

Biochemistry Research Trends

NATURAL PIGMENTS

Sources, Properties, and Health Benefits

Rashidi Othman, PhD

Qurratu Aini Mat Ali, PhD

Razanah Ramya, PhD

Farah Ayuni Mohd Hatta, PhD

Wan Syibrah Hanisah Wan Sulaiman, PhD

Nur Hanie Mohd Latiff, PhD

Contributor Copy

Natural Pigments

Sources, Properties, and Health Benefits



No part of this digital document may be reproduced, stored in a retrieval system or transmitted in any form or by any means. The publisher has taken reasonable care in the preparation of this digital document, but makes no expressed or implied warranty of any kind and assumes no responsibility for any errors or omissions. No liability is assumed for incidental or consequential damages in connection with or arising out of information contained herein. This digital document is sold with the clear understanding that the publisher is not engaged in rendering legal, medical or any other professional service.

Contributor Copy

Biochemistry Research Trends

More information about this series can be found at

<https://novapublishers.com/product-category/series/biochemistry-research-trends/>

Food Science and Technology

More information about this series can be found at

<https://novapublishers.com/product-category/series/food-science-and-technology-series/>

Contributor Copy

Rashidi Othman
Qurratu Aini Mat Ali
Razanah Ramya
Farah Ayuni Mohd Hatta
Wan Syibrah Hanisah Wan Sulaiman
and Nur Hanie Mohd Latiff
Editors

Natural Pigments

Sources, Properties, and Health Benefits



No part of this digital document may be reproduced, stored in a retrieval system or transmitted in any form or by any means. The publisher has taken reasonable care in the preparation of this digital document, but makes no expressed or implied warranty of any kind and assumes no responsibility for any errors or omissions. No liability is assumed for incidental or consequential damages in connection with or arising out of information contained herein. This digital document is sold with the clear understanding that the publisher is not engaged in rendering legal, medical or any other professional service.

Contributor Copy

Copyright © 2026 by Nova Science Publishers, Inc.

DOI: <https://doi.org/10.52305/GARO1418>

All rights reserved. No part of this book may be reproduced, stored in a retrieval system or transmitted in any form or by any means: electronic, electrostatic, magnetic, tape, mechanical photocopying, recording or otherwise without the written permission of the Publisher.

We have partnered with Copyright Clearance Center to make it easy for you to obtain permissions to reuse content from this publication. Simply navigate to this publication's page on Nova's website and locate the "Get Permission" button below the title description. This button is linked directly to the title's permission page on copyright.com. Alternatively, you can visit copyright.com and search by title, ISBN, or ISSN.

For further questions about using the service on copyright.com, please contact:

Copyright Clearance Center

Phone: +1-(978) 750-8400

Fax: +1-(978) 750-4470

E-mail: info@copyright.com.

NOTICE TO THE READER

The Publisher has taken reasonable care in the preparation of this book, but makes no expressed or implied warranty of any kind and assumes no responsibility for any errors or omissions. No liability is assumed for incidental or consequential damages in connection with or arising out of information contained in this book. The Publisher shall not be liable for any special, consequential, or exemplary damages resulting, in whole or in part, from the readers' use of, or reliance upon, this material. Any parts of this book based on government reports are so indicated and copyright is claimed for those parts to the extent applicable to compilations of such works.

Independent verification should be sought for any data, advice or recommendations contained in this book. In addition, no responsibility is assumed by the Publisher for any injury and/or damage to persons or property arising from any methods, products, instructions, ideas or otherwise contained in this publication.

The Publisher assumes no responsibility for any statements of fact or opinion expressed in the published contents.

This publication is designed to provide accurate and authoritative information with regard to the subject matter covered herein. It is sold with the clear understanding that the Publisher is not engaged in rendering legal or any other professional services. If legal or any other expert assistance is required, the services of a competent person should be sought. FROM A DECLARATION OF PARTICIPANTS JOINTLY ADOPTED BY A COMMITTEE OF THE AMERICAN BAR ASSOCIATION AND A COMMITTEE OF PUBLISHERS.

Additional color graphics may be available in the e-book version of this book.

Library of Congress Cataloging-in-Publication Data

ISBN: 979-8-90134-055-4 (Hardcover)

ISBN: 979-8-90134-119-3 (eBook)

Published by Nova Science Publishers, Inc. † New York

Contributor Copy

Contents

Preface		vii
Chapter 1	Natural Black Pigment: Tannins.....	1
	Rashidi Othman	
Chapter 2	Smart Packaging with Carotenoids: A Breakthrough in Food Quality and Preservation.....	41
	Ainaa Eliah Abu Bakar and Rashidi Othman	
Chapter 3	Carotenoids from Ulam: Bridging Traditional Knowledge with Modern Halal Pharmaceutical Needs	81
	Farah Ayuni Mohd Hatta, Qurratu Aini Mat Ali, Rashidi Othman and Latifah Amin	
Chapter 4	Exploring Algae Pigments for Eco-Friendly Design and Energy Efficiency in Architecture.....	101
	Muhammad Hanafi Ismail, Wan Syibrah Hanisah Wan Sulaiman, Rashidi Othman, Nursyafica Nadia Johari and Aina Zulaikha Muzafar Shah	
Chapter 5	Microalgae Pigments: Sustainable Solutions for a Greener Future	119
	Nursyafica Nadia Johari and Rashidi Othman	
Chapter 6	The Spectrum of Natural Pigments: Diversity, Industrial Applications, and Future Prospects	149
	Nur Hanie Mohd Latiff and Rashidi Othman	

Contributor Copy

Chapter 7	From Colour to Cure: Unveiling the Antimicrobial Power of Plant Pigments	169
	Qurratu Aini Mat Ali, Farah Ayuni Mohd Hatta, Rashidi Othman and Mastura Mohtar	
Chapter 8	Preserving Malay Heritage: The Intersection of Traditional Knowledge and Natural Pigments.....	189
	Razanah Ramya, Nur Atiqah Jamaludin and Rashidi Othman	
Chapter 9	Sustainable Extraction Methods for Beta-Carotene	215
	Ali Haghighi Asl, Pouya Mottahedin and Maryam Khajenoori	
Chapter 10	The Science and Applications of Natural Red Pigments: From Extraction to Innovation	267
	Mohd Abhar Haniff Jaafar, Eyzzatul Eyllia Yunos, Wan Syibrah Hanisah Wan Sulaiman and Rashidi Othman	
Chapter 11	The Evolution and Impact of Green Pigments in Halal Food Technology	295
	Eyzzatul Eyllia Yunos, Mohd Abhar Haniff Jaafar, Wan Syibrah Hanisah Wan Sulaiman and Rashidi Othman	
About the Editors.....		337
Index		341

Contributor Copy

Preface

Natural pigments have long been an integral part of human culture and industry, from their use in ancient art to their role in modern sustainability practices. *Natural Pigments: Sources, Properties, and Health Benefits* aims to highlight the multifaceted potential of these pigments, which go beyond their aesthetic value. As we continue to seek sustainable solutions in various fields—from food preservation to eco-friendly architecture—the unique properties of natural pigments offer transformative opportunities. With contributions from renowned experts in diverse disciplines, this volume explores how these pigments are sourced, their chemical properties, and their profound health benefits. Through this collection, we hope to inspire greater awareness and further innovation, fostering a deeper appreciation for the natural world and its gifts. By exploring the intersection of traditional knowledge and modern science, we aim to uncover new applications that align with both sustainability goals and human health, driving positive change in industries and everyday life.

Contributor Copy

About the Editors

Ts. Dr Rashidi Othman is a distinguished professor, certified professional technologist, and expert horticulturist at the Department of Landscape Architecture, International Islamic University Malaysia (IIUM). With a Doctorate in Philosophy from Lincoln University, New Zealand, Dr. Rashidi brings a wealth of knowledge and innovative thinking to his field. His multidisciplinary expertise spans plant biotechnology, environmental sciences, landscape ecology, and ethnobotany, where he seamlessly integrates ecological sustainability with cutting-edge scientific research. As a leader in his field, Dr. Rashidi's work explores the profound connections between humans and the natural world, focusing on how plant-based solutions can foster environmental resilience and biodiversity conservation. His contributions not only advance academic knowledge but also drive practical, sustainable strategies for managing landscapes and ecosystems. With a passion for bridging the gap between traditional ecological wisdom and modern scientific advancements, Dr. Rashidi remains committed to inspiring the next generation of environmental leaders while advancing the holistic understanding of our planet's ecosystems.

