Chapter

Lignocellulosic of Oil Palm Biomass to Chemical Product via Fermentation

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Abstract

The world's largest contribution to biomass comes from lignocellulosic material. Oil palm biomass is one of the most important sources of lignocellulosic material in Asia, with biomass produced four times that of palm oil. Oil palm trunk (OPT), oil palm empty fruit bunches (OPEFB), oil palm frond (OPF), and palm oil mill effluent (POME) are examples of biomass lignocellulosic materials produced. Unfortunately, the majority of waste is disposed of in landfills, causing serious environmental issues such as global warming and the greenhouse effect. These wastes are known to contain a high concentration of cellulose and hemicellulose. Because of its high carbohydrate content, it has a promising future as a feedstock for the fermentation process, which can produce a variety of chemical products at a low cost. This chapter will describe the biochemical products produced from various oil palm biomass via various fermentation processes involving various microorganism strains.

Keywords: Oil palm, fermentation, lignocellulose, biomass, lignin

1. Introduction

The largest component of biomass available on the world is lignocellulosic material. Oil palm is one of the most important sources of lignocellulosic biomass in Asia, especially in Malaysia and Indonesia. Malaysia, after Indonesia, is the world's second-largest producer of palm oil, with a capacity of 17.32 million tonnes and a cultivated area of 5.74 million ha [1]. According to the Malaysian Palm Oil Board (MPOB) statistics from 2016, the total volume of oil palm products was 25.64 million tonnes [2]. Oil palm biomass accounts for the remaining 90% of total dry matter palms, with oil accounting for just about 10% of total dry matter palms [3]. Oil palm empty fruit bunches (OPEFB), oil palm fronds (OPF), and oil palm trunks (OPT) make up the majority of oil palm biomass in Malaysia.

Malaysia's annual production of OPEFB, OPT, and OPF is approximately 84.23 million tonnes (dry basis) (**Table 1**) [4]. This massive amount (i.e. 7 million tonnes of OPEFB, 21.4 million tonnes of OPT, and 55.8 million tonnes of OPF) suggests that oil palm biomass is a readily available feedstock for chemical products, particularly through the biological fermentation process.

Nowadays, fermentation processes are the most commonly used method of utilizing biomass because they are non-toxic, environmentally friendly, and have

Production site	Biomass type	Estimated amount (million tonnes dwb)	Remarks
Mill	Oil palm empty fruit bunch (EFB)	7.03	Based on annual fresh fruit bunch (FFB) yield
	Oil palm trunk (from replanting activity)	21.38	Based on 5% estimated oil palm planted area due for replanting
Plantation	Oil palm frond (from replanting activity)	4.16	Based on 5% estimated oil palm planted area due for replanting
	Oil palm frond (from pruning activity)	51.66	Based on 75% of oil palm planted area pruned per annum

Sources: Adapted from Bukhari et al. [4].

Table 1.
Availability of lignocellulosic oil palm biomass in Malaysia.

a low operating cost. The current chapter outlined the role of microorganisms in the fermentation process for valorizing lignocellulosic oil palm biomass for various biochemical products.

2. Oil palm biomass

The biomass of the oil palm is a lignocellulosic biomass made up mainly of cellulose, hemicellulose, and lignin. The key component of oil palm biomass is cellulose

