AATCC Review

02 February 2024: Received
19 February 2024: Revised
03 March 2024: Accepted
18 March 2024: Available Online

www.aatcc.peerjournals.net

Review Article

Open Access

Sugarcane and Its Bioproducts - A Renewable Resource for a Novel Bioeconomy

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ABSTRACT

Sugarcane (Saccharum officinarum) existed in Papua New Guinea, for more than 12,000 years from where it spread to southeast Asia and India. Sugarcane which forms a major source of sugar and other sweetening agents for human consumption is one of the most abundantly grown crops across the globe which is used in sugar industries mainly for sugar production. Sugar, a traditional sweetener, contributes to the colour, texture, and flavour of food. Even in the Indian market, different types of sugars with various qualities are available meeting the needs of different customers. Growing instability in the market due to competition and imbalances in the demand-supply position of sugar, global surplus, sugarcane vis a vis sugar price etc, sugar industries urge the formation and application of new tools to improve its efficiency, potential, and productivity. Through innovative processes and products, sugar plants can develop competitiveness to compete in this continuously changing global market position. Hence, there is a need to explore other possibilities like industrial exploitation of by-products obtained from sugarcane. Besides sugar production, the by-products produced in the sugar plant during various stages of processing are press mud which is sent to farms to be used as fertilizer, ash to brick industries, molasses to distilleries, bagasse which is used either as a fuel for boiler or sent to paper industries and effluent which is used as irrigation water after treating it in an effluent treatment plant. Global warming and the harmful effects of greenhouse gas emissions have urged the use of biofuels and the sugar industry holds the promise of being a hub of it. Therefore in this aricle, an attempt has been made to review the production process of sugar at the industrial level and the potential and efficient use of by-products of sugar industries. In continuation, different feedstocks, and process for bioethanol production have been discussed.

Keywords: Bioethanol, Lignocellulose, Molasses, Sugarcane, Sugar, Press mud, by-products , Biofuel, Fermentation

Introduction

Sugarcane (*Saccharum* sp. hybrid complex) is one of the most important sources of food and bioenergy, cultivated in tropical and subtropical parts of the world. The crop is of economic importance due to its high productivity and efficient use of agricultural inputs [1]. Sugarcane is a species of grass whose juice is an ample source of sugar and contributes to around 80 percent of the world's sugar production [2]. Globally, it is now cultivated in diverse agro-climatic conditions stretched between 30° N and 30° S of the equator with its optimal performance around 20° latitude [3].

Sugar is made from sugarcane, and was domesticated around 8000 BC in New Guinea from where moved to east across Southeast Asia until it reached India [4]. India was a pioneer to start the organizing sugar production by using the process of juice extraction and obtaining crystals. After Brazil, India is the second largest producer of sugarcane [5]. In the country, sugar industry is the only industry that commercially utilizes all the by-products produced during processing [1].

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DOI: https://doi.org/10.58321/AATCCReview.2024.12.01.280

Prospects of Sugarcane By-Products for Commercial Utilization

The sugarcane plant is efficient in utilizing solar energy for sugar and biomass. It is a well-known source for food, fibre, fodder, chemical and fuel. However, its main by-products are bagasse, press mud and molasses [6]. The products manufactured from sugarcane are (Table 1; Fig. 1):

- **Sugar-** high-energy and natural sweetener.
- **Ethanol-** the source of renewable fuel.
- **Bio-electricity-** produced by burning leftover sugarcane biomass
- **Bio-plastics-** used for packaging food and other consumer products

Sugar Production

Sugarcane is an established source of sugar which accumulates in the stalks in the form of sucrose, a primary source for intensive plant improvement programs. Sucrose ($C_{12}H_{22}O_{11}$, Molecular weight: 342.30) is α-D-glucopyranosyl-β-D-fructofuranoside, a most abundantly occurring disaccharide containing fructose and glucose with both monosaccharides bound by their respective anomeric carbons, thereby rendering sucrose a nonreducing sugar. It is chemically inert and extremely soluble in water, although very sensitive towards acid-catalyzed hydrolysis.

Sucrose is synthesized in the leaves of sugarcane with the help of enzymes: *Sucrose phosphorylase* (more important in bacterial systems), *Invertases* (primarily responsible for inversion of sucrose) and *Transglucosylases*- Sucrose synthetase and Sucrose-P synthetase; the latter being more important. Sucrose is translocated as sucrose-P in the phloem (of vascular bundles) and stored in the parenchymatous cells in the stalks. It is stored not only in the vacuoles but also in the cytoplasm [8]. Ripe juice of sugarcane stalk contains 15-20 per cent sucrose, however, the maximum sucrose accumulation potential of fresh weight of stalk is 27 per cent with a minimum moisture content of 70 per cent [9].

The various steps of sugar production are; cane preparation, extraction of juice, clarification, filtration, evaporation, centrifugation and sugar drying (Fig. 2 and 3) which will be briefly discussed in the following sections [13,14].

Cane Harvesting

Cane harvesting can be done either manually or mechanically [15]. However, to obtain improved sugar recovery it is necessary to adopt proper harvesting tools to harvest the cane at ground level and the most important is to harvest the cane at optimum maturity.

1. Cane Management

As immature tops and extraneous matter like water shoots, roots, mud, trash and binding materials etc. affect the sugar recovery; clean cane should be supplied to the mills. The cane should be crushed immediately after harvesting to avoid staling losses. However, cane crushed at milling stations has generally been stale in quality due to time gap between the harvesting of canes to crushing as a result of transport constraints. This poor management at mill level results in the staling of cane. Transport management is a must for the synchronization of harvesting, transportation and crushing [16].

2. Extraction of Juice

Juice extraction is carried out using a massive roller. Firstly, the cane is prepared for crushing by using; revolving Knives which cut the cane stalks into chips followed by finer preparation through heavy-duty Shredders or Fibrizers which shred the cane stalk without extracting any juice. It is then passed on to mills/ crusher rolls (heavily grooved) which lead to breakage of the cane and extract the maximum amount of juice. The crushed cane or bagasse then successively passes through a series of mills, may be 4-5 having 3-6 rollers. After the first mill juice/hot water is applied over the bagasse blanket to leach out the maximum quantity of sugar, a process known as imbibition [13]. Juice extracted during the best possible milling process contains more than 95 per cent of the sugar which was present in the cane. This extraction is generally called as sucrose or Pol per cent. The final bagasse also contains some amount of unextracted sugar, fiber, and water. This material can be used as fuel, but many industries use it for wallboard or paper manufacturing. It can also be used as a cattle bed preparation or in other commercial forms.

