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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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Contents

Preface *xv*

About the Editors *xvii*

- 1** **A Glance on Biorefinery of Chemical Substitutes from Agriculture and Industrial By-products** *1*
Suraini Abd-Aziz, Misri Gozan, Mohamad F. Ibrahim, Lai-Yee Phang, and Mohd A. Jenol
 - 1.1 Introduction *1*
 - 1.2 Analysis of Feedstocks for Composition and Potential for Chemical Substitutes *3*
 - 1.2.1 Different Types of Agricultural Wastes and Associated Risks *4*
 - 1.2.2 Waste Utilization Routes *5*
 - 1.2.2.1 Fertilizer Application *5*
 - 1.2.2.2 Fibers for Textile Industry *5*
 - 1.2.2.3 Mushroom Cultivation *6*
 - 1.2.2.4 Organic Acids *7*
 - 1.2.2.5 Industrial Enzymes *7*
 - 1.2.3 Industrial By-products *8*
 - 1.2.3.1 Agriculture, Horticulture, and Landscaping *8*
 - 1.2.3.2 Use as Raw Material or Additive of New Products *8*
 - 1.3 Potential Application of Chemical Substitute Extracted from Selected Agricultural Wastes and Industrial By-products *9*
 - 1.4 Conclusions *13*
References *13*
- 2** **Antioxidants from Agricultural Wastes and their Potential Applications** *19*
Mohd A. Jenol, Yazmin Hussin, Pei H. Chu, Suraini Abd-Aziz, and Noorjahan B. Alitheen
 - 2.1 Introduction to Antioxidants and their Usages *19*
 - 2.2 Sources of Antioxidants *21*
 - 2.3 Alternative Antioxidants Sources from Agricultural Wastes *22*
 - 2.4 Extraction of Antioxidants from Selected Agricultural Waste *22*

2.4.1	Maceration	23
2.4.2	Pressurized Liquid Extraction	26
2.4.3	Microwave-assisted Extraction	27
2.4.4	Ultrasounds-assisted Extraction	28
2.4.5	Supercritical Fluid Extraction	29
2.5	Potential Applications of Antioxidants Extracted from Selected Agricultural Wastes	30
2.5.1	Food	30
2.5.2	Cosmetics	32
2.5.3	Therapeutics	33
2.6	Future Direction of Antioxidants from Agriculture Wastes	34
2.7	Conclusions	35
	References	35
3	Lemongrass Oleoresin in Food Flavoring	39
	<i>Madiyah Md Salleh, Shankar Ramanathan, and Rohaya Mohd Noor</i>	
3.1	Introduction	39
3.2	Types of Lemongrass and Their Components	40
3.3	Potential Chemical Substitutes from Lemongrass	42
3.3.1	Essential Oil	42
3.3.2	Phytoconstituents	43
3.3.3	Oleoresins	43
3.4	Characteristics and Properties of Oleoresin	44
3.5	Lemongrass Oleoresin Composition and Function	44
3.6	Extraction Technique of Lemongrass Oleoresin	46
3.6.1	Chemical Extraction	46
3.6.2	Steam Distillation	49
3.6.3	Pressurized Liquid Extraction (PLE)	50
3.7	Application of Lemongrass Oleoresin as Food Flavoring	51
3.8	Oleoresin Prospect	53
3.9	Conclusions	53
	References	54
4	Nanocarbon Material and Chemicals from Seaweed for Energy Storage Components	59
	<i>Tirto Prakoso, Hary Devianto, Heri Rustamaji, Praswasti PDK Wulan, and Misri Gozan</i>	
4.1	Introduction	59
4.2	Source of Seaweed	62
4.2.1	Red Seaweed	62
4.2.2	Brown Seaweed	62
4.2.3	Green Seaweed	63
4.3	Potential Material Substitute from Seaweed	64

