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Bioconversion of sugarcane crop residue for value added products – An overview

Raveendran Sindhu [a, *], Edgard Gnansounou [b], Parameswaran Binod [a], Ashok Pandey [a]

[a] Biotechnology Division, National Institute for Interdisciplinary Science and Technology, CSIR, Trivandrum, 695 019, India
[b] Ecole Polytechnique Fédérale de Lausanne, Institute of Urban and Regional Sciences, GC A3, Station 18, CH-1015, Lausanne, Switzerland

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ABSTRACT

Sugarcane is a major crop cultivated globally and the residue left over after the crop harvest and extraction of juice is a good biomass source that can be used for the production of several useful chemicals. The sugarcane bagasse is an excellent substrate for the production of various biochemicals and enzymes through fermentation. Now major interest is focused on the utilization of these residue for biofuel production. The sugarcane crop residue is rich in cellulose and hemicellulose, hence it can be used for the production of bioethanol and other liquid transportation fuels. The present review gives a detailed account of the availability of sugarcane residue and various commercially important products that can be produced from this residue. It also provides recent developments in R&D on the bioconversion of sugarcane crop residue for value added products.

1. Introduction

Sugarcane is a major crop cultivated in tropical and sub-tropical countries like Brazil, China, India, Thailand and Australia [1]. It belongs to grass family, Gramineae and its botanical name is *Saccharum officinarum*. It was first grown in South-East Asia and Western India. Then the cultivation of sugarcane extended to all tropical and sub-tropical regions. Sugarcane area and productivity differ from country to country. It is cultivated in about 200 countries and Brazil is the world's largest cane producer and contributes to 25% of world's total production. India is the second largest producer of sugar in the world.

Its distinguishing features are high biomass yield, high sucrose content and high efficiency in accumulating solar energy. After harvesting of sugarcane, leaves, tops and trash are left in the cane field while the sugarcane stalks are transported to sugar mills for the extraction of cane juice for sugar production [2].

Bio-refinery concept of complete utilization of sugarcane biomass will become a prime component for a sustainable sugarcane industry. Biorefinery involves fractionation and reforming of an input feed stock into multiple product streams. Lignocellulosic biomass offers tremendous biotechnological potential for use as substrate in bioconversion processes and can be effectively exploited for the production of bulk chemicals and value added products.

The annual global production of sugarcane is about 328 Tg. Asia is the primary production region which contributes to 44% while South America is the second largest production region producing 110 Tg of sugarcane which contributes to 34% [3]. Sugar production is the major use of sugarcane consuming about 92% of sugarcane. Other uses such as animal feed and so on contribute less than 3%. Studies have indicated that sugarcane crop when harvested comprises of 75% sugarcane stalk and 25% leaves and tops. This waste provides a huge potential fuel resource.

Harvesting of sugarcane lead to the production of large amount of post-harvest residues including sugarcane tops which could be an abundant, inexpensive and readily available source of lignocellulosic biomass. This can be used as good substrate for the production of bioethanol as well as for other value added products. In India, it is the most surplus available residue and is usually burnt in the field itself and does not find any suitable application. Burning of sugarcane tops produce fly ash, severely damages soil microbial diversity and raises environmental concerns [4]. Roofing and compost are some of the other uses. It can be used as an animal fodder for a few days before the leaves start rotting. Usually for every 1 MT of sugarcane produced, 0.20–0.30 MT of sugarcane tops

* Corresponding author. Tel.: +91 471 2515426; fax: +91 471 2491712.
E-mail addresses: sindhurgcb@gmail.com, sindhufax@yahoo.co.in (R. Sindhu).

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Sugarcane bagasse, the largest agro-industrial residue is a fibrous residue of cane stalks left after the crushing and extraction of juice from the sugarcane. This by-product of the sugar industry is mainly used by sugar factories as fuel for boilers [5]. Comparing to other agricultural residues, bagasse can be considered as a rich solar energy reservoir due to its high yields and annual regeneration capacity. Currently several processes and products have been reported using sugarcane bagasse as a raw material. This include electricity generation, pulp and paper production and various products based on fermentation like industrially important enzymes, bioethanol, organic acids, alkaloids, protein enriched cattle feed, antibiotics etc. Bagasse in most case is used for co-generation of heat and power or sometimes used for manufacture of building materials. Paper plants also purchase bagasse from sugar plants.

Sugarcane molasses are a dark, viscous and sugar rich by-product of sugar extraction from sugarcane. It is used as a feed ingredient, binder and as an energy source. Around 3–7 tons of molasses were generated from 100 tons of sugarcane. The composition of the molasses varies depending on cane variety, climate and processes employed for sugar extraction. Molasses contain approximately 34% of sucrose, 11% of reducing sugars (glucose and fructose) and several minerals. It can be used as animal feed, for yeast cultivation, for the production of ethanol, rum, other alcohols and organic acids.

