Global Journal of Science Frontier Research: D
Agriculture and Veterinary
Volume 16 Issue 6 Version 1.0 Year 2016
Type : Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4626 & Print ISSN: 0975-5896

Sweet Sorghum: A Sweet Grass for Bioenergy

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Abstract- *Sorghum bicolor* (L.Moench) is one of the most important multipurpose crop for production of golden syrup and treacle and alcohol from stalk juice. Its bagasse and green foliage could be used as an excellent fodder for animals, as organic fertilizer or for paper manufacturing. Sweet sorghum is a high-biomass and sugar yielding C4 plant containing approximately equal quantities of soluble glucose and sucrose, and insoluble carbohydrates (cellulose and hemicelluloses). Sorghum has been shown to be excellent silage in many areas of the world. Plant cell walls are vast reserves of photo synthetically fixed carbon. The brown midrib mutants have been used to identify and characterize the genes that encode the major enzymes for specific steps of monolignol biosynthesis for sorghum.

GJSFR-D Classification : *FOR Code: 820404*

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Sweet Sorghum: A Sweet Grass for Bioenergy

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Abstract- *Sorghum bicolor* (L.Moench) is one of the most important multipurpose crop for production of golden syrup and treacle and alcohol from stalk juice. Its bagasse and green foliage could be used as an excellent fodder for animals, as organic fertilizer or for paper manufacturing. Sweet sorghum is a high-biomass and sugar yielding C4 plant containing approximately equal quantities of soluble glucose and sucrose, and insoluble carbohydrates (cellulose and hemicelluloses). Sorghum has been shown to be excellent silage in many areas of the world. Plant cell walls are vast reserves of photo synthetically fixed carbon. The brown midrib mutants have been used to identify and characterize the genes that encode the major enzymes for specific steps of monolignol biosynthesis for sorghum.

I. Introduction

Sorghum bicolor L. Moench is commonly called as sorghum and also known as durra, jowar or milo belongs to family graminae. It is a genus with many species and subspecies and there are many types of sorghum, which includes grain sorghum, sweet sorghum and broomcorn.

Sorghum ranks fifth in worldwide among cereal crops. In India sorghum is grown for multiple purposes besides grain, the stem is used as fodder, fuel and fencing material. In many parts of Asia and Africa, their grains are used to make breads that form the staple food of many cultures. The grains can also be popped in a similar fashion to popcorn. Sorghum[*Sorghum bicolor* (L.) Moench.] is an important forage crop for grazing dairy cows in many milk producer regions of the world as frequent drought and high summer temperatures reduce forage production from pastures. Forage sorghums can be planted later than corn; use water much more efficiently; and, when exposed to drought, still produce acceptable yields [15].

Sorghum is C4 crop and tolerant to various abiotic stresses *viz.,* salt, water and drought. Therefore, it can be grown in arid regions. Bio-fuels (bio-ethanol and bio-diesel) produced from renewable energy sources are gaining importance in the light of rising fossil fuel prices, depleting oils reserves and increasing 'greenhouse emissions associated with the use of fossil fuels. Several developing and developed countries have made a mix of policies to promote the production and use of bio-fuels. Ethanol accounts for 90% of total bio-fuels production and use in different parts of the world at present. As bio-fuels are produced from biomass of crop plants, they offer enormous opportunities to improve the income levels of smallholder farmers in developing countries. At community level, farmers can cultivate energy crops that fetch more income while meeting their food needs. Local production of bio-fuels is projected to have a broad range of positive economic, social and environmental implications. Biomass is the oldest source of energy and currently accounts about 10% of total primary energy consumption. Traditional biomass in the form of wood fuel is still the main source of bioenergy.

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Bioethanol production has shown rapid growth during last decade. In 2008, global biofuel production reached about 83 billion liters, a more than fourfold increase compared to 2000 production volumes. The United States and European Union are amongst the largest producers of biofuel, emerging and developing countries increased their share to about 1.5% of global transport fuel consumption. This demand of fuel will be increasing in coming decades. In most developing countries clean cooking fuels is more urgent than the supply of clean transport fuels. Using lignocellulosic–biomass as feedstock, second- generation biofuels could avoid competition with food production and at the same time increase income opportunities for rural farmers. Cellulosic ethanol is a biofuel produced from wood, grasses, or the non-edible parts of plants .It is a type of biofuel produced from lignocelluloses, a structural material which makes most of the biomass of plant[4,18] reported several types of lignocellulosic biomasses have been explored as a feedstock for the production of bioethanol which include agriculture residue, soft and hard wood, waste paper and energy crops. Lignocellulosic biomass consists ofpolymers such as cellulose, hemicellulose and lignin[18,21]. These polymers are arranged in such a way that they make the biomass complex and recalcitrant. Lignocellulose is composed mainly of cellulose, hemicellulose and lignin. Sorghum, Corn, Switch grass and Miscanthus are popular cellulosic material for ethanol production. There are three ways of producing ethanol from cellulose.