Dr. Qurratu Aini Mat Ali is currently a Research and Development Executive at Tropica Beauty Sdn. Bhd. in Selangor, Malaysia. She holds a Doctor of Philosophy from the Institute of Islam Hadhari, The National University of Malaysia (2025), and a Master of Science in Built Environment from the International Islamic University Malaysia (2016). Dr. Qurratu Aini specializes in halal colorants and natural products, ethnobotany, environmental science, green technology, and landscape ecology. Her work aims to integrate sustainable and halal practices into various industries, with a focus on developing eco-friendly solutions that align with Islamic principles.

Contributor Copy

Dr. Razanah Ramya Dr. Razanah Ramya is a research fellow at the Institute of the Malay World and Civilization (ATMA), The National University of Malaysia. She holds a Doctor of Philosophy in Halal Industry (Science) from the International Institute for Halal Research and Training, International Islamic University Malaysia (IIUM), as well as a Master of Science in Built Environment and a Bachelor of Landscape Architecture, both from IIUM. Her research interests include landscape ecology, ethnobotany, and natural products. She is particularly focused on exploring the sustainable use of plant-based resources in traditional and modern contexts. Dr. Razanah is dedicated to bridging the gap between scientific research and the cultural heritage of the Malay world, contributing to both environmental and community well-being.

Ts. Dr. Farah Ayuni Mohd Hatta is a Research Fellow at the Institute Islam Hadhari, Universiti Kebangsaan Malaysia, and a certified Professional Technologist in Green Technology, accredited by the Malaysia Board of Technologists. She holds a PhD in Halal Industry (Science) from the International Islamic University Malaysia. With a multidisciplinary expertise in plant biotechnology, halal science, biopackaging, and environmental sustainability, her work bridges innovative solutions for both the halal industry and sustainable practices.

Dr. Wan Syibrah Hanisah Wan Sulaiman Dr. Wan Syibrah Hanisah Wan Sulaiman is an assistant professor at the International Institute for Halal Research and Training (INHART), International Islamic University Malaysia (IIUM). She earned her Doctor of Philosophy from IIUM in 2019 and holds a Master of Environmental Management and Sustainability from the University of South Australia (2013). Her research focuses on environmental sustainability, halal lifestyle, phytoremediation, and green technology in the built environment. Additionally, she investigates halal ingredients, including the development of halal colorants from natural pigments. Her interdisciplinary work encompasses halal tourism, inclusive design, and bioactive compounds, with the goal of aligning ecological innovation with Islamic values to promote sustainability in the halal industry.

Dr. Nur Hanie Mohd Latiff is an assistant professor at INHART, International Islamic University Malaysia (IIUM), where she has been teaching since 1 October 2019. She earned her PhD in Halal Industry from IIUM and holds both a Bachelor of Landscape Architecture (Hons) and a Master of Science in Built Environment, also from IIUM. A dedicated

Contributor Copy

researcher in environmental science, Dr. Nur Hanie's areas of expertise include landscape ecology, soil quality, heavy metal analysis, phytoremediation, renewable energy, and wastewater treatment. Her current research interests extend to the halal industry, focusing on halal lifestyle, Muslim-friendly hospitality, halal tourism, and sustainable development.

Contributor Copy

Contributor Copy

Index

β

β-carotene, 48, 61, 62, 69, 72, 74, 77, 84, 86, 87, 88, 89, 90, 91, 98, 99, 105, 123, 125, 126, 127, 128, 130, 131, 132, 133, 135, 136, 137, 138, 139, 140, 141, 144, 153, 202, 216, 217, 218, 219, 220, 221, 222, 223, 224, 225, 226, 227, 228, 229, 230, 231, 232, 234, 235, 236, 237, 238, 239, 240, 241, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 261, 262, 263, 264, 265

A

absorption, 21, 26, 56, 103, 105, 106, 111, 112, 113, 114, 123, 124, 125, 129, 130, 136, 157, 199, 299
accelerated solvent extraction, 220, 233, 234, 236, 252, 258, 265
active packaging, 42, 47, 52, 53, 62, 64, 71, 72, 76, 77, 78, 306, 316, 329
active pharmaceutical ingredients, 81, 82, 83, 85, 86, 91, 93, 94, 97, 98
additive(s), 34, 45, 46, 47, 52, 58, 66, 78, 128, 129, 130, 137, 141, 149, 153, 158, 160, 161, 162, 206, 250, 256, 286, 288, 297, 303, 306, 310, 312, 324, 332, 334
aesthetic(s), vii, 31, 36, 114, 154, 197, 200, 202, 268, 269, 270, 276, 280, 281, 295, 298, 304, 306, 307, 311, 318
agricultural residues, 2
algae cell growth, 103, 105
algae cultivation, 111
algae panels, 112, 113

algae pigments, 101, 102, 114
algae(s), 48, 50, 66, 101, 102, 103, 104, 105, 106, 108, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 125, 127, 128, 131, 139, 140, 141, 142, 144, 146, 152, 155, 156, 161, 162, 163, 167, 178, 179, 297, 299, 300, 314, 320, 321, 322, 328
algae-based materials, 101, 113
alkaloid(s), 84, 87, 152
allophycocyanin, 123, 125, 129, 135, 140, 157
aluminum (Al), 5, 6, 15, 92, 95, 96, 99, 100, 114, 115, 264, 321, 332, 333
amaranth, 161, 271, 274
Amaranthus, 156, 161
Ancient Malays, 197
animal(s), 2, 5, 48, 50, 51, 52, 56, 57, 66, 68, 85, 92, 99, 102, 116, 127, 130, 141, 149, 167, 193, 202, 217, 219, 267, 274, 297, 301, 304, 308, 309, 312, 314, 321, 322
animal-derived pigments, 149
annatto, 62, 66, 72, 75, 170, 175, 178, 179, 203, 211, 276
anthocyanins, 37, 53, 68, 74, 149, 152, 154, 158, 161, 165, 166, 167, 168, 199, 202, 208, 267, 268, 269, 270, 271, 272, 273, 274, 277, 278, 279, 281, 282, 284, 285, 287, 288, 292, 293, 294
antibacterial, 41, 42, 47, 50, 53, 54, 63, 64, 78, 87, 98, 147, 150, 202
antibiotic(s), 91, 175
anticancer, 41, 54, 55, 129, 130, 137, 141, 142, 154, 155, 156, 159

