WASTE VALORIZATION FOR VALUE-ADDED PRODUCTS

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Waste Valorization

(Volume 1)

Waste Valorization for Value-added Products

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FOREWORD

This book describes the critical and top-priority topic of current research, which is waste valorization for value-added products. The first chapter deals with plant-derived waste utilization. Abundant plant-derived organic wastes can be bio-transformed into bio-fuels like bio-ethanol, bio-butanol, biogas, and hydrogen. They can produce biochemicals like lactic acid, succinic acid, xylose, and xylitol. This chapter discusses some advanced methods for biofuel production. The second chapter discusses the various aspects of lignin bioconversion. Valorization of food waste is another critical area. The organic nature of food waste makes it fit to serve as the raw material for the enzyme industry, bio-fuels, bioactive compounds and bio-degradable plastic. The third chapter discusses this topic. The fourth chapter discusses the use of waste from the olive oil industry. This waste can be used to produce phytochemicals like phenols, flavonoids, and clean energy. Chapter five addresses the use of organic residues present in the waste using manufacturing platform chemicals. Date fruits have earned great importance in human nutrition, owing to their rich content of essential nutrients. Apart from nutraceuticals, a vast and diverse range of biomolecules can be produced, including active pharmaceutical ingredients. Date industry waste can be used for producing a vast array of antibiotics, phenolics, sterols, carotenoids, anthocyanins, flavonoids, different vitamins, economically helpful amino acids, organic acids, bio-surfactants, biopolymers, and exopolysaccharides. Date seeds can be used to produce bio-diesel and biochar and activated carbon. Citrus fruits are equally crucial as dates.

Industrial processing of citrus fruit produces various end-products like juices, concentrated jam, jellies, marmalades, and ice cream. Chapter seven is on the commercial utilization of citrus fruit processing waste to produce various chemicals like essential oils, flavonoids, pectin, enzymes, and methane. The increase in the use of plastic products has caused a significant problem in the disposal of plastic solid waste. The eighth chapter reviews how solid plastic waste can be converted into fuels and other valuable chemicals through thermal degradation, catalytic cracking and gasification, and other novel routes. Chapter nine discusses the lignin structure and the recent significant advancement in different synthesis methods for lignin nanoparticles.

Bio-plastics refer to polymers derived from plants, animals, and microorganisms. The integrated strategy of waste valorization with bio-plastic production is considered a cost-effective and sustainable approach to bio-plastic production and commercialization. Chapter ten describes biotechnological processes for valorizing food waste into commercially important biopolymeric components like Chitosan, polyhydroxyalkanoates, HAp and cellulose-based polymers. Chapter eleven discusses reliable methods for poultry waste management.

Chapter 12 deals with valorization of sugar industry waste for value-added products.

India is the second-largest cultivator of sugarcane. A significant amount of molasses and solid waste, including bagasse and filter cake, are produced every year. Sugarcane industries waste is a rich source of lignocellulosic organic biomass which can be used as a raw material to produce bio-fuel, single-cell proteins, enzymes and organic acids, food additives and nutraceuticals.

During the last century, rapid urbanization, industrialization, and globalization have increased the consumption of resources, polluting the environment. The concept of a circular economy based on restoration and regeneration by creating a connection between technology and biological cycles is gaining ground. Changing the linear economy of the produce-use-throw model into a circular economy can achieve several sustainable development goals. The last chapter discusses how the circular economy brings about transformation in Indian Industries.

This book is a very timely treatise on different valorization processes. Various government policies towards the environment and their implementation have also been discussed. It shall help formulate a business strategy that makes a way for waste valorization and brings actual revenue and tangible benefits to the environment and society.

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PREFACE

The presented book is a comprehensive compilation of the use of various wastes to produce useful products. The present book contains thirteen chapters. The book highlights the following topics in all the chapters: applications of plant-derived wastes utilization for value-added product formation; lignin valorization for fuels and chemicals production; use of date palm fruit processing wastes to produce high-value products; citrus waste valorization for value-added product production; valorization of sugar industry wastes for value-added products; olive oil wastes valorization for high-value compounds production; food waste bioconversion to high-value products; organic residues valorization for value-added chemicals production; valorization of waste plastics to produce fuels and chemicals and food valorization for bioplastic production and concepts of circular economy in the valorization process. The chapters are written in an organized and strategic manner, which will help the readers gain knowledge related to their subjects. The chapters also include the major research contributions in recent years. It will help researchers advance their knowledge in the areas.

This book covers multidisciplinary concepts, including very recent findings, which will be a great help to the researchers, students, and teachers working in the areas of environmental engineering, waste valorization, agricultural engineering, agricultural biotechnology, nanotechnology, food microbiology, bioremediation, biodegradation, organic chemistry, and agricultural economics. This book will be a great reference for undergraduate, postgraduate, and doctoral students. We are thankful to all the contributing authors for providing their valuable contributions to completing this book. We are thankful to all the reviewers for their valuable suggestions for the improvement of the book.

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CHAPTER 1

Utilization of Plant-derived Wastes For Value Added Product Formation

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Abstract: Depletion of fossil fuels and environmental concern has impelled to search for alternative biofuels and biobased chemicals. Biofuels have been considered an alternative clean energy carrier due to their environmentally friendly nature. Recently, research has been focused on finding a readily available, low-cost and renewable lignocellulosic biomass to produce value-added products. In this context, the plant-derived organic wastes can be transformed to produce biofuels (bioethanol, biobutanol, biogas and biohydrogen) and biochemicals (lactic acid, succinic acid, xylose and xylitol). It will be a sustainable effort to reduce the huge amount of plant waste generated. In addition, in the recent decades, several efficient conversion methods have been invented.

During the past few years, a large number of chemical pretreatment methods have also been developed for efficient lignocellulosic conversion. The current chapter discusses the advanced methods for biofuels and biochemicals' production, focusing primarily on different pretreatment methods for effective conversion of plant derived wastes.

Keywords: Anaerobic digestion, Biomass, Biofuels, Bioethanol, Biobutanol, Biogas, Biochemicals, Biohydrogen, Detoxification, Fermentation, Inhibitors, Lignocelluloses, Ligninolytic enzymes, Lactic acid, Plant derived wastes, Pretreatment, Succinic acid, Value added products, Xylitol, Xylose.

INTRODUCTION

Energy plays a crucial role in the socio-economic development of a country. According to the Global Status Report on energy, the major part of energy share of around 78% is obtained from nonrenewable resources (fossil fuels such as petroleum, gases and coal) and only 19% comes from renewable energy resources

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(solar, wind, hydropower and biomass) [1, 2]. The fossil fuel reserves are diminishing very rapidly, and also its overuse is creating serious pollution in the environment. Therefore, it is necessary to explore alternative resources of energy to meet the future demand of energy [3]. In this context, plant biomass containing starch and lignocellulose has emerged as a renewable, sustainable and economically feasible source for biofuel production. Scientists and investors have coined a term to the bio-based economy, that is circular bio-economy because of its renewable nature [2 - 4]. In this context, plant biomass containing starch and lignocelluloses can be used to produce value-added products.

Biofuels are classified into primary and secondary biofuels based on the type of biomass used [4]. First-generation biofuels are produced from edible food crops such as starch and sugar containing crops [5]. Since the first-generation biofuels directly compete with the food items, the focus has shifted to second-generation biofuels which are obtained from lignocellulosic materials. Lignocellulosic biomass resources are generally discarded as residual and agricultural wastes. The most significant and abundant renewable biomass resources include crop residues like corn stover, wheat straw, rice straw and sugarcane bagasse [3, 6 - 11]. Due to their abundance and renewable nature, lignocellulosic biomass is considered an excellent alternative substrate for production of several value-added products [12]. Several biofuels and biochemicals can be produced from lignocellulosic biomass [13 - 15].

Lignocellulose is the connecting link between cellulose and lignin. Hemicellulose is present as the matrix surrounding the cellulose skeleton, while lignin is an encrusting material serving hemicelluloses and celluloses as a protective layer [12]. All three components are covalently cross-linked among the polysaccharides and lignin, making biomass a composite material [16, 17]. Therefore, a pretreatment step is mostly required to break these bonds. Pretreatment is an essential pre-requisite to convert lignocellulosic biomass into fermentable sugars with the help of enzymes [18, 19]. Sometimes, these pretreatment strategies further lead to the production of inhibitors such as vanillic acid, uronic acid, 4-hydroxybenzoic acid, phenol, furaldehydes, cinnamaldehyde, and formaldehyde which may intervene with the growth of the fermentative microorganisms. Much advancement has been featured in the field of chemistry which has led to the development of novel processing technologies. These technologies are available at a commercial scale and emerge as promising solutions. In addition, they proved to be low cost at commercial scales [15, 20, 21].

This chapter has been focused on the production of biofuels, and biochemicals. In addition, the nature of inhibitors is also discussed at the end of the chapter.

PLANT BASED BIOMASS PRETREATMENT

Pretreatment is an indispensable step for the preparation of lignocellulosic biomass for its further processing. Pretreatment is essential to weaken the recalcitrant structure of lignocellulose making cellulose, lignin, and hemicellulose more accessible for enzymes or chemicals. Moreover, pretreatment is followed by the removal of lignin, degradation of hemicellulose, reduction in cellulose crystallinity, and an increase of surface porosity [2, 22]. Pretreatment is considered as the most expensive step in the entire biomass processing. Therefore, necessary efforts should be made to lower the operating costs, and increase the process effectiveness, and recovery of lignocellulosic components [23]. The critical factors for biomass pretreatment that should be considered are: (1) The possibility of large-scale feedstock processing; (2) High yields regardless of the type and origin of biomass; (3) Reducing the waste and inhibitors; (4) Compatibility of the pretreatment with further processing; (5) Efficient recovery of lignin; and (6) Reducing equipment and energy cost. Pretreatment methods of plant based biomass are classified into three basic categories: physical, chemical and biological [1, 24, 25].

Physical pretreatment consists of an increase in temperature and/or pressure, which causes structural changes in the biomass. Chemical treatment is characterized by the use of organic or inorganic compounds, which disrupts the lignocellulosic structure [2, 23]. Although individual pretreatment methods are effective, but their combination has higher efficacy. Biological pretreatment includes the microorganisms and enzymes for the hydrolysis of lignocellulosic polymers into their monomers [2]. An extensive number of the research papers concerning plant based biomass pretreatment have been published in the last decade focusing on the strengths and weaknesses of various technologies to get a competent pretreatment suitable for an eco-friendly cost effective process. The schematic route of pretreatment is shown in Fig. (**1**).

