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A Novel Approach: Value Addition and Utilization of Residual Biomass from Indian Medicinal and Aromatic Plants

Dr. Shilpa Purkait[1], Prof. Aheli Guha[2]

[1,2]Assistant Professor, Department of Medical Lab Technology, Dr. B.C. Roy Academy of Professional Courses, (Formerly known as Dr. B. C. Roy Engineering College), Durgapur, West Bengal-713209, India

Abstract

Bioethanol could be used as alternative fuels due to its positive impact on the environment. Now a days, ethanol was produced from renewable raw materials by different bioprocess operational modes mostly from sugar and starch containing raw materials. Traditionally, ethanol has been manufactured from food grains viz. corn and wheat. However, the production of bioethanol from food crops has received criticism and raised concern over food verses fuel dispute. Transfer of currently available technologies for utilizing inedible plant materials could reduce pressure on food crops. Agricultural residues present an attractive and low-cost feedstock for bioethanol production. There is an increasing demand to produce bioethanol due to their dual as oil-based energy sources as well as for the production of chemicals and solvents. The production of bioethanol involves two steps: i. Enzymatic breakdown of starch into glucose. ii. Fermentation of glucose by yeast. Furthermore, the steam treated could be easily transformed to ethanol in comparison with biomass which has not been pre-treated with hot steam. This is the extra benefit of using aromatic plant as a feedstock for ethanol production. The essential oil containing plants are useful for the production of a number of medicinal, herbal, and their products. After the harvesting of the utilising part from its plant, the whole plant is discarded or sometimes used as a soil conditioner or cattle feedstock. Occasionally, the biomass is burnt within the field, thereby causing inevitable environmental consequences. This review proposal will highlight the residual part of medicinal plant valorization to increase biorefinery profitability. It can be considered a promising strategy of “circular economy” as well as “waste to wealth” in the society.

Keywords: Biorefinery, Fermentation, Waste to wealth, Plant valorization, Bioethanol

1. Introduction

Ethanol is a clear liquid alcohol that is made by the fermentation of different biological materials. This alcohol is known to have many uses, but one in particular is becoming more popular. Ethanol, the most widely used biofuel. There are many sources used for the production of ethanol. The main of this study was to find out new source for ethanol production and to optimize the various factors to increase its concentration.

Biofuel generation from agricultural renewable feedstocks has great impact in scientific world because they have been used for supplying energy and also recommended as substitute of traditional fuel. This biofuel is environmental-friendly and most importantly they could be obtained from sugar and starch containing feedstocks. Lignocellulosic raw materials are a mixture of carbohydrates which should be treated by a suitable pretreatment treatment to make simple conversion of enzymes to manufacture fermentable sugar compounds. After hydrolysis, the carbohydrate is transformed into ethanol by the process of fermentation. In spite of technical and economical challenges, sustainable lignin-derived feedstocks exhibit cost-effective raw materials that is not comparable with food and feed chain which can also stimulate the "sustainability" approaches of the environment. Several bioprocess techniques have been developed for bioethanol production from inexhaustible feedstocks. Simultaneously alternative separation and purification techniques have also been extensively studied in recent times (Bušić et al. 2018). Recently, there is a gaining of criticism and raising concern of the production of bioethanol from food crops. Because it may rise a food insecurity issue in the next generation (Gamage et al. 2010). Bioethanol production from second generation is sustainable and profitable than the other three generations. In case of first generation of biofuel, it is produced from food sources such as vegetative oil, starch, sugar, or animal fats using traditional methodologies which can creates an imbalance in the food economy, address to increase food prices and hunger. On the other side, in comparison with third and fourth generation of bioethanol, which leads to environmental pollution. But in case of second generation of biofuel, it emits low amount of greenhouse gases when compared to other generation biofuels and they also do not affect food economy as well (Saha and Basak 2020).

2. Residual biomass of MAPs

A huge amount of solid, liquid and gaseous biomass is generated from agro-waste industries throughout the world every year (Santana-Meridas et al. 2012). These biomasses can make negative environmental impact if they are not properly recycled through a biological approach (Liang et al. 2011). Residual biomasses are regarded as net-zero emission of carbon because they do not produce extra Co_2 to the environment. Conversely, the reusing of waste biomass is important to reduce environmental pollution due to inappropriate disposal methods (Zhu et al. 2012). There is a chance of binary utilization of residual biomass, one is distillation of biochemical component and further modification into valuable materials. Within this frame of reference, proper utilization and recycling of residual biomass revived from Indian medicinal and aromatic plants can be a potential source regarding their economic profitability, waste-management approachability as well as social beneficially (Saha and Basak 2020).

