Approaches to Agro-industrial Solid Waste Disposal and Bioenergy Generation

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Aneet Kaur

Abstract

Increasing concern about the environment, food and feed shortages, and hike in the price of petroleum has stimulated interest in the new ways of producing more bioenergy. The interest is rapidly increasing toward converting agricultural and industrial wastes to commercially valuable products. Waste disposal and pollution are inextricably linked. Unwanted residues that are usually perceived to be of negative value are described as waste. The production of citrus juice on an industrial level leads to a considerable quantity of solid and liquid residue (8–20 million tons year^{-1}), which is considered as waste. Citrus processing residues possess no economic value. They are rich in soluble sugars, cellulose, hemicellulose, pectin, and essential oils that could form the basis of several industrial processes. Possible applications of these waste residues include fertilizer, cattle feed, charcoal, adsorption of chemical compounds, bioethanol production, and extraction of essential oils and pectin.

The majority of waste disposal situations involve pollution of various kinds. Thus, the solid wastes and its disposal is one of the serious problems in developing countries, which require eco-friendly treatment options. The bioethanol made from citrus waste biomass can offer immediate and sustained greenhouse gas advantages and also solve the problem of its disposal. The study proposes alternatives for the minimization and recovery of solid and liquid residues generated in the production of citrus processing with a view of industrial plants for its reuse and value addition, thus saving environment from its hazards.

A. Kaur (✉)
Department of Biosciences, Asian Educational Institute, Affiliated to Punjabi University, Sirhind Road, Patiala 147001, Punjab, India
e-mail: aneetkaur1@rediffmail.com

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11.1 Introduction

11.1.1 Agro-industrial Waste Generation and Disposal

11.1.1.1 Solid Waste Generation

Rapid population growth and socioeconomic development in the country have increased the generation of waste. There is an estimated increase of 1–1.33% in solid waste generation during the last few decades in India (Beukering 1999). This enormous increase in solid waste generation will have significant impacts in terms of the land required for disposing this waste as well as on methane emissions. The increase in solid waste generation would impose serious threat to the environment. It is evident from the fact that the cumulative requirement of land for disposal of agro-industrial solid in India would amount to around 1400 km by 2047 (Singhal and Pandey 2001). Solid waste generation, urbanization, and increase in population are highly interlinked and affect the process of land acquisition for disposal of waste. Improper disposal of waste practices in the past has created several hazards as well as aesthetically unpleasant sites. According to the Environmental Protection Agency (EPA), in a global level, it is estimated that in a 1990 survey, in cities approximately 1.3 billion metric tons of municipal solid waste was generated, averaging about the average person dumps almost 4.5 pounds of waste into landfills every single day (Beede and Bloom 1995). In terms of composition, the difference between the wastes of high- and low-income countries is considerable (Cointreau et al. 1984). Two problems are foremost in India and in the other developing countries:

- Absence of adequate dumping sites
- Absence of appropriate primary treatment of agro-industrial waste

In addition, the hazardous content in the waste is quite high since the regulatory and enforcement system to control such waste disposal is usually nonexistent or not functional. This is a particular problem with waste from hospitals located within the urban area, often found mixed with other solid municipal wastes which get dumped in open fields resulting in landfills (Fig. 11.1). With the population skyrocketing explosion across the globe, landfill dumps and solid waste will only become more of a public concern as time passes by. Despite the arguments over landfills in general, there are no legislatives available which help to combat the problem, and this actually contributes to the environmental problem of landfills.

Differences in waste management systems thus require distinct approaches to solve it. The nature and contents of waste in the developing countries are highly organic and susceptible to rapid decomposition or decay. Studies have shown that

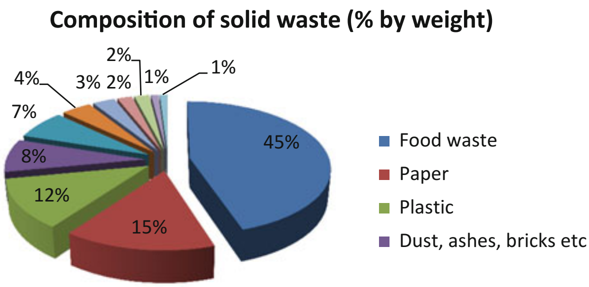

Fig. 11.1 Typical composition of solid waste in Indian cities (Source: Status of solid waste generation, collection, treatment, and disposal in metropolitan cities (Beukering et al. 1999)

expensive collection trucks and compactors developed and used in urban countries are difficult to operate as it requires skilled operators, are difficult to maintain, and are unsuitable for densely populated narrow lane areas (Cointreau and de Kadt 1991).

11.1.2 Global Bioenergy Demand

11.1.2.1 World Scenario

Increasing world energy demands and environmental concerns due to the fossil fuel consumptions motivate considerable efforts toward the development of sustainable and renewable energy resources, such as biofuels. There is a rapid increase in interest toward converting agricultural wastes to commercially valuable products. Biofuels made from waste biomass offer greenhouse gas effect and sustainable environment. The strategic and economic matters associated to the oil economy have promoted new interest for the so-called biofuels, which include bioethanol, biodiesel, and biogas.