3. Clarification (Purification of Juice)

Next step after extraction is clarification to remove or separate impurities. Clarification is done by using flocculants which react with the organic material and precipitate the debris (press mud). The juice obtained from the milling process is acidic and turbid.

Lime along with heat treatment act as clarifying agent which removes impurities by neutralizing the acidic juice and formation of insoluble salts. The precipitates contain solid as well as fine particles. The insoluble particulates obtained during process called as press-mud is separated by gravity or centrifuge. The press-mud is filtered using rotatory drum vacuum filters. The brown clarified filtered juice is directly transferred to evaporators and the press cake is utilized as biofertilizer [17].

4. Evaporation

After clarification, juice is preheated by passing through heat exchangers. Evaporation is initially performed to concentrate the juice in an evaporator and then to sugar crystallization in vacuum pans. The clarified juice contains about 85 per cent water which was added during lime treatment. Some amount of this water is evaporated in a vacuum, consisting of series of vacuum boiling cells which are arranged in such a series so that every next cell has a higher vacuum to boil juice at a lower temperature than the previous one. The decrease in temperature from one evaporator to other also decreases the pressure, lead to the boiling of juice at the lower temperature in the succeeding evaporator. Thus, the vapors from one cell help in boiling of the juice in the following cell. By this process of evaporation, the stream discharged into the first cell has multiple effects on evaporation. The parameter used for the juice analysis after evaporation is measured in terms of Brix which is per by weight of total soluble solids in juice and expressed in degrees [18].

5. Clarification of Raw Syrup

After evaporation, the syrup is clarified, aerated, and filtered in the clarifier, (the Jacob type or talo clarifier). The syrup is then passed to the vacuum pans for crystallization.

6. Crystallization

Crystallization is carried out in vacuum pans having a single-effect where syrup is evaporated to maximum saturation [19]. At this point, seed grain is added which acts as a base for sugar crystal formation. Subsequently, as the water evaporates, more syrup is supplemented. The process is continued up to its full capacity. The dense mass formed by crystals and syrup is known as massecuite. The content of the vacuum pan is moved into a crystallizer with the aid of foot valve. The massecuites boiling and molasses re-boiling is carried out using boiling systems.

7. Centrifugating or Purging; Reboiling Molasses

This step is carried out to separate the crystals from the molasses. The massecuite is centrifuged to obtain molasses in the outer shell and crystals remain in the inner basket.

The boiling of raw syrup yields raw sugar and A molasses. The A molasses is again passed to a vacuum pan and re-boiled which yield B molasses, that in turn yields crystals of second batch. The B molasses is then again re-crystallized and centrifuged to separate the raw sugar. The crystals obtained in all batches are combined to enhance the sugar output. The B molasses obtained during processes is impure, hence, again re-boiled to form C molasses. This remains in crystallizers for several days to cool down. The final molasses serve as seeding in vacuum pan, cattle feed and in the manufacturing of alcohol, etc. Finally, sugar is dried, cooled and transferred to packing bins.

Kinds of Sugar

Sugars are of different types and have different applications depending on its specific property (Fig. 5). Sugar can act as a flavouring agent and sweeten baked goods, savory dishes, and drinks. It also works to manage texture by making dough tender and also as a decorative ingredient by providing baked goods, a nice golden-brown colour. Sugar is prepared by processing juice from sugarcane or sugar beet plants. Different kinds of sugars have been developed by slight adjustments in the sugar processing procedure at the stage of clarification, crystallization and drying. Sugars of various types of crystals, their sizes and unique properties of pol% and colour make them suitable for different kinds of foods and beverages. Its colour is mainly determined by the quantity of molasses or mother liquor remaining or supplemented to the crystals. Even varying the level of molasses results in a specific type of product giving pleasurable flavors. Heating sugar alters the moisture content and changes the colour and flavour. There are some kinds of sugar which are used only in food industries and are generally not available in the market [10, 13, 14, 20-23].

Broadly sugar can be categorised into crystallized (centrifugal) and non-crystallized sugars (non-centrifugal sugars). Crystallized sugars can be either single crystallized or double crystallized

Crystallized Cane Sugar

Crystallized cane sugars are the free flowing granular sugars formed by separation of the molasses/mother liquor and crystals.

1. Organic Cane Sugar

Organic cane sugar is a single crystallized cane sugar obtained by processing juice from organic sugarcane. The juice is clarified and concentrated into a syrup having sugar and molasses. The syrup obtained is then seeded with sugar crystals and finally boiled and centrifuged to separate out some (but not all) of the molasses. Organic cane sugar crystals are golden in colour and have a pleasant aroma with a characteristic flavour, provided by retained molasses.

2. Conventional White Sugar

Conventional white sugar is a double-crystallized sugar, also labeled as table sugar, granulated sugar or refined sugar. White cane sugar is made from re-melting of single crystallization sugar and further refined to remove all the leftover traces of molasses and minerals prior to re-crystallized in the form of pure sucrose. It is whitened, by using carbon filtration and ion exchange and then dried and packaged. It is available in many sizes such as:

a. Caster Sugar

The crystals of caster sugar are superfine and dissolve much faster than standard granulated white sugar. Caster sugar is therefore generally used for making syrups, meringues, and cocktails.

b. Pearl Sugar

Pearl sugar is also called nib or hail sugar having an opaque colour and hard texture. Its unique property is that it withstands high temperatures. Pearl sugar is commonly used to decorate cookies and pastries.

c. Sanding Sugar

Sanding sugar has large crystals which makes it suitable for decoration purposes. Sanding sugar adds extra crunch and texture to baked products.

