87	21.10±0.33
Rice straw	87.00±0.05	13.6±0.05	6.00±0.04	45.6±0.03	30.02±0.10	23.89±0.09

The proximate analysis of pearl millet biomass in our study revealed that the contents were moisture (8±0.32 %), ash (6.27±0.08 %), total solids (92 ±0.14%), water extractives (6.43±0.12%), ethanol extractives (5.72±0.34), cellulose (41.6±0.01%) hemicellulose (22.32±0.65%), glucan (28.47±2.88%), galactan (2.12±2.46%), arabinan (3.78±0.04%), xylan (17.24±0.62%), acid soluble lignin (16.32±0.49%) and acid soluble lignin (5.49±0.08%). The chemical composition of pearl millet is comparable and even superior to that of the other major cereals [27]. Pearl millet biomass is a rich source of sugar polymers namely cellulose (41.6±0.01%) and hemicellulose (22.32±0.65%). These sugar polymers or carbohydrates are essential for biofuel production. Cellulose is a long chain polymer of cellobiose units and difficult to break down the structure. Cellobiose is repeated units of cellulose which are tightly held tighter by glucose units. Cellulose is a polymer of glucose units that are bound with long chain molecule by β-(1,4) - glycosidic linkages. Cellulosic polymers are tightly packed in a matrix like structure with hemicellulose and lignin fractions by covalent and non-covalent linkage. Cellulose is not soluble in all the solvents. It is partially soluble or swellable in nature. It could be digested into fermented sugar by acid and enzymatic saccharification. Hemicellulose consists of pentose and hexose sugars. Xylose is the major sugar molecule that can be mainly derived from hemicellulose. It is a short chain and amorphous type of polymer in nature. It is highly soluble in alkaline condition.

Lignin is a non- sugar type of aromatic macromolecule. It is also having a variety of functional groups like hydroxyl, methoxyl and carbonyl groups and these groups are plays a major role in the polarity of the lignin. It provides structural strength and rigidity to the cell wall and also prevents the chemical or microbial degradation. These polymers should be converted into fermentable sugar before fermented in to ethanol. The complex structure of biomass should be broken down by suitable chemical or enzymatic hydrolysis before fermentation. The carbohydrate components are the major contributors of biofuel production and it should be converted into monomeric sugars before fermentation.

3.2. Storage

In large scale production, the raw material storage facility is required for staple supply of biomass throughout the year. Ethanol production capacity is mainly depends up on the availability of biomass for energy production, storage capacity, transportation distance from producer field to processing unit. The cost effective enclosed form of storage is required for lignocellulosic biomass. However, unprotected storage results in feedstock compositional changes and feedstock losses. It is not suitable for biofuel ethanol production.

3.3. Cattle Feed

Indian agriculture generates large amounts of biomass 840 million tons in 2010, a large part of which consists of residues [28]. Livestock population is also increasing with year as well as feed requirement is also high. The considerable quantities of agricultural crop residues are generated during the harvest and the processing of agricultural produces and these wastes are unfit for human consumption [29,30]. India has a 294 million of cattle population [28]. As per the 19th livestock census data, the total livestock population was recorded 51.20 crore numbers in India. In 2012, cattle population is 1.90 crore and buffalo population is 10.87 crore. However, India has more than 10 mha of graze land. Grass productivity is decreased due to land degradation, climatic condition, poor soil and total dependence of the cattle on the crop residues of pulses and cereals. All the available biomass are not suitable for biofuel production because they are mainly used for livestock feed and fodder. The total biomass used as fodder was 360Mt in 2010 - 2011. In rural areas, cereal crop residues are used a fodder. The allocation of cereal crop for fodder crop worth is to produce 124 billion liters of bioethanol in 2010 - 11, 143 litres in 2020 - 21 and 160 liters in 2030 - 31.

The agricultural crop residues are available for biofuel production is expected at 187 Mt, of which 163 Mt of can be used to production of 50 billion litres of ethanol annually. The net crop residue availability in 2020 - 21 and 2030 - 31 for bioethanol production is expected at 187 Mt and 209 Mt. The net ethanol production is expected at 58 and 65 billion litters. This quantity could be sufficient to meet out the 20 % of ethanol with petrol target in 2030 - 31. A lot of potential for increasing the production of forage in country is available.

Lignocellulosic biomass ethanol production costs are too high. The overall ethanol production cost is associated with feedstock cost, feedstock transport cost from field to processing unit, capital investment, processing or conversion efficiency cost and storage cost. Lignocellulosic biomass to ethanol production consists of four major consecutive steps: pretreatment, hydrolysis, fermentation, purification and packing. The chemical properties of the biomass have been difficult to breakdown the structure. Hence, it requires a suitable pretreatment technique. It can be broken down by microbes or chemical pretreatment. Enzymes are expensive and existing enzymes are not ideal for this task. It is difficult to access the microbes. Cost effective ethanol production process highly depends on the rate of hydrolysis, minimum level of sugar degradation products, enzyme dosage, temperature and incubation period. This analysis represents overview of ethanol production from pearl millet biomass.

