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A Glance On Oil Producing Plants, Pretreatment and Bioenergy Production Using Oil Producing Plant

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Oil producing plant is defined as any of the numerous plants, either under cultivation or growing wild, used as sources of oil. Oil producing plants include trees such as palm, herbaceous plants such as flax, and even fungi (*Fusarium*) (Encyclopaedia Britannica 2020). Oil producing plants can be categorized as edible and non-edible. In particular, this book focuses on oil producing plants in Asia that are widely distributed throughout Brunei, Burma (Myanmar), Cambodia, Timor-Leste, Indonesia, Laos, Malaysia, the Philippines, Singapore, Thailand, and Vietnam.

Apart from the most prominent oil crops (palm oil, soybean, rapeseed, and sunflower), many other crops such as canola, mustard, flax, jatropha, corn, coconut, castor, hemp, and pennycress are good resources of oil. Vegetable oils are used principally for food mostly as shortening, margarine, salad, and cooking oils and for non-food production in the manufacture of soap, detergents, paints, varnishes, and various other industrial items. Oil is found in large amounts usually in the seeds of the plants and occasionally in the fleshy part of the fruit, as in the olive and the oil palm. Seeds may contain from 1% to more than 60% oil. The oil is a reserve of high-energy food for use by the germinating seed, and large amounts of oil are associated with large amounts of protein.

The book consists of two volumes.

Volume 1 begins with Chapter 1: Introduction to Volume 1. It discusses the biorefinery of oil producing plants that cover the topics from the availability of the oil producing plants, the types of pretreatment, and the generation of bioenergy.

Part 1: Availability of oil producing plants consists of five chapters. This part provides an overview of oil producing plants that are palm oil, castor oil, jatropha, nyamplung, and coconut.

The oil palm tree (*Elaeis guineensis*) originates from West Africa, where it was grown in the wild, and later, it was developed into an agricultural crop. Palm oil is the second largest source of edible oil, next only to soybean. As the demand for palm oil rises significantly over the coming decades, the sustainability of the palm oil

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industry must be maintained to serve billions of people (Abd-Aziz et al.: Chapter 2). Palm oil also serves as feedstock for both food and non-food industries, which makes a significant contribution to the growth of the economy. The processing of palm oil has been monitored by the respective agencies, the Indonesian Sustainable Palm Oil (ISPO) Certification Scheme for Indonesia, and The Malaysian Sustainable Palm Oil (MSPO) Certification Scheme for Malaysia to ensure all the operations meet the standards and legislative regulations. Palm oil plays a very important role in feeding the world's demand for fat and oil. Thus, its sustainability to keep on serving billions of people worldwide must be maintained, improved, and supported by all the parties.

As both government and industries shift toward environmentally friendly practices, emphasizing finding renewable resources, the global oil producing plants market has seen positive growth in the last few decades.

Jatropha (*Jatropha curcas*) plant is originated in Mexico and now grows widespread in tropical and subtropical areas in Latin America, Asia, and Africa (Dias et al. 2012). Jatropha seeds generally contain toxic components but produce 27–40% oil, rich in palmitic acid ($C_{16:0}$, 13.4–15.3%), oleic acid ($C_{18:1}$, 34.3–45.8%), and linoleic acid ($C_{18:2}$, 29.0–44.2%) (Meher et al. 2013). *J. curcas* L. is an oil crop with great potential to be used as the feedstock for biodiesel production (Srinophakun et al.: Chapter 3). This non-edible oil has advantages over edible oil in terms of stable price and free of food-feed-fuel dilemma. Nevertheless, jatropha trees can grow in many soil and rainfall types, are drought resistant, and have more tolerance to insects and pathogens than other energy plants such as corn, cassava, soybean, etc. This chapter reveals the five-year yield trial results of two jatropha varieties, KUBP 78-9 and KUBP 202, developed by the Center of Excellence for Jatropha at Kasetsart University. KUBP 78-9 has been selected and field trialed since 2004, while KUBP 202 was an interspecific hybridization variety and first yield trial was in 2012.