3. Demerara, Turbinado, and 'Sugar in the Raw'

The crystals of both Demerara and Turbinado formed by single crystallization are large in size, pale golden in colour with a mild flavour of molasses. The larger size add a smooth flavour and crunch in the bakery products.

4. Brown Sugar

Brown sugar consists of crystallized sugar and molasses, but a slight change during processing leads to variations in its size, colour, and stickiness. On the basis of the intensity of the colour, brown sugar can be categorized as light and dark brown sugar. Generally, there are two methods for brown sugar processing:

a. In the first method of processing, the crystals of brown sugar are formed at a step where molasses is removed either completely or partially. The type of brown sugar is called as Muscovado or Barbados sugar. The crystals of Muscovado are moist and of dark colour and have a burnt sugar flavour.

b. In the second method, molasses is supplemented into organic cane sugar or conventional sugar after the full production of sugar crystals. Here, the crystals are slightly less moist and sticky, and give a fruity or floral aroma.

5. Confectioners' Sugar

Confectioners' sugar or powdered sugar or icing sugar is prepared from conventional white or organic cane sugar. Confectioners' sugar made by conventional white sugar is generally prepared using corn starch whereas confectioners' sugar made by organic cane sugar makes use of tapioca starch in place of corn starch, without impacting the flavour.

6. Liquid Sugar

Liquid sugar is also made by organic cane sugar or conventional white cane sugar. Liquid sugar is a type of crystalline sugar which has been pre-dissolved in water. Liquid sugar utility is in ingredients when its addition is preferable in dissolved form. Liquid sugar is best for large-scale applications like the preparation of beverages or yogurt

7. Invert Sugar

Invert sugar is prepared when sucrose crystals are broken down into fructose and glucose. Invert sugar is mostly used to enhance the retention of moisture; hence, it is a good option for packaged foods.

Non-Crystallized Cane Sugar (Non-Centrifugal Sugar) or Whole Cane Sugar

In non-crystallized sugar, after clarification of juice from crushed cane stalks, evaporation is carried out until the sugar crystallizes spontaneously followed by cooling to room temperature to a solid block. Non-crystallized sugar or whole cane sugar is a specialized healthy option rich in nutrients as it retains all minerals present in molasses. This sweetener is not free flowing therefore becomes very difficult to use in large-scale industries.

Diversification and Utilization of Sugarcane By-products

The economies of many countries are completely reliant on earnings from export of sugar and any drop down in global rates will have a detrimental effect on their economy. In such cases diversification and utilization of by-products becomes the decisive factor for the stable maintenance and remarkable progress of the industry. Installation of by-products based industries is an economic way to diversify and utilize the sugarcane by-products like molasses, bagasse and pressmud [24]. The other sugarcane products which are least exploited at the commercial level are green leaves, tops and trash, including seepage generated during sugar and bioethanol production [25]. Major sector/industries that utilize sugarcane bio-products for commercialization are bagasse, molasses and press mud-based industries.

Bagasse based Industries:

Bagasse is a waste material left after extracting juice from cane during sugar production which contains huge quantity of fibres. Conventionally, it is used as a fuel to generate power during sugar processing. Bagasse is a most important sugarcane by-product which is used to produce many value-added products like the pulp, paper, particle boards, cattle-feed etc [26-29]. Different technologies have been developed for the utilization of bagasse, hence, efforts are made for saving bagasse. For setting up bagasse-based industries, surplus from a number of factories should be pooled to support the plant. Today, there is a need to conserve forest resources as their exploitation by industries for the production of timber, pulp and paper, has reached an exhaustive limit. Bagasse-based industries can act as a best substitute to depleting natural resources. Bagasse-based fiber and particle boards are used for manufacturing cupboards, table tops, ceiling, office racks etc. [30, 31].

In some countries, bagasse is used as cattle feed after pre-hydrolysis treatment on a commercial level as bagasse lignin content causes problems in its digestibility by the animals. In the future, there is scope of developing this type of industry in the country.

Molasses based Industries:

Molasses is the final viscous mother liquor resulting during sugar production normally sent away by sugar factories as a waste product. Molasses contains about 45-55 percent total sugar. therefore, it is an important raw product to be used in making of value-added products at the commercial level like ethyl alcohol, citric acid, oxalic acid, cattle feed, baker's yeast, etc. and many alcohol-based chemicals [32-36].

Press Mud-based Industries

Pressmud is an industrial waste, released during the process of sugar manufacturing which is of no use to the sugar industry [37, 38]. However, press mud alternate use as a biofertilizer is worth mentioning, as it enriches the nutritional status of soil with iron, manganese, calcium, magnesium, silicon, and phosphorus [6, 39, 40]. Its high moisture content boosts the growth of soil-friendly microorganisms e.g. earthworms [41] and help in increasing the organic matter of soil. Pressmud with trace amounts of sugar increases its decomposition in soil [42, 43] and find its use as a substrate for composting [44]. All these properties make, pressmud a valuable bio-fertilizer for agricultural crop production [45].

The viability of sugar industry is in danger. Exploration of sugarcane as a multiple product commodity to be used as alcohol, biofertilizer, paper along with other possible value-added downstream products is a saving step for the industries profitability and sustainability.

Bioethanol Production from Sugarcane

Sugarcane is currently being used to produce sugar at commercial level. India is a top sugar consumer because of its massive population and sugar being an essential energy source of common man [46]. World markets are facing continued low production price for raw sugar which led to the investigation of alternative products possessing the capacity to overcome sugar industry from the posed challenges. Bioethanol production from sugarcane can act as a potential alternative which can assure the functional and profitable viability of the sugarcane industry [47]. Ethanol as a blend in some specific proportion with petrol or diesel for domestic use is today's major focus. In addition, alcoholic drinks and industrial chemicals, are other optional uses of bioethanol which can strengthen the industries' economy.

Worldwide popularity of biofuel in recent times has been highlighted because of depleting oil reserves, and climate change due to harmful gas emissions. Biofuel, being a renewable energy source in contrast to limited fossil fuels, can be an ecofriendly option.