Recent hike in oil prices has led to increased interest in biofuels. With the lower price and more advanced state of development, they are drawing the greatest attention globally. It is expected that in the future, technological advances will increase the competitiveness of second-generation biofuels. Currently, many governments worldwide are looking to biofuels as a way of reducing reliance on oil imports and reducing greenhouse gas emissions. The Biofuels Initiative goals of the US Department of Energy include making cellulosic ethanol costs comparable with gasoline and replacing 30% of the current levels of petrol consumption with biofuels by the next decade.

The high price of petroleum and other factors, such as environment degradation and global warming have raised the demand for bioenergy. The most commercially spread biofuel is ethanol. This is the main alternative to fossil fuel. There are many increasing potential benefits on our dependence on renewable sources of energy, such as biofuels. They cause lesser pollution in the environment, thus being potentially more environmentally friendly. The bioenergy generation by taking advantage of biomass conversion or organic waste utilization is one of the future industries. The source plants absorb carbon dioxide from the air as they are growing, and consequently, the carbon dioxide that is released when biofuels are burned does not represent a net addition of that greenhouse gas to the atmosphere (Cherubini 2010). The main advantage of second generation biofuels are that they offer the best way to reduce greenhouse gas emissions and alternate to the pollutant fossil fuels (Searcy and Flynn 2008; Fleming et al. 2006).

11.1.2.2 Indian Scenario

In 2005, India ranked seventh in the world in terms of energy demand, accounting for 3.4% of the total energy utilized. As the population in the country is growing on a fast pace, the demand is also expected to grow exponentially in the near future. India is also initiating the use of ethanol as an automotive fuel and to produce a cost-effective method of ethanol production. Under the approved National Biofuel Policy, India aims to rise the blending of biofuel with petrol and diesel by 20% by the year 2017.

11.2 Approaches for Production of Bioenergy

11.2.1 Conversion of Solid Waste

Utilization of available solid wastes from existing industries to produce bioenergy is the gaining interest globally. Production of value-added products from agro-industrial and food processing wastes is now a focusing area, as it reduces environmental pollution in addition to energy generation. Low-cost crop and forest residues, wood process wastes, and the organic fraction of municipal solid wastes can all be used as lignocellulosic feedstocks for the generation of bioenergy (Sims et al. 2010). In the recent years, different new substrates and new processes have been employed for the production of ethanol.

Substrates for ethanol production ranging from sugar cane molasses, corn meal, cassava wastewater, and potato flour to banana biomass fruit peels and bread wastes, brewer's spent grain, etc. were utilized by direct fermentations as well as by using pretreatments and enzymatic hydrolysis using various enzymes from microbial sources like cellulases, pectinases, and polygalacturonases that have been used for the transformations.

There is a considerable industrial interest in the enzymatic transformation of flavonoids to hydrolysis products that offer a pathway to bioenergy generation. Hydrolysis of flavonoids by specific enzymatic action liberates important sugars from the citrus wastes. Ethanol is considered a valuable biofuel and is a renewable energy resource. From the application and industrial point of view, bioethanol production from citrus waste has been very beneficial to the society and has a lot of economic potential (Grohmann et al. 1994).

Many countries have established the setup for converting waste and production of bioethanol. In India we have a large amount of solid residue available, but lack of technology and resources is restricting their use, and the waste is posing serious problems for the environmental communities. Conventional crops, such as corn and sugarcane are unable to meet the global demand of bioethanol production due to their primary value of food and feed. There are various other sources from which bioethanol could be produced, and various researches have worked and explored different sources. Many studies are currently conducted on the development and optimization of biofuel production from various other biomasses, such as wood and agricultural/industrial and municipal wastes. Various new methods and techniques are being developed to convert the waste material by microorganisms to valuable products such as biogas, ethanol, citric acid, chemicals, various enzymes, volatile flavoring compounds, fatty acids, pectins, essential oils, antibacterial agents, and microbial biomass (Dhillon et al. 2004).

11.3 Production of Bioethanol from Citrus Industry Waste

World citrus production has been significantly increasing since the 1980s and is about 120 million tons per year. As a result, citrus processing industries, especially in developed countries, have expanded rapidly (Khadir and Khan 2011).

India is ranked sixth in citrus fruit production throughout the world. The estimated annual production of citrus waste is approximately 15 million tons (Marin et al. 2007). In India, more than 1.7 million metric tons of citrus fruits are produced annually. The Punjab state produces about 90% of the country's orange and grapefruit juice, and the citrus industry generates about 5 million tons a year of pith and peel. India is also one of the potential producers of bioethanol.