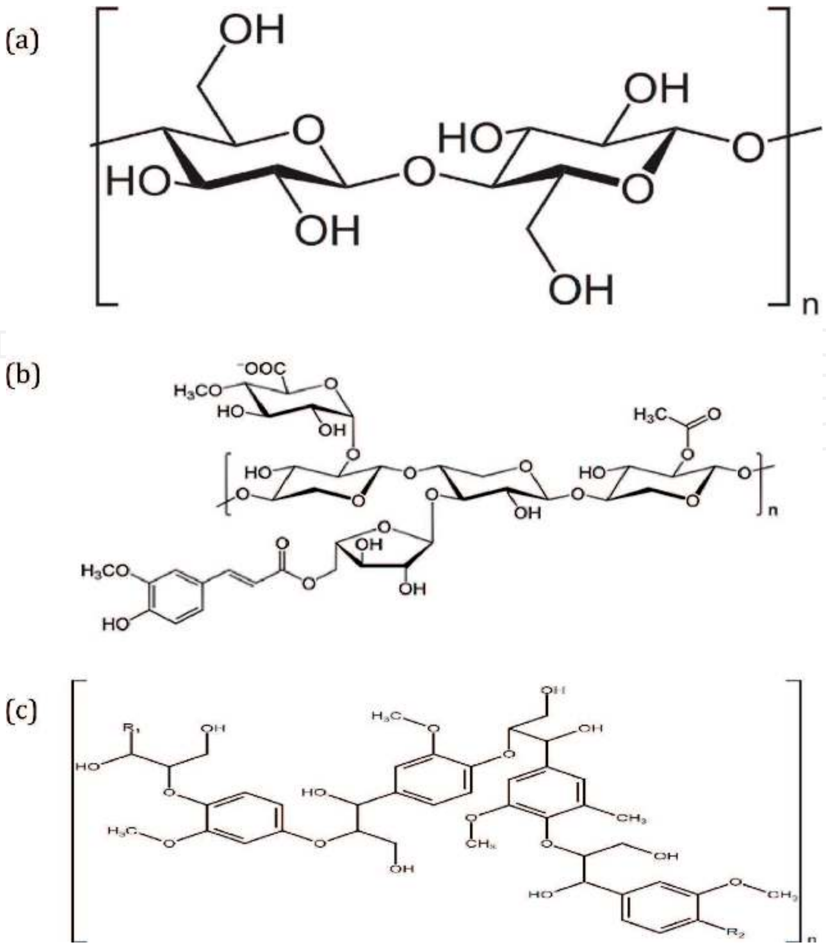

Figure 1.
Structure molecules; (a) cellulose; (b) hemicellulose, (c) lignin.

$(C_6H_{10}O_5)n$ (**Figure 1a**) which is the main component of oil palm biomass. Cellulose is a rigid, solid, and difficult-to-break linear polymer of glucose with additional hydrogen bonding [5]. By adding water to the polysaccharide, it is hydrolyzed into free sugar molecules (i.e. glucose, sucrose, and fructose) [6]. Saccharification is another name for this method.

Hemicellulose $(C_5 H_8O_4)n$ (**Figure 1b**), on the other hand, is made up of small, highly branched chains of various pentoses (such as xylose and arabinose) and hexoses and is found in secondary cell walls (i.e. mannose, galactose and glucose). Hemicellulose is simpler to hydrolyze than cellulose because of its weaker amorphous and branched structures [7].

The main non-carbohydrate component is lignin $[C_9H_{10}O_3(OCH_3)0.9–1.7]n$ (**Figure 1c**), which is a highly complex compound with a three-dimensional cross-linked polyphenolic structure [4]. Lignin is found between the cellulose cell wall and the hemicellulose cell wall, and it is responsible for the cell wall and the plant's overall strength. As a result, when used as a lignocellulosic biomass in the fermentation process, lignin presents a significant disadvantage because it is resistant to chemical and biological degradation.

3. Conversion of oil palm biomass into biochemical product

Oil palm biomass can be converted into biochemical products using a variety of methods, including fermentation, esterification, and anaerobic digestion. Fermentation is the most widely used of these because it is a non-toxic and environmentally friendly process.

Prior to the fermentation process, lignocellulosic biomass is typically pre-treated to break down the cellulose into simple sugars (i.e. maltose, glucose, fructose). The most important impact on fermentation results comes from pre-treatment [8]. Pre-treatment breaks down the biomass's recalcitrant structures, making cellulose more accessible to the organism.

The cellulose and hemicellulose content of oil palm biomass is high, which are primary sources for the fermentation process (**Table 2**). Microorganisms convert sugars extracted from lignocellulosic biomass to a variety of desired products during the fermentation phase. For example, *Saccharomyces cerevisiae* produces ethanol, *Lactobacillus sp*. produces lactic acid, and *Actinobacillus succinogenes* produces succinic acid.

There are two forms of fermentation that can be used in the fermentation method. The solid-state fermentation (SSF) method is the first. SSF creates a natural environment for filamentous fungi to grow, which has proven to be a more efficient method of producing various products [9, 10, 15–17]. Submerged fermentation (SmF) is the other kind of fermentation. Due to easier control and maintenance of fermentation factors, most cellulases and xylanase enzymes are commercially generated using SmF [18].