Bioethanol is chemically ethyl alcohol produced by microbial fermentation of biomass sugar which is subsequently distilled to be utilized as a transportation fuel [48]. Exploration of easily assessable, economical and high-yielding carbohydrate sources for bioethanol production is the need of the hour [49]. Mainly, three types of feedstocks i.e. sugar and, starchy crops, along with lignocellulosic materials, are being used for bioethanol production. Bioethanol feedstocks can be categorized as first generation feedstocks; second generation feedstocks and third generation feedstocks on the basis of carbohydrate source being exploited for bioethanol production.

First Generation Feedstocks

First-generation bioethanol feedstocks are derived from agricultural sugar-rich crops that are generally edible and serves as a human or animal food source (Fig. 6). Sugarcane [50, 51], sugar beet [52, 53], sorghum [54] are the sugar rich candidates along with molasses [55] which serve as first generation feedstocks for bioethanol generation..

Sugar transformation into ethanol from sugar crops is a relatively simple process as it does not require any step of hydrolysis but only a sugar extraction process which is ultimately fermented to alcohol. In addition to cane juice, molasses which is a co- product obtained after crystallization of sugar, can also be processed for ethanol production [53].

In brief, production of first generation fuel using sugarcane as feedstock, involves cane preparation by removing impurities adhered to the cane followed by juice extraction [56-58]. The extracted juice is then clarified and concentrated [59]. Clarified juice is feeded into the fermentor [60-62]. Desired end product i.e. bioethanol, is recovered by distillation and dehydration. The initial steps for raw sugar and bioethanol production are common up to juice concentration. We have already discussed all the steps of raw sugar manufacturing, but here we will briefly go through all the important alterations in specific steps in context of bioethanol production from cane juice and molasses.

Juice Concentration and Sterilization

The concentrated juice after multiple serial evaporations in

MEE (multiple effect evaporator) systems results into sucrose concentration of 22 per cent. Optimization of sucrose concentration in sugarcane molasses is achieved by diluting it to 14-18 per cent. Prior fermentation step, sucrose concentration of the feedstock, determines the fermentation rate. This concentration step is crucial in terms as it make the distillation step energy efficient [63]. Fermentation is possible only in sterile environment so, concentrated syrup is sterilized and further cooled till the temperature drops down to 28°C.

Fermentation

Bioethanol production involves biological fermentation which converts sugars such as glucose, fructose, and sucrose to ethanol and CO2, with the help of microorganisms.. Several strains of microorganisms like fungi, yeasts, and bacteria can be used for the production of ethanol. However, Saccharomyces cerevisiae is the most preferred microbe which is capable of very rapid rates of glycolysis and ethanol production [64]. Sugarcane feedstock mainly contains sugar in the form of sucrose, a disaccharide, which upon fermentation by S. cerevisiae yields ethanol. In the fermentor, sterilized juice undergoes inversion, and sucrose gets converted to glucose and fructose. Yeasts feed upon these reducing sugars producing main products i.e. ethanol and CO2, along with some co-products, like yeast, glycerol, higher alcohols and organic acids, Fermentation gases, so produced during the process are treated to recover ethanol, while yeasts is recovered from wine by centrifugation [63]. Fermentation should be preferably done at 28°C to get the maximum yield of ethanol and with least losses on account of sugar and ethanol. Vinasse, a by-product left after biomass distillation in the process of ethanol production, generation is also checked at low fermentation temperatures [65-67]. High temperatures in bioreactors, above 30-32°C, has a detrimental effect on ethanol production levels and should be maintained using appropriate cooling systems [68].

Ethanol Recovery: Distillation and dehydration

Distillation, the most dominant industrial purification technique, exploits the different volatilities of components of a mixture. In water-ethanol mixture, ethanol is more volatile and vaporizes at 78°C in comparison to water which vaporizes at 100°C. So, the proportion of ethanol to water is more in the vapour phase on heating. This type of differential separation is based on the principle that on heating a mixture, low boiling point components with low boiling point gets accumulate in the vapour phase whereas high boiling compounds remain in liquid phase. The conventional distillation process comprises of a distillation column and a rectification column. Preheated wine from the fermentor enters the distillation columns having pressure in the range of 133.8 to 152.5 kPa, to yield phlegms containing 40 per cent ethanol along with vinasse containing 0.02 percent ethanol and volatile ethanol. However, hydrated residues of ethanol, termed as phlegmase and fuel oil are obtained in the rectification column with a pressure range of 116 to 135.7 kPa. Additionally, an extractive separation process with Monoethylene glycol was used to recover anhydrous bioethanol in the upper portion of the column along with recovery of extractive solvent in a recovery column.

Recently, high grade fuel ethanol with purity of more than 99.5 per cent is achieved by using molecular sieve dehydration operations, post distillation. Molecular sieves, made up of specialized Zeolite materials possessing efficient and preferential adsorbing capacity, removes the residual water content from the azeotropic mixture thus increasing the overall efficiency and purity of the end product [69]. Another option to molecular sieves is corn grits with the same function but, with the additional advantage of being bio-renewable, economical and easily disposable material [70]. However, corn grits have some issues in terms of its long term mechanical stability which limits its use [71]. Another technique termed "pervaporation" can concentrate ethanol to maximum purity by combining the differential permeability property of the membrane with the added advantage exerted by vacuum pressure for the speedy ethanol recovery. Pervaporation is considered as an energy-efficient option in relation to distillation. Therefore, curtailing of energy requirement of crucial steps, by continuous refining can make the whole bioethanol production system an economical and viable one.

Sugarcane juice and molasses are generally utilized as sugar source for the production of first-generation bioethanol. The feedstocks available to a sugar factory include raw sugar, C molasses or final molasses, B molasses, A molasses, evaporator supply juice (ESJ), secondary express juice. Among the molasses, C molasses is routinely utilized as ethanol generating feedstock in comparison to A and B molasses, which only add to the raw material content. A molasses or B molasses are more beneficial in the context of recovering crystallized sugar to increase the overall sugar recovery and thus sugar yield of the sugar industry. Sugarcane molasses are rich source of sucrose (31 %) along with inverted sugar (15 %) [72]. High sucrose concentration is fatal for the growth of microorganisms facilitating fermentation, so the sucrose concentration of sugarcane molasses should be droped down to approximately half (14 to 18 %) of its concentration before fermentation. With regard to government policies, approximately 70 per cent of molasses is allocated for alcohol production where as the remaining proportion can be used for other alternative end product possibilities e.g. feed or fuel [73].