DIFFERENT PRETREATMENT METHODS

Physical

Plant materials require a rigorous method to break them into components. There are several physical methods available for plant-based biomass pretreatment. Mechanical, microwave, ultrasound, and hydrodynamic cavitation are the most common techniques used for plant-based biomass pretreatments [23, 26].

CHAPTER 2

Current Biotechnological Advancements in Lignin Valorization For Value-added Products

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Abstract: Recent years have seen a tremendous demand in bioenergy. The technological advancements in the production of second-generation biofuels have opened a plethora of opportunities for the valorization of natural polymers. Lignin is one of the most abundant and recalcitrant materials available on earth. Advancements in genetic engineering, metabolic engineering and synthetic biology applications fueled tremendous interest in the valorization of lignin into fuels as well as platform and commodity chemicals. Though there is a growing continuum for biofuel advancements in recent years, at the same time, a rising upsurge has also been envisaged in the valorization of waste bioresources. Therefore, this chapter entails about various aspects and embodiments related to lignin bioconversion and their routes for obtaining various products. This chapter also highlights current biotechnological interventions for the improvement of the valorization process as well as the current challenges and future perspectives in this burgeoning area.

Keywords: Genetically encoded biosensors, Lignin valorization, Microbial fermentation, Metabolic engineering, Metagenomics, Synthetic biology, Value-added products.

INTRODUCTION

The overwhelming boost in attaining sustainability for energy requirements leads to rapid developments in exploring various natural and synthetic energy resources. The depletion of fossil fuels as well as rising environmental security urges the scientific community to develop and rely on biobased energy sources. Among this continuum, the development of bioethanol, biodiesel, and biohydrogen through renewable biomass imparts significant contributions to moving ahead in this direction. However, the utilization of biomass is a technologically demanding task that leads to the voluminous generation of lignin, one of the most recalcitrant and The current research estimates 300 billion tons of available lignin with an annual

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increment of approximately 20 billion tons complex polymers on the earth [1]. Lignin is released mainly through various industrial sectors including paper and pulp industries and second-generation biofuel plants [2]. Thus, it was estimated that 140 million tons of lignin have been simply burned per year despite having immense hidden resources that have been unraveled through synthetic retrospection. Therefore, the valorization of lignin is currently a thrust area of research for up-scaling bio-based economy. Currently, the potential of lignin valorization is not limited to the production of various commodity chemicals like alcohol, hydrocarbons, ketones, and acids but also bio-based value-added products like coumarins, flavonoids, stilbenoids, poly-hydroxy butyrate (PHA), *etc* [3]. The value of currently produced lignin is estimated to be 3.3 Billion dollars with an energy occupancy of 89% of the market [4]. The percentage of lignin available in different countries across the globe is depicted in Fig. (**1**).

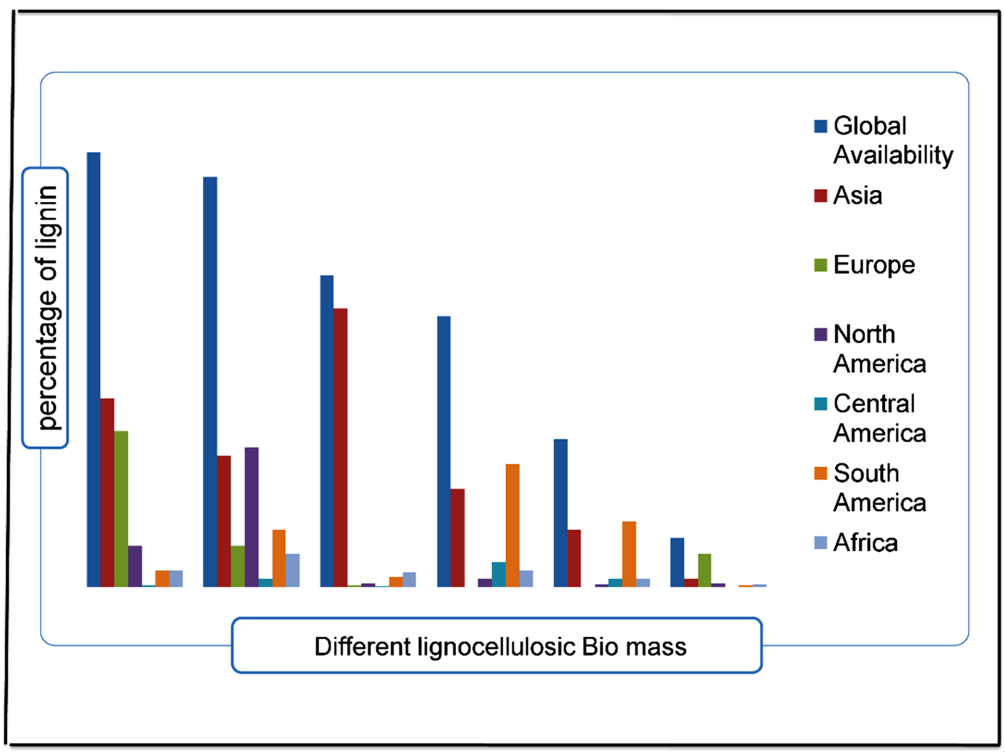

Fig. (1). Availability of lignin in various lignocellulose biomass at global scale.

Though nature embraced lignin with marvelous credentials of making an essential component of living systems as plants but still its utilization by humans for commercial use is an arduous task and a long road to cover till date [5]. Research studies speculated various physio-chemical and biological approaches for lignin valorization but the ecofriendly approach of bioconversion of lignin into value-added products is the most feasible approach utilized till date and there have been continuous advancements in this realm [6]. The current interventions of "omics" technology and the advent of synthetic biology lead to a paradigmatic shift in lignin depolymerization and modification. Therefore, this chapter advocates about recent biotechnological advancements in lignin valorization as well as emphasizes on the challenges and future prospects in this budding area.

Chemical Structure of Lignin

Lignin is considered the most heterogeneous polymer and a renewable resource for the production of aromatics. It is generally considered a side product in biorefineries but holds tremendous potential for harnessing sustainable bioproducts such as bioactive compounds, fuels and other useful industrial chemicals. The chemistry of lignin is quite complex as it's mainly comprised of three phenylpropanoid units: the monolignols coniferyl alcohol (G), sinapyl alcohol (S) and p-coumaroyl alcohol (H) [5]. Various oxidoreductases such as laccases and peroxidases enzymes present in plants are being used for assembly of these sub-units through reactive radical intermediates to form lignin polymers [7]. The linkage of these subunits is characterized by carbon-carbon and ether bonds and the most common linkage is β-O-4 ether linkage [8]. Apart from that, subunits are also connected through α-O-4 linkages, β-β linkages, 5-5 linkages, β-5 linkages, and biphenyl and diaryl ether structures resulting in the enhancement of complexity of a tridimensional framework of lignin [9]. The various linkages present in softwood and hardwood lignin are represented in Fig. (**2**). However, the lignin composition and its percentage vary with respect to plant species. Softwood contains the highest G-type lignin content and hardwood contains an equal proportion of G/S-type lignin [1]. Thus, for complete utilization of such an important renewable biomass, all three major subunits must be efficiently transfigured to value added compounds that lead to the fulfillment of sustainable and cost-effective bio refineries.

Biological Valorization of Lignin

Lignin has diverse structural heterogeneity resulting in various classes of products followed by the application of various chemical procedures for the breakdown of lignin. The well appreciated procedures that have been documented immensely in the literature for the modification of lignin are the application of heat, supercritical fluids, ionic fluids, and fractionation by ultrafiltration. Currently, there is a fascinating research frontier in the biological route for lignin depolymerization and fractionation. In nature, both bacteria and fungi have been

CHAPTER 3

Food Waste Bioconversion To High-value Products

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Abstract: During the last few decades, food remains a primary concern throughout the world as it is depleting day by day. On the other side, its residual waste is accumulating over time. Around one-third of food produced for human consumption is wasted which escalates the environmental issues and ecological burden. Management of waste food by current methods is cost-ineffective with adverse impacts on the environment. Therefore, attempts have been made to convert food waste into high-value by-products. Being a rich source of carbohydrates, proteins, sugars, and fats, it acts as a potential source for high-value products. The organic nature of food makes it a raw material for industries related to biofuel, bioactive compounds, prebiotics, livestock food, and biodegradable plastics. Bioconversion of food waste into valuable products not only provides economic advantage but reduces stress on landfills. The valorization of low-cost, abundantly available food waste into biofuel can decrease the demand for fossil fuels and economic loss for their manufacturing. Minimum food wastage and re-utilization of wasted food can be a sustainable approach to combating this problem. In this chapter, various techniques used for bioconversion and the valuable products produced by waste food processing have been discussed with their prospects.

Keywords: Bioconversion, Food waste, Sustainable, Value-added products, Valorization.

INTRODUCTION

Food waste (FW) has gained attention in the last few years due to several environmental, social and economic concerns, as well as climate change and scarcity of fossil fuel resources [1, 2]. Around 1.3 billion tonnes of food are wasted each year throughout the world which cost $750 billion, causing huge economic losses [3, 4]. In Asian countries, FW has seen a continuous increase from 278 to 416 million tonnes from 2005-2025 [5]. An alarming rise in the

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human population leads to an increase in food requirements and consequently in food waste. Efforts have been made to convert food waste into high value products. According to FAO (Food and Agricultural Organization), around one-third of food produced globally for human consumption is lost along the food supply chain. About less than 30% of municipal solid waste comprises FW in all countries except highly populated countries like India and China where it ranges from 30-60% [6]. The lack of effective waste management, disposal and treatment strategies results in environmental problems [7]. Waste collection, storage and proper segregation are major concerns in suitable waste conversion. However, inappropriate management of waste resulted in several environmental issues and health hazards [8]. Being high in nutritional content, purefaction of FW occurs rapidly which creates a breeding ground for several disease-causing organisms [7]. Food waste is rich in several molecules *viz.* carbohydrates (starch, cellulose and hemicelluloses), protein, lipids, lignin, and organic acids, [9, 7]. In order to produce heat or energy from FW, it is incinerated which leads to air pollution [10]. Management of FW can be done by the conversion of food waste into value-added products *viz*. ethanol, enzymes, organic acid, biopolymers and bioplastic [11 - 21]. Several types of innovative strategies are being utilized for waste valorization such as the conversion of FW into biofuel and animal feed. Various methods such as biological, chemical as well as thermal are used to recover nutrients and high-value products from FW which are an important source of energy [22 - 27].

Food waste (FW) is divided into two types. These include pre-consumption food wastes (PrCFWs) and post-consumption food wastes (PCFWs) [28]. PrCFWs include vegetables, fruits, and other peeling wastes. PCFWs include 40-60% starchy waste (meats and meat trimmings, cheese whey and coffee filters), 5-10% protein (fish processing wastes and eggshells) and 10-40% various other fatty or oily contents [29 - 32]. PrCFWs waste is easy to decompose whereas decomposing of PCFWs management is challenging because of separation issues and the huge amount of oil contents [28].