Essential oils of medicinal plants are extracted by hydro-distillation of fresh aromatic herbs. The steam-heated biomass can be easily converted to bioethanol in comparison with other types of biomasses which has not been treated with hot steam during their pretreatment technique (Burducea et al. 2018). This is extra advantage of using residual feedstock of aromatic plant for ethanol production. During the process of steam-distillation, a large quantity of spent water is manufactured as a liquified waste material which is called "hydrosol". This hydrosol has a sweet smell and also contain a sufficient amount of valuable oil (Zhu et al. 2012). Regarding this matter, Saydut et al. 2008 reported in his literature that the sesame essential oil has many applications in medicinal and herbal properties. After the harvesting of sesame crop, the complete portion of the plant is discarded or used as a soil fertilizer or fodder (Xie et al. 2011). Sometimes this biomass is incinerated within the ground which may lead to environmental pollution (Li et al. 2017). Consequently, a huge amount of extraction biomass residues produced from aromatic plants kept unused. So, utilizing reusing of these residual biomasses could be a potential source of additional benefit for aromatic plants grower.

Considering these facts, in this study we are trying to highlight production of bioethanol from the residual part of aromatic or medicinal plant biomass which leads to a sustainable approach of the environment as well as society.

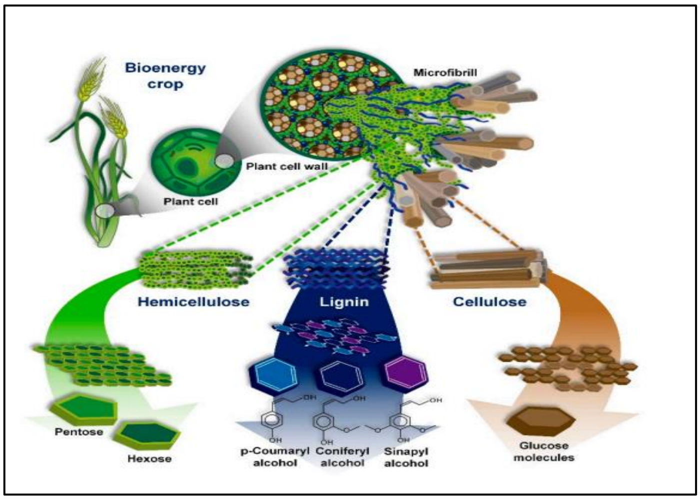

Fig: Structure of lignocellulosic biomass and its biopolymers (Hernández et al. 2019).

Composition (%Dry Basis)				
Substrate	**Cellulose**	**Hemicellulose**	**Lignin**	**References**
Sugarcane bagasse	45	32	17	Yadav et al., 2022
sorghum straw	35.87	26.04	7.52	Hernández et al. 2019
Corn stover	42.21	22.28	19.54	Hernández et al. 2019

3. Utilization of MAPs other than Biofuel:

As MAP residue consist of non-utilized part of various medicinal & aromatic plant, it can cause serious damage to the environment. So proper management of these waste in on demand. Residual biomass of MAP can also be utilised by various method of bioconversion compiled with chemical, physical and physiochemical process into different sustainable products. Other than biofuel production MAP can also employ to produce biosorbent, biogas, biochar, animal feed, biocompost and so on (fig. 2.)

1. **Biosorbent:** Wastewater of Agriculture and Industry sometimes contain pesticides and heavy metals that leads to environmental damage and fatal health issues. Removal of contaminants from wastewater using effective methods are become demanding. Residual biomass from MAP can be a good alternative for production of Biosorbent by removing Heavy metals, toxic compounds and dyes (Ajoy and Basak 2020). For this purpose, waste water remediation can be achieved through Adsorption due to easy design and cost effectiveness. Distillation waste of mentha can remove Cu and Zn by surface modification immobilized through alginate beads (Hanif et al. 2009). The discarded fruit waste or peel of medicinal plants like *Garcinia cambogia* and *Limonia acidissima* and can be utilized as a biosorbent for reducing of metal and dye, accordingly (Torane et al. 2010).
2. **Biochar:** Biochar is the solid product of biomass pyrolysis. It has been generated and utilized for several long times and best known as charcoal when produced from woody biomass (Weber and Quicker 2018). It is used as an ideal soil improvement for development of sustainable crop and environmental management. Soil fertility is improved by effective application of biochar produced from distillation biomass of *Java citronella* (*Cymbopogon winterianus Jowitt*) and menthol mint

(*Mentha arvensis*) (Nigam et al. 2018). Chemical fertilizer accompanied by lemongrass (*Cymbopogon flexuous*) distillation waste biomass, enhanced the crop yield and properties of soil (Saha et al. 2020).