Castor plant (*Ricinus communis*) is one of the potential oil producing plants commercially used by chemical industries (Fatimah et al.: Chapter 4). This plant is cultivated around the world because of the commercial importance of its oil. Castor seeds contain about 30–50% oil, which is rich in a triglyceride called ricinolein. The "ricin" in ricinolein is referred to as the ricin protein contained in the bean, which is toxic. Castor oil is derived from the castor bean of the plant *R. communis*, originally from Ethiopia (Milani and Nobrega 2013). This oil has the possibility of being transformed into several different materials, including a potential alternative to petroleum-based starting chemicals. This chapter discusses many aspects of castor oil, including the cultivation, technical processing, chemical and physical quality, and its economic potency in the scheme of renewable chemicals and energy. It should be noted that the techno-economical evaluation of the synthesis reaction should be considered in conjunction with castor plant cultivation.

Nyamplung (*Calophyllum inophyllum* L.) is one of the oil producing plants that can be found in Indonesia, which has high potential to become biodiesel feedstock because of its high seed oil content. The seed oil content in nyamplung is in the range of 40–75% (dry weight basis), higher than jatropha seed oil content (40–60%) and rubber seed oil content (40–50%) (Hanafi et al.: Chapter 5). Nyamplung is a genus of an evergreen tree commonly found along the coastal region of eastern Africa, Madagascar, Papua New Guinea, India, Northern Australia, and tropical America along the east and west coast of the Peninsula, the islands of the Pacific Ocean, Melanesia and Polynesia, and tropics of Asia, mainly in the Indo-Malaysian region and Ceylon (Habibullah et al. 2015). Despite its high seed oil content, the yield and quality of nyamplung oil are affected by its extraction method. The common oil extraction method used in industry is mechanical extraction. It has more economic benefits than other oil extraction methods.

Coconuts are natural products that are beneficial to humans (Gozan et al.: Chapter 6). Coconut fruit can provide economic and health benefits. Factors such as the variety of the palm, stages of maturity of the nut, and growth conditions determine the kernel composition. The mesocarp and endocarp parts of the coconut fruit can be used as coconut coir and activated carbon, while the coconut kernel can be used as a source of coconut oil. The extraction process of coconut oil is divided into two, namely, wet and dry extraction. Dry extraction produces refined, bleached, and deodorized (RBD) coconut oil. Wet extraction produces a product in the form of virgin coconut oil (VCO). Almost all parts of the coconut fruit have been industrially utilized. The application and economics of coconut oil are discussed in this chapter.

Part 2: Pretreatment consists of six chapters. This chapter discusses the types of pretreatment. The importance of selecting suitable microorganisms, substrates, and pretreatment methods to determine the process parameters accounted for upstream and downstream techniques for attaining high sugar yield is discussed.

Physical and chemical pretreatment of lignocellulosic biomass (Zhao et al.: Chapter 7) underlines the importance of physical and/or chemical methods before enzymatic hydrolysis by cellulase to destroy the biomass recalcitrance. A suitable pretreatment process is essential because it affects cellulase dosage and production of end products during enzymatic hydrolysis and fermentation and influences the costs of manufacturing facilities and process operation and environmental pollutions. Although various pretreatment methods that can be used for oil producing plants have been described, there is no one pretreatment method to meet all the requirements of different plants. The chapter reviews the research progress in the physical and chemical pretreatments, including pretreatment methods and fundamental mechanisms of different pretreatment processes.

Ionic liquid pretreatment of lignocellulosic biomass (Wan et al.: Chapter 8) discusses newly developed chemical pretreatment methods. The pretreatment aims to improve the rate of production as well as the total yield of liberated sugars in the hydrolysis step. The Industrial Technology Research Institute (ITRI) has developed two chemical pretreatment methods, including an ionic solution way containing zinc chloride ($ZnCl_2$) and a solid acid catalyst way. Among them, the ionic solution pretreatment has advantages of high sugar yield and low cost compared to others. Therefore, this chapter introduces the main concept of lignocellulosic pretreatment, and the ITRI's ionic solution hydrolysis experience is also discussed.