Contributor Copy

- antidiabetic, 84, 87, 95, 157
antihypertensive, 84
anti-inflammatory, 8, 23, 50, 54, 84, 87,
90, 120, 127, 129, 131, 137, 139, 141,
142, 154, 155, 157, 159, 164, 202, 216,
218, 219, 221, 274, 282, 283, 287, 293,
303, 317, 329
antimicrobial, 8, 9, 22, 36, 47, 52, 63, 70,
71, 73, 75, 81, 84, 87, 91, 93, 94, 96,
129, 156, 159, 160, 167, 169, 170, 173,
175, 176, 178, 209, 275
antimicrobial properties, 8, 22, 36, 81, 156,
159, 160, 170, 275
antimicrobial resistance, 93, 209
anti-obesity, 155
antioxidant activity, 23, 24, 25, 31, 40, 50,
52, 55, 59, 64, 67, 71, 77, 84, 85, 96, 97,
99, 131, 138, 141, 153, 156, 218, 265,
272, 283
antioxidant(s), 4, 9, 17, 19, 20, 22, 23, 24,
25, 31, 34, 35, 36, 38, 40, 41, 42, 44, 45,
47, 49, 50, 51, 52, 54, 55, 59, 60, 62, 63,
64, 65, 67, 68, 70, 71, 72, 74, 75, 76, 77,
78, 81, 83, 84, 85, 87, 90, 91, 95, 96, 97,
98, 99, 120, 126, 127, 128, 129, 130,
131, 132, 133, 137, 138, 139, 140, 141,
142, 144, 145, 147, 151, 153, 154, 155,
156, 157, 159, 163, 164, 201, 202, 215,
216, 218, 219, 221, 222, 232, 238, 242,
246, 247, 248, 249, 251, 256, 263, 265,
268, 269, 271, 272, 273, 274, 275, 281,
282, 283, 285, 287, 293, 296, 297, 298,
300, 302, 303, 306, 310, 311, 315, 316,
317, 319, 324, 327, 329, 333
anti-tumor, 157
antiviral treatment, 155
apparatus, 123, 125, 127, 130, 155, 231
appetite suppression, 304
apple(s), 75, 154
aquatic ecosystem, 8, 9, 10, 32, 103, 108,
121
aqueous extraction, 1, 10, 11, 12, 13, 35,
180
architecture, vii, 1, 41, 81, 101, 115, 116,
117, 118, 119, 149, 151, 169, 189, 267,
295, 337, 338
art and craft, 7
arthrospira, 123, 129, 145, 157, 163
artistry, 150
aseptic, 177
assay(s), 1, 16, 17, 18, 19, 20, 21, 23, 25,
31, 35, 169, 177
astaxanthin, 54, 56, 61, 66, 67, 96, 103,
120, 121, 123, 125, 127, 128, 130, 131,
132, 133, 134, 135, 136, 138, 139, 140,
141, 143, 144, 145, 146, 147, 262, 269,
272, 273, 274, 281, 282, 285
astringency, 2, 4, 5
authenticity, 151
average consumption, 84
Avicennia marina, 8, 36, 38
- ## B
- bacteria, 42, 46, 48, 49, 50, 52, 64, 91, 128,
131, 151, 153, 158, 164, 178, 274, 275,
288, 297
bacterial, 175
bacterial pigment, 150
bactericidal effects, 170
bark, 2, 7, 8, 9, 10, 13, 15, 17, 204
batik, 7, 195, 198, 199, 203, 205, 206, 209,
210, 211, 212, 213, 214
benzotropolones, 152
berries, 2, 8, 70, 154, 228, 241, 242, 264,
281, 288
beta-carotene, 43, 50, 51, 52, 55, 56, 58,
61, 62, 66, 215, 216, 221, 223, 246, 261,
264, 265, 272, 273, 274, 282, 300
betalain(s), 43, 152, 156, 158, 161, 162,
165, 166, 167, 168, 169, 170, 171, 175,
176, 178, 180, 181, 199, 262, 267, 268,
269, 270, 271, 272, 273, 274, 277, 278,
279, 281, 283, 284, 287, 288, 293
bioactive colourant, 150
bioactive compounds, 12, 14, 39, 67, 73,
86, 87, 91, 97, 103, 129, 142, 156, 158,
160, 162, 189, 202, 221, 223, 226, 229,

233, 235, 236, 244, 247, 255, 259, 260, 263, 265, 268, 292, 300, 334, 338

bioactive ingredients, 23, 164, 295, 296

bioactive properties, 128, 150, 153, 156, 218, 220, 259, 333

bioactivities, 82

bioavailability, 150, 156, 232, 240, 245, 248, 249, 263, 264, 287

bio-based solvent, 220, 230, 243, 248, 254, 258, 263

biocompatibility, 47, 53, 60, 150, 160

biodegradability, 2, 3, 32, 34, 35, 44, 46, 47, 53, 220, 231, 250, 280, 320

biodegradable, 1, 2, 12, 32, 33, 34, 35, 46, 47, 48, 53, 59, 61, 62, 68, 69, 73, 74, 75, 77, 78, 150, 220, 230, 245, 252, 256, 259, 283, 291, 296, 298, 299, 305, 306, 316, 319, 320, 326, 329, 331, 333, 334

biodegradable packaging, 59, 61, 74, 298, 299, 305, 316, 329, 331, 334

biodegradable pigment, 150

bio-derived solvents, 220

biodiversity, 108, 116, 118, 121, 151, 166, 189, 191, 193, 196, 202, 205, 206, 208, 209, 210, 214, 337

bioenergy, 111

biomass, 44, 46, 47, 70, 102, 103, 104, 111, 112, 113, 116, 117, 118, 121, 122, 128, 129, 131, 132, 133, 134, 143, 144, 166, 167, 223, 224, 229, 239, 240, 244, 252, 260, 277

bioprocessing technology, 293

biotechnological, 97, 140, 143, 157, 162, 164, 165, 167, 222, 268, 269, 277, 279, 284, 285, 287, 288, 295

biotechnological production, 167, 222, 269, 287

biotechnology, 65, 69, 73, 74, 76, 99, 115, 116, 117, 119, 127, 142, 143, 144, 145, 146, 147, 157, 162, 164, 165, 167, 263, 268, 275, 279, 287, 288, 291, 292, 293, 315, 317, 327, 331, 334, 337, 338

Bixa orellana, 178, 179, 198, 203, 276

Bixa orellana L., 170, 175, 178

bixin, 62, 75, 77, 170, 178

black pigments, 1, 2, 3, 4, 5, 6, 7, 16, 26, 27, 31, 37

blackness (My), 26, 30, 31

bloodstream, 127, 158

blue applicability grade index, 252

blueberries, 281, 293

blues, 150

botanical, 149, 209, 210

Bruguiera gymnorhiza, 8, 38, 39

built environment, 101, 110, 111, 114, 337, 338

butylated hydroxytoluene, 45, 83

C

cancer, 25, 51, 54, 55, 66, 67, 83, 90, 91, 120, 127, 132, 137, 140, 141, 153, 154, 166, 215, 218, 219, 281, 283, 288, 303

cancer therapies, 154

canthaxanthin, 49, 55, 56, 58, 61, 66, 123, 125, 127, 131, 133

carbon footprint, 33, 47, 111, 113, 252

carbon offsetting, 111

carbon sequestration, 101, 111, 117

carbon-neutral energy, 110

carcinogenic behaviour, 83

cardiovascular disease, 25, 51, 54, 66, 83, 130, 154, 156, 168, 303

carmine, 275, 276, 282, 283, 286, 290

carrot(s), 49, 52, 72, 156, 162, 215, 221, 224, 227, 228, 231, 234, 235, 239, 242, 243, 244, 245, 249, 256, 260, 261, 262, 265

