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Review

Lignocellulose: A sustainable material to produce value-added products with a zero waste approach—A review

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ABSTRACT

A novel facility from the green technologies to integrate biomass-based carbohydrates, lignin, oils and other materials extraction and transformation into a wider spectrum of marketable and value-added products with a zero waste approach is reviewed. With ever-increasing scientific knowledge, worldwide economic and environmental consciousness, demands of legislative authorities and the manufacture, use, and removal of petrochemical-based by-products, from the last decade, there has been increasing research interests in the value or revalue of lignocellulose-based materials. The potential characteristics like natural abundance, renewability, recyclability, and ease of accessibility all around the year, around the globe, all makes residual biomass as an eco-attractive and petro-alternative candidate. In this context, many significant research efforts have been taken into account to change/replace petroleum-based economy into a bio-based economy, with an aim to develop a comprehensively sustainable, socially acceptable, and eco-friendly society. The present review work mainly focuses on various aspects of bio-refinery as a sustainable technology to process lignocellulose 'materials' into value-added products. Innovations in the bio-refinery world are providing, a portfolio of sustainable and eco-efficient products to compete in the market presently dominated by the petroleum-based products, and therefore, it is currently a subject of intensive research.

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1. Introduction

From the last few years, biorefinery approach is emerging as a promising sector with a considerable potential to capitalize various lignocellulose materials into a variety of industrially relevant bio-products [1]. Undoubtedly, the driving force behind the bio-refineries establishment is a sustainability concept. The sustainability concept is shown in Fig. 1. The term 'bio-refinery' is defined as: "a sustainable approach to biotransform raw materials e.g. biomass into energy and a wider spectrum of everyday commodities in an economical and eco-friendly manner". Fig. 2 illustrates a schematic overview of a bio-refinery concept. Whereas, some potential advantages and disadvantages related to the biomass utilization are presented in Tables 1 and 2, respectively [2]. Research is underway around the globe on the development of 'greener' technologies. The invention of green chemistry under a green agenda principle has either directed or redirected current search towards the development of high added-value eco-friendly, eco-efficient, and recyclable materials. Words like renewability, recyclability, and sustainability are emphasized in growing scientific knowledge and environmental awareness. In this context, the divergence from non-renewable (petroleum-based resources) to renewable materials (biomass-based resources) is becoming the center of interest for research in industrial communities, worldwide [3,4]. The fact is that petroleum resources are finite and becoming increasingly costly. Moreover, the consistent depletion of petrochemical resources has pushed up prices in essential sectors, worldwide, including energy, materials, and medical [5]. Therefore, one of the biggest challenges of the modern world is in decreasing the dependency on such petrochemical resources based products. Herein, the bio-refinery approach should ease disputes on eco-pollution and reliance on fossil resources, thus can be considered as an evolution of concepts like "*Green Chemistry*" [6]. Though the refinery concept is not a new, however, in recent years, bio-refineries, in particular, integrated bio-refineries, are seen as a promising route to meet our aims for sustained prosperity and safeguarding the natural ecosystem. So the focus has been shifted to bio-refineries for target applications in different sectors of the modern society to address the growing environmental concerns where petroleum-based resources are unsustainable. In comparison to the petroleum-based refineries, bio-based bio-refineries have great potential to utilize a variety of feedstocks at larger level using diverse technologies. The present review focuses on various aspects of bio-refinery as a sustainable technology to process lignocellulose 'materials' into value-added products. Explicitly, many significant efforts have been devoted to converting these lignocellulosic to value-added products including composite, fine chemical, animal feed, pulp and paper, biofuels and enzymes (Fig. 3) [7]. During the last few years, we have demonstrated considerable improvement in many processes related to Lignocellulose biotechnology and triggered in-depth studies of lignocelluloses, different fungal consortia, ligninolytic enzymes including Lignin peroxidase (LiP) and manganese peroxidase (MnP), and laccase, their purification and immobilization to present their potential for a wider spectrum of biotechnological applications [8–24]. Innovations in the bio-refinery world are providing, a portfolio of sustainable and eco-efficient products to compete in the market presently dominated by the petroleum-based products, and therefore, it is currently a subject of intensive research.

2. Revalorization of natural biomass materials

Interestingly, a bio-refinery has an enormous potential to use/capitalize all types of biomass-based sources that includes agricultural, agro-industrial, algae, and municipal, etc. Moreover, the materials mentioned above are the most promising feedstock as a natural, abundant, and renewable resource essential to the functioning of industrial societies and critical to the development of a sustainable global economy [25]. On the other hand, this should also result in substantial improvement both in quality and quantity integration and process optimization aspects of all types bio-refineries and bio-refinery subsystems. Large amounts of wastes are generated through agricultural and many agro-based industrial practices [7]. For many years, these potential materials were considered among other environmental threats as a major source of ecological pollution and had also been categorized as a global issue. However, in recent years, these materials have gained considerable importance owing to their novel characteristics that include, renewability, recyclability, and sustainability [4,7,19]. Their physicochemical and biological characteristics make them a substrate of enormous industrial and biotechnological value to develop a range of value-added products [7,26–30]. Some potential applications include but not limited to the generation of various energy types like bio-fuels, easily accessible and readily available energy sources for microbial fermentation purposes, production of novel enzymes, platform chemicals, alternative sources for pulp and paper industry, animal feedstuffs, and novel composites. In this background, in the past decade, a substantial development in many ongoing practices related to the bio-refinery concept and bioconversion of bio-renewable bio-based natural polysaccharides has been achieved for the future, to develop a variety of different industrially relevant value-added products. This review article mainly focused on the fundamental aspects of the sustainable biorefinery approach, concentrating on the following important areas: (1) Bio-refinery-based bio-economy – considerations, (2) various biorefinery platforms and (3) processing of low-cost agro-industrial wastes 'natural polysaccharides' into value-added products. Towards the end, information is also given on the potential future considerations for the sustainability assessment of the current bio-refinery methods.

3. Bio-refinery-based bio-economy – considerations

Many considerations are being taken to replace the current, in practice, petrochemical-based approaches to a more sustainable bio-based bio-refinery to enhance the greater use of natural polysaccharides e.g. lignocellulosic materials. Furthermore, the current price hike, increasing demand for eco-friendly practices, bio-based green products, and population growth vs. limited resources, all have opened a lot of opportunities for the development of bio-refinery-based bio-economy, to jointly produce food, energy, and chemicals [31].

From the historical point of view, bio-based producers have targeted value-added products, platform chemicals, and specialty markets, often where multi-functional characteristics played a critical role to justify the end product goal. This integrated transition