Biological pretreatment of plant biomass (Prasongsuk et al.: Chapter 9) pays special attention to the production of value-added product from lignocellulosic biomass. Pretreatment is an important step for breaking the chemical bond present in lignocelluloses. A biological pretreatment is a promising approach among the different pretreatment strategies, being eco-friendly and producing fewer inhibitors. This chapter presents an overview of biological pretreatments of lignocellulosic biomass from oil producing plants, such as oil palm and corn, to produce various value-added products. Moreover, microbes and their enzymes affecting the biological pretreatment process and future perspectives are also addressed.

Lignocellulose is fundamentally constituted by cellulose, hemicellulose, and lignin, although biomass-specific composition varies depending on different factors. However, to effectively degrade cellulosic components into sugar, the protective layer made of lignin needs to be removed. Thus, a group of lignin-degrading enzymes (Ibrahim et al.: Chapter 10) can be produced and employed to delignify lignin and expose the internal structure of cellulose and hemicellulose. How these lignin-degrading enzymes can be produced, the range of these enzymes and their reaction mechanism, and the roles of lignin-degrading enzymes in the biorefinery concept are discussed in this chapter.

Enzymes for hemicellulose degradation (Bankeeree et al.: Chapter 11) discusses hemicellulose degradation using xylanases and associated debranching enzymes. Inspired by nature, recombinant enzymes have been engineered to achieve a certain manufacturing process optimal properties. Therefore, understanding the action of these multifunctional enzymes in lignocellulose breakdown is essential. This chapter describes the natural and recombinant enzymes of microbial origins reported to date and their distinctive roles in efficient hemicellulose degradation. Besides this, potential applications of these xylanolytic enzymes in the industry are also discussed.

Cellulase from oil palm biomass (Hyeon and Han: Chapter 12) discusses the cooperative action of a multitude of cellulolytic enzymes for the degradation of the plant cell wall structure. Due to the structural complication of the cell wall in oil palm biomass, the collective actions of a variety of cellulolytic proteins, such as exoglucanase, endoglucanase, and β-glucosidase, are essential. Cellulases act synergistically and contribute to the turnover of cellulosic material. Various attempts have also been made to use oil palm biomass substrates by utilizing cellulose-degrading enzymes in industrial microbes to create a valuable commodity. As a strong strategy to achieve whole-cell biocatalysts with different functions as well as feasible and cost-effective biomaterial development, the usefulness of cellulases for production in different industrial microbes has attracted interest.

Part 3: Generation of bioenergy consists of seven chapters. To overcome the current energy crisis and deterioration of environmental conditions, bioenergy production from sustainable and renewable sources is the major goal for an energy-demanding society. Oil producing plants and their wastes are major fractions of biomass. These resources can be utilized as feedstocks for the generation of bioenergy, i.e. biogas, bioethanol, biobutanol, biochar, fuel pellet, biohydrogen, and biodiesel. The classification of agricultural wastes, their compositions, and different processing and biofuel production routes are discussed.

Biogas generation in the palm oil mill (Gozan et al.: Chapter 13) discusses the closed anaerobic digestion system, a very sustainable form of processing in which methane gas (a potent greenhouse gas) was not released into the air. Palm oil mill effluent (POME) was characterized by high biological oxygen demand (BOD) and chemical oxygen demand (COD) content. The anaerobic digestion pond is a very sustainable form of processing because it does not release methane gas into the air, potent greenhouse gas. Proper pretreatment strategies are necessary to handle recalcitrant materials. Nutritional addition methods and digester configurations have been developed to produce and capture as much methane gas as possible to reduce impurities. Organic loading rate (OLR) is one of the key parameters that must be maintained high to ensure the biogas production's continuity and stability. Various operating conditions, especially the feed and pond temperatures, affect the OLR and removal of organics and biogas purification, which were discussed in this chapter.