In Brazil, ethanol in major proportion is produced from sugar cane juice whereas in minor percentage using cane molasses [74]. In contrast, the main feedstock for ethanol production in India is cane molasses. 'C-Heavy' molasses is the conventional source of ethanol for Indian sugar industries, but now in times of surplus sugar, the wise choice is to divert sugar for ethanol production [75]. In July, 2018, the government permitted to make ethanol from sugarcane juice and B molasses. This new venture is experimented by a cooperative sugar mill in Kolhapur district of Maharashtra, which becomes a pioneer in producing fuel-grade ethanol directly from sugarcane juice.

Evaporator supply juice (ESJ) and Secondary express juice (SEJ) are potential options for distillery. Bioethanol production from evaporator supply juice or clarified juice is equivalent to ethanol production from raw sugar and final molasses in combination. The process is cost effective as raw sugar manufacture expenses are avoided with a limitation of production of ethanol to the crushing season. Similarly, ethanol production from secondary express juice or mixed juice helps in cutting down the processing costs of the sugar industry. The process of maceration efficiently extracts all the available sugar (Reducing and Non Reducing) present in cane which ultimately increases the sugar load for feeding to the distillery

Second Generation Feedstocks

First-generation feedstocks are derived from edible sugar-rich crops, so biofuel production utilizing such crops is a threat to food security. So exploitation of an alternative feedstock, in the name of second-generation ethanol, is the need of the hour for sustainable bioethanol production. Second-generation biofuels are defined as fuels produced from lignocellulosic material which is a non-food carbon source with abundance availability on the earth Inexhaustible nature of lignocellulosic biomass due to its production by universal photosynthetic process mark it as a suitable feedstocks for second generation ethanol production. Sugarcane bagasse, rich in cellulose and hemicelluloses agricultural residues of the lignocellulosic category, is a potential candidate for bioethanol production [76]. A schematic outline for the conversion of biomass to fuel is shown in Figure **7**.

Sugarcane bagasse is an ideal feed stock for second-generation ethanol production as, this carbohydrate rich cellulosic biomass is a renewable source and do not compete with food/feed demand. In comparison to first-generation feedstocks i.e. sugar, starch and molasses, the fermentation of plant biomass (lignocellulosic material) is a complex process and its complex polymeric structure is a challenge in its efficient bioconversion to ethanol [77]. However, this process has high ethanol production costs due to the complexity of plant cell wall structure and composition [78].

The bioconversion of lignocellulosics to ethanol, consists mainly of two processes: The primary step involves the hydrolysis of cellulosic and hemicellulosic sugars to reducing sugars which in a subsequent step gets fermented to ethanol.

Enzymatic Hydrolysis

The hydrolysis is catalyzed by cellulase enzymes and subsequently, yeasts or bacteria do the fermentation part [79]. Cellulase enzyme, efficiency and accessability, of hydrolysis is hindered because of the complex integrity of lignin and hemicellulose fibrils in lignocellulosic materials [80]. So, pretreatment of lignocellulosic biomass is a must for altering the complex structure. Pretreatment methods, expose the surface area to ease out hydrolysis. of the polymer to fermentable sugars efficiently [81-87]. Cultivation of fungal cultures is being used at the Commercial level for the production of cellulases. Cellulases producing fungal species are; *Sclerotium rolfsii*, *Trichoderma*, *Aspergillus*, *Schizophyllum*, *Fusarium* and *Penicillium* [76, 83, 88-91].

Pretreatment methods depending upon the treatment used can be categorized as physical, chemical, physico-chemical and biological as presented in Table 2 [91].

Physical pretreatment

Physical pretreatment of Biomass can be done by several mechanical and non-mechanical methods. Mechanical methods reduce biomass size and cellulose crystallinity by a combination of efficient chipping and fine grinding during the process of milling [86]. Irradiation, using gamma rays and microwave energy are non-mechanical methods to improve enzymatic hydrolysis of lignocelluloses [92].

1. Chemical pretreatment

Degradation of hemicelluloses to release lignin can be done using chemical pretreatment methods. Chemicals being used for such treatment include organic solvents, acids, alkalis, ozone and hydrogen peroxide [89].

2. Physico-chemical pretreatment

Chemical and physical pretreatment methods when used in combination to effect the hydrolysis of the lignocellulosic material is termed as physico-chemical processes [93].

3. Biological pretreatment

Microorganisms can also serve as pretreatment agents for carrying out enzymatic hydrolysis of lignocelluloses.

Fermentation

After enzymatic hydrolysis, the lignocellulosic substrates are converted to monosaccharides, which are further fermented to ethanol by microorganisms to produce ethanol and CO_2 [64].

Third Generation Feedstocks

First and second-generation biofuels have some major limitations that inspired the exploration of an alternative feedstock i.e. third third-generation feedstocks, for biofuel production [94, 95]. Third-generation biofuels relates to algal biomass that utilize CO_2 as feedstock for ethanol production. Exponential growth pattern of microbial cultures lead to biomass doubling in no time and possess distinct ethanol yield in comparison to lignocellulosic feedstocks [96]. Microalgae nutritional components that serve as precursors for bioethanol and biodiesel production includes lipids, carbohydrates and proteins. Microalgae-based feedstocks require very low maintenance and can be a potential bioenergy source for biofuel production.

Conclusion

Mankind is exploiting plants to act as biofactories that produce a vast array of compounds of commercial value. Sugarcane is an important example of biofactory because this biomass is harvested and used for sugar production. After the sugar has been extracted, the leftover material i.e. baggasse is burnt to generate energy (steam and electricity). Sugarcane's potential to act as a substrate for biorefineries is also being demonstrated. The ethanol and bioplastics examples show how a sugarcane industry be transformed. Such a transformation is no doubt an expensive and long-term enterprise that requires the cooperation of sugarcane industries, government, private corporations and investors. Together these groups can cooperate to make the economy a financial reality for sugarcane growers and millers.