Diminishing natural resources, such as petroleum, rising fuel prices and increasing environmental concerns have enforced us to look for alternative sources of energy [2, 33]. Several types of food wastes are generated worldwide in huge quantities which are rich in important constituents that may serve as a starting point for the production of various types of valuable products, through several bioconversion pathways [33].The food industry is responsible for one of the highest consumptions of natural resources [34]. Food processing by-products also account for the huge amount of leftover resources that could be valued for the recovery of value-added products [35].

CURRENT SCENARIO

About 1/3rd of food is wasted globally which could be used to feed millions of people around the globe [36]. Food waste occurs at different levels *viz:* prematurely harvesting of crops by farmers, lack of processing technologies, inefficient storage, market system, and sales conditions, overproduction than the requirement and many more [37]. Displayed high standards of fresh products in supermarkets or retail stores make them unsalable, contributing to countless food waste [38].

FW has the potential to transmute into economically valued products [39]. The most widely used approaches for food valorization are composting, using the animal feed, landfilling, and incineration [40]. Composting is one of the most important approaches for bioconversion. It is an eco-friendly and highly acceptable practice because it reduces stress on landfills and provides fertilizers. Thereby it also helps the farmers to reduce or eliminate the need to rely on chemical fertilizers [41, 42]. One of the important advantages of composting is that it avoids the emission of methane [42]. The most cost-effective method for food supply chain waste is animal feed unless there are regulatory issues as well as the nature of the co-product generated in the process [2]. A large amount of food waste ends up in landfills. Dumping of a huge amount of food waste in landfills is very costly and it also poses serious environmental concerns *i.e*. by the production of greenhouse gases (Methane and Co_2) directly or indirectly [42]. To exploit value-added products, advanced conversion, and extraction technologies should be implemented on the basis of green chemistry. The diversity of food composition reflects its potential which affects food valorization to be converted into an economic value-added product [43].

BIOLOGICAL AGENTS USED FOR BIOCONVERSION

Insects

Food waste bioconversion using insects involves the breakdown of food waste into smaller biomass [44, 45]. It is one of the most economically viable methods for turning large quantities of food waste into valuable materials such as feed for animals, biofuel, lubricants, pharmaceuticals, dyes, *etc* [45]. On the other hand, it has the advantage of reducing the load on the environment [46]. Commercial rearing of insects can efficiently turn several tonnes of FW feedstock into valuable products [47]. Few species of insects have been used so far for insect-based bioconversion of food waste. Some of the important species are *Hermetia illucens* (L.) commonly known as Soldier fly larvae, *Musca domestica* (Housefly), *Cydia pomonella* (Codling moth), *Teleogryllus testaceus* (Cambodian field crickets) and *Tenebrio molitor* (Yellow Mealworm) [48, 52] (Table **1**). The

CHAPTER 4

Olive Oil Wastes Valorization for High Value Compounds Production

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Abstract: The consumption of olive oil is deeply rooted in human history and the production of olive oil contributes greatly to the economy of Mediterranean countries. Olive oil is generally extracted following three different methods; the traditional pressing method, two-phase decantation system and three-phase decantation system. These extraction processes generate mainly two different types of waste which are olive mill solid waste (OMSW) and olive mill wastewater (OMWW). Olive mill by-products are considered a major environmental hazard in Mediterranean regions as they are high in phenol, lipid and organic acid content. To eliminate this problem, valorization of these waste products is the need of the hour. Phytochemical compounds like phenols, and flavonoids are important and useful for pharmaceutical industries. Other than the recovery of these value-added compounds, olive waste can be used as animal feed and a source of clean energy. Biological treatment of these wastes reduces the percentage of phenols and organic acids and then it can be used in agricultural applications. The valorization strategies of olive mill wastes depend on factors like socio-economic conditions, and agricultural and industrial environments. In this chapter, the olive oil production process, phytochemical characteristics of generated waste and their environmental impact are discussed. This discussion also emphasized the available valorization techniques of olive oil by-products, their advantages, and disadvantages.

Keywords: Anaerobic treatment, Animal feed, Biological oxygen demand, Biofuel, Chemical oxygen demand, High value added compound, Microbiological treatment, Olive wastes, Olive mill waste water, Olive mill solid waste, Pressing method, Phyto-toxicity, Physical treatment, Phytochemical characteristics, Phenolic acids, *Phanerochaete chrysoporium*, *Pleurotus ostreatus*, Two phase decantation system, Three phase decantation system, Valorization techniques.

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INTRODUCTION

Olive (*Olea europaea* L.) trees are evergreen and commercial crop with major economic importance in the Mediterranean region. The cultivation and production of olive oil is an important agricultural sector in Europe [1]. Olives are consumed either as table olives or as olive oil. As a rich source of essential fatty acids and antioxidants, olive oil is widely consumed all over the world and deeply rooted in the diet of the Mediterranean world. In recent times, olive oil is on high demand and cultivation of olive trees has increased in Greece, Italy, Spain and other countries. In 2013, the global production of olives reached 20,000,000 tons per year and total production of table olives reached 2,900,000 tons. In 2018, the estimated consumption of olive oil worldwide exceeded 3,300,000 tons per year [2]. According to a study by Khdair and Abu-Rumman [3], total 11 million hectare of land was used for olive tree cultivation in 2015 and almost 50% of the total land was covered by European Union countries. Approximately 72% of total annual olive oil produced comes from Europe. Other than Mediterranean countries, Asia, Africa and America are also producing 15%, 12%, and 2% of global olive production.

Olive oil production practices can be dated back to 6500 years ago [2]. The recent increase in olive oil consumption can be explained by exploring its health benefits. Slow aging, decline in age-related cognitive issues, improvement in thrombosis and gastric issues, and reduction in lipoproteins and cholecystokinin bile secretion are among several health benefits that have been linked to the incorporation of olive oil in everyday diet [4]. These health benefits can be ascribed to oleic acid (55-83%) [5] (Miranda *et al.,* 2019) and phenolic compounds present in olive oil [6]. Phenolic compounds are known for their antioxidant, anti-inflammatory, anti-proliferative, anti-atherogenic, antimicrobial and anticancer properties [7 - 13]. The Health benefits of olive oil are explained in detail in Table **1**.

Table 1. Health benefits of olive oil according to Ciriminna *et al.,* [14].

	HEALTH BENEFITS
Joint	Decreases swelling and maintains bone joint health, reduces joint inflammation and pain, increases joint flexibility and improves mobility.
Skin	Helps skin conditions caused by auto immune diseases, improves skin moisture retention, reduces premature aging skin, supports healthy and radiant skin, and reduces damage from sun exposure.
Other	Reduces cardiovascular issues, helps in the repair of cartilage, and reduces fatigue.

Increased production of olive and unregulated disposal of olive mill waste into the immediate environment have raised serious environmental concerns in olive-producing countries [15]. Industrial production of olive oil generates mainly two types of waste which include olive mill wastewater (OMWW) and olive mill solid waste (OMSW). High concentrations of different phenolic compounds and fatty acids are associated with the phytotoxicity of olive mill waste. These bioactive compounds are reported to inhibit plant and bacterial growth [2]. Disposal of both solid and liquid waste into agricultural soil affects the chemical and physical properties of soil like porosity, acidity, salinity and heavy metal content [1, 16]. Oxidation and further polymerization of tannins result in the discolouration of water and are difficult to remove from water. The lipid content of liquid waste forms a thin layer of film that blocks the penetration of sunlight and oxygen, inhibiting microbial growth. High phosphorus content leads to eutrophication and fatty acid content produces a pungent odor during dry warm weather [17].

Olive processing by-products are a richand abundant source of macromolecules (proteins, sugars, fatty acids, plant enzymes and pigments) and bioactive compounds like polyphenols, vitamins, and many other aromatic and aliphatic compounds. These compounds have great importance in pharmaceutical, cosmetics and food industries and can be recovered by valorization of the waste products. Waste valorization is the most recent approach involving different modern technologies for recycling or reuse of waste materials to convert them into high-value products instead of dumping them into the environment [18, 19]. Vandermeersch *et al.,* [20] have explained a detailed hierarchy of waste management such as prevention, use for human nutrition, conversion for human nutrition, use for animal feed, use as raw materials in industry (a biobased economy), process into fertilizer by anaerobic digestion or composting, and use as renewable energy, incineration, and landfill [21]. In this chapter, we have discussed olive oil production process and generated waste material and the available valorization methods.

OLIVE OIL PRODUCTION PROCESS AND GENERATED WASTE MATERIALS

Olive oil is extracted and separated from olive fruits by both traditional and industrial processes. The quality of olive oil depends on different factors like the quality of olives, the time of harvest and extraction process [1]. The production of olive oil involves picking the fruits, removal of leaves and washing, crushing, mixing, pressing the fruits and separating the oil [2]. There are two main olive oil production processes available. These include discontinuous and continuous processes. The discontinuous process involves a traditional pressing procedure and the continuous process involves the centrifugation process [6].

CHAPTER 5

Organic Residues Valorization For Value-added Chemicals Production

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Abstract: In recent years, more studies on waste valorization are emerging due to excessive accumulation in the land, foul-smelling, and lack of conventional disposal practices to sustain a proper ecosystem. The decline in the supply of fossil fuels and their high-cost led to finding alternative technologies that use renewable resources as raw materials to manufacture value-added goods. The waste contains organic residues like carbohydrates, proteins, and fats, which are helpful in producing bio-based chemicals. However, several roadblocks ought to be crossed for adopting organic waste as nutrients for microbes to obtain high yields of desired products. Many studies have shown potential ways to solve these problems and have achieved high yields. Nevertheless, this technology has not been globally explored to manufacture commercial products, as many other issues are associated with biorefinery and product costs. This chapter addresses the organic residues present in the wastes, their use in manufacturing platform chemicals, methods for the pretreatment process, and ways to overcome the challenges.

Keywords: *Aspergillus terreus*, Acid catalyst hydrolysis, Building blocks chemicals, Cellulose, Detoxification, Food and fruit waste, Gluconic acid, Itaconic acid, Levulinic acid, Lignocellulose biomass, Microwave-assisted heating method, Organic wastes, Succinic acid, Sugar alcohols, Sugarcane bagasse, Spent aromatic wastes, Transesterification, Xylose, 5-HMF SSF.

INTRODUCTION

In this growing population, enormous amount of waste is created as a result of human lifestyle, and industrial development. The waste produced poses challenges to waste management technology. The conventional waste disposal practice is incompetent to build a sustainable system to maintain a healthy ecosys-

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tem and human well-being [1]. Indeed, a large part of the waste constitutes organic residues collected from the household (food, fruits, and vegetables), municipal waste, animal excretes, agricultural waste, public places (shops, hotels, and office activity), and industrial by-products that are usually processed by incineration [2].