Biodiesel refinery from jatropha (Srinophakun et al.: Chapter 14) summarizes biodiesel production techniques from jatropha in general and focuses on optimization of transesterification of fatty acid methyl ester (FAME) using the base as a catalyst by response surface method (Box–Behnken design). Optimized conditions obtained were at reaction temperature 45 °C, reaction time 90 minutes, 1.3% KOH, and the mole ratio of methanol to the oil of 7 : 1, resulted in the jatropha biodiesel of 97.9% FAME, the viscosity of 4.53 cSt, pour point of 6 °C, the flashpoint of 197 °C, and an acid value of 0.388 mg KOH/g. Due to the high unsaturated fatty acid composition, jatropha biodiesel has relatively low oxidation stability (4.21 hours), whereas at least 6 hours is required according to biodiesel specifications in many countries. The oxidation stability was improved by the addition of propyl gallate to jatropha biodiesel. The long-term storage of jatropha biodiesel was also studied and compared with other biodiesel types.

By-products from oil producing plants (Cheng et al.: Chapter 15), such as oil meals/cakes, have great potential to be utilized as feedstock for bioethanol production. More interestingly, when the feedstocks are derived from the residues left from biodiesel production, it would be beneficial to integrate bioethanol production to develop the in-house biodiesel process. Overall, the bioethanol production from oil plants could be part of the circular economy and deserves comprehensive investigations for further commercial implementation to supply the increasing demand for second-generation biofuel. The integrated production of fermentable sugars and oil from the same feedstock could also potentially maximize the utilization of plant biomass. In this chapter, different residues and by-products are reviewed and discussed for their potentiality in bioethanol production.

Production of biobutanol from oil palm biomass (Ibrahim et al.: Chapter 16) involves several processes: (i) pretreatment of oil palm biomass to remove and/or alter the lignin structure, (ii) saccharification process to produce sugar, (iii) acetone–butanol–ethanol (ABE) fermentation to produce biobutanol, and (iv) recovery and purification step to obtain pure biobutanol. Each of the processes poses challenges that limit the biobutanol yield and productivity. Therefore, many studies have been done to improve biobutanol production so that the biorefinery of biobutanol from oil palm biomass could be viable for the industry. Thus, each of these processes must be improved to enhance overall biobutanol production, for example, by selecting a suitable pretreatment for oil palm biomass and a suitable recovery process for biobutanol. Overall, the biobutanol can be produced using oil palm biomass as a raw substrate; however, the whole process must be improved to make sure the biobutanol production meets the industrial perspective.

Biochar from oil palm biomass (Zainal and Idris: Chapter 17) is the best alternative raw material for biochar production to reduce environmental impacts and generate additional income for the palm oil industry. However, industrial-scale pyrolysis of biomass for biochar production, in general, is still in its early stage of development. To realize its potential in the industry, it is essential to produce biochar in an economical, clean, and energy-efficient process by integrating pyrolysis. More research is needed on the optimization techniques for the maximum biochar production yield, cost-factor analysis for biochar production, multi-component study, dynamic investigation, modeling, and biochar regeneration. Besides, some of the challenges in promoting biochar to a potential market are highlighted in this chapter.

Fuel pellet from oil producing plants (Alamsyah: Chapter 18) discusses biomass usage from oil producing crops directly as fuel without pretreatment, such as in boilers, or direct combustion for domestic energy purposes focus on biomass pelletizing. Biomass pelletizing is a densification process that improves biomass characteristics as a fuel. Pelletizing can enhance the volumetric calorific value; reduce the transportation and storage costs; reduce the moisture content; and improve biomass's handling characteristics. Inside a gasifier, the fuel pellets are burned to produce a synthetic gas (syngas) with high energy content. The resulting pellet must have good quality and meet the specified wood pellet quality requirements concerning DIN 51731 standards related to solid fuel for compress-untreated wood to obtain a good combustion result. The resulting high-quality pellets can be gasified to produce high amounts of energy. The gas produced (synthetic gas) can be used for drying agricultural products and for cooking in households. It is hoped that the information contained in this book can support small and medium industries/enterprises interested in further developing businesses in processing biomass pellets as solid fuel.