Caryophyllales, 156, 271, 274

cataract, 83

cellulases, 239, 245, 278

Cerriops tagal, 8

chelate complex, 15

chemical diversity, 156

chemical energy, 105, 128, 155, 299

chemical structure, 5, 48, 129, 130, 151, 199, 270

chemical structures, 169

- chlorella, 102, 104, 106, 110, 112, 115,
 117, 123, 128, 129, 133, 146, 178, 179,
 222, 234, 265, 300, 309
Chlorella vulgaris, 102, 104, 106, 110,
 115, 128, 146, 170, 175, 178, 179, 222,
 234
 chlorophyll, 77, 86, 105, 115, 120, 121,
 125, 128, 133, 134, 135, 136, 137, 139,
 143, 144, 155, 158, 161, 167, 169, 170,
 171, 175, 176, 178, 181, 199, 202, 295,
 296, 297, 298, 299, 300, 301, 302, 303,
 304, 305, 306, 307, 308, 309, 310, 311,
 312, 313, 314, 315, 316, 317, 318, 319,
 320, 321, 322, 323, 324, 325, 326, 327,
 328, 329, 330, 331, 332, 333, 334, 335
 chlorophyll a, 105, 125, 128, 134, 135,
 137, 139, 144, 167, 298, 299, 300, 301,
 302, 303, 304, 305, 306, 307, 308, 310,
 312, 313, 314, 315, 316, 317, 322, 323,
 324, 325, 326, 327, 328, 330, 331, 332,
 333, 335
 chlorophyll b, 105, 125, 137, 143, 299,
 301, 303
 chlorophyllin, 128, 301, 307
 chromaticity, 28, 29, 30, 31
 cidal inhibition, 178
 circular economy, 2, 33, 218, 221, 255,
 257, 260, 289
 cis-isomers, 77, 247
 cis-trans isomerization, 228, 247
 clean-label, 268, 290, 291, 292, 297, 298,
 299, 301, 302, 305, 306, 310, 311, 312,
 316, 318, 319, 320, 324, 325, 333, 334
 cochineal, 149, 268, 269, 275, 276, 282,
 283, 285, 286, 290, 292, 293
 Codex Alimentarius, 307
 cognitive, 51, 54, 84, 100, 201, 209, 215
 cold pressing, 215, 301
 color fastness, 15
 color stability, 2, 34, 38
 colorant, 76, 190, 206, 207, 219, 262, 334
 coloration, 56, 57, 131, 141, 142, 219
 colorimetry, 1, 31, 35
 colour, 36, 41, 42, 44, 46, 48, 50, 51, 52,
 53, 56, 57, 59, 60, 61, 62, 64, 67, 86,
 119, 121, 122, 127, 129, 132, 150, 151,
 155, 160, 163, 169, 170, 209, 268, 269,
 270, 271, 272, 273, 274, 275, 280, 281,
 282, 283, 284, 285, 286, 290, 291, 297,
 300, 303, 304, 305, 314, 318, 319, 320,
 327
 colour range, 150, 160
 compositional selectivity, 251
 concentration, 5, 6, 13, 16, 17, 18, 20, 21,
 23, 24, 58, 62, 131, 135, 136, 170, 177,
 178, 179, 201, 239, 240, 254
 condensed tannins, 4, 11, 12, 13, 17, 18,
 19, 20, 21, 25
 confectionery, 301, 305, 307
 consumer health, 43, 70, 295, 296, 297
 consumer perception, 197, 296, 324, 327,
 332, 334
 consumer preferences, 160, 253, 268, 290,
 293, 302, 313, 315, 316, 330, 334
 contemporary design, 151, 211
 conventional drug, 154
 conventional method, 153, 217, 227, 244,
 263
 coordination complex, 15
 copper (Cu), 5, 6, 15, 128, 129
 cosmetics, 1, 3, 14, 15, 16, 17, 19, 20, 22,
 23, 25, 34, 35, 38, 57, 66, 83, 119, 120,
 121, 129, 130, 132, 133, 139, 140, 141,
 149, 151, 152, 153, 154, 157, 158, 159,
 160, 165, 166, 190, 198, 202, 203, 208,
 211, 212, 217, 219, 221, 224, 227, 246,
 259, 267, 268, 269, 273, 274, 275, 276,
 280, 282, 284, 286, 289, 290, 291, 292,
 294, 328
 cost-effective, 1, 11, 13, 17, 20, 21, 34,
 120, 126, 157, 221, 225, 226, 244, 250,
 252, 255, 257, 260, 267, 269, 277, 286,
 287, 288, 291, 295, 328
 COVID-19, 51, 71, 73, 98, 155, 216
 cross-contamination, 321, 322
 cultivation, 104, 123, 131, 134, 139, 141,
 151, 153, 155, 222, 223, 280, 286, 287,
 289, 308, 314
 cultural heritage, 190, 205, 206, 208, 294,
 338

culture, vii, 113, 117, 118, 130, 135, 136, 143, 145, 146, 150, 190, 191, 192, 193, 197, 199, 206, 208, 209, 210, 213, 268, 270, 276, 313

custom(s), 193, 195, 214

customizable properties, 220

cyanobacteria, 48, 102, 105, 120, 121, 125, 129, 133, 134, 136, 137, 139, 140, 142, 144, 145, 147, 150, 155, 156, 159, 162, 165, 167, 299

D

dairy alternatives, 304, 312, 316, 318, 320

deep eutectic solvents, 220, 228, 231, 243, 244, 245, 248, 250, 252, 254, 255, 259, 265

degradation, 4, 5, 10, 11, 15, 23, 25, 32, 64, 81, 94, 199, 207, 218, 224, 230, 234, 238, 239, 244, 246, 247, 248, 249, 254, 256, 257, 271, 273, 278, 279, 281, 284, 285, 286, 289, 314

derivatives, 39, 45, 47, 48, 51, 53, 130, 144, 155, 166, 167, 169, 301, 303, 307, 328

detoxification, 67, 145, 297, 302, 303, 305, 306, 310, 311, 316, 317, 324, 329

diabetes, 51, 77, 83, 84, 90, 142, 154, 201, 303

digestive health, 297, 302, 303, 306, 310, 311, 316, 318, 319, 324, 327, 329

distillation, 215

dosage forms, 86

double bond conjugations, 86

downstream processing, 145, 249, 250, 251, 254, 260

DPPH assay, 23, 24, 25

dragon fruit, 178, 179, 274

drug-resistant microbes, 169

Dunaliella salina, 123, 131, 132, 134, 140, 141, 143, 144, 147, 222, 224, 239, 242, 243, 263, 264, 300

dye(s), 3, 6, 10, 15, 17, 33, 37, 39, 40, 44, 53, 71, 140, 150, 159, 162, 166, 190, 197, 198, 199, 203, 205, 208, 209, 210,

211, 212, 213, 214, 269, 275, 276, 282, 284, 291

dynamic phase, 233

E

eco-conscious consumers, 312

eco-friendly, vii, 1, 2, 3, 7, 10, 11, 12, 14, 15, 25, 32, 33, 34, 35, 37, 39, 40, 68, 101, 139, 159, 160, 198, 211, 216, 218, 221, 226, 227, 229, 230, 235, 236, 238, 244, 251, 259, 263, 268, 283, 284, 286, 288, 291, 296, 298, 299, 305, 308, 316, 317, 319, 320, 326, 327, 328, 329, 330, 333, 337

eco-scale, 252

eco-sustainable, 150

edible packaging, 298, 306, 316, 319, 320, 326, 329

edible part, 84

ellagic acid, 4, 8, 9, 20

encapsulation, 59, 69, 156, 168, 209, 247, 248, 249, 261, 264, 273, 281, 282, 285, 289, 294, 315, 334

endogenous, 155

energy consumption, 102, 113, 158, 225, 226, 232, 252, 255, 258, 259

energy efficiency, 101, 102, 112, 114, 115, 116, 227, 245

energy usage, 218, 252

enhancing stability, 150

environmental,

concerns, 3, 216, 268, 287, 298

conservation, 153, 190

factors, 5, 57, 106, 140, 248, 273, 284, 286, 292

impact, 1, 3, 12, 32, 33, 34, 36, 68, 115, 159, 216, 218, 221, 223, 229, 230, 231, 238, 241, 250, 252, 258, 259, 260, 269, 286, 291, 298, 308, 312, 314, 316, 320, 325, 328, 334

