mm 244 x 170 mm

WILEY VCH

Edited by Suraini Abd-Aziz, Misri Gozan, Mohamad Faizal Ibrahim, and Lai-Yee Phang

Chemical Substitutes from Agricultural and Industrial By-Products

Bioconversion, Bioprocessing, and Biorefining

Abd-Aziz • Gozan
Chemical Substitutes from
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Cover Image: © ARTFULLY PHOTOGRAPHER/Shutterstock

Library of Congress Card No.: applied for

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at <http://dnb.d-nb.de>.

Print ISBN: 978-3-527-35186-2
ePDF ISBN: 978-3-527-84112-7
ePub ISBN: 978-3-527-84113-4
oBook ISBN: 978-3-527-84114-1

Typesetting Straive, Chennai, India

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Preface

The emerging field of exploitation for agricultural wastes and industrial by-products is the alternative way to find potential feedstocks for chemical substitutes. This is our second book with Wiley-VCH-GmbH that discusses the bioconversion, bioprocessing, and biorefining of chemical substitutes from agricultural and industrial by-products. Some biomass can be directly extracted or processed and purified as a chemical substitute for other platforms. However, biomass may require various pretreatment before bioconversion and purification. Chemical substitution focuses on finding new and less hazardous solutions for a particular process or product through a biorefinery approach. The advanced biorefinery is capable of transforming agricultural wastes and industrial by-products into various chemical substitutes or value-added products. Therefore, the development of sustainable biorefining approaches will contribute to cost-effective technology.

Our recently published book in January 2022 with Wiley-VCH-GmbH entitled *Biorefinery of Oil Producing Plants for Value-Added Products* is a two-volume set that delivers a comprehensive exploration of oil-producing plants, from their availability to their pretreatment, bioenergy generation, chemical generation, and bioproduct generation, concluded with an insightful analysis of the economic effects of oil-producing plants.

This book presents several substitutes for chemicals obtained from biomass of agricultural wastes and industrial by-products covering upstream to downstream perspectives including antioxidant, oleoresin, nanocarbon materials, enzymes, essential oil, biobleaching agents, biosugars, biofertilizers, cocoa butter substitute, bio-succinic acids, furfural derivatives, levulinic acids, cellulases, and 1,3-propanediol. In each chapter, the individual aspect of bioconversion, bioprocessing, and downstream process of chemical substitutes produced from selected agricultural and industrial by-products to selected chemical substitutes is discussed.

We thank and express our appreciation of the multidisciplinary team of authors for the discussion and communication, especially for their scientific contribution to this book. Thanks to the reviewers for the improvement of the book's contents. We also thank reviewers whose suggestions immensely helped to improve the quality of the chapters. We sincerely thank the Wiley-VCH team composed of Dr. Lifen

Yang, Project Manager – Ms. Lesley Fenske, and their production and typesetting teams for constantly supporting us during the editorial process. We firmly believe that the information in this book will enhance the interdisciplinary scientific skills of readers, while also deepening their fundamental knowledge of the chemical substitutes that can be derived from agricultural and industrial by-products.

April 2023
Malaysia

Suraini Abd-Aziz

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Suraini Abd-Aziz is a professor at the Department of Bioprocess Technology, Faculty of Biotechnology and Biomolecular Sciences, Universiti Putra Malaysia, Malaysia. She is currently the Asian Federation of Biotechnology (AFOB) Vice President of Malaysia region, President of AFOB Malaysia Chapter, and AFOB Co-chair of Bioenergy and Biorefinery Division. She graduated with a BSc (Honors) in Clinical Biochemistry from Universiti Kebangsaan Malaysia (the National University of Malaysia) in 1992, MSc (Biochemical Engineering) from the University of Wales Swansea, United Kingdom in 1994, and PhD (Biochemical Engineering) from the University of Wales Swansea, United Kingdom in 1997. In research, she developed her research interest in the field of Industrial Biotechnology specializing in bioenergy and bio-based chemicals, which focused on the utilization of agro-wastes for bioenergy and value-added products toward zero waste emission. She is one of the Malaysia's Top Research Scientists (TRSM 2018). She has been recognized as World's Top 2% Scientist in 2021 and 2022 (Career Achievement) published by Stanford University and Elsevier BV. In 2021, she received the Research Exchange Award 2021 by The Korean Society for Biotechnology and Bioengineering. Apart from being the project leader of her own research grants, she also actively contributed to other projects in her capacity as an expert in enzyme technology, fermentation technology, bioprocess engineering, and environmental biotechnology. With an *h*-Index of 37 (total citations more than 3800), she has published more than 200 refereed journals internationally.