Biohydrogen from POME (Jahim et al.: Chapter 19) as a substrate is technically feasible and exhibits high potential in the future. Fermentative hydrogen production is a promising method that converts the organic contents in POME to biohydrogen by the anaerobic bacteria. However, this technology faces a few challenges, such as the low yield and rate of biohydrogen. Therefore, various biohydrogen systems are evaluated in this chapter. As one of the efforts to achieve sustainable development of the palm oil industry, biohydrogen production from POME is proposed to solve both economic and environmental issues. In this chapter, biohydrogen production through dark fermentation, which does not require light energy input, is discussed. The process performance is evaluated at different reaction conditions, i.e. temperature, pH, hydraulic retention time (HRT), inoculum to substrate ratio, substrate concentration, bioreactor type, OLR, and mixing speed. Microbial mixed cultures have been proposed as an alternative to single cultures that can respond to microbial diversity and withstand sudden process fluctuations, removing the need for sterilization. This chapter provides a detailed review of the most recent experiments to treat POME anaerobically and produce biohydrogen gas under optimum conditions.

Volume 2 discusses a variety of high value-added biobased chemicals derived directly from oil producing plants and their byproducts through various processes. The importance of oil producing plants, especially as a feedstock for the synthesis of added-value molecules, has not diminished over several decades. Volume 2 is divided into three parts – Generation of biobased chemicals, Generation of other bioproducts and reviews on technical and economic aspects, and the economic impact of the biorefinery activities of oil producing plant products.

Part 4: Generation of biobased chemicals consists of nine chapters. This chapter provides an overview of several biobased chemical generations, i.e. bio-oil from the tobacco plant, biosurfactants from the oil producing plant, palm catanionic surfactant for drug delivery application, glycerol and derivatives, biovanillin from oil palm biomass, diacids from oil producing plants, bioplastic production from oil producing plants, plant-oil-based polyurethane and bioresins from oil producing plants.

Part 5: Generation of other bioproducts consists of three chapters. Three types of other by-products discussed include biocompost from oil producing plants, animal feed from oil producing plants, and amino acids from oil producing plants.

Part 6: Economic analysis of oil producing plants consists of two chapters. It discusses the technical and economic aspects of the oil producing plants and concludes with a chapter on the economic impacts on the oil producing plant's biorefinery.

Remarks

Biorefinery of oil producing plants represents an innovative approach in environmental management. Products/by-products after oil extraction of respective plants at the end of their service life or waste materials are seen as valuable resources for high production value-added bioproducts and are produced from renewable sources. A biorefinery is defined as the integrated and sustainable biomass processing into various marketable chemicals, materials, fuels, and power. In the biorefinery concept, hybrid technologies from various fields, including agriculture, chemistry, engineering, and microbiology, are applied to an integrated process to separate biomass into its building blocks, such as carbohydrates, proteins, and oils. These compounds can be further converted to other value-added products such as platform chemicals, energy, and biofuels (Cherubini 2010). According to Kamm and Kamm (2004), biorefinery can be divided into three phases: biomass, targeted products, and processes used. A phase I biorefinery has almost no or little flexibility during the whole process; it normally uses one type of biomass, one process, and one targeted product. In phase II biorefinery, more products can be produced during the process. A phase III biorefinery has even higher flexibility than a phase II biorefinery in which it can produce multiple value-added products, final products, and routes (technologies) to convert biomass to final products, which are three key points in a biorefinery design.

The design of biorefinery processing routes needs to be considered thoroughly. Different technological processes such as mechanical, chemical, thermochemical, and biochemical processes are normally jointly applied to convert feedstock into several value-added products in an integrated process. Mechanical treatment is commonly used in the first step for size reduction. Such technologies include pressing, milling, and pelletization. This process usually does not affect the composition of biomass. Still, it only changes the particle size and shape, improving the mass transfer characteristics, enzymatic hydrolysis, and biodegradability of biomass in the following steps (Menon and Rao 2012). Chemical processes such as acidic or basic hydrolysis, transesterification, hydrogenation, and oxidation are applied to change biomass chemical structures. Thermochemical processes are often used to produce syngas by gasification (>700 °C) and liquid pyrolytic oil and solid charcoal by pyrolysis (300–600 °C) (Cherubini 2010). As to biochemical processes, enzymatic conversion, anaerobic digestion, and fermentation are mostly used in biorefinery processing. Structural compounds such as cellulose and hemicellulose in biomass can be enzymatically hydrolyzed to their component sugars, including glucose and xylose. These monosaccharides are then used to produce biofuels such as ethanol, hydrogen, and butanol and organic acids such as succinic acid through fermentation. A biorefinery can be considered to be an integral unit that can accept various biological non-food feedstocks and convert them into a range of useful products, including chemicals, energy, and materials. Biobased products are a great curiosity question of whether it gets to replace fossil-based products. Biomass, a renewable source of carbon, is guaranteed a place in the new energy portfolio for the foreseeable future.