4.3.1	Activated Carbon from Seaweed	64
4.3.2	Graphene from Seaweed	66
4.4	Utilization of Seaweed-based Material for Energy Storage Component	76
4.4.1	Seaweed-derived Carbon Material for Supercapacitor Component	76
4.4.2	Seaweed-derived Chemical Materials for Battery Component	79
4.5	Future Prospects and Challenges	82
4.6	Conclusions	83
	References	83
5	Spent Mushroom Substrate as Alternative Source for the Production of Chemical Substitutes	87
	<i>Vikineswary Sabaratnam, Chia Wei Phan, Hariprasath Lakshmanan, and Jegadeesh Raman</i>	
5.1	Introduction	87
5.2	Spent Mushroom Substrate (SMS) as Source of Bulk Enzymes	90
5.2.1	Enzymes Extracted from SMS for Bioremediation	91
5.2.2	Enzymes Extracted from SMS for Green Fuel Feedstock Production: Case Study	92
5.3	Various Challenges and Future Prospects in the Use of SMS	94
5.3.1	Challenges in the Use of Enzymes in SMS	94
5.3.2	Future Prospects for Use of SMS for Production of Green Chemicals	95
5.4	Conclusions	97
	References	98
6	Essential Oil from Pineapple Wastes	103
	<i>Mohamad F. Ibrahim, Nurshazana Mohamad, Mariam J. M. Fairus, Mohd A. Jenol, and Suraini Abd-Aziz</i>	
6.1	Introduction	103
6.2	Pineapple Wastes	104
6.3	Pineapple Essential Oil	105
6.4	Extraction of Essential Oils	106
6.4.1	Distillation	106
6.4.1.1	Hydro-distillation	107
6.4.1.2	Soxhlet Extraction	107
6.4.2	Enzyme-assisted Extraction	109
6.4.3	Supercritical Fluid Extraction	109
6.5	Extracted Essential Oil Compounds	112
6.5.1	Essential Oils and Hydrosols	114
6.5.2	Applications of Essential Oils and Hydrosols	114
6.5.3	Market Analysis of Essential Oils and Hydrosols	116
6.6	Conclusions	117
	References	118

7	<u>Chicken Feather as a Bioresource to Produce Value-added Bioproducts</u> <i>123</i> <i>Kai L. Sim, Radin S. R. Yahaya, Suriana Sabri, and Lai-Yee Phang</i>
7.1	<u>Introduction</u> <i>123</i>
7.2	<u>Valorization of Chicken Feathers</u> <i>124</i>
7.2.1	<u>Feather Composition</u> <i>125</i>
7.2.2	<u>Types of Feathers Treatment</u> <i>125</i>
7.3	<u>Bioprocessing of Chicken Feathers into Chemical Substitutes</u> <i>128</i>
7.3.1	<u>Feather Meal</u> <i>129</i>
7.3.2	<u>Bioplastic</u> <i>130</i>
7.3.3	<u>Biofertilizer</u> <i>130</i>
7.3.4	<u>Keratinase</u> <i>131</i>
7.4	<u>Molecular Approaches to Improve Keratinolytic Propensity of Native Host</u> <i>132</i>
7.4.1	<u>Overexpression of Keratinase from Native Host</u> <i>132</i>
7.4.2	<u>Strain Engineering</u> <i>134</i>
7.4.3	<u>Enzymatic Consortium</u> <i>134</i>
7.5	<u>Molecular Approaches to Improve Recombinant Keratinase Production and Characteristics</u> <i>135</i>
7.5.1	<u>Propeptide Engineering</u> <i>136</i>
7.5.2	<u>Promoter Engineering</u> <i>136</i>
7.5.3	<u>Signal Peptide Engineering</u> <i>137</i>
7.5.4	<u>Directed Evolution</u> <i>137</i>
7.5.5	<u>Alteration of Protein Domains</u> <i>138</i>
7.6	<u>Challenges and Future Perspectives</u> <i>138</i>
7.7	<u>Conclusions</u> <i>140</i> <u>References</u> <i>140</i>
8	<u>Bio-bleaching Agents Used for Paper and Pulp Produced from the Valorization of Corn cob, Wheat Straw, and Bagasse</u> <i>145</i> <i>Kanya C. H. Alifia, Tjandra Setiadi, Ramaraj Boopathy, Hendro Risdianto, Muhammad Irfan, and Ibnu M. Hidayatullah</i>
8.1	<u>Introduction</u> <i>145</i>
8.2	<u>Characteristics of Biomass Substrate for Bio-bleaching Enzyme Production</u> <i>146</i>
8.3	<u>Microbial Sources of Bio-bleaching Enzymes</u> <i>148</i>
8.3.1	<u>Fungi</u> <i>148</i>
8.3.2	<u>Yeast</u> <i>149</i>
8.3.3	<u>Bacteria</u> <i>149</i>
8.4	<u>Bio-bleaching Enzymes and Their Usage in Pulp and Paper Industry</u> <i>150</i>
8.4.1	<u>Xylanase</u> <i>150</i>
8.4.2	<u>Cellulase</u> <i>151</i>
8.4.3	<u>Laccase</u> <i>152</i>