Oil palm biomass	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Extractive (%)	Ash (%)
Oil palm empty fruit bunches (OPEFB)	38–65	17–33	13–37	2–4	1–6
Oil palm frond (OPF)	40–56	16–38	15–26	2–5	2–3
Oil palm trunk (OPT)	29–45	12–29	18–23	4–11	2–3

Sources: Adapted from references [4, 9–14].

Table 2.
Type of oil palm biomass and the chemical composition.

4. Type of oil palm biomass and the biochemical products

4.1 Oil palm trunk

The huge biomass output of the oil palm trunk (OPT) has piqued the interest of researchers. OPT has a 25 to 30 years average active life period [19]. The OPT is usually chopped into small pieces and left to rot naturally in the plantation area during the replanting period. Leaving the trunk in the plantation area may cause pollution because the OPT's high sugar and starch content will attract microflora and microfauna, raising the risk of plant diseases [20].

When compared to the other sections of oil palm trees, OPT sap contains liquid with a lower lignin percentage and a higher percentage of free fermentable sugars [20]. As a result, there is little to no need for pre-treatment (chemical or biological) to delignify or convert lignocellulose to fermentable sugar. **Table 3** lists the different biochemical products that are made with OPT as a substrate. The product's differences are mainly determined by the type of microorganisms used and the fermentation conditions (i.e. temperature, pH, oxygen level).

Organism	Fermentation system	Type of reactor	Product	References
Aspergillus fumigatus SK1	SSF	Flask	Enzymes • CMCase • Fpase • β-Glucosidase • Xylanase	[9]
Aspergillus fumigatus SK1	SSF	Flask	Enzymes • CMCase • Fpase • β-Glucosidase • Xylanase	[9]
Saccharomyces cerevisiae Kyokai no.7 (ATCC 26622)	SmF	Flask	Ethanol	[20]
A. niger	SSF	Flask	Enzymes • CMCase • FPase • β-Glucosidase • Xylanase	[21]

Table 3.
Biochemical products from different organisms using OPT as substrate.

4.2 Oil palm empty fruit bunches

One of the most significant lignocellulosic biomasses in Malaysia is oil palm empty fruit bunches (OPEFB). From palm oil production, OPEFB contributed 20% of total biomass [22]. In 2019, approximately 2.9 million tonnes of OPEFB were made, a figure that is expected to rise as global demand for oil palm grows [10]. OPEFB contains a high percentage of cellulose (38–65%), lignin (13–37%), and hemicellulose (17–33%) (**Table 2**). OPEFB can be processed into useful products, such as biochemical products, due to its abundance and high cellulose content (i.e. CMCase, Fpase, ethanol).

Organism	Fermentation system	Type of reactor	Product	References
Botryosphaeria sp.	SSF	Flask	Enzymes • CMCase • Fpase • β-Glucosidase	[9]
Aspergillus niger EFB1	SmF	Rotary drum reactor	Enzymes • CMCase • Fpase • β-Glucosidase	[23]
Yeast	SmF	Flask	Ethanol	[24]
Amauroderma rugosum SDBR-CMU-A83	SSF	Flask	Phytase	[25]
Mesophilic and thermophilic bacteria	SmF	100 ml serum vial	Biomethane	[26]
Trichoderma asperellum USM SD4	SSF	Flask	Xylanase	[27]
Pycnoporus sanguineus	SSF	Flask	Laccase	[10]

Table 4.
Biochemical production from different organisms using OPEFB as substrate.

Table 4 shows the results of various fermentation processes on biochemical products using OPEFB as the substrate. The goods are unique to each organism.

4.3 Oil palm frond

The most plentiful residue of oil palm trees is oil palm frond (OPF), which accounts for up to 70% of total palm waste [15]. According to recent studies, OPF is an excellent source of renewable carbon and lignocellulosic content for cultivating a variety of species to produce essential biochemical products such as pigments, enzymes, and succinic acid. **Table 5** summaries the biochemical product by various microorganisms using OPF as a substrate. When fermentation conditions such as temperature, pH, and oxygen level, are allowed, a variety of organisms may produce a variety of products. As shown in **Table 2**, OPF contains a high percentage of cellulose (40–56%) and hemicellulose (16–38%), making it ideal for microbial growth.

4.4 Palm oil mill effluent

The liquid waste released during the palm oil extraction process is known as palm oil mill effluent (POME). POME is one of the world's most polluting wastewaters due to its high organic matter content and it is 100 times more polluted than municipal sewage [30]. Each tonne of palm oil produces approximately 5.5–7.5 tonnes of POME [31, 32]. While, about more than 50 million m^3 of POME is generated globally each year [33].