Introducing a new process to utilize organic waste not only replaces the traditional waste disposal method but also reduces the accumulation of toxic substances in the environment by generating various bio-based products. Considering environmental, economic, and social perspectives, the application of recycled waste for agricultural purposes is more promising as it lessens environmental contamination [3]. However, the direct application of organic waste as manure in agricultural land is harmful due to the presence of lignocellulose material. Composting organic waste into stabilized manure is a good fertilizer for plant cultivation and agriculture [4].

The evolution of new microorganisms and the development of synthetic biotechnology can utilize recalcitrant waste as carbon and nitrogen substrates to produce various bio-based chemicals. For instance, a biodiesel refinery generates about 10% crude glycerol as the main by-product. The glycerol is utilized as a feedstock by microbes to produce potential chemicals (1,3- propanediol, citric acid, poly hydroxyalkonates, phytase, *etc*.) and as animal feed [5]. The characterization of the waste material is a prerequisite to segregating the potential organic compounds from undesirable hazardous materials. Agricultural waste contains cellulose (40%), hemicellulose (30%), lignin (20%), proteins (5%), and minerals (5%) [6]. Food waste hydrolysate contains polymers such as starch (30-60%), cellulose, lignin, proteins (5-10%), lipids (10-40%), organic acids, and inorganic compounds. They serve as a rich nutrient medium for microorganisms' growth [7]. The biochemical conversion of wastes into simple sugars as a hydrolysate requires chemical, enzymatic, or hydrothermal treatment. Depending on the type of biomass, the pretreatment methods vary. A simple enzyme hydrolysis step is adequate for recovering nutrients from food wastes, starch, sucrose, *etc*. Lignocellulose biomass requires harsh treatment due to its complex heterogeneous structure [8].

Therefore, building a biorefinery to produce multiple products from one raw material, like a petroleum refinery, has remarkable strength. Current technologies can make industrial products derived from fossil fuel resources from organic waste biomass [9]. However, certain limitations must be overcome to achieve this transition of using biodegradable raw materials from waste to value-added chemicals. Herein, the chapter gives detailed information about organic waste valorization, process strategies, and difficulties overlooked for value-added chemicals. The chapter covers industrial organic acids reported in the top 12 building block chemicals by the U.S. Department of Energy [10].

3-Hydroxypropionic Acid

3-Hydroxypropionic acid (3-HP) is the third most crucial chemical among the top twelve value-added platform chemicals produced from biomass [10]. It serves as a versatile precursor for diverse high-value compounds such as 1,3-propanediol, acrylic acid, acrylamide, malonic acid, 3-hydroxypropionaldehyde, and acryl-based polymers by a slight modification of chemical reactions [11, 12]. These compounds are extensively used in food preservations, as a crosslinking agent for polymer coatings, medical sutures, *etc*. The global market potential of 3-HP was projected to be >1 million tons per year. Commercially 3-HP is produced by chemical processes. However, fermentative routes have also been extensively studied [13, 14]. Until now, glucose and glycerol have been the major sources of renewable raw materials to produce 3HP. Besides, several other organic residues were successfully investigated, such as sucrose from sugar beet, corn starch, and pre-treated lignocellulose materials from hydrolyzed food waste, forest biomass, agricultural industry, and municipal waste [15, 16].

A recent study has shown to achieve 3-HP production at a low concentration from CO_2 and xylose, although considerable research is in progress. Kildegaard and co-workers [17] reported the feasibility of producing 3-HP in *S. cerevisiae* strains from xylose through the β-alanine pathway that achieved a high titer of 6.09 ± 0.33 g/L. A recent study focused on *L. reuteri* growth in wheat and sugar beet by-products [18]. The suspended solid particles in low-purity sugar beetroot syrup and wheat extract were filtered and used directly as sugar sources. The bacteria in this medium displayed a high product yield of 0.40 g/g compared to the conventional MRS medium. However, it is to be noted that almost very few attempts have been made at producing 3-HP from organic waste (except glycerol). Substrate and recovery costs play a critical role in the commercialization of bio-based compounds, especially in the case of 3-HP. Though significant progress has been made in improving fermentative production of 3-HP using crude glycerol, establishing this on a commercial scale remains insignificant mainly due to the toxicity of 3-HP and the regeneration of NAD^+. Thus, intensive research efforts are required to enhance 3-HP synthesis from available renewable resources.

Succinic Acid

Succinic acid is recognized as one of the top twelve potential chemical building blocks used in synthesizing various high-value commodity derivatives such as 1,4-butanediol tetrahydrofuran, polybutylene succinate, and polyurethanes that find extensive application in the field of pharmaceutical, food, antibiotics,

CHAPTER 6

Use of Date Palm Fruit Processing Wastes to Produce High-Value Products

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Abstract: Fruits of the date have found great value in human nutrition because of their rich content of essential nutrients. Tons of palm fruit waste are being discarded daily. Waste such as date holes represents 10% of date fruit. Within the framework of the bio-economy, there is a high potential for date waste use in ligne-cellulosic products in a broad spectrum of bio-industries. Extensive and varied biomolecules may capture energy for use in the pharmaceutical industry as an active pharmaceutical ingredient (API), or in the development of nutraceuticals without using them as substrates for mass production of bacteria, phenolic, sterols, carotenoids, anthocyanins., procyanidin, flavonoids, minerals, various vitamins, economically beneficial amino acids, organic acids, biosurfactants, biopolymers, biofuels, exopolysaccharides, probiotics with date flavors, *etc*. Date fruits are commonly used to prepare many kinds of products such as date juice concentrate (distribution, syrup, and liquid sugar), date products (wine, alcohol, vinegar, organic acids) and date pastes for different uses (*e.g*., bakery and -confectionery) without the direct use. Date seeds can be converted into high-value liquids (bio-oil), gas, and solid products (bio-char) by pyrolysis, and coal and activated carbon can be produced from date seeds. Significant progress has been made in developing specific date fruit products and using products from packaging and processing. Additional economic benefits will also increase so far as farmers increase the number of commodities they produce, as well as diversify their sources of income.

Keywords: Date fruit waste, Industrial and medical applications, Traditional use.

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INTRODUCTION

Date palm is undoubtedly the world's oldest cultivated tree [1], with a history dating back 10,000 years, and is one of the most widely cultivated trees. It is an ancient grown crop in tropical and subtropical regions, as its production, use and industrial development are increasing mainly in Arabia. Conquerors brought palms to the conquered lands for example, Alexander to western India (now Pakistan) and the Moors to Spain [2]. Next, traders and explorers spread the word to other lands, including Mexico and North America. Palm tree is currently planted across a large belt that covers most of the ancient regions, 8,000 miles from east to west and 2000 Km from north to south [1]. North Africa and South Asia are the major producers of date and global date production is increasing day by day in recent decades [3]. Date fruit is considered as an essential source of livelihood in the desert. This is due to its various useful properties. The palm tree has a special place in economic and social life. Some of the best products based on palm tree residues are now available and affordable. These developments have led to the gradual use of palm fossils in manufacturing traditional, handmade products. In addition, palm plantations have increased recently. The processing of palm is a cost-intensive process that generates a huge amount of waste with no economical applications [4]. Therefore, it would be helpful to develop an effective and economical way to use these dates in producing value-added fermented products. The presented chapter discusses the use of date palm for value-added products such as antibiotics, organic acids, biofuels, *etc*.

Arecaceae is the palm family composed of several genera and thousands of species [5, 6]. Five significant varieties of palm are cultivated as commercial varieties. These include palm, coconut palm, palm oil, nut palm, and areca palm. The oasis area of the date palm is different from the other four species, which are wet palm trees in tropical areas. All five of them were cultivated mainly for their fruit. In the subsistence economy of the farm, all parts of the five palm trees would be carefully processed to obtain any utility or product. Considering the need for survival in the arid region, the palm tree can regenerate the burned parts lost in a fire accident. This ability may have led to the naming of the palm tree by the mythical bird Phoenix, which is said to have lived for 500 years and to have risen with renewed vigor after being burned to ashes [7]. Fruits of different dates weigh 2 to 60 g, 8 to 110 mm long, 8 to 32 mm wide, and yellow to black Table **1** presents the top date producers in the world.

The development of date fruit can be classified into three steps Rutab, Tamr and Khalal. Dates are usually harvested in the fully mature Tamr phase, following the formation of the Total Soluble Solids (TSS) 60–70. Brix is consumed at this phase. Rutab and Tamr are the ripe and fully ripe stages Therefore, the fruit can be eaten at these stages without processing. The large amount of waste produced from the Kabkab date can be used to produce syrup [8]. There are various reports available for palm oil cultivation. But most of the studies are focused on the pharmacology and chemistry of date fruit [9]. Date palm has a range of health benefits, making it a great fruit [10]. The disposal rate of the date palm industries is too high in various countries [11]. These large figures, which are obtained annually in a sustainable manner, provide ample opportunities for the emergence of new bio-entrepreneurs and commercial entrepreneurs in developing countries to fully use palm in addition to better management of palm fruit waste. The date processing wastes can be used to produce various valuable products [10].

Table 1. The significant producers countries of date fruit [3].

Country name	Total annual production per 1000 metric tons
Egypt	1502
Algeria	848
Iran	1084
Iraq	676
Saudi Arabia	1065
Pakistan 527	-
South Sudan	432
Sudan	438
United Arab Emirates	245
Oman	269

Price of Nutrition and Organic Chemicals

Date contains many other vitamins and minerals and is considered a complete diet [1]. Currently, a small portion of waste is used as animal feed [12]. They are widely used and can be used as food for future generations because of their fantastic nutrition, health, and economy. Date contains a high amount of sugar, magnesium, potassium, calcium and vitamins [13]. In addition, it contains various fatty acids [14]. Due to its high sugar content, it can be stored in dried form for longer periods. It has beneficial properties such as anti-inflammatory, antioxidant and antimicrobial [15]. In recent years, the dates have attracted much attention because of their several health benefits [9]. Table **2** presents the date flesh and date seed chemical composition.

CHAPTER 7

Citrus Waste Valorization for Value Added Product Production

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Abstract: With the growing population, resource production and utilization, including citrus fruit consumption, have amplified tremendously. Citrus foods include sweet orange, sweet blood orange, tangerine, grapefruit, lemon, lime, and Seville orange. Industrial processing of citrus fruits is done to produce various end products like juice concentrates, jams, jellies, sweets, candies, marmalades, and ice creams, which simultaneously produce tons of peels and waste as well. Like all industrial waste dumping, the negligent discard of citrus waste has legal repercussions. Therefore, the global treatment seems to be a virtuous option, which results in improved earnings, thereby ultimately reducing the reprocessing expenditure.