safety, 151, 242

stress, 128, 131, 144, 154

sustainability, 1, 32, 36, 37, 149, 160, 204, 208, 223, 238, 294, 338

- environmentally friendly, 2, 11, 13, 34, 46, 49, 59, 68, 93, 110, 121, 149, 158, 224, 234, 239, 241, 244, 278, 279, 280, 287, 288, 289, 300, 301, 305, 306, 307, 308, 312, 315, 316, 323, 326, 328
- enzyme(s), 1, 14, 15, 25, 37, 38, 59, 129, 145, 155, 159, 220, 232, 238, 239, 240, 243, 245, 260, 262, 263, 264, 272, 273, 278, 279, 280, 292, 293, 294
- enzyme-assisted extraction (EAE), 1, 14, 15, 37, 38, 159, 220, 232, 238, 239, 240, 243, 245, 263, 278, 279, 280, 292, 293, 294
- equipment cost, 244, 245, 259
- Escherichia coli*, 91, 170, 174, 176, 209
- ethanol, 11, 12, 17, 18, 21, 24, 94, 176, 180, 224, 228, 234, 237, 242, 243, 244, 245, 247, 253, 254, 258, 261, 263, 264, 277
- ethical sourcing, 296, 301, 305, 308, 311, 324, 325
- ethnobotanical, 86, 193, 196
- ethnobotany, 100, 193, 209, 210, 337, 338
- ethnomedicinal plants, 83, 85
- ethnopharmacological, 86
- ethnoscience, 190, 196, 198, 211, 212
- ethyl acetate, 11, 180, 234, 249
- European Food Safety Authority (EFSA), 51, 286, 290, 307, 332
- European Union, 155, 286, 290, 307, 310
- Ex electrogenic, 111
- extract(s), 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 21, 24, 33, 36, 55, 61, 67, 71, 74, 75, 76, 91, 94, 95, 98, 117, 141, 149, 151, 163, 165, 169, 174, 179, 180, 181, 198, 199, 202, 210, 216, 217, 220, 221, 224, 225, 226, 227, 228, 229, 231, 235, 237, 239, 242, 244, 246, 247, 248, 250, 251, 252, 253, 254, 255, 257, 259, 261, 263, 278, 289, 314, 322, 328
- extraction methods, 1, 10, 14, 33, 34, 35, 156, 157, 160, 165, 199, 204, 207, 216, 218, 220, 236, 240, 241, 243, 244, 246, 250, 252, 257, 258, 259, 260, 261, 264, 267, 269, 277, 279, 280, 287, 288, 289, 291, 293, 301, 302, 308, 309, 314, 322, 328, 334
- extraction yield, 13, 159, 226, 230, 235, 247, 248, 328
- extremophile, 157
- ## F
- fatty acid composition, 222
- fermentation, 47, 65, 66, 152, 222, 223, 275, 277, 279, 280, 285, 288, 289, 328, 334
- flavonoid(s), 4, 84, 87, 95, 152, 154, 163, 166, 270, 271, 272
- flavylum cation, 271
- flexibility, 155
- flower(s), 8, 9, 37, 54, 82, 154, 156, 269, 270, 274, 279
- fluorescent properties, 157
- Folin-Ciocalteu assay, 1, 16, 21, 31, 35
- folklore, 195
- Food and Drug Administration (FDA), 104, 129, 132, 250, 286, 290, 307, 334
- food by-products, 155, 162
- food colouring, 130, 152, 275, 281, 295, 300
- food industry, 34, 37, 63, 64, 67, 71, 74, 78, 83, 128, 150, 156, 158, 160, 165, 167, 169, 171, 172, 173, 219, 238, 248, 257, 284, 288, 293, 294, 295, 296, 297, 298, 299, 300, 301, 302, 305, 306, 310, 312, 313, 315, 316, 317, 320, 323, 324, 325, 326, 327, 329, 331, 332, 333, 334
- food packaging, 1, 20, 34, 35, 42, 43, 45, 46, 52, 53, 58, 61, 63, 64, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 295, 298, 299, 305, 307, 312, 316, 319, 320, 329, 331, 332, 333, 334, 335
- food preservation, vii, 60, 75, 76, 298, 306, 307
- food safety, 41, 42, 45, 51, 52, 63, 71, 72, 74, 78, 169, 220, 286, 290, 292, 307, 308, 310, 330, 332, 334
- food sector, 44, 51, 59, 65, 312, 327, 328

food technology, 295, 296, 297, 298, 299, 301, 302, 306, 313, 315, 317, 327, 328, 331, 332, 334, 335
 formulation(s), 23, 139, 140, 169, 192, 197, 208, 209, 270, 290, 298
 fossil(s), 47, 158, 167
 free radical, 23, 50, 67, 72, 136, 156, 246, 283, 303
 fruit(s), 7, 8, 9, 10, 17, 25, 40, 43, 49, 50, 51, 59, 67, 69, 72, 76, 77, 78, 81, 82, 84, 86, 90, 91, 94, 96, 153, 154, 165, 166, 178, 179, 189, 203, 215, 216, 221, 228, 229, 231, 235, 237, 245, 261, 262, 264, 265, 269, 270, 272, 274, 277, 279, 281, 282, 285
 functional foods, 66, 71, 217, 221, 232, 246, 256, 274, 281, 283, 295, 300, 305, 311, 318, 319, 324, 326, 327, 329, 331, 332, 334, 335
 functional ingredients, 143, 144, 299, 331
 fungi, 7, 46, 48, 50, 86, 151, 153, 156, 222, 274, 275, 279, 288

G

gallic acid, 4, 8, 9, 17, 20, 24, 39, 54
Garcinia mangostana, 9, 39
 gastronomy, 199, 200
 generally recognized as safe (GRAS), 223, 224, 226, 244, 250, 307
 genetic engineering, 156, 280, 289, 293, 315, 327
 genus, 37, 127, 128, 156, 276
 global standards, 290
 gram-negative, 176, 179
 gram-positive, 176, 178
 grape(s), 14, 154, 261, 274, 281
 green algae, 102, 117, 134, 144, 146, 170, 172, 175, 178, 179, 212
 green building, 111
 green chemistry, 36, 218, 226, 233, 236, 257
 green colour, 128, 154, 299, 302, 306, 312, 320, 329

green extraction methods, 216, 220, 234, 240, 241, 252, 255, 256, 258, 260
 green innovation, 110, 333
 green juices, 302, 304, 305, 311, 317, 325, 329
 green packaging, 298, 305, 326
 green pigments, 128, 295, 296, 297, 299, 300, 301, 302, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314, 315, 316, 317, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 330, 331, 332, 333, 334, 335
 green technology, 211, 229, 337, 338
 greener solvent(s), 153
 guideline(s), 86, 92, 96, 286, 296, 307, 309, 314, 320, 325, 335

H

Haematococcus pluvialis, 123, 132, 133, 140, 141, 143, 144, 145, 146, 147
 halal, 41, 81, 82, 85, 86, 91, 92, 93, 94, 96, 97, 98, 99, 101, 149, 212, 267, 295, 296, 297, 298, 299, 300, 301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314, 315, 316, 317, 318, 319, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 330, 331, 332, 333, 334, 335, 337, 338, 339
 halal alternatives, 82
 halal beverages, 333
 halal certification, 81, 92, 97, 296, 298, 308, 309, 310, 311, 313, 320, 321, 322, 323, 325, 330, 331, 332, 333, 334, 335
 halal food industry, 91, 295, 296, 298, 299, 301, 305, 306, 310, 313, 317, 320, 327, 330, 331, 332, 333
 halal products, 82
 halal standards, 299, 300, 301, 302, 308, 309, 321, 322, 323, 330
 harmful residues, 12, 215, 229, 249, 305
 hazardous solvent, 63, 153
 health, vii, 3, 8, 23, 34, 35, 42, 43, 45, 49, 50, 54, 56, 57, 65, 67, 72, 73, 76, 78, 81, 82, 84, 85, 86, 90, 91, 94, 95, 96, 97, 98,