The industrially important citrus crops include oranges, lemons, grapefruit, and mandarins. These industries processed the citrus crops for juice extraction, where few other industries processed citrus including their peels, segment membrane, and seeds that end up as wastes (Wilkins et al. 2007a). These solid residues are referred to as citrus processing wastes (CPWs) with an estimated worldwide production of 15 million tons per year (Marin et al. 2007). Citrus peel wastes are considered as an important feedstock for ethanol production since two decades ago (Grohmann and Baldwin 1992). These solid remains are generally a very good source of carbohydrates. The cell wall polysaccharides and other functionally important bioactive contribute to various important industrial processes. Citrus peel waste constitutes various polysaccharides, bioactive compounds, and phenolic compounds which can be hydrolyzed to sugars, and these sugars are fermented into ethanol. Limonene, as well as pectin, can also be recovered from the citrus processing waste (Pourbafrani et al. 2010). These carbohydrate polymers and polyphenols make it an ideal feedstock for bioenergy generation through biological conversion to biofuels, such as ethanol and biogas (Wilkins et al. 2007b). Various pretreatment methods of lignocellulosic waste can yield high ethanol and also biogas production (Zhou et al. 2007).

The global concerns are to identify technically feasible and environmentally acceptable options for converting these solid residues into usable forms of energy. Out of many potential options of waste management, each option addresses the environmental problems and can be used to generate significant amounts of usable bioenergy.

Collectively the various practices of waste management remain insufficient and carry many disadvantages. Out of most of the practices of the solid waste disposal, a large amount is incinerated in disposal yards and dumped into the ocean bottom, which leads to eutrophication and death of marine biodiversity posing severe consequences.

Recently, parts of the dried CPWs are being used for low-protein cattle feed production. These are called as "citrus pulp pellets (CPP)" or biopellets, and the rest of the debris are disposed in landfills, resulting in severe environmental problems. Further, the operating cost would also require for landfilling activities in addition to existing waste disposal costs (Tripodo et al. 2004).

The problem with aerobic digestion of citrus wastes is the presence of citrus oil, inhibit its digestion creates the concern for additional research to ascertain the digestibility of peel press liquor and other liquid citrus wastes. Solid citrus wastes can also be reduced through mechanical pressing and subsequent drying to a low moisture level to sustain combustion, but this has apparently not been tried commercially. In fact, such dried and shredded citrus wastes have similar characteristics to cane bagasse, which is commonly used as fuel for energy generation by combustion. The anaerobic digestion of these waste materials consists of various technical processes not attempted so far on a commercial level for such agro-industrial wastes. By combining the energy produced from combustion of solid wastes with the energy from anaerobic digestion could produce large amount of steam sufficient for all of the facility's process steam and electrical requirements. The resultant would be able to displace 100% of current fossil fuel consumption or oil-fired boiler-based systems.

Cattle feed and by-product recovery from agro-industrial waste were also tried from several processes but found to be uneconomical in many countries as liquid effluent would also need to be properly treated before they are discharged to minimize environmental pollution. Although this option has been the focus of much attention, the options described below are considered more attractive for a country like India.

Kinnow (*C. reticulata*) is the most important commercial crop in India. It occupies about 39% of the area under citrus cultivation. The chief centers of production are Nagpur, Assam, and Punjab. Areas considered to be good for production of kinnow Hoshiarpur, Muktsar and Abohar districts. The growth of agricultural-based industries worldwide has generated huge quantities of fruit wastes (25–40% of the total fruits processed). Production of bioethanol using yeast *Saccharomyces cerevisiae* through fermentations has also been well established and extensively exploited. Suitable conditions with chosen microorganism are used for ethanol production for rapid fermentation and ethanol production. Simultaneous saccharification and fermentation (SiSF) process by *Saccharomyces cerevisiae* is the most tested process which increases the hydrolysis rate, simplifies the operational process, and also decreases the processing time, thereby improving process economics. These options represent the maximum potential generation of usable energy from citrus wastes while simultaneously alleviating current waste disposal problems.

11.4 Conclusions

The appropriateness of different bioenergy production systems in economic, environmental, and social terms will depend to a large extent on national and local circumstances. To plan a bioenergy strategy, analysis of different options and their broad impacts should be carried out to achieve the policy objectives. Dramatic improvements in policy and technology are needed to meet global demand for both food and biofuel feedstocks. Citrus waste material being potentially valuable for production of bioethanol drags the area of interest these days. All of these constituents of citrus waste have been extensively studied by various researchers for the production of ethanol, but one of the constituents which is flavonoids has yet to be fully exploited. The flavonoid naringin which is responsible for the bitterness of citrus fruit juices can be used for sugar production (rhamnose) with the help of enzyme naringinase. This will add up in ensuring the replacement of non-eco-friendly fuels with the renewable green fuel that is bioethanol and help save the environment. Biofuel could replace petroleum fuels, such as natural gas, diesel, jet fuel, and gasoline. This replacement reduces dependency on oil and gas and also helps the environment through reduction of greenhouse gas emissions.

The economics of ethanol production by fermentation can be significantly influenced by the availability and cost of the raw materials, which accounts for more than half of the production costs. To achieve a lower production cost, the supply of cheap raw material is thus a necessity. The rationale of the chapter was to identify feasibilities and environmentally acceptable options for converting agro-industrial waste or dumped wastes in India into usable sources of bioenergy. Many of the options generate significant amounts of usable energy. Many potential options have already been identified by many researchers. Each option addresses the environmental as well as economical aspects. Production of value-added products from agro-industrial and food processing wastes is now a focusing area, as it reduces pollution in the environment in addition to energy generation.

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