Conversely, despite the low cost, citrus waste management and valorization still have not reached a virtue that makes it an ideal candidate. Valorization technically refers to the process of industrial recycling or waste composting into commercially valuable products. To fix the citrus wast essential to understand the various ways to recycle and manage the left-over better. This requires research and knowledge of different techniques involved in the commercial utilization of citrus waste for the production of various components, counting-essential oils, flavonoids, pectin, enzymes, ethanol and methane *etc.,* along with the applications of these bioactive components in various ventures. This study summarizes the bioactive components obtained from citrus foods and their possible industrial utilization.

Keywords: Biofuel, Citrus waste, D-limonene, Dietary fibre (DF), Essential oil, Enzymes, Flavonoids, Hydro-distillation (HD), Industrial processing, Microwave-assisted Steam Distillation (MSD), Microwave Hydro-diffusion and gravity method (MHG), Nutritious supplement, Organic Acids, Pectin, Pharmaceutics and Cosmetics, Single Cell Protein (SCP), Supercritical Fluid Extraction (SFE), Subcritical Water Extraction method (SWE), Ultrasonic-Accelerated Extraction method (UAE), Valorization.

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INTRODUCTION

Citrus fruits are affiliated with the Rutaceae family. The term 'citrus fruits' refers to several varieties, including-sweet orange, sweet blood orange, tangerine, grapefruit, lemon, lime, bitter/Seville orange, *etc.* These fruits typically have a sour and sweet flavor in varied ratios. They are rich in juice, have attractive colors, and are known for their taste and health benefits. The harvest is done mainly for juice, which comprises 45% weight, consumed either fresh or in refined form. The waste is produced as pulp and seeds, which are generally discarded Fig. (**1**) & Table **1**, describes the worldwide citrus fruit production. The juice obtained can be used for making concentrates, jams, jellies, sweets, candies, marmalades, ice creams, *etc* [1].

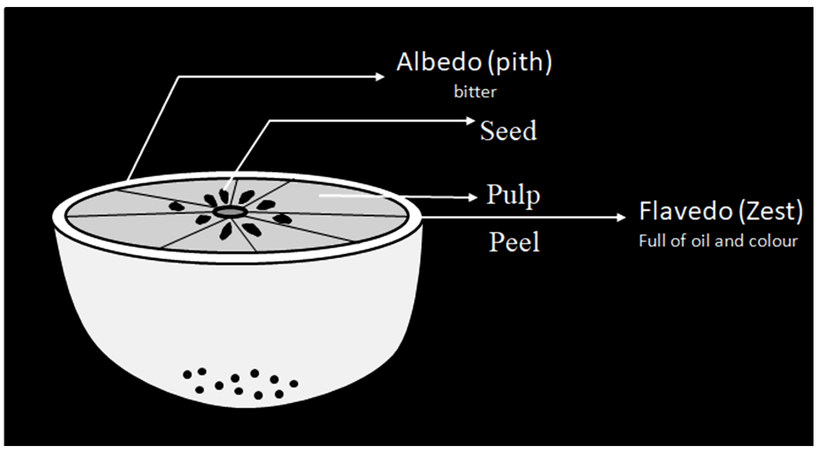

Fig. (1). Diagrammatic composition of citrus fruits

Table 1. Total production of citrus in the world in thousand tons from 2010-2016 [2].

	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016 Preliminary**
World	**117,441**	**123,824**	**123,002**	**128,611**	**131,707.7**	**130,947.0**	**124,246.0**
Northern Hemisphere	88,058.5	91,905.4	93,412.8	99,820.1	103,317.4	102,059.5	97,848.9
India	8,855.8	6,875.0	6,955.0	9,235.0	10,401.1	9,216.2	9,755.8
USA	10,193.9	10,919.5	10,813.0	10,301.0	8,751.0	8,208.0	7,829.0
Mediterranean Region	22,355.7	22,689.5	21,945.4	23,195.0	24,541.1	23,825.4	25,216.0
Cyprus	113.3	128.7	112.4	106.4	106.5	118.7	114.4
Greece	1,127.7	1,078.1	1,097.1	1,123.6	958.2	1,049.6	1,041.5
Italy	3,779.3	3 537.0	2,883.9	2,678.7	2,661.6	2,808.5	3,150.2
Spain	6,076.4	5,720.4	5,553.8	6,685.7	7,041.6	6,100.5	6,882.0

(Table 1) cont.....

	2010	2011	2012	2013	2014	2015	2016 Preliminary
Algeria	788.1	1,106.8	1,087.8	1,204.9	1,271.0	1,289.9	1,372.4
Egypt	3,518.2	3,724.9	3,975.0	4,096.9	4,402.2	4,646.6	4,930.4
Morocco	1,345.5	1 636.3	1,867.0	1,452.1	2,213.6	1,899.4	2,018.9
Tunisia	300.2	325.7	337.8	309.3	326.4	329.9	331.4
Israel	531.9	556.5	467.5	525.9	512.5	534.6	476.0
Lebanon	245.4	230.9	250.8	239.0	239.5	228.7	206.2
Turkey	3,570.0	3,611.6	3,472.9	3,678.6	3,781.4	3,803.3	3,652.1
Portugal	243.2	277.4	258.1	287.3	304.0	296.1	307.9
Japan	850.2	983.4	892.7	937.3	1,273.9	1,103.4	1,143.3
Mexico	6,753.4	7,031.1	6,603.2	7,467.8	7,655.2	7,291.7	6,634.0
China	23,974.9	28,939.9	31,830.4	34,261.7	36,467.0	38,153.9	32,705.9
Indonesia	2,028.9	1,818.9	1,611.8	1,654.7	1,926.6	1,625.9	1,574.8
Pakistan	2,150.0	1,982.2	2,036.0	2,008.8	2,010.4	1,915.8	1,907.4
Thailand	1,089.6	1,030.5	995.5	966.8	1,202.4	1,106.1	1,102.1
Vietnam	1 129.5	955.6	958.3	971.6	1,056.2	985.6	998.7
Others Northern Hemisphere	3,632.1	3,846.2	3,928.3	3,894.0	3,918.5	3,996.6	3,979.4
Southern Hemisphere	29,382.8	31,918.8	29,589.4	28,791.0	28,390.2	28,887.5	26,397.1
Argentina	2,559.4	3,613.4	2,895.8	2,433.7	2,164.2	2,753.3	2,800.7
Bolivia	319.5	324.1	330.2	332.2	337.7	356.8	371.4
Brazil	20,721.1	22,018.8	20,258.5	19,734.7	19,073.9	18,921.6	16,555.1
Paraguay	404.2	403.7	416.9	417.2	429.8	431.0	431.4
Uruguay	315.0	270.2	329.9	234.7	287.7	251.3	270.6
Venezuela	484.6	563.3	474.3	516.7	500.1	460.8	333.9
Chile	287.1	299.5	301.0	303.8	275.0	286.9	282.2
Australia	522.8	423.1	512.6	584.2	487.2	466.6	584.6
South Africa	1,997.0	2,169.2	2,133.6	2,169.9	2,169.9	2,662.6	2,409.2
Others Southern Hemisphere	918.9	948.6	988.6	1,069.4	1,213.2	1,195.4	1,246.0

In citrus fruits-based industries, although the prices paid to the farmers are lesser, transport, packaging, and marketing along with damaged fruits further add up to the prices. Besides that, the processing of fruits ends up rendering loads of discard and waste, like peels, pulp, seeds, rind, *etc.*. The common alternative for the waste produced is dumping to landfills which results in bad stink and disease expand. However, citrus waste has antimicrobial compounds, organic matter, low pH, and high-water contents, which may contaminate soil and water in the environment

CHAPTER 8

Valorization of Waste Plastics to Produce Fuels and Chemicals

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Abstract: The increase in the use of plastic products caused the major worldwide disposal problem of plastic solid waste (PSW). Plastics are becoming appropriate materials of interest for everyone due to their attractive applications in households, packaging, healthcare, and industries owing to their durability and versatile functionality at affordable prices. Statistics show that a large number of waste plastics are dumped in landfills, and only a tiny amount of plastic is recycled for making valuable materials *e.g.*, shampoo bottles, film, sheets, trash bags, kitchen-wares and packing materials. About 26,000 tonnes of plastic waste is generated in India every day, of which 40% remains uncollected and littered leading to adverse impacts on human health and the environment. Further, the incineration of plastic wastes emits many harmful gases such as nitrous oxide, sulfur oxides, dust clouds, dioxins and other toxins that pollute the atmosphere. To reduce waste plastics generation in the environment, the Indian government has implemented the Plastic Waste Management Rules, 2016 and its amendments, which explain ways for collection and management of plastic waste, its recycling, and utilization. Plastic wastes can be valorized to produce fuels using techniques such as thermal degradation, catalytic cracking, and gasification. This chapter is focused on waste plastic handling approaches, and novel routes to convert plastic wastes into energy and other valuable chemicals. This approach may compensate for high-energy demands and plastic waste management.

Keywords: Biodegradable, Catalytic, Chemicals, Conversion, Disposal, Degradation, Environment, Energy, Fuel, Hydrogen, Management, Plastic, Polymer, Production, Pyrolysis, Recycling, Revenue, Sustainable, Valorization, Waste.