3. **Animal feed:** MAP residues contain carotenoids, polyphenolics along with dietary fibers which acts as nutraceutical and bioactive compounds. After the processing of essential oil from MAP, the residual contains lignocellulosic biomass and silica which can be an alternative source of animal feed (Ajoy and Basak 2020). For instance, Ginseng after extraction of bioactive compounds facilitates protein rich diet to cattle and chicks that in turn increase the quality and yield of milk product. (Kim et al. 1994).
4. **Biogas:** There increasing demand for bio-gas produced from agricultural waste encourage the utilization of herbal industries waste for generation of biogas. Problem arises because of the high-water content, complexity and rigidness of the MAP residues that contains cellulose, hemicellulose and lignin yield less quantity of methane (Slavov et al. 2017). To enhance the production of biogas, pretreatment based on microwave or alkaline compound can be employed (Ajoy and Basak 2020). The most commonly used method for biogas production is hydrolysis followed by anaerobic digestion. Hydrolysis convert the LCB into its simpler sugar form and make it accessible for methanotrophic bacteria under anaerobic condition. Occasionally biomass of MAP residue is associated with carbon rich substrate to achieve better result (Alfa et al. 2014). Co-digestion of *Phyllanthus emblica* residues with food waste generate large amount of methane which leads to production of biogas (Panyadee et al. 2013).
5. **Biopesticides:** Interest is growing to use biopesticide instead of chemical pesticides to reduce environmental and human health issues. MAP biomass also include some pesticidal properties. Hydrosols of *Mentha suaveolens* and *M. pulegium* contain strong insecticidal properties against a pest of *Toxoptera aurantii* (Aphididae) (Zekri et al. 2016). Likewise, *Ocimum basilicum* and *Ruta chalepensis* hydrosols facilitates a meaningful impact on the death rate against the crop pests *Aphis gossypii* and *Tetranychus urticae* (Traka et al. 2018).
6. **Biocompost**: Composting is considered much safer than land filling to convert organic waste for improvement of soil properties and sustainability of environment (Biswas et al. 2009). This process alter the lignocellulosic biomass into essential and available nutrients necessary for plant growth. Distillation waste biomass from Palmarosa reported to produce enriched potassium compost more efficiently than chemical fertilizer (Basak, 2018). Menthol mint (*Mentha arvensis*), patchouli (*Pogostemon cablin*) and citronella (*Cymbopogon winterianus*) residual waste provide better result in comparison with chemical fertilizer. Earth worm (*E. eugeniae*) has significant role in conversion of citronella biomass into vermicompost with higher plant nutrient composition than regular compost (Boruah et al. 2019).