Cellulolysis processes which consist of hydrolysis on pretreated lignocellulosic material, using enzymes to break cellulose into sugars such as glucose followed by fermentation and distillation. Gasification is the process that transforms the lignocellulosic raw material into gaseous carbon monoxide and hydrogen. These gases can be converted into ethanol by fermentation.

a) Sorghum as feedstock

There is a growing interest for alternative energy sources because of the fossil fuel crises. Ethanol used as automotive fuel has increased at least six times in the current century. According to the Renewable Fuels Association, in 2010 the USA bio-refineries generated 13 billion gallons of bio-ethanol and the year before worldwide production reached 19 billion. This noteworthy increment is in its majority based on maize and sugar cane as raw materials (Berg, 2004; Renewable Fuels Association, 2010)

IEA (2010) provides a clear definition of first generation biofuels and second generation biofuels. Sorghum is a multipurpose crop with the potential to achieve sustainable biofuel production, human food and animal feed products. Typical first generation biofuels are sugarcane ethanol, starch-based or "corn" ethanol and biodiesel. Sugar rich crops especially those that yield multiple end products, are promising. Alternative energy sources that are cost effective and technologically sound need to be developed. First generation biofuels, like ethanol and fatty acids ethyl esters mixed with gasoline and diesel are used in several countries.

b) Ethanol production

Sweet sorghum is an attractive feed stock for ethanol production. The juice extracted from the stalk contain soluble sugars and can be fermented into ethanol [21].Sweet sorghum is sugar crop with biofuel potential and found to be competitive with corn for theoretical ethanol yield with less input of energy.(Smith etal., 1987; Smith and Buxton, 1993; [8].If starch and cellulosic ethanol are considered sweet sorghum likely produce 50%-100% more ethanol per acre than corn grain and stover[14]. In sweet sorghum the sugar is contained in the main stalk, and is recovered by pressing the stalks with rollers (similar to the process used for sugar cane). Yields, on average, are 20 gallons of ethanol per ton of stalks [7].The average ethanol production for the Top 76-6 variety was approximately 220 g ethanol per kg of dry stem, which is equivalent to 2465 l of ethanol per ha.[9].Sweet sorghum, also known as sugar sorghum, belongs to the common grain sorghum plant. It is regarded as the most promising feedstock source for ethanol production because of several advantages, including rich germplasm resource, high biomass yield, rapid growth, wide adaptability, rich sugar content in stalk, clean and relatively low production cost [6,23,1,10,11,12,13,25].

Production of bioethanol from lignocellulosic biomass through a biological route involves three major steps: pretreatment, enzymatic hydrolysis, and fermentation [3]. Pretreatment is a critical step. The purpose of pretreatment is to break up the lignin seal, prehydrolyze the hemicellulose, and disrupt the crystalline structure of the cellulose, thus allowing cellulases better access to cellulose during enzymatic hydrolysis [5,9,22,4]. The bioconversion efficiency of *N. crassa* DSM 1129 was found superior to *S. cerevisiae* 2541. *N. crassa* fermented both glucose and pentose sugars present in SB cellulose and hemicellulose, reaching almost double ethanol production than *S. cerevisiae*.

c) Biomass

Lignocellulosic materials are the most promising feedstock as natural and renewable resource essential to the functioning of industrial purposes. A considerable amount of such materials as waste byproductsare being generated through agricultural practices mainly from various agro based industries. [16]

Biomass energy has the potential to greatly reduceour greenhouse gas emissions. Biomass creates about the same amount of carbon dioxide as fossil fuels, but every time a new plant grows, carbon dioxide is actually removed from the atmosphere. The net emission of CO_2 will be zero as long as plants continue to be replenished for biomass energy purposes. These energy crops, such as fast-growing trees and grasses, are called biomass feed-stocks. The use of biomass feed-stocks can also help increase profits for the agricultural industry. Agro-industrial biomass comprised on lignocellulosic waste is an inexpensive, renewable, abundant and provides a unique natural resource for large-scale and cost-effective bio-energy collection [26]Dedicated biomass crops are typically non-food crops grown as feed-stocks for the purpose of transportation fuel, energy production and a wide range of industrial end uses. Instead of crop residue, dedicated biomass crops such as Sorghum Miscanthus and switchgrass among others, could be used for bioenergy production since both species have been reported to produce high yields of biomass with relatively low nutrient. Plant biomass is the most important trait because of abundant amount of Cellulose which can be converted into monomeric sugars.