Vinasse is a by-product of sugar-ethanol industry and is acidic compost with a pH of 3.5–5.0 with a high organic content and unpleasant odor. On an average 10–15 L of vinasse is generated while preparing each liter of ethanol [6]. Inadequate and indiscriminate use of vinasse in soils and water bodies leads to several environmental hazards. Several studies have been carried out for finding adequate uses and treatments of vinasse. It can be used for fertirrigation, yeast production, energy production and as a raw material for the production of livestock and poultry feed [7]. The chemical composition of vinasse varies depending upon the source used for ethanol production and distillation. The study revealed that fertirrigation or the use of vinasse as a fertilizer is the best alternative for vinasse reuse and disposal. Several new green methods need to be explored for developing novel uses of vinasse [8]. Cortez et al., 2007 [9] carried out anaerobic digestion of vinasse for the production of biogas. The anaerobic digestion was carried out in two stages-the acidogenic phase and the methanogenic phase. In the acidogenic phase the complex chains of carbohydrate, lipids and proteins were hydrolyzed to organic acids and in the methanogenic phase these acids were converted to methane and carbon dioxide. Laime et al., 2011 [10] utilized vinasse for the production of yeast. Additional supply of ammonium and magnesium salts as well as high energy consumption for water removal from the process made it economically unviable.

Chemical compositions of the bagasse may vary for different sugarcane varieties depending upon the genotype. Several other factors like location, age of crop, environmental and cultivation parameters also affect the composition of the biomass. A study conducted by Benjamin et al., 2014 [2] showed wide variation in agronomic parameters, chemical composition and sugar released after pretreatment of sugarcane varieties harvested for two growing seasons. A significant difference was observed among varieties over harvest years. The study revealed severe drought negatively influenced the performance in cane yield except for variety containing the highest lignin.

Leaves and tops contain higher amounts of salts and nutrients. The sugar contained in the stem is 90% sucrose and small amounts of glucose and fructose. The greatest difference in composition of sugarcane is seen in the moisture content which varies between 13.5% in the dry leaves and 82.3% in the tops. The content of carbon, hydrogen, nitrogen and sulfur showed similar values in dry leaves and in tops.

Bagasse contains 50% of cellulose, 25% each of hemicellulose and lignin. Chemically it contains about 50% α-cellulose, 30% pentosans and 2.4% ash [5]. Bagasse offers numerous advantages over other crop residues like rice straw and wheat straw because of its low ash content. Rice straw and wheat straw have 17.5% and 11.5% of ash respectively. Bagasse is the raw material for 20% of total paper production.

Sugarcane tops contain 29.85% of cellulose, 18.85% of hemicelluloses and 25.69% of lignin [11]. The composition may vary depending on the geographical location, variety etc.

The present review addresses the potential of sugarcane crop residue for the production of various value added products.

2. General conversion methods

Native form of lignocellulosic biomass is a tough feed stock for hydrolysis due to crystallinity of cellulose and due to the compact packing of cellulose, hemicelluloses and lignin. Due to recalcitrant nature of the lignocellulosic biomass a pretreatment process is essential for the removal of hemicelluloses and lignin and to increase cellulose conversion efficiency. The basic objective of the pretreatment is to make cellulose accessible by the action of cellulases which is achieved by removal of hemicelluloses or lignin from the biomass. A wide range of physical, mechanical, chemical, biological, combination and alternative strategies were reported for achieving these goals. In addition to pretreatment, an effective cellulase cocktail, enzyme loading and hydrolysis conditions and nature of the lignocellulosic material are critical for maximum hydrolysis.

Several reports were available for the pretreatment of sugarcane tops like acid [11], alkali [12], surfactant assisted acid pretreatment [13], surfactant assisted ultrasound pretreatment [14] and sequential pretreatment [15]. Among these methods the highest reducing sugar yield was observed with sequential pretreatment (0.796 g/g) followed by alkali pretreatment (0.775 g/g). But there were generation of inhibitors during acid and alkali pretreatment. The alternative strategies like surfactant assisted ultrasound pretreatment and surfactant assisted acid pretreatment strategies did not generate any inhibitors. Compared to other pretreatment strategies employed for sugarcane tops, sequential pretreatment was found to be better in terms of improved reducing sugar yield without any inhibitor generation as well as better removal of hemicelluloses and lignin from the biomass compared to conventional acid and alkali pretreatment as well as other alternative strategies of pretreatment. Selection of the pretreatment strategy will be based on the economic feasibility as well as the targeted product.

Pretreated bagasse serves as an efficient inert support material for fungal cultivation in SSF. Several pretreatment strategies were reported for bagasse like acid [2], alkali [16], combined [17], organo-solvent [18], organic acids [19] and physical [20]. Though several pretreatment strategies were available only a few seems promising. One of the most important challenges associated with pretreatment is to identify the composition of the feed stock and to device the best pretreatment strategy of the selected item. Proper pretreatment can improve the biomass digestibility and increase accessibility of enzymes to the materials. Cellulose crystallinity, accessible surface area, degree of cellulose polymerization, lignin and hemicelluloses seal as well as degree of acetylation of hemicelluloses are the critical factors to be considered for developing a suitable strategy for pretreatment of a specific biomass. Composition plays an important role. Hence fine tuning of specific pretreatment strategies to be developed for each biomass which will