INTRODUCTION

In recent years, the disposal of waste plastics has become a major worldwide environmental problem. Plastics are made from natural materials such as cellulose

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coal, natural gas and crude oil through polymerization and polycondensation processes. Further, physical properties of plastics i.e, lightweight, durability, versatility and relatively low cost make them a suitable candidate for applications in materials such as concrete, glass, metals, wood, natural fibers, and paper. Plastic production has increased by 3-4% annually since the 1990s and its consumption is projected to increase dramatically in developing countries due to economic expansion [1]. Nowadays, it is reported that only 9 -12% of global plastic waste is recycled and incinerated, while up to 79% is discarded into landfills or the natural environment, indicating that there is a great need for exploring innovative recycling methods to dispose of plastic wastes [2]. Over the past seventy years, the plastic industry has witnessed drastic growth, in the production of synthetic polymers represented by polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET), polyvinyl alcohol (PVA) and polyvinyl chloride (PVC). Plastic packaging is the largest application by weight, but plastics are also used widely in the textile, consumer goods, transport, and construction sectors. Further, the disposal of plastics has become a major environmental and economic issue. Moreover, inadequate waste plastic management causes serious environmental impacts, such as their accumulation in the oceans leading to marine debris [3]. The harmful effects of plastic are shown in Fig. (**1**). Plastics are typically organic polymers of high molecular mass and often contain other substances. The burning of plastics releases toxic gases like dioxins, furans, hydrogen chloride, airborne particles, and carbon dioxide into the atmosphere which contribute to climate change and air pollution. Burning of plastic wastes increases the risk of heart disease, aggravates respiratory ailments such as asthma and emphysema and causes rashes, nausea, or headaches, and damages the nervous system [4]. Recycling plastic and conversion of waste into energy are the best possible solutions for the management of plastic waste. Due to the high cost and poor biodegradability, it is undesirable to dispose of plastics in a landfill. Comparatively, plastic recycling based on pelletizing and molding to low-grade plastics has attracted the interest of many scientists worldwide, but recycled plastic possesses poor mechanical strength and color properties, hence having low market values and restricted applications [5]. The recycling of virgin plastic material can be done 2-3 times only because after every recycling, the plastic material deteriorates due to thermal pressure resulting in a reduced lifespan. Further, waste-to-energy technologies enable converting waste plastics into heat, hydrocarbon fuels and chemicals, therefore reducing the number of plastics to be landfilled [6]. Plastic Solid Waste (PSW) recycling processes could be allocated to four major categories, re-extrusion (primary), mechanical (secondary), chemical (tertiary), and energy recovery (quaternary). Each method provides a unique set of advantages that make it particularly beneficial for specific locations, applications or requirements [7]. The re-extrusion (primary) process involves re-introducing scrap plastics into valuable products. Mechanical recycling (Secondary) involves various operations that aim to recover plastics *via* mechanical processes (grinding, washing, separating, drying, re-granulating, and compounding), thus producing recyclates that can be converted into plastic products, substituting virgin plastics. Chemical recycling (tertiary), that is, the conversion of waste plastics into feedstock or fuel has been recognized as an ideal approach and could significantly reduce the net cost of disposal. The energy recovery (quaternary) process involves complete or partial oxidation of the material, producing heat, power, gaseous fuels, oils, and chars. These by-products must be disposed of. Among these processes, the chemical recycling process is useful in the production of fuel. Chemical recycling processes are like those employed in the petrochemical industry *e.g*., Pyrolysis, liquid gas hydrogenation, viscosity breaking, steam or catalytic cracking and the use of plastic solid waste as a reducing agent in furnaces. These are suitable methods for producing different fuels from plastic solid waste. Developed countries like japan, Germany and the United States have successfully implemented plastic in the fuel conversion process in their countries [8]. This review is helpful to convert waste plastic into value-added chemicals.

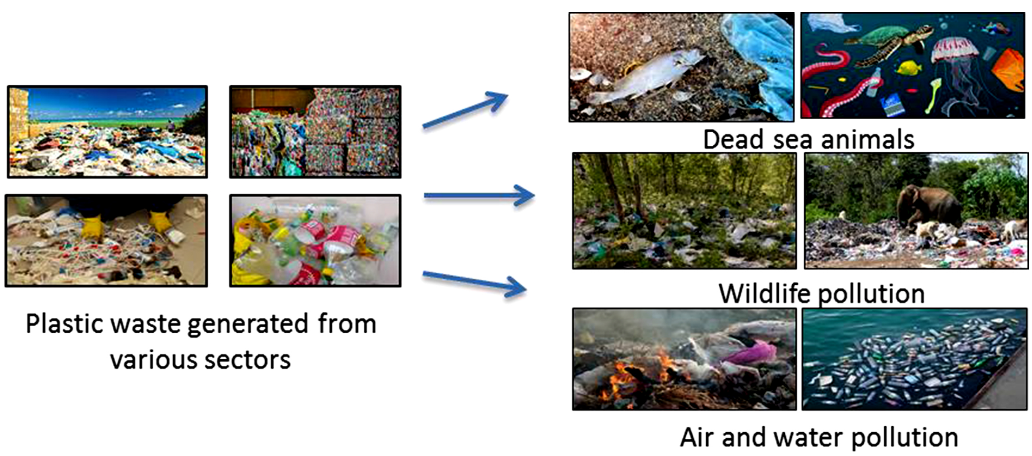

Fig. (1). Waste plastic and its harmful effect.

GLOBAL SCENARIO OF WASTE PLASTICS PRODUCTION AND ITS MANAGEMENT

On an average, the production of plastic globally crosses 150 million tonnes per year. Plastic waste is also a growing concern and is present in all the world's ocean basins, including around remote islands, the poles and in the deep seas. Since 1950, close to half of all plastic has ended up in landfill or dumped in the

CHAPTER 9

Wood Biomass Valorization for Value-added Chemicals

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Abstract: Wood biomass is a vital component in producing various value-added products. It can be used to produce biofuels and chemicals. Agriculture practices produce a lot of lignocellulosic biomass, a waste management concern for years. Most of this lignocellulosic biomass is considered waste. But in recent years, efforts have been made to utilize and valorize this biomass to produce value-added products. The major challenge with lignocellulosic biomass is that it cannot be used in production processes. Therefore, it requires several physical and chemical pretreatments. This chapter discusses various pretreatment technologies involved in valorizing lignocellulosic biomass. In addition, it also discusses lignin pretreatment, saccharification, and microbial biodiesel production.

Keywords: Biodiesel, Lignocellulosic biomass, Pretreatment, Saccharification, Value-added chemicals, Wood biomass, Waste.

INTRODUCTION

Biomass as a feedstock is one of the most copious materials on the earth, and it is considered an essential renewable supply [1]. It has various advantages. For instance, it is a green sustainable feedstock with zero carbon emissions. It saves the planet from the effect of global warming. Several studies have shown that lignocellulosic biomass can be used as a renewable feedstock for better quality of biofuels and biochemicals. On an annual basis, agriculture projects produce many lignocellulosic residues and create an issue of waste management. Lignocellulosic waste biomass can be converted into valuable products such as fuels. The adequate consumption of these wastes can provide a solution to meet the demand for value-added products worldwide.

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Over the last decades, it was observed that vigorous growth of biorefining produces value-added fossil fuel substitutes and biochemicals (like furfurals, organic acids, and alcohol). Bio-based technologies application continuously bring up sustainable bioeconomy growth. As per the European context, the economy needs to have circularity and sustainability at its heart to enable the change from a linear economy to a circular economy [2]. As per the prediction of the International Energy Agency, the bioenergy demand will increase considerably by almost 3-times by 2060 worldwide [3]. Sustainable biomass resources like crops, waste, and algae must be used more effectively for this drastic change. Moreover, to achieve biochemical and bioenergy targets in the future, it is necessary to develop circular and bio-cascading approaches [4]. Biorefinery and bioenergy products have become progressively inter-disciplinary, bridging several chemicals, biological, and physical technologies [5]. Hydrothermal treatment is an important technique for treating recalcitrant biomass into valuable products.

Pretreatment Technologies

Lignocellulosic biomass can be converted into cellulose, hemicellulose and lignin fractions. These products can further be converted into intermediate compounds such as 5-Hydroxymethylfurfural and furfural. The pretreatment technologies to convert lignocellulosic biomass are pyrolysis, hydro-liquefaction, gasification, catalytic hydrolysis, and solvolysis [1]. Among various pretreatment technologies, pyrolysis and gasification are considered essential. In pyrolysis, the thermal decomposition of cellulose, lignin and hemicellulose takes place in the absence of oxygen and the presence of a heterogeneous catalyst. Fast pyrolysis is much more efficient in lignocellulosic biomass hydrolysis than slow pyrolysis and hydrolysis. It produces green aromatics, phenolic compounds, furfural, hydroxy-methylfurfural and levoglucosenone. The pyrolysis process involves liquid evaporation and mass transfer of vapors through solid, solid-phase chemical, and liquid-phase reactions. The pyrolysis products are divided into gases, biochar, and pyrolysis oil. For the first and foremost product, the composition of crude bio-oil and pyrolysis oil mainly depends on the source and type of lignocellulosic biomass. Gasification produces gaseous fuel by burning biomass in a medium such as steam, oxygen and air to produce a mixture of gases at high temperatures, *i.e.*, 500-1500°C and pressure, *i.e.*, 30-40 bars [1]. Fig. (**1**) presents a lignocellulosic biomass pretreatment method.

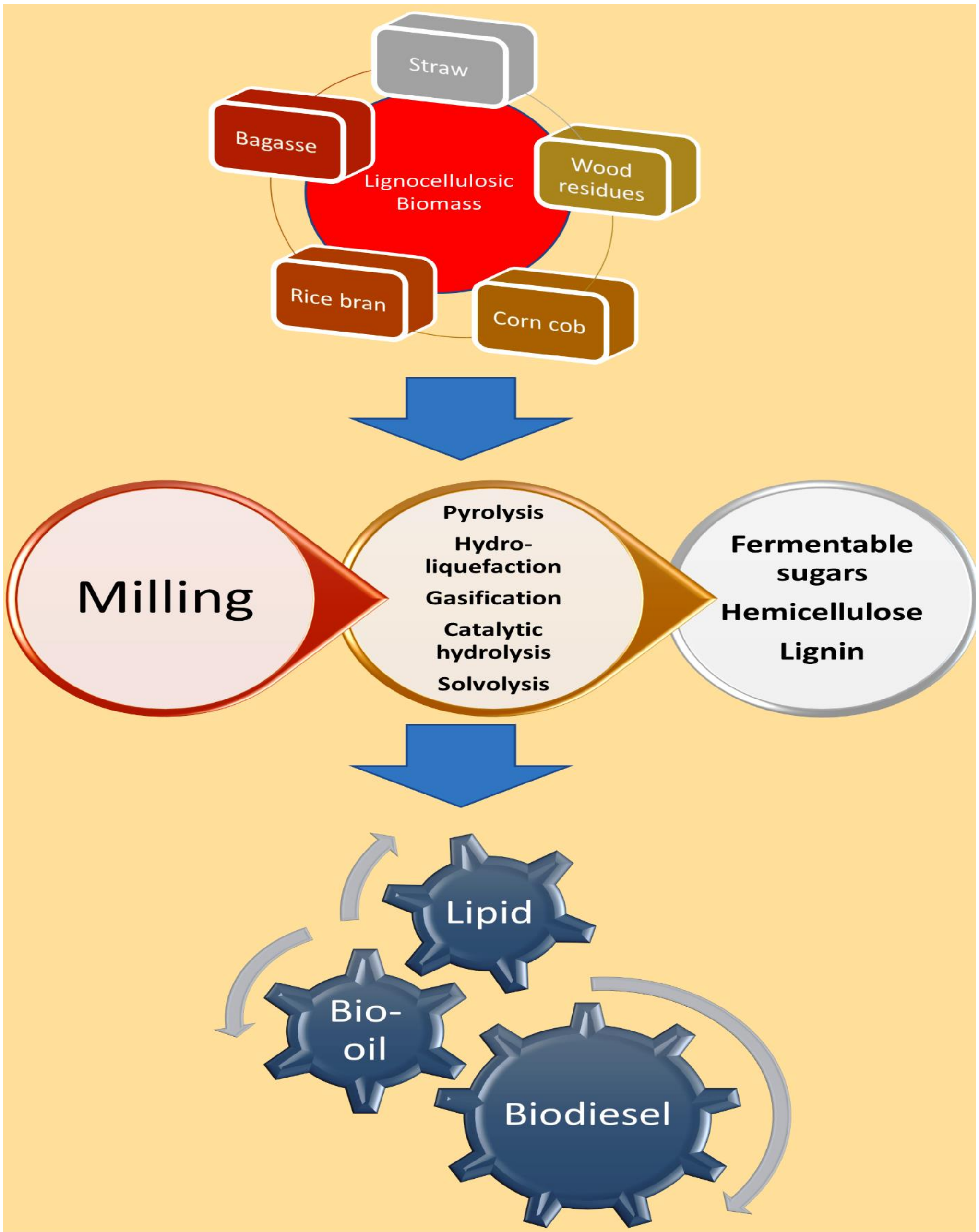

Fig. (1). A schematic route for lignocellulosic biomass treatment methods.