- 99, 119, 127, 130, 140, 141, 142, 143,
150, 153, 154, 155, 156, 158, 159, 161,
162, 164, 165, 196, 197, 201, 210, 211,
215, 216, 217, 219, 221, 224, 226, 241,
246, 248, 249, 251, 255, 256, 259, 261,
267, 268, 269, 272, 274, 275, 276, 280,
281, 282, 283, 284, 285, 287, 288, 291,
292, 293, 294, 295, 296, 297, 299, 300,
302, 303, 304, 305, 306, 307, 310, 311,
313, 315, 316, 317, 318, 319, 320, 324,
325, 326, 327, 328, 329, 330, 331, 333,
334, 335
- health and environmental concerns, 216
- health benefits, vii, 23, 49, 50, 54, 73, 82,
90, 96, 97, 119, 130, 141, 142, 150, 153,
154, 155, 156, 158, 160, 161, 162, 217,
221, 246, 248, 251, 255, 256, 261, 267,
268, 272, 274, 275, 280, 281, 282, 284,
291, 292, 294, 297, 300, 302, 303, 304,
305, 310, 311, 313, 317, 318, 319, 320,
324, 327, 329, 331, 335
- healthcare, 74, 82, 83, 85, 98, 127, 160
- health-conscious alternatives, 150
- health-conscious consumers, 303, 304,
305, 306, 310, 316, 317, 318, 324, 325
- heat regulation, 112
- heat stability, 265
- heath forest ecosystem, 8
- heme, 157
- hemicellulases, 239, 278
- hemoglobin, 157
- herbal teas, 305
- heritage, 189, 196, 199, 213, 277
- hexane extraction, 180, 225, 252
- high pressure, 11, 63, 216, 233, 234
- high production costs, 284, 285, 287
- hue angle, 28, 29, 30, 31
- human health, vii, 50, 54, 65, 67, 76, 81,
83, 90, 92, 93, 94, 137, 147, 154, 216,
249, 260, 270, 272, 275, 286, 293, 306
- human safety, 236
- hybrid methods, 241
- hydrolyzable tannins, 4, 10, 11, 13, 17, 18,
20, 21, 22, 25, 36, 37
- hydrophobic, 21, 48, 217, 232, 234, 243,
248, 250, 254, 256
- hydrophobic compound, 48, 217, 243
- hydroxyl group, 4, 5, 271
- I**
- identification techniques, 151
- immune function, 213, 215, 216, 219, 221,
303
- indigenous communities, 189, 191, 194,
205, 206, 207
- indigenous culture, 192
- indigenous knowledge, 189, 190, 191, 192,
193, 195, 205, 206, 207, 208, 210, 211,
212, 213, 214
- indigenous practice, 190, 196
- indigenous resources, 196
- indigenous wisdom, 193
- indigo, 150, 204
- inflammation, 51, 83, 90, 137, 154, 218,
281, 303
- inflammatory, 87, 141, 218, 283, 303
- ingredient(s), 35, 42, 44, 47, 58, 59, 61, 66,
83, 84, 85, 86, 91, 97, 98, 121, 130, 131,
137, 144, 145, 162, 200, 202, 203, 208,
210, 211, 217, 221, 226, 235, 239, 241,
251, 253, 255, 256, 257, 259, 260, 269,
274, 280, 282, 288, 290, 291, 296, 297,
300, 301, 303, 304, 306, 307, 308, 310,
311, 312, 313, 316, 317, 318, 320, 321,
322, 324, 325, 326, 327, 329, 330, 331,
332, 338
- inhibition status, 178
- initial cost, 216, 245
- ink production, 8, 9
- innovation, vii, 113, 149, 167, 190, 207,
208, 211, 214, 229, 235, 246, 267, 268,
270, 273, 277, 291, 296, 306, 316, 330,
331, 334, 338
- intangible, 205, 206
- intelligent packaging, 41, 42, 52, 59, 60,
64, 69, 72, 73
- iron (Fe), 2, 4, 5, 6, 7, 10, 15, 38, 68, 129,
136, 143, 149, 157, 198, 269

iron binding, 5
 iron oxides, 149
 Islamic, 1, 41, 81, 91, 92, 95, 101, 119,
 149, 169, 189, 205, 214, 267, 295, 296,
 308, 309, 321, 322, 323, 324, 337, 338
 Islamic law, 91
 isomerization, 48, 49, 66, 224, 235, 246,
 247
 isoprenoid, 48, 86, 127, 130, 216, 221, 272

J

Jetness (Mc), 1, 16, 26, 27, 29, 30, 31, 37,
 98

L

laboratory-scale, 220, 228, 229, 232, 251
 leather tanning, 7
 leftover contaminants, 236
 life cycle assessment, 214, 220, 226, 229,
 232, 235, 240, 246, 251, 252, 255, 257,
 259
 light, 5, 15, 26, 27, 30, 44, 48, 49, 62, 63,
 66, 67, 77, 86, 103, 104, 105, 106, 110,
 112, 114, 117, 121, 123, 124, 125, 127,
 128, 129, 130, 131, 133, 134, 135, 139,
 140, 143, 144, 145, 147, 154, 156, 157,
 198, 218, 228, 230, 235, 238, 246, 248,
 249, 254, 259, 268, 269, 271, 273, 281,
 282, 283, 284, 285, 286, 289, 290, 298,
 299, 301, 314
 light degradation, 268
 light energy, 103, 104, 106, 154, 271, 299
 light intensity, 112, 114, 127, 130, 133,
 134, 140
 lightfastness, 1, 31, 34
 light-harvesting, 123, 125, 144, 155, 156
 light-harvesting antenna, 155, 156
 lignocellulosic, 153
 lipid oxidation, 155
 lipophilic components, 254
 lipopolysaccharide layer, 181
 liver health, 71, 303, 304
 local knowledge, 193

low toxicity, 2, 32, 35, 220
 low water solubility, 231
 lutein, 48, 49, 51, 54, 55, 56, 58, 61, 66,
 72, 86, 87, 88, 89, 90, 105, 121, 123,
 125, 127, 128, 131, 133, 141, 143, 144,
 153, 201, 273

M

macroalgae, 102, 116, 150, 228, 263
 macular degeneration, 49, 50, 54, 67, 90,
 138, 153, 202
 Madder, 268, 269, 276, 283, 286, 294
 Malay, 81, 85, 94, 189, 190, 193, 194, 196,
 197, 198, 199, 200, 201, 202, 203, 204,
 205, 208, 209, 210, 211, 212, 213, 338
 Malay archipelago, 195
 Malay indigenous knowledge, 190, 193,
 205, 208
 Mangrove ecosystem, 8, 38
 Maqasid al-shariah, 91, 92, 93, 99
 marine environment, 120, 151
 marine natural pigment, 150, 164
 matcha drinks, 302
 mechanical process, 215
 mechanism, 7, 15, 52, 111, 124, 155, 164,
 230
 metabolic disorder, 156
 metabolite, 86, 94, 208
 metal ions, 4, 5, 6, 15
 metaphysical understanding, 195
 methanol, 11, 12, 18, 24, 176, 277
 methoxy group, 271
 microalgae, 97, 102, 103, 104, 110, 111,
 112, 113, 115, 116, 117, 118, 119, 120,
 121, 122, 123, 124, 126, 127, 128, 129,
 131, 132, 133, 134, 135, 136, 137, 139,
 140, 142, 143, 144, 145, 146, 147, 150,
 155, 159, 161, 162, 163, 164, 165, 222,
 224, 234, 239, 243, 245, 264, 265, 269,
 272, 275, 293, 299, 300, 301, 309, 312
 microbes, 47, 50, 52, 153, 156, 159, 260,
 275, 277