d) Brown midrib sorghum

Wild relatives of sorghum species and land races are good source of genetic variation. Brown midrib sorghum Sudan grass could be exploited to create varieties with low lignin and high biomass through introgression breeding. Forage sorghum developed and bred to contain the BMR gene, has less lignin and will be good substrate for cellulolytic enzymes. Less lignin ensures the plants are softer and easier to apply pretreatment methods.

A class of low lignin mutants that were discovered in maize (first identified in Minnesota) (Jorgenson L.R 1931) were the brown midrib mutants(bm)The bm mutants were named based on the red-brown coloration of lamina midrib, which intriguingly accompanied low levels of lignifications in stem

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tissue(20 Nelson OE 1964,. General screening of chemical mutagenesis populations subsequently expanded the number of allelic and non-allelic brown midrib lines in maize and sorghum [2].

The brown midrib trait was discovered during the 1930's at Purdue University and early breeding work identified reduced vigor and yield concerns. These problems have been overcome and results show reduced lignifications, reduced cell-wall concentration, and increased palatability. Of 38 bmr mutant reported in sorghum four have been identified as individual group bmr2, bmr6, bmr12, bmr19 based on allelic test. Brown midrib (*bmr*), tan coloration to reddish brown of leaf midrib is a morphological marker to identify a popular genetic mutation in C4 grasses. Brown midrib, a genetic mutation in several grassy species, reduces lignin content in the total plant parts. Lignin is mostly indigestible, supporting material and in plants. During the past several years the brown midrib (*bmr*) trait has been introgressed into forage sorghum, Sudan grass, and corn. The results have been significant for the most part. IVTD values for *bmr* sorghum have demonstrated that differences between corn and sorghum silages have been removed.

Brown midrib (*bmr*) mutations in sorghum is characterized morphologically by brown vascular tissue in leaf blade and sheath, as well as in stem [17].Low lignin bmr-mutant of forage sorghum stalk, lignin content of sorghum bagasse, wheat straw, miscanthus and switch grass were evaluated and compared for bio-ethanol production. Also enzymatic hydrolysis yield of sugars and fermentation yield of ethanol studied.[24]

List of *bmr* source and derivative evaluated for biofuel traits

Sr No	Entries	Traits	BMR source/Derivative
1	IS 23253	New bmr source	Bmr source
2	IS 23789	Bmr 6	Bmr source
3	IS 21890	Bmr7	Bmr source
4	IS 23787	Bmr6	Bmr source
5	IS 21887		Bmr source
6	SPV 2017	Tall, bmr	Bmr source
7	SPV 2018	Tall,bmr	Bmr source
8	COS 26 X IS 21888	Mid tall	Derivative
9	PC 5 X IS 21888	Mid tall	Derivative
10	Palem 2 X IS 21891-2	Mid tall	Derivative
11	EC 582508 X NSSV 352	Mid tall	Derivative
12	BN 111 X(CSV 15X IS 21891)	Tall, high biomass	Derivative
13	SSV 84 X IS 21890	Mid tall, broad leaves	Derivative
14	RS 647 X EC 582508	Mid tall, broad leaves	Derivative
15	NSSV 258 X EC 582508-1	Mid tall, broad leaves	Derivative
16	NSSV 258 X EC 582508-2	Mid tall, broad leaves	Derivative
17	[(CSV 15 X IS 21891-1-1-1)X(HC 260XB 35)-2-1-1-1	Mid tall, broad leaves	Derivative
18	EC 582508 X RS 647	bloomless	Derivative

e) *Current Status*

At present, researchers are more interested in sugars-based ethanol (first generation ethanol)which can also be used as food source (examples are corn, sorghum and sugarcane) to non food based ethanol (second generation ethanol) such as lignocellulosic biomass and as a consequence limit the competition between fuels and food production. Field crops are one of the best sources of renewable energy which can be used as feed-stock for biofuels production. The cell wall of plant biomass consists of several major polymers: cellulose, hemicellulose, lignin, and minor components such as organic acids, proteins, tannins as well as secondary metabolites of intrinsic value. A complete understanding of the lignin biosynthetic pathway, including the underlying regulatory mechanisms, is essential for efficiently engineering and harnessing the energy stored in lignocellulosic material.

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