3.4. Milling Cost

Milling is also one of the types of mechanical pretreatment. The biomass sample was milled in a wiley mill sieve through 10 or 20 mesh size. The milling of biomass can also cause shearing of the biomass. Sample preparation and size reduction is the first step of pretreatment. Particle size is also one of the sugar releases determining parameter. The size reduction in particle size leads to an increase of available specific surface area and degree of polymerization. Generally, homogenized or uniform particle size of the biomass (2 μ) is required for pretreatment. This technique has several advantages before the catalytic pretreatment. The ash (inorganic material) content should be less than 10 % because it is having the buffering effect capacity. If it is more than 10 % means, we can go for biomass size reduction. The wiley mill grinding capacity is 10 kg / h. This consumes [1.5 unit X cost (Rs. 6.35)]. The milling cost of pearl millet biomass feedstock is 9.53 /10 kg of biomass.

3.5. Pretreatment Cost

The detailed pretreatment cost of pearl millet biomass feedstock is furnished in Table 4. Cellulosic biomass contains major quantities of cellulose, hemicellulose and lignin, minor quantities of minerals or ash, soluble sugars, starch proteins and oils and these compounds play an important role in plant functions. The carbohydrates are the subsequent plot form for ethanol production. The cost-effective carbohydrates extraction process is very difficult from the pearl millet biomass due to complex structure of biomass. Various pretreatment methods (acid, alkali, hydrothermal and its combination) have been focused on conversion of biomass to sugars, but the process cost is still high with low sugar release. The effective pretreatment is to maximum recovery of fermentable sugars, separation of hemicellulose and to prepare the residual biomass for enzymatic hydrolysis. The proper method has been selected based on safer to human beings, environmental friendly, easy to use, easy to recover and the overall production cost and not in a single (pretreatment) process. The pretreatment cost is also varies with the type of pretreatment which consumes about 33 % of the total cost [31].

Table 4. Benefit cost ratio of pearl millet biomass

Particulars	No.	:	Cost (Rs.)
Land preparation (ploughing)		:	
Disc plough (Rs.1200/h) – (2.5 h/ha)	1	:	3000
Tiller plough (1.5 h/ha)	2	:	3600
Ridges and furrows bullock cart (Rs. 600/pair)	4	:	2400
Seed cost 5 - 8 kg/ha		:	400
Sowing	15 Labour	:	3000
FYM (Rs. 4000/t) tractor (6t/tractor)		:	8000
Cost of fertilizer		:	
Urea - 150 kg/ha	Rs.330 *3	:	990
SSP - 150 kg/ha	Rs.420 *4	:	1680
MOP - 50 kg/ha	Rs.450	:	450
Fertilizer application cost	5 labour (labour cost- Rs.200)	:	1000
Biofertilizer cost		:	
Azospirillum	(2000 g)	:	40
Phosphobacteria	(2000 g)	:	40
Cost of weeding (2 weeding)	30 labour /ha	:	12000
Irrigation cost	6 Labour/ Irrigation	3 times	600
Water cost	(900 - 1200) Rs.45/ h 20 h for 3 irrigation	:	
Cost of harvesting and threshing	15 labour /ha	:	3015
Cost of threshing	8 labour /ha	:	1608
Transportation cost	13 labour /ha	:	2600
	Expenditure	:	44423
Yield(kg/ha)		:	
Grain (q/ha)	14 Q	:	11200
Straw (q/ha)	200 q	:	50000
	Income	:	61200
Benefit cost ratio	1	:	1.377665

Table 5. Cost for chemical pretreatment of pearl millet biomass

Parameters	Orthophosphoric acid	Alkaline hydrogen peroxide	Lime (calcium hydroxide)	Hydrothermal pretreatment
Cost/litre (Rs.)	650.00	106.13	204	650.00
Used for 1 kg biomass (L)	1.19	0.96	0.125	1.19
Cost (Rs.)	773.5	316.8	25.5	773.5
Reaction time (h)	4	3	3	1
Electricity consumption (kW/h)*	4.50	3	3	2
Cost for electricity consumption (Rs.)**	28.58	19.05	19.05	12.70
Electrical charges (Rs.)	6.35	6.35	6.35	6.35
Lignin reduction (%)	67.88	45.77	46.81	61.94
Sugar release (g/ 100 g of biomass)	41.8	17.65	22.5	0.21

* -kWh-1000 watt, ** - kWh X 1 unit cost (tangedco rate)

3.6. Neutralization

The pretreated slurry samples should be neutralized which requires a large volume of water or chemicals. Neutralization of the biomass is required to detoxify or neutralize the inhibitor compounds. Acid pretreatment requires large amount of water (20 ml of water/ g of biomass) for its neutralization process. Alkaline hydrogen peroxide pretreatment does not require for neutralization. In lime pretreatment CO_2 is required for recycling of chemicals. HCl or NaOH is required for neutralization of pretreated liquid fraction. The neutralization cost is also varies in the types of pretreatment chemical and this cost is also included in the production cost.