Future Prospectives of the Study: The future prospects of sugarcane and its bioproducts in the context of a novel bioeconomy are promising, as they align with the global shift towards sustainable and renewable resources. The growing awareness of environmental issues and the increasing demand for sustainable products provide a favourable market for sugarcane-based bioproducts. Consumers, governments, and industries are showing a keen interest in adopting renewable resources and reducing their carbon footprint. Sugarcane, with its renewable nature and versatile applications, fits well into this trend. Ongoing research and technological advancements in the field of biotechnology, genetic engineering, and process optimization are likely to improve sugarcane varieties, increase yields, and enhance the efficiency of bioproduct extraction. These innovations will contribute to the economic viability and competitiveness of sugarcane-based bioproducts. Moreover, as technology and awareness continue to advance, sugarcane is likely to play a key role in shaping the bioeconomy of the future.

Conflict of interest: No potential conflict of interest was reported by authors

Acknowledgement: Not Applicable

Table 1. Major By-Products from Sugarcane for Its Possible Exploitation at Industry Level

	Direct Utilization	Distillery Industry	Fermentation Industries	Miscellaneous
Molasses	Exportation	Rum	Vinegar & Acetic acid	Monosodium Glutamate
	Fertilizer	Ethyl Alcohol	Butanol-Acetone	Dextran
	Animal Feed	Rectified Spirits	Citric acid	L-Lysine
		Anhydrous Alcohol	Lactic acid	Xanthan gum
		Alcohol Derivatives	Glycerol	Itaconic acid
			Yeast	
Bagasse	**Utilization as Fuel**	**Fibrous products**		**Miscellaneous**
	Electricity	Bleached pulp		Furfural
	Charcoal briquettes	Fibre board		Alpha Cellulose
		Particle Board		Plastics
		Writing Paper		Poultry Litter
		Bagasse concrete		Animal feed
Press Mud	**Fertilizer**	**Animal Feed**		**Cane Wax**

Table 2. Different Methods of Pretreatment used during Bioconversion of Lignocellulosics to Ethanol

Physical	Physicochemical	Chemical	Biological
Milling	Steam explosion	Ozonolysis	Fungi
Pyrolysis	Ammonia fibre explosion	Acid hydrolysis	Bacteria
	Liquid hot water	Alkaline Hydrolysis	
	CO_2 explosion	Oxidative delignification	

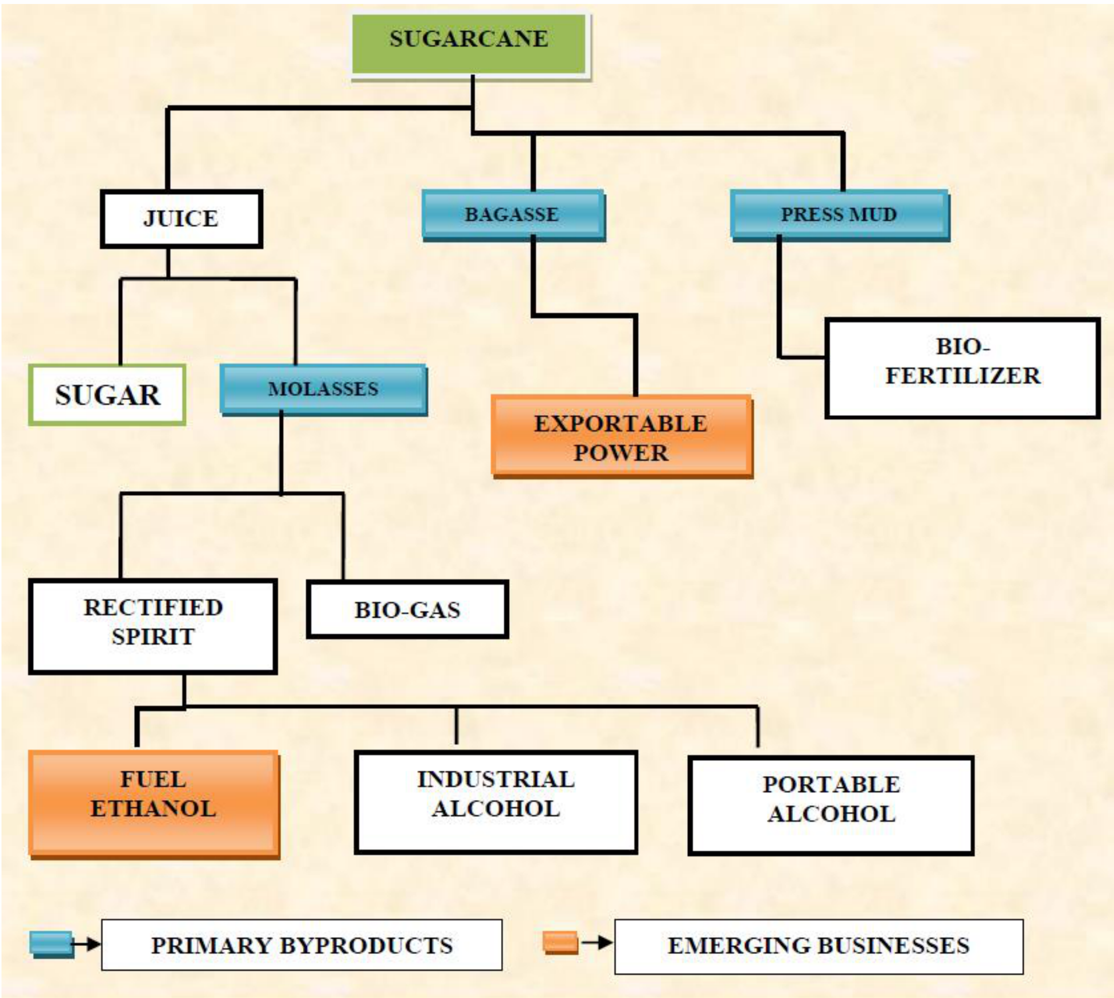

Fig1. By-products of sugarcane [7]