- microbial fermentation, 151, 152, 268, 275, 279, 280, 285, 287, 288, 289, 292, 295, 328, 334
 - microbial growth, 176, 177, 181
 - microbial oils, 222, 223
 - microbial sources, 151, 160, 223, 239, 275, 277, 278, 293
 - microencapsulation, 273, 281, 285, 290
 - micronutrients, 90
 - microorganism, 291
 - microwave-assisted extraction (MAE), 1, 14, 35, 37, 159, 220, 226, 227, 228, 229, 232, 240, 241, 244, 245, 247, 251, 259, 262, 263, 267, 278, 289, 301, 308, 314, 315
 - mineral, 2, 39, 136, 149
 - mineral pigments, 39, 149
 - minimum bactericidal concentration, 169, 176, 177
 - minimum inhibitory, 176
 - minimum inhibitory concentration, 169, 176, 177, 179
 - modern architecture, 101
 - modern innovation, 151
 - molecular, 6, 45, 66, 70, 77, 97, 100, 144, 146, 165, 217, 227, 238, 258, 261, 263, 269, 270, 273
 - Molnupiravir, 155, 162
 - mordant(s), 2, 7, 10, 15, 16, 34, 35, 38, 40, 160, 198, 284
 - morphological, 179
 - multidrug-resistant bacteria, 156
 - Muslim consumers, 82, 92, 94, 308, 310, 312, 317, 320, 321, 322, 323, 324, 325
- N**
- nanostructure(s), 158, 164
 - naphthoquinones, 152
 - natural,
 - carotenoid, 82, 212, 217, 218, 248, 251
 - colourant(s), 2, 12, 17, 19, 20, 23, 24, 34, 41, 42, 49, 50, 52, 60, 63, 65, 74, 98, 127, 129, 140, 154, 156, 157, 159, 161, 162, 163, 166, 189, 190, 196, 198, 199, 202, 203, 205, 206, 207, 208, 211, 212, 238, 250, 256, 267, 268, 281, 290, 293, 294, 297, 298, 299, 300, 301, 302, 304, 305, 306, 307, 308, 310, 315, 323, 324, 328, 331, 334
 - dyes, 3, 4, 22, 32, 36, 38, 39, 137, 150, 160, 166, 167, 197, 198, 199, 202, 204, 205, 211, 212, 213, 283, 284
 - mordants, 15, 33
 - pigment, vii, 3, 37, 38, 39, 43, 53, 61, 64, 66, 95, 104, 115, 119, 126, 127, 128, 139, 142, 149, 150, 151, 152, 153, 154, 157, 158, 159, 160, 162, 163, 164, 165, 166, 167, 189, 197, 221, 227, 268, 269, 276, 277, 281, 282, 283, 284, 285, 286, 287, 289, 290, 291, 292, 293, 294, 298, 300, 304, 305, 314, 315, 316, 323, 326, 327, 332, 334, 335, 338
 - preservatives, 23, 25, 35
 - products, 36, 38, 39, 69, 94, 95, 96, 169, 198, 243, 250, 254, 284, 324, 337, 338
 - red pigments, 166, 267, 268, 269, 270, 272, 273, 274, 275, 276, 277, 279, 280, 282, 283, 284, 285, 286, 287, 288, 289, 290, 291, 292
 - sciences, 195, 196
 - source, 2, 48, 50, 52, 53, 58, 59, 64, 77, 83, 92, 93, 103, 120, 132, 133, 142, 151, 156, 157, 159, 164, 190, 197, 217, 221, 224, 227, 229, 236, 238, 268
 - natural pigments, 170, 172
 - natural source, 179
 - neutralize, 156, 246, 283, 303
 - nitrogen, 73, 122, 124, 126, 128, 132, 133, 136, 139, 146, 156, 172, 176, 222, 237, 239, 271
 - nitrogen-containing vacuolar pigment, 156
 - non-biodegradability, 159, 197
 - non-polar compounds, 216, 236, 244, 249, 278

non-toxic, 1, 3, 12, 15, 32, 34, 36, 53, 123,
139, 150, 159, 198, 215, 220, 223, 229,
230, 236, 241, 244, 245, 248, 250, 252,
256, 259, 278, 280, 283, 287, 288, 289,
291
nutritional value, 65, 82, 97, 123, 219, 247,
250, 254, 300, 303, 306, 311, 318, 324
Nymphaea spp., 9, 36, 39

O

oak galls, 2, 13, 14, 20, 36, 38
ochre, 150, 269, 292
ohmic heating, 159
optimisation, 261
opuntia, 156, 162
oral traditions, 195
orange, 48, 50, 51, 52, 56, 57, 62, 86, 105,
130, 131, 132, 153, 154, 202, 216, 221,
232, 265, 271, 274, 276, 282, 300
organo-photocatalyst, 155, 161
oxidation, 38, 42, 48, 49, 53, 62, 63, 64,
69, 131, 134, 138, 141, 230, 246, 247,
248, 250, 285, 306, 314
oxidative stress, 23, 25, 49, 55, 67, 70, 72,
90, 98, 127, 131, 134, 141, 142, 153,
154, 155, 215, 218, 246, 275, 281, 282,
283, 303
oxygen, 5, 48, 50, 62, 64, 66, 72, 102, 103,
121, 124, 125, 134, 138, 145, 156, 158,
218, 230, 235, 238, 246, 248, 249, 254,
269, 273, 285, 290, 298, 299, 301, 306

P

packaging design, 47, 306
pathogen contamination, 91
pathogens, 7, 42, 55, 93, 96, 98
pectinases, 239, 245, 278
Peltophorum pterocarpum, 9, 39, 204
personal care, 99, 189, 202, 203, 208, 210,
282, 291
pH, 6, 13, 41, 42, 52, 60, 61, 63, 64, 69, 71,
74, 75, 76, 78, 127, 129, 130, 132, 135,

139, 154, 240, 269, 271, 273, 274, 278,
281, 284, 289, 294
pH sensitivity, 271, 289
pharmaceutical, 12, 15, 19, 23, 25, 31, 35,
59, 66, 68, 81, 82, 83, 84, 85, 86, 90, 91,
92, 93, 94, 97, 98, 99, 119, 120, 125,
128, 129, 137, 139, 151, 153, 154, 156,
157, 159, 161, 166, 169, 175, 203, 219,
220, 227, 230, 235, 244, 246, 248, 253,
264, 282, 283, 297
pharmacology, 158
phenolic compounds, 16, 17, 18, 20, 21,
25, 83, 129, 278, 293
phenolic hydroxyl groups, 5, 6
photo bioreactor, 112
photosynthesis, 49, 67, 86, 102, 103, 104,
105, 110, 111, 112, 113, 114, 121, 123,
125, 127, 128, 130, 136, 141, 145, 147,
155, 156, 158, 167, 271, 297, 299
photosynthetic, 48, 50, 86, 102, 103, 104,
111, 112, 113, 119, 120, 121, 122, 123,
124, 125, 127, 128, 130, 135, 136, 137,
139, 140, 155, 299
phototoxicity, 158
phycobiliproteins, 105, 120, 121, 123, 124,
125, 129, 134, 135, 136, 137, 139, 140,
144, 146, 152, 156, 157, 161, 162, 163,
164, 167, 264
phycocyanin, 103, 105, 121, 123, 125, 126,
129, 134, 135, 137, 139, 140, 143, 145,
146, 150, 157, 163, 212, 300
phycoerythrin, 103, 105, 121, 123, 129,
134, 135, 140, 157, 161
phycoerythrocyanin, 105, 125
phycology, 116, 122, 143, 145, 146, 147,
161, 163, 164, 263
phytochemicals, 116, 181, 189, 208
pigment stability, 31, 34, 35
plant biology, 144, 154, 274
plant crude, 176, 177
plant defense, 2, 4, 17, 37
plant pigment, 158, 162, 164, 169, 170,
199, 202, 292

plant sources, 1, 7, 10, 33, 35, 39, 83, 92,
126, 154, 158, 163, 164, 167, 215, 221,
222, 274, 289, 297, 299

plant-based biomaterial, 110

plant-based diets, 304, 312, 317, 325, 327

plant-based dyes, 3

plant-based foods, 304, 312, 315, 325, 330,
332, 334

plant-based meat, 304, 312, 316

plant-based milk, 304, 312, 318

plant-based pigments, 150, 168, 214, 292,
293, 294

polar impurities, 254

polar solvent, 48, 236, 277

polymer(s), 4, 44, 45, 46, 47, 53, 58, 59,
60, 61, 62, 64, 68, 70, 71, 72, 74, 75, 76,
77, 78

polyphenolic, 1, 2, 3, 17, 23, 36, 37, 39, 53,
154

polyphenolic compounds, 1, 2, 3, 17, 23,
36, 37, 39, 54, 154

polyphenolic fractions, 180

polysaccharide(s), 15, 47, 48, 53, 59, 68,
73, 103, 142, 223, 279, 290

pomegranate, 4, 7, 34

porphyrin, 158, 161, 164, 166, 167

premature skin, 153

pressurized liquid extraction, 159, 220,
233, 234, 236, 244, 252, 263, 265

proanthocyanidins, 4, 8, 9, 11, 17, 18, 19,
20, 37, 39

processed foods, 219, 269, 281, 298, 301,
302, 303, 305, 315

product integrity, 82

protein precipitation, 20, 21, 36

protein precipitation method, 20, 21, 36

provitamin A, 48, 137, 138

pulsed electric field, 60, 159, 220, 243, 263

purity, 12, 157, 216, 220, 223, 225, 227,
232, 233, 235, 251, 252, 253, 254, 255,
257, 259, 289, 290, 301, 302, 303, 305,
307, 310, 311, 315, 320, 321, 325, 333