3.7. Enzymatic Saccharification

The detailed enzymatic saccharification cost of raw and pretreated residual pearl millet biomass is furnished in Table 5. Enzymatic saccharification is required to utilize or degrade carbohydrate polymers prior to fermentation. The enzyme (Cellulase enzyme) cost is also one of the most important technical barriers for lignocellulosic ethanol production. To reduce the enzyme cost and maximum recovery of fermentation is mainly depends upon temperature, substrate loading, pH, mixing rate, enzyme loading, surfactant and incubation time. Process integration approach is highly reduces the capital cost. The enzymatic saccharification cost of pretreated residual pearl millet biomass is Rs.160 /kg.

3.8. Distillation of Fermented Product

The fermented product was loaded in a distillation unit. The Distillation unit capacity is 3 litre. It requires 6 h for its complete distillation process. The distillation cost is Rs. 38 / 3 litre. From this, we obtain 90 ml of alcohol. From one kg of sugar can generate upto 300 ml of alcohol.

4. Conclusion

In this way, the demand for foreign fuel can be initially reduced. When compared to the sugar yielding of different crops (sorghum, Bamboo, rice husk, cotton stalk, arecanut sheath, corn dric and shank, rice husk and straw) pearl millet crop has been tapped for biofuel production. Pearl millet scores a rich source of carbohydrates namely cellulose and hemicellulose which accounts for 41.6 % and 22.32 %. So many technologies are existing for biofuel production from cellulosic ethanol production. Several enzymes can break down the cellulose to glucose. These fermentable sugars can be further fermented into ethanol by microorganism. Pearl millet biomass may be used as commercial scale-up of ethanol production within a few years due to low cost.

Table 6. Cost for chemical pretreatment of pearl millet biomass

Parameters	Orthophosphoric acid
Enzyme Cost (Rs.)	8000/ 5g
Used for 1 kg of biomass (mg)	100
Buffer cost (Rs.)	25
Cost (Rs.)	160
Reaction time (h)	
(Electricity consumption (kW/h)* for incubation)	72
Electrical charges (Rs.)	6.35
Cost for electricity consumption (Rs.)**	457.2
Sugar release (g/l)	17.14
Conversion efficiency (%)	84.96

* 1000 watt – kW/h, ** kW/h X 1 unit cost (tangedco rate)

Table 7. The cost economics of ethanol

Parameters		Alcohol production cost
Cost of the reactor (Rs.)	:	1,00,000
Milling cost (Rs./kg)		2.0
Life span of the reactor (years)	:	10
Average cost of pearl millet biomass (Rs./kg)	:	5
Used for 1 kg biomass (L)	:	1.19
Ortho-phosphoric acid Cost/litre (Rs.)	:	650.00
Ortho-phosphoric acid Cost (Rs.)	:	773.5
Reaction time (h)	:	1
Electricity consumption (kW/h)*	:	2
Cost for electricity consumption (Rs.)**	:	12.70
Electrical charges (Rs.)	:	6.35
Repair and maintenance cost (Rs.)	:	5 % of capital cost
Reactor capacity	:	3 litre
Processing capacity of reactor	:	1.75 litre per batch (3 batch per day)
Average of water used for neutralization (L)	:	3.0
Average of cost of water (Rs.)		10
Labour charges per day (Rs.)		200
(P = Rs. 1,00,000, R= 10 %, N= 10 years Depreciation		34,867
Enzyme cost (Rs./kg)		160
Distillation Rs.38/ litres		422

The choice of the plant species is mainly depends on the low rainfed area, short period of crop rotation, adaptation to poor soils, requirement of low inputs for establishment, high biomass yield per unit area, non-food crop, readily available cheap, renewable, desirable chemical composition of the biomass, taste, energy yield potential and market price. These characters are present in the bajra crop which makes the crop suitable as a bioenergy crop. The expected future demand with depletion of fossil fuels requires the need for alternative biomass resources. At present, newly installed biofuel industries will give only 5 to 6 % of blending. For this reason, the biofuel production is mainly focused on cellulosic waste or plant based biomass. Hence, ethanol production from pearl millet biomass is one of the most suitable alternative biomass for significant fraction of replacement of fossil fuels.

The biofuel production capacity mainly depends upon the feedstock quality, yield, location and climatic factors. In India, the geographical area is 328.72 mha, in which the net cropped area is 200.86 mha and in this the pearl millet crop accounts for 7.12 mha. The left unutilized land for cultivation is 16.48 mha. India has enough waste land and agricultural land to produce biomass for biofuel production. The diversion of 10 % of this waste land into pearl millet cultivation for biofuel production would give us (1.648 mha x 5500 t) 9.06 mt of biomass. From this biomass approximately 18.12 lakh litres of alcohol can be generated. Beyond the supply chain of raw material, cellulosic biomass could greatly increase the energy production as well as environmental impact.

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