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Sago Wastes as a Feedstock for Biosugar, Precursor for Chemical Substitutes

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10.1 Introduction

Sago or scientifically known as *Metroxylon sago* is one of the most important crops in Malaysia. To promote the growth of the sago sector, the Malaysian government has provided RM20 million in subsidies for sago palm plantations [1]. Sago palm plantation has unique adaptability against extreme growth conditions, which include variety of climate adaptability and wide range of pH (neutral to extremely acidic) soil conditions. According to Flores [2], sago palm has higher production capacity of starch as compared to cassava, corn, or rice, which accounted for 20–25 tonnes/ha/year. Sarawak has been acknowledged as one of the main sago starch exporters in the world, providing more than 47 thousand tonnes per year. Additionally, with the increasing demand, the value is expected to rise significantly, leading to the increment in waste production.

Generally, sago industry generates two types of wastes, which are in-plantation site and in-mill wastes. Sago fronds are the first-point waste generated in-plantation site of sago industry. It is generated during pruning and harvesting activities, which accounted for 7500 fronds discarded daily [3]. Meanwhile, in the processing mill, sago industry has generated another three main by-products, which are bark, hampas, and effluent. Sago bark resulted from the debarking process of sago palm trunk, which accounted for 5–15 tonnes daily [4]. Concurrently, sago hampas is a starchy lignocellulosic biomass produced upon completing the process of starch extraction. It is one of the largest solid biomass produced in the sago starch processing mill, which accounted for 150 tonnes per day [5]. Despite all the solid biomass generated, effluent is the largest by-product of sago starch processing mill, due to the huge amount of water used. The wastewater produced covers up to 97% of the total

Chemical Substitutes from Agricultural and Industrial By-Products: Bioconversion, Bioprocessing, and Biorefining, First Edition. Edited by Suraini Abd-Aziz, Misri Gozan, Mohamad Faizal Ibrahim, and Lai-Yee Phang.

by-products generated, which accounted for 10^6 l of wastewater generated for every 1 tonne of sago starch produced [6].

Both solid and liquid wastes produced from sago industry has potential value to be converted into higher value-added products. Enormous efforts have been done exploring the utilization of each sago waste as a feedstock. Bioconversion of sago wastes, including sago bark [7], sago hampas [8], sago frond [3], and sago wastewater [9], into biosugars has been proficiently demonstrated by various works. This is due to the high concentration of starch and cellulosic content, which can be converted to wide range of pentoses and hexoses by the implication of enzymatic hydrolysis. This indicates the promising potential of sago wastes, which requires further efforts to explore their full potential.

Therefore, this chapter is aimed to bring light to the current development of each type of sago waste into value-added products, especially biosugars and other bioproducts. The challenges and future prospects of sago waste biorefinery are also discussed.

10.2 Current Status of Sago Starch Industry

10.2.1 Sago Palm Cultivation

Sago palm, a starch producer is a palm that can thrive well in lowland freshwater swamps and tropical rainforests, normally found in Southeast Asia including Papua New Guinea, Malaysia, and Indonesia [10]. The sago palm is characterized as soboliferous, grows in a cluster, produces a substantial amount of starch lump at the trunk, and is classified as a perennial plant. These characteristics of sago palm allow it to adapt to a variety of climate settings. It can grow on uncertain lands such as deep peat soils and areas with a high water table. The development of sago palm as a novel source of starch is crucial for increasing the output of global starch crops to meet the rising demand proportional to population growth. The innovative starch source can alleviate global hunger while overcoming crop production issues caused by climate change and global warming. According to Bintoro et al. [11], the extremely acidic and brown color of peat soil is the optimal setting for the mutually beneficial microorganism to develop with sago palms, which enables sago palms to thrive on riverbanks, near lakes, and in damp soil. Sago palms are well-adapted to marginal soils in Papua New Guinea, where most cash crops cannot grow. Sago palms can grow in a wide range of neutral to acidic soil conditions, from uplands to low-flooded places.

Sago palm has the remarkable ability to survive and thrive following a forest fire. The resilience of the sago palm against wildfires can lessen the time and expense required for replanting and help farmers recover from the devastation. The tropical climate in Malaysia is not only limited to severely hot and dry weather but is also vulnerable to monsoon seasons classified as Geo-Hazards in Malaysia that can inflict devastation owing to extended high rainfalls. Sago palm virtually resides in the freshwater of the swampy area, allowing it to be adept and withstand prolonged or