Biorefinery of oil producing plant-derived waste is generated annually from agricultural activities and subsequent food processing. It should be noted that the exact composition of a particular waste may vary from different regions or processing methods. Generally, the major structure of oil producing plant-derived waste consists of cellulose, hemicellulose, lignin sugars, proteins, oils, and phytochemicals. In this chapter, the oil producing plants discussed include palm oil, jatropha, castor (*R. communis*), jatropha (*J. curcas*), nyamplung (*C. inophyllum*), and coconut. For industrial usage, cellulose can be used to produce biofuels, organic acids, and nano-cellulose materials. Hemicellulose can be degraded to xylose and then xylite and furfural, which are valuable chemical products. Lignin is used as a natural binder and an adhesive; moreover, valuable compounds such as phenols can be derived from lignin (Kamm and Kamm 2004). Besides structural compounds, other reserves rich in plant-derived waste also show potential for various applications and are worthy of recovery. Proteins in plant-derived waste with well-balanced essential amino acids can be introduced to food to enhance sensory and functional properties. For example, soy protein has been used in imitation cheese, soy milk, and whipped toppings (Oreopoulou and Tzia 2007). Phytochemicals, such as polyphenols and carotenoids, have been related to health-promoting effects, including lowering cholesterol and lipid oxidation (O'Shea et al. 2012). Besides health-promoting effects, the addition of these antioxidant compounds into food matrices can extend their shelf life and delay the formation of off-flavors of food products (Oreopoulou and Tzia 2007). Vegetable oils in the plant-derived waste can be used to derive sugar-based surfactants (e.g. alkyl polyglucosides) with low toxicity and good detergent properties compared to traditional surfactants derived from fossil oil (Foley et al. 2011).

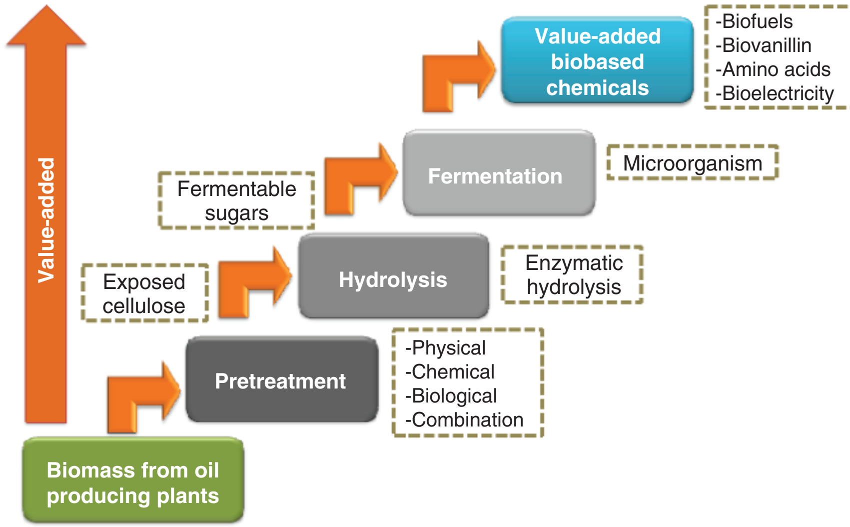

Figure 1.1 Conversion of biomass from oil producing plants (specifically lignocellulosic biomass) into value-added biobased chemicals. Source: Abd-Aziz and Gozan.

Therefore, more research focuses on the extraction, purification, and production of valuable chemicals, materials, and biofuels from plant-derived wastes. Graphical illustration in Figure 1.1 summarizes the overall process of converting biomass from oil producing plants (specifically lignocellulosic biomass) into value-added biobased chemicals.

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