AN OVERVIEW OF THE BIOREFINERY CONCEPT APPLICATION THROUGH BIOPROCESSING OF OIL PALM EMPTY FRUIT BUNCH

A. Shevchenko[1], V. Timchenko[2], L. Myronenko[3]

Alfa Laval Application & Innovation centre, Copenhagen, Denmark
[1] Global Technology Department Manager, alexey.shevchenko@alfalaval.com
National Technical University "Kharkiv Polytechnic Institute", Kharkiv, Ukraine
[2] c.t.s., docent, professor of fat and fermentation products technology department, valentinatimcenko05.08@gmail.com
State Biotechnological University, Kharkiv, Ukraine
[3]c.t.s., docent of biotechnology, molecular biology and water bioresources department, mironenko@btu.kharkiv.ua

The usage of palm-oil serves as one of the economic catalyst within the Asian context, making certain contribution to the national economy of countries like Indonesia, Malaysia, Thailand and Central America. As attested by Alkusma et al. [1], the burgeoning palm-oil industry correlates with a heightened generation of waste materials, notably including substantial quantities of oil palm empty fruit bunches (OPEFB) – a form of solid waste. As reported by Yanti and Hutasuhut [2], in the year 2018, up to 6.7 million tons of OPEFB were disposed of, raising environmental challenges due to pollution and landfill congestion.

OPEFB is classified as lignocellulosic biomass waste, representing a reservoir of substantial untapped potential. Its constitution includes cellulose (ranging from 24 % to 65 %), hemicellulose (comprising 21 % to 34 %), and lignin (constituting 14 % to 31 %) [3]. Particularly noteworthy is its significant hemicellulose content, a complex polysaccharide polymer that includes glucose, mannose, arabinose, and xylose units, thereby conferring structural support to the cellular walls. Importantly, up to 82 % of the hemicellulose in OPEFB can be converted into xylose, thereby serving as a pivotal precursor for xylitol production [4].

Xylitol is a sugar alcohol used in several sectors, including the food, pharmaceutical, and health industries. It is commonly used in the manufacturing of confectioneries, chewing gum, carbonated beverages, and oral hygiene items. In a study conducted by Muryanto et al. [5], the residue obtained after the extraction of xylitol, rich in cellulose, has the potential for conversion into bioethanol, a kind of liquid fuel energy. Additionally, residues of xylitol and ethanol production may contain partially degraded lignin, as well as incompletely converted hemicellulose and cellulose, serving as substrates for enzymatic reactions. Enzymes like cellulase, xylanase, and laccase are often derived from the metabolic processes of microorganisms.

In the pretreatment phase, the primary objective is to eliminate lignin, reduce cellulose crystallinity, and convert OPEFB into pulp to enhance the feasibility of hydrolysis and fermentation. This is achieved by subjecting the polysaccharide crystals to a heating process at a temperature of 120ºC. During hydrolysis, hemicellulose is degraded, facilitating the extraction of fibers, and polysaccharide chains are broken down into monosaccharides. The hydrolysate is then used in the fermentation phase, where xylitol is produced by the yeast *Meyerozyma caribbica*. This particular yeast strain is recognized for its resilience to inhibitory substances, making it an ecologically sustainable and cost-effective choice for this process. The achievement of effective xylitol bioconversion through fermentation is contingent upon many parameters, including temperature, pH, aeration conditions, substrate concentration, and the existence of other molecules apart from xylose, such as glucose. In addition, the xylose solution undergoes a conversion process, resulting in the formation of the xylitol solution [6]. The adequate preparation of the medium is crucial for achieving good fermentation of xylitol. The use of different compositions of the medium has a significant impact on the resulting products.

On the other hand, the solid waste produced during the process of xylitol manufacture from OPEFB is significant due to its substantial cellulose content, making it a promising feedstock for bioethanol production within a biorefinery framework. Enzymatic hydrolysis can degrade cellulose polymers into glucose, enabling further processing of residual solid waste. Compared to acid hydrolysis, enzymatic hydrolysis generates more glucose, resulting in more significant bioethanol production.

While previous studies have mostly focused on bioethanol production, studies of recent years adopt a novel perspective by examining bioethanol generation using varying quantities of cost-effective and readily available fermentation media. The objective is to maximize the extraction of ethanol from a cost-effective substrate. Based on the findings of Mardawati et al. [4], it is imperative that the materials used in the process satisfy the fundamental nutritional demands necessary for the proliferation of microorganisms. These needs include key components such as carbon, nitrogen, non-metallic constituents (specifically sulfur and phosphorus), metallic elements including calcium, zinc, sodium, potassium, copper, manganese, magnesium, and iron, as well as vitamins, water, and energy.

Modern studies employ a two-stage enzymatic hydrolysis technique, focusing on using OPEFB waste for bioethanol synthesis and xylitol production. Both steps of hydrolysis require the use of hemicellulase enzymes to catalyze the breakdown of hemicellulose into xylose, serving as a substrate for xylitol fermentation. The cellulose-rich xylitol residue is subjected to further hydrolysis to produce glucose hydrolysate that may be used for ethanol production. The resulting solid waste from the process of hydrolysate separation is used as a substrate for lignocellulosic enzyme synthesis. Recent studies have demonstrated usage of the OPEFB biorefinery for the combined synthesis of xylitol and bioethanol, with subsequent fermentation using different medium compositions [7].

Enzyme synthesis can be accomplished through fermentation by microbial organisms, often bacteria or fungi. It has been shown that fungi exhibit a greater hydrolysis rate in comparison to yeast and bacteria. They are capable of producing a diverse range of hydrolytic and oxidative enzymes that have the ability to break down the components of lignocellulosic materials. One group of researchers has focused on *Aspergillus niger*, a filamentous fungus known for its production of cellulase, xylanase, and laccase enzymes, was based on its favorable performance and cost-effectiveness compared to other choices [8]. The development of fungi is influenced by several parameters, including substrate concentration, nutrient supply, aeration, pH, temperature, incubation conditions, moisture content, and fermentation duration [9].

Microorganisms play an active role in fermentation and naturally reproduce in environments conducive to their development. In one of the studies submerged fermentation technique to produce the three enzymes was used. The methodology used a liquid substrate, with the addition and replacement of nutrients conducted in a continuous manner within the submerged fermentation medium. This environment is particularly appropriate for microorganisms, including fungi, that prefer elevated levels of moisture [10].

The primary aim of recent studies was to evaluate the use of a fermentation medium in conjunction with a two-stage enzymatic hydrolysis procedure for the production of xylitol and bioethanol. Furthermore, an additional objective for research was to assess the enzymatic activity of cellulase, xylanase, and laccase enzymes produced by *Aspergillus niger* during cultivation on an integrated OPEFB substrate. The enzyme evaluation was conducted by taking into account key variables, including activity, protein content, specific activity, and enzyme mass.

Therefore, our literature review emphasizes the promise of a two-step enzymatic hydrolysis process for integrated ethanol and xylitol production using OPEFB as a substrate. A group of researchers successfully increased cellulose content to 62.0 % and produced glucose at concentrations suitable for bioethanol production. The preserved hemicellulose content offers prospects for xylitol production, although the yield of xylitol was limited. Substantial ethanol production and effective enzyme generation were achieved from ethanol residue. These findings highlight the potential for integrated xylitol, enzyme, and bioethanol production in future research efforts. Key challenges to be addressed include optimizing xylitol yield and scalability. We believe that commercial viability of this approach will depend on cost-effectiveness at scale and market demand for these products in countries where Palm Oil Production is a main growth driver. Further research and development are needed to fully exploit the benefits of this innovative approach.

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