CHAPTER 10

Food Waste Valorization for Bioplastic Production

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Abstract: The alarming concern over the environment created due to the uncontrolled use of based petrochemical-based synthetic plastic created a research thrust on bioplastics. Bioplastics, in general, refers to the polymers derived from plants, animals, and microorganisms that have close material properties to their synthetic counterparts. Despite having good biodegradability, their commercialization still faces hurdles majorly contributed by the high production cost involved. An integrated strategy of waste valorization with bioplastic production was a sustainable approach toward their cost-effective production and commercialization. Food waste represents a continuous and rapidly available substrate containing high-value nutrients that can be exploited for the production of bioplastics through microbial fermentation and chemical treatment methods. This chapter describes the biotechnological strategies for valorizing food waste into commercially important biopolymeric components like chitosan, polyhydroxyalkanoates, HAp, and cellulose-based polymers. It presents a comprehensive outlook on their chemical nature, production strategy, and application in various fields.

Keywords: Biocompatibility, Biodegradability, Biopolymers, Bioactivity, Biomaterial, Bleaching, Chitosan, Cellulose, Crystallinity, Calcination, Deacetylation, Demineralization, Deproteinization, Dewaxing, Food waste, Hydrolysis, Hydroxyapatite, Polyhydroxyalkanoates, Thermoplastic, Valorization.

INTRODUCTION

The demand for food, fuel, and feed will keep increasing as long as the population of human beings keeps increasing. The big question looming around us is how best we can utilize available resources to the maximum extent in a sustainable manner. The drive towards sustainable development will be significant in the coming years as we have already exploited almost all-natural resources to a large extent, and it's high time that we give back or at least stop the over-exploitation of

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Mother Earth. In this context, food waste valorization assumes significance. Every year 1300 million tonnes of food is wasted globally. Most of these are dumped into landfills or into water bodies. The dangers of this are twofold. First, we are underutilizing a potential energy source without a sustainable approach. Second, the huge amount of dumped waste pollutes the environment. In water bodies, it can lead to dangers like eutrophication, which can cause havoc to the entire aquatic ecosystem, and groundwater pollution, which can affect water portability.

According to FAO, one-third of the food produced in the world goes to waste. This happens at multiple levels starting from the farm to food reaches the dining table. 30% of cereals and 20% of pulses are lost. Also, almost 8% of the caught fish is thrown back into the sea, mostly in dead or damaged condition, and 20% of meat also goes to waste. The maximum wastage is in the case of vegetables and fruits (45%). This implies that almost half of the global production of vegetables and fruits is wasted in some manner. One should translate this wastage to the enormous losses incurred in the form of resources utilized to produce these food items [1].

The concept of bioplastic manufacture from food waste has multiple advantages. It can lead to the reduced use of synthetic plastic and also prevent food wastage. The more considerable advantages also include reaping maximum benefits from the resources invested in making the food products, starting from the water and fertilizers in the field, labor cost, transportation, and processing costs, etc. If one accounts for all these factors, food waste valorization for biopolymer manufacture becomes highly sustainable. This is because the per capita cost of synthetic plastic production is much less than that incurred for bioplastics. This is very environmentally friendly as it is a renewable and sustainable process in which materials are synthesized from carbon-neutral resources. Bioplastics produced in this manner are primarily biodegradable and compostable [2].

Creating biopolymers from food waste can reduce food wastage and generate more employment in the processing sector. This will, in turn, help boost the local economy too. This is in line with goal number 12 of the “UN2030 agenda for sustainable development” to valorize food waste into commercially important products, thereby increasing employment with fewer resources via the circular economy model [3].

The long periods of industrialization have paved the way for the depletion of many natural resources. So in the 21st century, humankind may have to rely on sustainable methods to satisfy the ever-increasing needs for food, feed, fuel, and other luxuries. Soon a time will come when the natural wholly get completely depleted, and we may have to rely on biological systems more than chemical ones. In this scenario, biopolymer production from food wastes assumes paramount importance. While the policymakers in different countries have to look at this from different angles, it is better to give more thrust on increasing food waste utilization based on local needs. For instance, if this has to be implemented in a predominantly seafood-based economy in a coastal area, studies can be oriented toward fish waste valorization. This is the need of the hour as it simultaneously takes care of multiple aspects- reducing food waste, preventing pollution, full utilization of resources, and increasing employment among local people. This chapter focuses on the production of four major biopolymers from food wastes- chitosan, cellulose, polyhydroxyalkanoates, and hydroxyapatite.

Cellulose is the most abundant biopolymer on planet Earth. Non-toxic and biodegradable properties have led to its use in industries like food, paper, cosmetics, textiles, and pharmaceuticals. In the biomedical field, it is used in drug delivery, scaffolds, implants, etc. A significant amount of cellulose-based waste is generated across the world, most of which remain untapped. Hence ways of extracting cellulose from waste materials can have dual advantages in waste management and sustainability.

Chitosan is one of the naturally occurring polymers which is highly abundant in nature after cellulose. Its physicochemical and unique biological properties like biocompatibility and biodegradability, have given chitosan an important place in many industries, including food, medical, cosmetics, water treatment, metal extraction, etc. Different structural forms like gels, beads, membranes, films, sponges, etc. are made using chitosan and its derivatives. Chitosan can be derived from insects, mollusks, crustaceans, etc. More than 2000 tons of chitosan is produced annually, which is mainly extracted from shrimp and crab shell residues [4]. Since chitosan has a lot of applications and the demand is very high, tapping the best and cheapest sources could be a matter of great interest. To this effect, utilizing the byproducts of crustacean processing can be profitable as they yield high-value compounds like chitosan and its derivatives [5].

Hydroxyapatite (HAp) is yet another essential biopolymer used in bone repair and substitution and as scaffolds in tissue engineering for bone regeneration. It is compatible with bone without causing any toxic or inflammatory responses, and hence it is widely used as a scaffold for animals and plants [6]. HAp can be synthesized chemically or extracted from biological sources. A source of potential interest is fish waste in the form of scales and bones, as these are rich in phosphate, calcium, and carbonate [7].

Polyhydroxyalkanoates (PHA) are biopolymers that have attracted significant attention as they can be substitutes for synthetic plastics. Though their

CHAPTER 11

Waste Valorization Technologies for Egg and Broiler Industries

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Abstract: The poultry industry is one of the fastest-growing markets at the global level. As the industry expands, the solid waste generated from the poultry sector increases. However, a large amount of waste are generated in poultry farms which needs proper management and disposal to avoid many serious issues like environmental pollution, the spread of diseases due to pathogens residing in the waste as well as breeding of flies and rodents near the waste. Several methods are implemented for the proper utilization and disposal of residues produced in the farms. The methodology used for management varies widely based on many factors like the type of waste generated, nutritional value, and potential hazards to humans and the environment. The techniques adapted for utilization or disposal of the waste generated have evolved from simple conventional methods to highly advanced and more reliable methods (Pyrolysis, anaerobic digestion and catalytic pyrolysis), which are practiced increasingly nowadays, especially in large-scale poultry farms. Many projects and research are being held to improvise waste management techniques in the coming years. The appropriate processing, utilization and disposal of waste and its by-products are important to prevent unwanted side effects and increase the pecuniary output.

Keywords: Anaerobic digestion, Bio-diesel, Bio-char, Bio-filters, Catalytic pyrolysis, Composting, Incineration, Litter, Manure, Poultry waste, Pyrolysis, Rendering, Zeolites.

INTRODUCTION

Poultry Farming is one of the rapidly emerging industries at the global level, involving raising birds domestically or commercially for products such as meat and egg. According to the food and agricultural organization of the United States, poultry products form a significant part of animal-based food eaten by people following different religions, castes, cultures, traditions and beliefs [1]. In the present scenario, the critical role played by small-scale poultry production in reducing and eliminating major problems like poverty and unemployment in rural

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areas is gaining recognition. The fact that it has excellent employment opportunities, especially in rural areas for people belonging to diverse categories such as youngsters, middle-aged men and women, small as well as marginal farmers, *etc*., is gaining momentary recognition. The emergence of the poultry industry has also helped upgrade nutrition levels by ensuring food security to citizens in rural areas. Vocational training is an essential tool that helps farmers by providing them with knowledge, which can ensure the success of rural poultry, including information regarding poultry management, use of locally available feed resources, disease control through vaccination and hygienic management practices [2, 3].

Poultry farming is a much more favorable source of income for rural farmers as compared to urban farmers because the latter face various problems that include highly compact living conditions with limited surrounding space and closely located houses in most of the residential areas which is not an issue faced by most people living in the rural environment. Some municipalities and cities have prohibitions on backyard poultry farming while others have strict rules that must be followed to begin a farm. The owners have to take into consideration the discomfort which may occur to the neighbors in an urban setting due to the noise, odour, flies and insects which need to be controlled by taking proper measures. These problems are less to be faced by rural farmers due to the availability of more open space with fewer houses and people residing nearby [4].

With the increasing population, the food requirements also undergo a steep rise. Though crop production is the major food source, animal husbandry contributes significantly to fulfilling the increasing demand. Poultry farming has several advantages over crop production and other animal-rearing practices for farmers. The primary benefit is the low capital requirement to start small-scale poultry farming compared to an agricultural field for crop production or breeding of other animals like cattle. Another major benefit is the absence of seasonal breeding in poultry which ensures continuous income.