8.5	<u>Bioprocessing of Agricultural Wastes for Bio-bleaching Enzyme Production</u>	154
8.5.1	<u>General Block Flow Diagram</u>	154
8.5.2	<u>Upstream Processing</u>	157
8.5.3	<u>Downstream Processing</u>	158
8.6	<u>Techno-economic Evaluation</u>	159
8.6.1	<u>Technical Analysis</u>	159
8.6.2	<u>Economic Analysis</u>	162
8.7	<u>Challenges and Future Outlooks</u>	165
8.8	<u>Conclusions</u>	167
	<u>References</u>	168
9	<u>Recovery of Industrially Useful Enzymes from Rubber Latex Processing By-products</u>	173
	<i>Tan W. Kit, Yong Y. Seng, Siti N. Azlan, Nurulhuda Abdullah, and Fadzlie W. F. Wong</i>	
9.1	<u>Introduction</u>	173
9.2	<u>Processing of Natural Rubber Latex for the Production of Rubber Products</u>	175
9.2.1	<u>NRL Overview</u>	175
9.2.2	<u>NRL Structure</u>	176
9.2.3	<u>NRL Preservation</u>	176
9.2.4	<u>Deproteinization of NRL</u>	176
9.3	<u>General Characteristics of Plant-derived Lysozymes and Chitinases</u>	177
9.4	<u>Conventional and Alternative Activity Assays for Lysozymes and Chitinases</u>	178
9.5	<u>Potential Application of Plant-derived Lysozymes and Chitinases</u>	182
9.6	<u>Potential Strategy for Recovering Lysozymes and Chitinases from NRL</u>	182
9.7	<u>Conclusions</u>	187
	<u>References</u>	188
10	<u>Sago Wastes as a Feedstock for Biosugar, Precursor for Chemical Substitutes</u>	193
	<i>Mohd A. Jenol, Muhd N. Ahmad, Dayang S. A. Adeni, Micky Vincent, and Nurashikin Suhaili</i>	
10.1	<u>Introduction</u>	193
10.2	<u>Current Status of Sago Starch Industry</u>	194
10.2.1	<u>Sago Palm Cultivation</u>	194
10.2.2	<u>Sago Starch Industry in Malaysia</u>	195
10.2.3	<u>Sago Starch Processing in Sarawak</u>	195
10.3	<u>Sago Wastes Biomass</u>	196
10.3.1	<u>Sago Wastewater</u>	196
10.3.2	<u>Sago Bark</u>	197
10.3.3	<u>Sago Hampas</u>	199

10.3.4	Sago Frond	200
10.4	Bioconversion of Sago Wastes into Biosugars and its Derivative Precursors	200
10.5	Bioprocessing Sago Wastes Fermentable Sugar for Chemicals Substitute	202
10.5.1	L-Lactic Acid	202
10.5.2	Antimicrobial and Prebiotic Sugar (Cellobiose) from Sago Frond	203
10.5.3	Sago Frond Silage	204
10.5.4	Enzymes	205
10.5.5	Kojic Acid and its Derivatives	206
10.6	Challenges and Prospect of Sago Wastes Biorefinery	207
10.6.1	Challenges	207
10.6.2	Future Direction of Sago Waste Utilization	207
10.7	Conclusions	209
	References	209
11	Biofertilizer and Other Chemical Substitutes from Sugarcane By-products	213
	<i>Is Fatimah, Ganjar Fadillah, Tatang S. Julianto, Rudy Syahputra, and Habibi Hidayat</i>	
11.1	Introduction	213
11.2	Sugarcane By-products Conversion into Biofertilizer	216
11.3	Sugarcane Bagasse as Raw Material for Soil Improver: Phenol Degradation	218
11.4	Sugarcane By-products Conversion into Chemical	223
11.5	Sugarcane By-product as Material for Biocomposites	227
11.6	Future Perspective of Sugarcane By-products Conversion in the Sugarcane Industrial Cycle	228
11.7	Future Usage and Applications of Sugarcane By-products	229
11.8	Conclusions	230
	References	230
12	Cocoa Butter Substitute from Tengkwang (<i>Shorea stenoptera</i>)	235
	<i>Muhammad A. Darmawan, Suraini Abd-Aziz, and Misri Gozan</i>	
12.1	Introduction	235
12.2	Composition and Characteristics of Tengkwang Butter	237
12.2.1	Fatty Acids Profile of Tengkwang Butter	237
12.2.2	Quality Parameters of Tengkwang Butter	238
12.2.3	Solid Fat Content of Tengkwang Butter	239
12.2.4	Thermal Properties of Tengkwang Butter	240
12.3	Traditional Treatment Process	241
12.4	Extraction and Purification Process of Tengkwang	242
12.4.1	Chemical Purification of Tengkwang	243