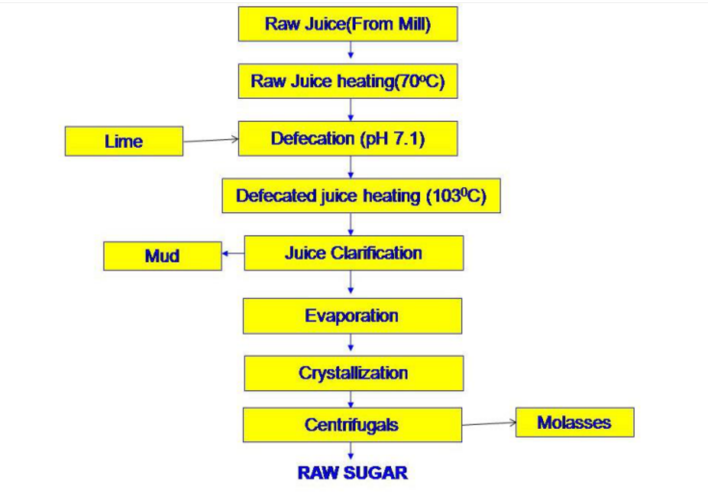

Fig 2. Flow chart showing process of raw sugar process [10]

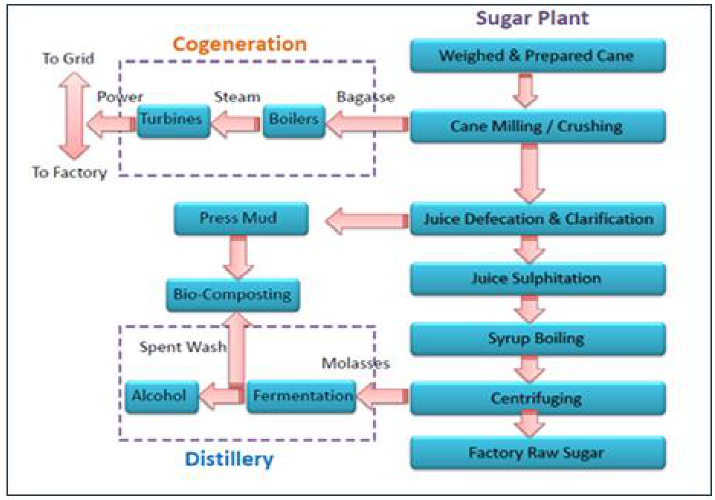

Fig. 3 Simplified process of sugar Production from sugarcane [11]

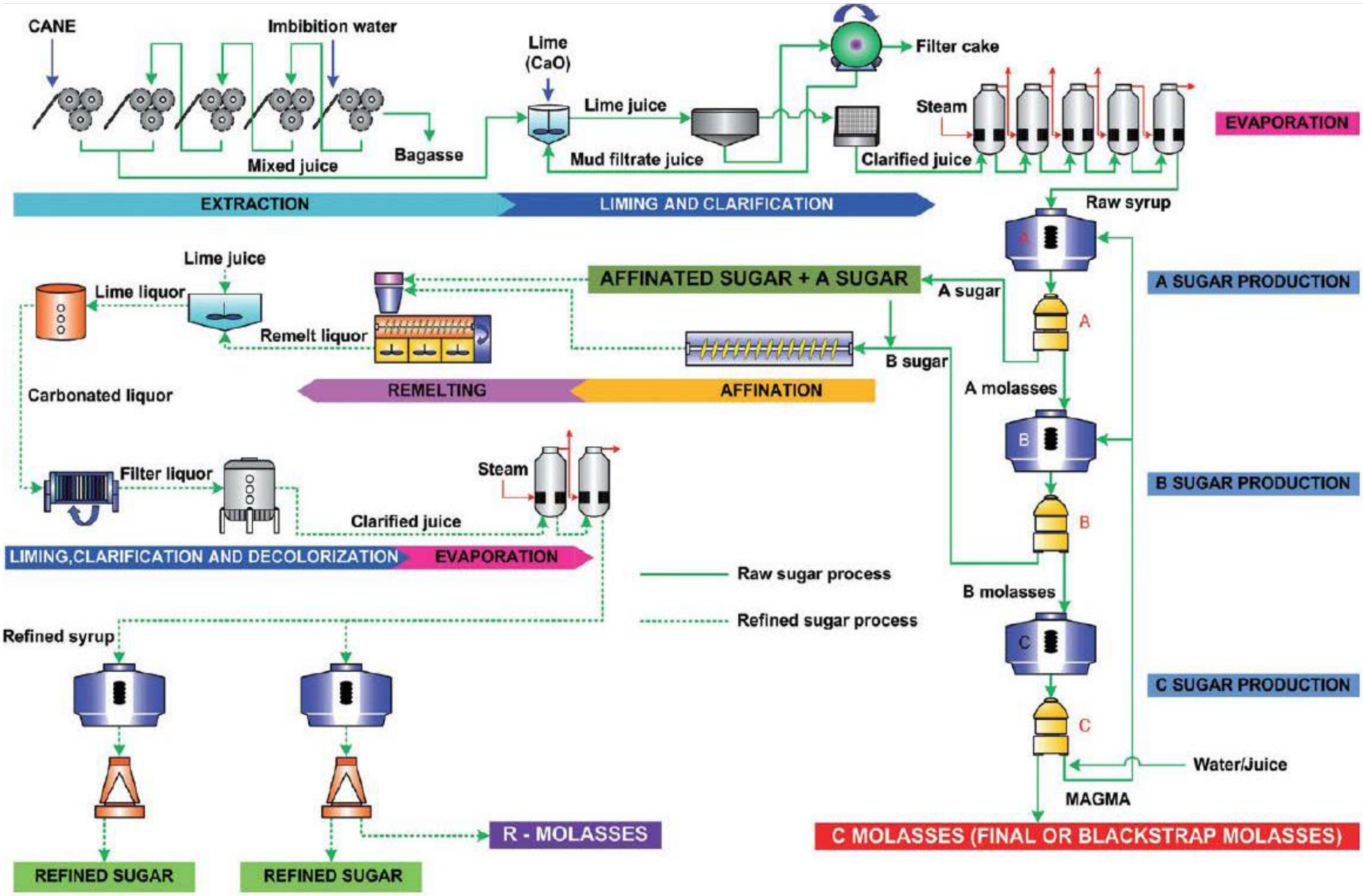

Fig 4. Raw and Refined Sugar Manufacturing Process [12]