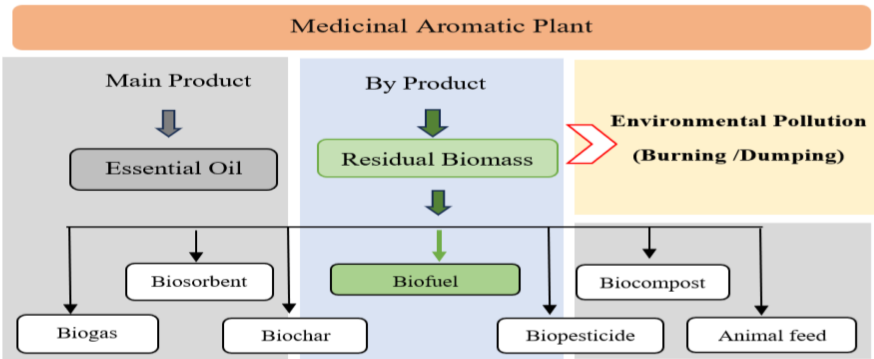

Fig. 2. A possible route for utilization of Medicinal and aromatic plant

Techno-economic assessment

The multipurpose use of MAPs decreases the expenditure of other economic challenges in these industries (Zhu et al. 2012). At first the bio-active components from those parts of medicinal plants, which are not used and then the rest of the residual biomass can be utilized for further value addition. There are several modern advanced technologies has been developed to improve value addition of the residual biomass of MAPs. This way of reusing of these types of residual biomass can lead the sustainable development of the society. For economically scaling up of a trending process, it is required to have techno-economic aspect for this assessment. This strategy will make a pioneer for the growth and development process of capital investment, for calculating expenditure for involvement of maintenance and operation charge, evaluating the profit and also finds the route for future research development. There is a lacuna of research in this area. Even though, this appraisal is very trending now a days because the traditional biorefinery techniques are complicated due to the investment of large capital (Lesage-Meessen et al. 2018). The residual biomass of MAPs can be treated for the production of biopolymer, bio-coal and biochar. The purification process of residual biomass from MAPs carries large amount of lignocellulosic component and can also be reused as an alternative source of commercial cellulose to reduce the availability of cellulosic fibre in India (Mishra et al. 2018a; Mishra et al. 2018b)..

3. Tentative methodology:

3.1. Pretreatment: Bioethanol production from Lignocellulosic biomass by using feedstock of sugarcane baggage is the most emerging technique in modern biorefining area. (Arijana Bušić et al. 2018). LCB consisting of complex polysaccharide that is converted into fermentable sugar by a series of pretreatment methods (Cardona. 2010). These methods could be divided into four groups i) Physical methods breakdown larger particles into smaller ones by cutting, milling or grinding ii) Chemical methods uses organic solvents, acids or alkalis iii) physicochemical methods such as steam explosion iv) biological methods using microbial association or consortia (Hernández-Beltrán. 2019). These methods in combination results delignification of biomass.

Physicochemical pretreatments involve explosion like (steam explosion, Carbon dioxide explosion, Sulfur dioxide explosion, ammonia fibre explosion), microwave, wet oxidation, ultrasound and liquid hot water pretreatment. Ammonia fibre explosion (AFEX) is a crucial pretreatment that include high temperature, pressure and ammonia for physical and chemical processes respectively to achieve effective feedstock hydrolysis. AFEX increases the surface availability for hydrolysis, facilitates decrystallization of cellulose and partial hemicellulose depolymerization and remove lignin recalcitrance in the treated feedstock. However, this process is not appropriate for high lignin content biomass (Kumar P et al., 2009).

This study suggest that milling followed by NaOH treatment and steam explosion can be better for conversion of feedstock as fermentable sugar (Yoo J et al. 2011). In compared to acid pretreatment sodium hydroxide is widely used because of its low cost with high efficiency conversion of feedstock (Kucharska, 2018). NaOH enhance cellulose accessibility for saccharification by disrupting structural linkage, effect the lignin barriers, which results in a sharp increase in saccharification yield (Mosier et al. 2005). NaOH treatment with steam explosion could be an efficient alternative for pretreatment of bagasse before enzymatic hydrolysis (Goshadrou et al. 2011).

3.2. Hydrolysis and Fermentation: Previous section described a combination of pretreatment techniques of lignocellulosic raw materials for better access of cellulose in the bioethanol production. After pretreatment cellulose and hemicellulose is obtained as crystalline and liquid form respectively. Cellulose can be further degraded into glucose by enzymatic degradation which is known as saccharification. Different strategies have been introduced to prevail against the obstacles such as separate hydrolysis and fermentation (SHF), simultaneous saccharification and fermentation (SSF), simultaneous saccharification and co-fermentation (SSCF) and consolidated bioprocessing (CBP) (Rodionova et al. 2022). In SHF the fermenting biomass hydrolysates involves a sequential process where the hydrolysis of cellulose and the fermentation are carried out in different units (Sánchez and Cardona, 2008). Instead of using monoculture of *S. cerevisiae*, coculture with *S. cerevisiae* and *P. stipites* obtain higher yield of ethanol (Yadav et al. 2011).