POME is a viscous, dense brownish liquid with significant quantities of colloidal matter that is acidic (pH 3.7 to 4.5) [34]. POME also has a high chemical and biochemical oxygen demand (COD and BOD), ranging between 69,500 and 89,591 mg/L and 34,771 and 48,300 mg/L, respectively [34]. The physicochemical

Organism	Fermentation system	Type of reactor	Product	References
A. niger EFB1	SSF	Petri dish	Enzymes • Endoglucanase • β-glucosidase • Exoglucanase • Xylanase	[15]
T. asperellum UC1	SSF	Flask	Enzymes • CMCase • FPase • β-glucosidase • Xylanase	[14, 28]
R. oryzae UC2	SSF	Flask	Enzymes • CMCase • FPase • β-Glucosidase • Xylanase	[14]
Actinobacillus succinogenes 130Z	SmF	Serum vial	Succinic acid	[29]
Monascus purpureus FTC5356	SSF	Flask	Red pigment	[17]
Monascus purpureus FTC 5357	SSF	Stirred drum bioreactor	Red pigment	[16]

Table 5.
Biochemical production from different organisms using OPF as substrate.

properties of POME are shown in **Table 6**. A large amount of amino acids, inorganic nutrients (Na, K, Ca, Mg, Mn, Fe, Zn, Cu, Co, and Cd), small fibers with nitrogenous compounds, free organic acids, and carbohydrates are also found in POME [37]. Organic matter such as lignin (4700 ppm), phenolics (5800 ppm), pectin (3400 ppm), and carotene (8 ppm) are also present [34]. This suggests that POME is an appropriate source for biological treatment.

POME's physicochemical properties can vary depending on local and process factors (climate, organisms, pre-treatment, and oil extraction process, for

Parameters	Range concentration
Biochemical oxygen demand (BOD_5) mgO_2/L	34,771 – 48,300
Chemical oxygen demand (COD) mgO_2/L	69,500 - 89,591
Total dissolved solid (TDS) (mg/L)	9,310
Total suspended solid (TSS) (mg/L)	36,560 - 47,690
Total solid (TS) (mg/L)	47,050 – 62,000
pH	3.4–5.2
Reducing sugar (mg/L)	228

Sources: Adapted from references [31, 32, 35, 36].

Table 6.
Physico-chemical characteristics of POME.

Organism	Fermentation system and mode	Type of reactor	Product	References
Clostridium beijerinckii ATCC 8260	SmF batch	Hungate tube	Biohydrogen	[35]
Mixed cultures	SmF batch	Serum bottles	Biohydrogen	[31]
Mixed culture	SmF batch	Bioreactor	Biohydrogen	[38]
Mixed	SmF 2 stages operation	1. UASB -methane 2. ASBR -hydrogen	• Biohydrogen • Methane	[32]
Mixed	SmF continuous	UASB	Methane	[32]
Mixed microalgae	SmF batch	Flask	Biodiesel	[39]

Note: UASB, up flow anaerobic sludge blanket reactor; ASBR, anaerobic sequencing batch reactor.

Table 7.
Biochemical production from different organisms using POME as substrate.

example) [34]. Other biochemical products may be produced using the treatment technique. **Table 7** summarizes the different fermentation processes on various biochemical products using POME as a substrate.

5. Conclusion

Lignocellulosic material, especially from oil palm biomass, is a promising source as a feedstock for the fermentation process as it has a high content of cellulose and hemicellulose. Substrate selection is the most important factor in determining the techno-economic viability of large-scale chemical products. The substrate should be on the basis of easy availability, conversion efficiency, being toxic-free and low operational cost. Thus, the bioconversion route in chemical product production may create business opportunities to utilize the abundant agro-industrial waste that is being generated, particularly in terms of environmental pollution.

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Conflict of interest

The authors declare no conflict of interest.

Nomenclature

OPT	oil palm trunk
OPEFB	oil palm empty fruit bunches
OPF	oil palm frond

POME	palm oil mill effluent
ha	hectares
sp.	species
SSF	solid-state fermentation
SmF	submerged fermentation
COD	chemical oxygen demand
BOD	biochemical oxygen demand
ppm	part per million
UASB	up flow anaerobic sludge blanket reactor
ASBR	anaerobic sequencing batch reactor

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