Crop production can put farmers at risk of seasonal unemployment caused by several factors like crop selection, nature of the soil, methods of farming, the possibility of multiple cropping, *etc*. Farming practices that involve poultry and crop production simultaneously have been of great benefit to the farmers. This practice is profitable because some of the crops like wheatgrass, corn, barley, peas, oats, *etc*., can be used as poultry feed. This also helps in the management of waste produced in poultry farming as it can be processed to make organic fertilizers that can be utilised for crops which are discussed in detail in the following sections [3, 5].

The rapid growth of the poultry industry is mainly driven by the countries that are the largest poultry meat producers, exporters, and importers, an overview of which suggests an annual growth rate of 3.0% in the market value by 2027 [6]. Advancements in technology, improved breeding methods, modern ways of farming, increasing population, and urbanization act as a driving force in the intensification of poultry farming in developing countries. Another major reason that favors poultry growth is the product's affordability and high nutritional value [7].

According to the statistics of the international poultry council, countries like the USA, Canada, Russia, Israel, Saudi Arabia, Iraq, Brazil, China, Japan, India, and the European Union currently form the hub of the poultry industry. The United States of America is the largest meat producer in the world followed by China, Brazil, and Russia. Poultry is considered one of India's most organized sectors, worth about 14,500 million €. In India, the need for processed meat has increased by about 15-20% per annum [2, 6].

China is the largest egg producer followed by USA and India. World poultry meat and egg production escalated from 9 to 122 million tonnes and 15 to 87 million tonnes, respectively, between 1961 and 2017. Apart from soaring as a large-scale industry, traditional small-scale poultry plays a crucial role in encouraging income in rural parts of developing countries [1].

A typical poultry industry produces a huge amount of solid waste materials. These waste materials cause severe environmental problems, producing extremely offensive odours and promoting rodent breeding and flies. Also, derisory methods and careless disposal of waste products will eventually lead to increased disease ailments among the birds. Thus, these wastes have to be managed properly, in order to protect society from unwanted side effects.

Kinds of Waste Generated and its Nutritional Value

Poultry waste is known by several names such as chicken litter, poultry litter, layer litter, dry broiler litter, poultry compost, poultry excreta and broiler excreta. Poultry wastes mainly include, bedding material or litter, a mixture of urinary or faecal excreta, broken eggs, dead birds, wasted feeds, and feathers. Basically, poultry excreta can be classified into poultry litter and confined layers. Confined layer wastes are from the concerned animal and poultry excreta consist of waste from sheet material and excreta.

One of the major reasons for a steep rise in poultry production worldwide is the high nutritional value at an affordable expense, making it available for people from a broader range of socio-economic backgrounds. The nutrient content of

CHAPTER 12

Valorization of Sugar Industry Waste for Value-Added Products

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Abstract: India is the second-largest cultivator of sugarcane worldwide, the primary source of refined sugar. Increased demand for sugar has driven this industry as a mainstream pollutant-generating industry. Every year, a tremendous amount of liquid (molasses) and solid wastes (sugarcane bagasse, filter cake) are generated, posing a major bottleneck for waste management. Although there exist traditional approaches like incineration, landfills are being employed for handling sugarcane waste which leads to the emission of greenhouse gases, and foul odour and adds more cost to running a sustainable industry. Moreover, no value-added product is formed from such traditional approaches resulting in an immense loss of bioenergy. Researchers have emphasized transforming waste into a sustainable economic generation of higher\-value products over the past few decades. Sugarcane industrial waste is a rich source of lignocellulosic organic biomass, which is used as a raw material for the production of biofuel (bioethanol, biogas), single cells proteins, enzymes, organic acids, food additives and nutraceuticals. Day by day, with advanced technology, novel applications are evolving, adding more thrust to this area. In this chapter, the potential of valorization of sugarcane waste to value-added products is discussed comprehensively.

Keywords: Biochemical, Biofuel, Lignocellulosic, Sugarcane waste, Value-added products.

INTRODUCTION

Agro-industrial residues are generated in vast quantities and pose major issues in handling and disposing of waste into the environment. These residues are either burnt openly or dumped directly into the environment owing to their biodegradable nature. Nowadays, these organic, renewable, energy-rich agro-industrial residues are bio-transformed into a wide array of valuable products. Sugarcane is a tropical crop with a planting and harvesting cycle of 12 months. It

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has high sucrose content and yields a large amount of sugarcane organic biomass ideal for bioconversion into many important industrial products [1, 2]. Asia is the biggest producer of sugarcane and contributes to 44% of global production [3]. Brazil and India are the largest producers of sugarcane and thus, generating the sugarcane industry waste [4]. The sugarcane industry is one of the mainstream industries which generate a large amount of solid, liquid and gaseous waste. Waste is generated at every step of sugarcane processing, from its harvesting to the final stage of packaging. Solid (Sugarcane Bagasse, Bagasse fly ash, Press mud) and liquid waste (Molasses) generated during processing need proper management for the sustainable sugar industry. Wastewater has high BOD (Biological oxygen demand) and COD (Chemical oxygen demand), thus need to be treated before disposing of into water bodies. This industry is generating a large quantity of sugarcane trash (leaves, dried stalk and roots) which has tremendous potential as fuel and feedstock; water effluent is generated, which is worrisome to handle and disposed off. Sugarcane trash is either burnt in open fields or dumped as it is, so causing problems of pollution and health risks. Sugarcane bagasse is the biggest agro-industrial fibrous waste left after the crushing of sugar stalks [5]. Molasses are dark colour nutrient-rich waste generated during the final stage of sugar syrup processing [6]. Vinasse waste is generated from the sugar-alcohol industry and has great potential for its bioconversion into valuable high-demand products [7, 8]. Nowadays, much emphasis is on the conversion of waste generated through the sugarcane industry to value-added products for maintaining the socioeconomic sector and sustainability of the industry. Valorization of sugarcane industry waste could solve the problem of pollution generated through this industry to a large extent. Biorefinery emergence in sugarcane resulted in combinatorial approaches for the sustainable sugar industry. Sugarcane bagasse has several applications in the bioenergy sector, paper industry, feed industry, enzymes, antibiotics, organic acid, alkaloids and other biochemical productions [2, 5, 9, 10]. In this chapter, we are going to study different waste generated so far by the sugarcane industry and their utilization as a raw material for the production of various high-value products.

Sugarcane Processing

Solid and liquid waste is generated during the processing of sugarcanes Fig. (**1**). The processing of sugarcane starts right from its harvesting as some stalk and dry leaves left behind, are either burnt or dumped in the field to be used as biofertilizers. The canes are washed, shredded and crushed to extract the juice. The juice is separated from solid organic waste termed sugarcane bagasse (SB). Further raw sugarcane is concentrated and precipitated to form clear sugarcane juice at the top and slurry left at the bottom called sugarcane filter cake (pressed). The clear sugarcane juice is heated to form a thick syrup catalyzed by sugar granules. Finally, after crystallization, the mixture was spun to separate the remaining syrup, termed sugarcane molasses (SCM) [1, 5]. The wastewater composition generated during each step is variable and contributes to a vast wide array of products Fig. (**1**). Composition shown in Table. **1**.

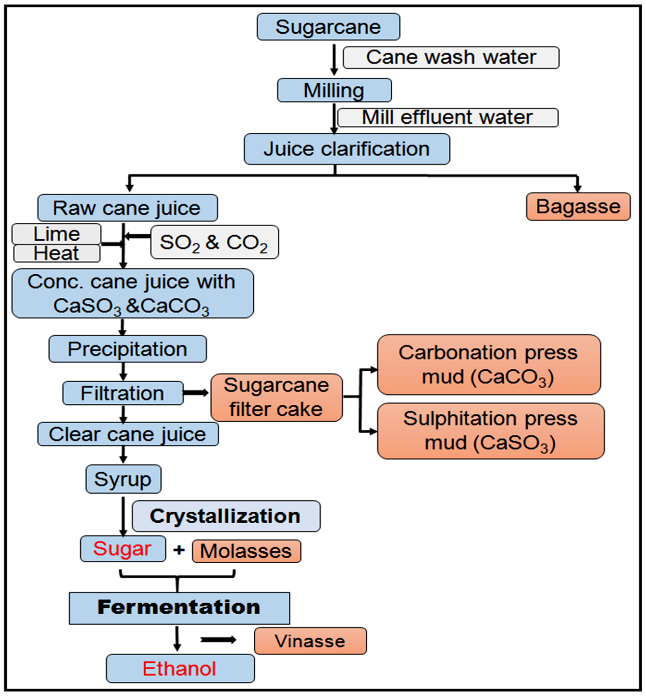

Fig. (1). Schematic presentation of sugarcane processing and waste generated during various steps of processing.

Table 1. Composition of sugarcane waste (Sugarcane bagasse, molasses, press-mud and Vinasse) where cellulose: C; Hemicellulose: HC; Lignin: L; Saccharose: S; Other Polysaccharides: OP; Ash: A.

Waste% dry weight												References
Sugarcane bagasse	pH	Fibers	Water	Soluble solids	Lignocellulosic content							[7, 9, 11, 12]
					C	HC	L	S	OP	A		
	4.5-5.5	48	50	2	42	28	20	4.6	3	2.4		
Molasses	5-5.5	-	-	46	-	-	-	49.9	-	10.25		
Vinasse	4.8	-	93	5.3	-	-	-	-	-	21.4		
Sugarcane filter cake (Press-mud)	4.95	15-30	75	-	11.4	27.1	9.3	1-15	-	9-20		

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Prof. Vinay Kumar completed Ph.D. in Biotechnology from the School of Biotechnology, Jawaharlal Nehru University, New Delhi, India. He received prestigious awards including CSIR-JRF, DBT-JRF, CSIR-NET, GATE, and ICAR-NET. In addition, he completed a research grant from SERB as principal investigator at IIT Roorkee. He worked in various countries as a postdoctoral fellow. He has more than twelve years of research experience working on environmental engineering, nanobiotechnology and nanotoxicology. He published several outstanding research publications in prestigious journals. Moreover, he has research collaborations with prominent scientists from Finland, Mexico, Malaysia, Thailand, China, Switzerland, Chile, Brazil, Ireland, Greece etc. Currently, he is working as professor in the Department of Community Medicine, Saveetha Medical College, Saveetha Institute of Medical and Technical Sciences, Chennai, India.

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NEHA SHARMA

Mrs. Neha Sharma is a researcher working for the last twelve years in the areas of biotechnology, environmental biotechnology, nanotechnology, and environmental decontamination. She acquired expertise in several advanced areas of research. In addition, she worked with several national and international organizations including academic and industrial industries. She published several research papers in reputable journals. Currently, she is working on exploring the potential of biowastes to produce nanomaterials for biomedical applications.