3.3 Microbial Fermentation: This process includes microbial conversion of simple sugars (hexoses and pentoses) to ethanol. In separate hydrolysis and fermentation (SHF), hydrolysis of cellulose and fermentation carried out in different bioreactor. This step can be achieved through sequential process where solid fraction of pretreated lignocellulosic material undergoes hydrolysis called saccharification (Sánchez and Cardona 2008). The choice of organism for this step is *Saccharomyces cerevisiae*, the most common organism for the production of ethanol from hexoses. Although, *S. cerevisiae* cannot convert all the sugars present in lignocellulose into ethanol for instance pentoses. In this context, filamentous fungus *Mucor hiemalis* has some benefits over other ethanol producing microbes as it able to grow higher temperature than yeast and assimilate ethanol from pentoses (Millati et al. 2005). To avoid this circumstances thermotolerant organisms have been studied. Simultaneous saccharification and fermentation (SSF) most often uses *Trichoderma ressei* and *S. cerevisiae* (Cardona. 2010). SSF include hydrolysis and fermentation which occur in single bioreactor. As a result, microorganisms utilise sugar hydrolysate instantly after conversion (Pavlečić et al. 2017).

3.4 Separation: Ethanol is separated from fermentation bioreactor by using Polymeric membranes like polydimethylsiloxane, porous polypropylene, polyether block amide membranes. Among these membranes, Polydimethylsiloxane is widely used for its stability and good filtration capacity (Hwang and Ku 2014). Pervaporation can be done simultaneous to fermentation for in situ extraction of ethanol. A microfiltration or ultrafiltration unit is associated with the pervaporation membrane for removal of biomass to enhance efficacy of this technique (Kaewkannetra et al. 2011).

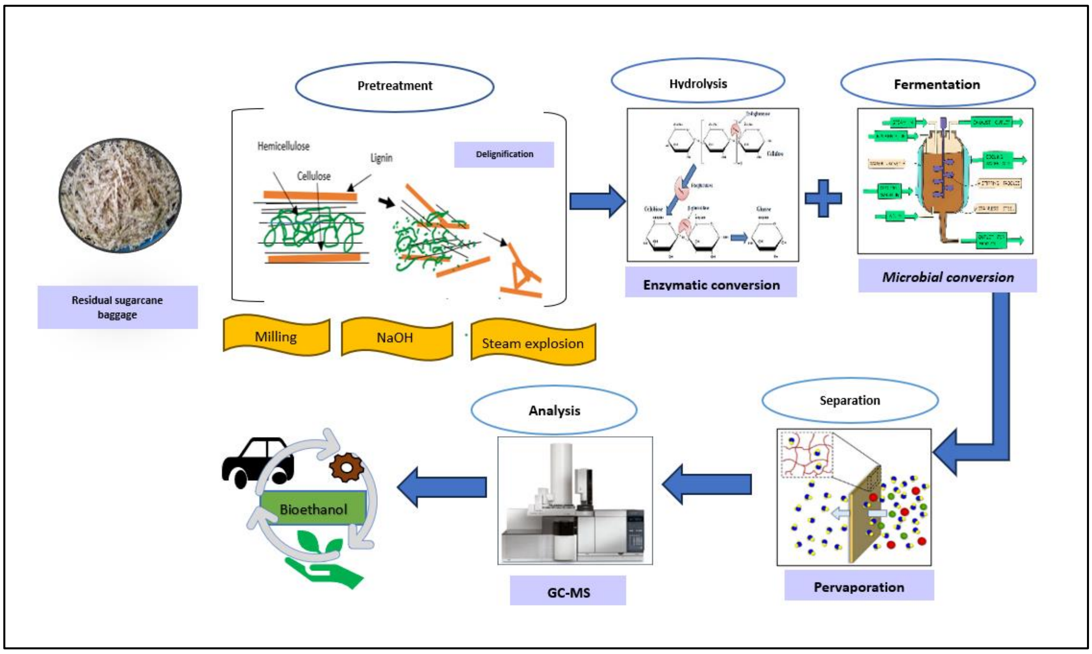

Fig. 3. Schematic of ethanol production from residual biomass of MAPs

Conclusion

The use of residual biomass from underutilized part of medicinal aromatic plants (MAPs) and extraction of waste materials addresses a sustainable approach to the social and environmental impact in the society. The possible outcome of environmental pollution is decreased by transforming the residual biomass from these aromatic plants into valuable products which can be economically profitable to the stakeholders. These approaches have pleasantly accepted in pharmaceutical, cosmetics and dietary industries. Extra advantages may come from MAPs by utilizing residual biomass as feedstocks for biogas, biosorbent, biopesticides and animal feed as well. Regarding this, the MAPs valorization technologies are required to investigate in more advance manner for commercial development to diminish the environmental management as a result of discarding or burning of MAPs residual biomass.

Declaration of Competing Interest

The authors declare that they have no conflict of interests.

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