15.5	Purification Technologies	309
15.6	Economic Feasibilities	312
15.7	Case Studies	313
15.8	Conclusions	314
	References	314
16	Cellulase as Biocatalyst Produced from Agricultural Wastes	319
	<i>Wichanee Bankeeree, Suraini Abd-Aziz, Sehanat Prasongsuk, Pongtharin Lotrakul, Syahriar NMM Ibrahim, and Hunsu Punnapayak</i>	
16.1	Introduction	319
16.2	Cellulases Diversity	320
16.2.1	Functional Types of Cellulases	320
16.2.2	Cellulase Structures	321
16.2.3	Catalytic Mechanisms	322
16.3	Cellulase-producing Microorganisms	323
16.3.1	Aerobic Microorganisms	323
16.3.2	Anaerobic Microorganisms	323
16.4	Cellulase Properties	325
16.5	Strategies to Improve Cellulase Production	326
16.5.1	Utilization of Agricultural Waste	326
16.5.2	Production Processes	328
16.5.3	Consolidated Bioprocessing	330
16.6	Techno-economic Analysis to Produce Biofuels	331
16.7	Conclusions	332
	References	332
17	Conversion of Glycerol Derived from Biodiesel Production to Butanol and 1,3-Propanediol	337
	<i>Prawit Kongjan, Alissara Reungsang, and Sureewan Sittijunda</i>	
17.1	Introduction	337
17.2	Crude Glycerol Characteristics and Impurities	338
17.3	Bioconversion of Crude Glycerol into Butanol and 1,3-Propanediol	340
17.4	Purification and Recovery of 1,3-Propanediol and Butanol	343
17.4.1	1,3-Propanediol	343
17.4.1.1	Ion-exchange Resin-based Separation	343
17.4.1.2	Hydrodistillation-based Separation	343
17.4.2	Butanol Separation	345
17.4.2.1	In Situ Gas Stripping	345
17.4.2.2	In Situ Pervaporation	346
17.5	Applications of 1,3-Propanediol and Butanol	346
17.6	Challenges and Future Perspective	348
17.7	Conclusions	349
	Acknowledgment	350
	References	350

18	<u>Sustainability of Chemical Substitutes from Agricultural and Industrial By-products</u> 355 <i>Lai-Yee Phang, Suraini Abd-Aziz, Misri Gozan, and Mohamad F. Ibrahim</i>
18.1	<u>Introduction</u> 355
18.2	<u>Sustainable Development Strategies, Policies and Regulations in Indonesia and Malaysia</u> 358
18.2.1	<u>Indonesia's National Sustainable Development Strategy</u> 358
18.2.2	<u>Malaysia's Policies and Regulations for Sustainable Development</u> 359
18.3	<u>Case Study 1: Techno-economic Analysis for the Production of Cellulase</u> 360
18.3.1	<u>Cost Analysis Using SuperPro Designer</u> 360
18.3.2	<u>Environmental Impact Analysis</u> 363
18.3.3	<u>Social Aspect</u> 364
18.4	<u>Case Study 2: Techno-economic Analysis for the Production of Biofertilizer</u> 364
18.4.1	<u>Cost Analysis Using SuperPro Designer</u> 364
18.4.2	<u>Environmental Impact Analysis</u> 367
18.4.3	<u>Social Aspect</u> 367
18.5	<u>Challenges and Market Opportunities</u> 368
18.5.1	<u>Availability and Reliability of By-products as Feedstocks</u> 368
18.5.2	<u>Production Cost</u> 368
18.5.3	<u>Technical Challenges</u> 368
18.5.4	<u>Market Opportunities</u> 369
18.6	<u>Conclusions</u> 369
	<u>References</u> 370
	Index 375

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 bio-product 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

About the Editors



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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.

10

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

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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 bio-products. 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