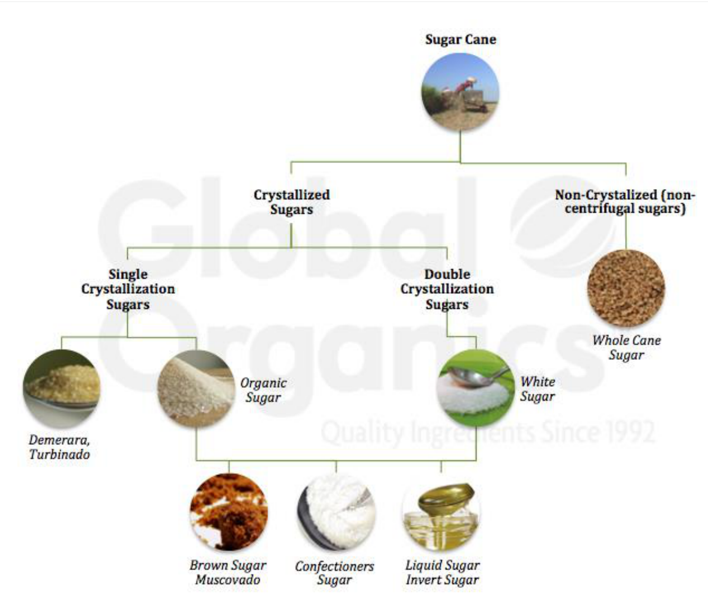

Fig 5. Different types of sugar produced after processing of sugarcane [20]

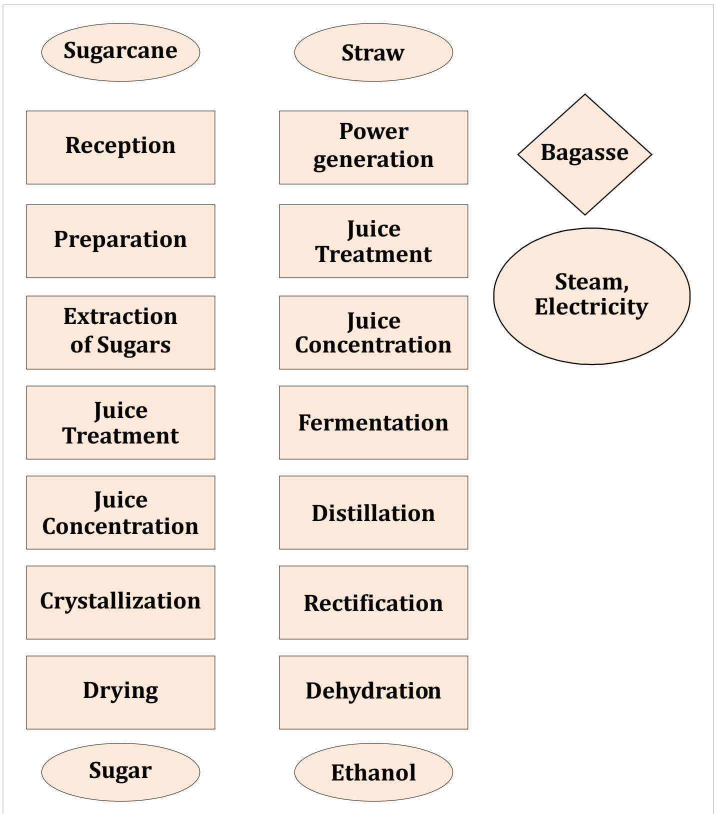

Fig 6. Simplified scheme of first generation sugar and ethanol production from sugarcane

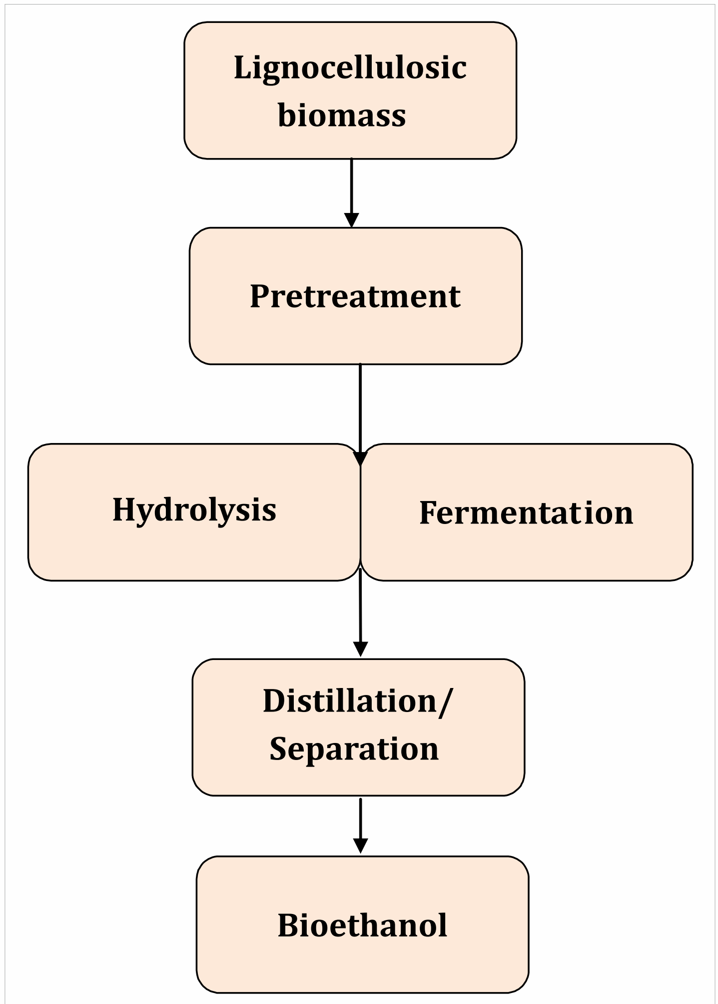

Fig 7. General outline of the lignocellulose to bioethanol production process

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