purple shades, 149, 157

Q

quality control, 31, 290

R

radical reaction, 155

recycling, 33, 111, 226, 240

red, 8, 18, 28, 43, 48, 49, 51, 52, 55, 56,
75, 86, 98, 99, 105, 116, 117, 121, 125,
127, 129, 130, 131, 132, 133, 134, 135,
139, 140, 141, 147, 149, 153, 154, 156,
157, 161, 162, 167, 198, 202, 203, 204,
216, 221, 224, 239, 242, 263, 267, 268,
269, 270, 271, 274, 275, 276, 277, 280,
281, 282, 283, 284, 288, 289, 291, 293,
299

red beet, 156, 293

red blood cell, 157

red cabbage, 75, 154, 274

red pigments, 267, 268, 269, 270, 274, 275,
276, 277, 280, 281, 282, 283, 284, 288,
289, 291

red-violet betacyanin, 156

regulatory framework, 288, 290, 291, 307,
310, 320, 323

renewable, 3, 32, 44, 68, 111, 116, 117,
119, 142, 146, 147, 149, 160, 217, 230,
241, 250, 256, 283, 293, 300, 301, 339

renewable energy, 111, 117, 160, 339

reusability, 33

S

safety, 41, 42, 45, 49, 52, 64, 70, 82, 151,
152, 153, 155, 158, 160, 162, 213, 216,
218, 221, 223, 241, 250, 253, 280, 286,
290, 292, 293, 294, 307, 314, 332

safflower, 269, 276, 283, 286, 294

Salvinia molesta, 9, 36, 37

scalability challenges, 235

science, vii, 36, 37, 39, 40, 68, 69, 70, 71,
72, 73, 74, 75, 76, 77, 78, 79, 94, 96, 98,
99, 115, 116, 117, 118, 120, 142, 143,
144, 146, 149, 160, 162, 163, 164, 165,

- 166, 167, 168, 192, 193, 196, 205, 208,
209, 210, 211, 214, 261, 262, 263, 264,
265, 267, 268, 270, 277, 290, 292, 293,
294, 332, 333, 334, 335, 337, 338, 339
- sensory effects, 251
- Sharia-compliant, 91
- shelf life, 23, 43, 52, 57, 60, 63, 72, 74,
169, 251, 269, 273, 281, 282, 285, 290,
306, 314, 315, 316, 329, 331, 334
- singlet oxygen, 50, 67, 246
- smoothies, 296, 300, 302, 304, 311, 317,
325, 329
- snack foods, 303
- solvent extraction, 215, 277, 278, 279, 280
- solvent recovery, 12, 244
- solvent(s), 7, 10, 11, 12, 13, 14, 17, 18, 21,
24, 33, 38, 48, 58, 61, 63, 64, 158, 176,
181, 199, 215, 217, 220, 223, 224, 226,
227, 228, 229, 230, 231, 232, 233, 234,
235, 236, 237, 238, 239, 241, 242, 243,
244, 245, 246, 247, 248, 249, 250, 252,
253, 254, 255, 256, 257, 258, 259, 260,
261, 264, 265, 277, 278, 279, 280, 289,
307, 309, 314, 321, 322, 328
- solvent-based extraction, 11, 13
- Sonneratia alba, 8
- Soxhlet extraction, 215, 227, 260
- spectra, 129, 157
- spectrum, 50, 86, 105, 121, 124, 125, 149,
150, 197, 272, 274
- spiritual, 92, 195, 196, 204
- Spirulina, 117, 123, 129, 133, 134, 135,
137, 140, 141, 143, 144, 145, 146, 212,
234, 265, 299, 300, 309
- stability, 1, 4, 5, 6, 7, 10, 13, 15, 16, 19, 26,
46, 62, 64, 69, 75, 76, 78, 96, 137, 145,
150, 151, 154, 155, 156, 157, 158, 160,
163, 165, 199, 209, 224, 228, 232, 240,
242, 243, 246, 247, 248, 249, 261, 262,
263, 264, 265, 268, 269, 270, 271, 273,
277, 279, 280, 281, 282, 284, 285, 287,
289, 292, 293, 294, 298, 299, 301, 314,
315, 333
- stabilization techniques, 281, 285, 294
- stabilize bioactive compounds, 232
- standard Malaysia, 92
- standardization, 24, 177, 290, 330
- Staphylococcus aureus*, 63, 170, 174, 176
- static inhibition, 178
- subcritical water, 159, 216, 236, 237, 243,
244, 247, 249, 258, 260, 261, 262, 263,
264
- Sumac, 2, 4, 7, 13, 14, 15, 20, 34, 37, 40
- sunlight, 110, 113, 114, 155, 222
- supercritical CO₂, 11, 12, 33, 216, 244,
278, 289
- supercritical fluid extraction (SFE), 11, 12,
13, 33, 34, 35, 39, 158, 220, 223, 224,
225, 226, 240, 242, 244, 250, 252, 253,
254, 256, 259, 261, 265, 267, 277, 278,
280, 289, 292, 294, 295, 301, 302, 308,
309, 314, 315, 328
- sustainability, vii, 2, 3, 14, 15, 32, 33, 35,
36, 37, 41, 44, 64, 101, 102, 114, 150,
151, 153, 155, 158, 164, 165, 190, 193,
196, 198, 205, 207, 208, 209, 212, 213,
214, 216, 221, 226, 227, 229, 232, 235,
240, 246, 252, 255, 257, 258, 259, 267,
269, 280, 287, 288, 289, 296, 297, 298,
300, 301, 302, 305, 309, 310, 312, 313,
314, 315, 316, 319, 320, 323, 325, 326,
327, 328, 329, 330, 331, 332, 333, 334,
335, 337, 338
- sustainable design, 37, 102, 110, 114
- sustainable dyeing, 2, 32, 37, 156, 166
- sustainable environment, 93, 120
- sustainable extraction, 150, 215, 220, 221,
222, 226, 233, 241, 251, 253, 255, 259,
260
- sustainable materials, 34, 75
- sustainable packaging, 12, 296, 306, 320,
326, 332, 335
- sustainable production, 214, 229, 275, 279,
293, 320
- sustainable sourcing, 32, 268, 308, 311,
326, 327, 331
- synthetic antibiotic(s), 170, 175
- synthetic antioxidants, 24, 83, 90
- synthetic biology, 100, 151, 268, 293
- synthetic colorants, 2, 127, 293

synthetic dye, 1, 2, 3, 5, 32, 33, 35, 43, 57,
63, 150, 154, 156, 159, 160, 197, 198,
204, 268, 269, 273, 276, 280, 281, 283,
284, 285, 287, 288, 291, 303, 312

T

tannic acid, 8, 9, 15
tannin-iron complex, 6
tannins, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,
13, 14, 15, 16, 17, 19, 20, 21, 22, 23, 25,
26, 32, 33, 34, 35, 36, 37, 38, 39, 40
techno-economic, 145, 220, 224, 226, 228,
232, 235, 240, 251, 252, 255, 257, 258
technology, 41, 42, 53, 60, 63, 64, 67, 68,
69, 70, 71, 72, 73, 74, 75, 76, 77, 79, 95,
99, 116, 117, 143, 145, 163, 165, 166,
167, 168, 189, 190, 191, 196, 199, 205,
206, 208, 210, 214, 226, 232, 235, 253,
262, 263, 264, 270, 292, 293, 296, 317,
332, 333, 334, 335
temperature, 6, 11, 13, 24, 38, 42, 52, 58,
63, 64, 66, 73, 74, 106, 112, 114, 127,
131, 132, 133, 134, 135, 139, 143, 154,
191, 217, 222, 223, 224, 228, 230, 231,
232, 233, 234, 235, 236, 237, 238, 240,
243, 245, 247, 248, 249, 253, 254, 256,
257, 258, 262, 268, 273, 278, 281, 282,
284, 286, 289, 294
terpenoid, 125
textile dyeing, 6, 7, 11, 12, 16, 17, 20, 34,
37, 198, 210, 276, 283, 294
textile industry, 19, 150, 156, 198, 283
textile(s), 1, 2, 3, 5, 6, 7, 11, 12, 15, 16, 17,
19, 20, 22, 25, 34, 35, 36, 37, 38, 57,
122, 149, 150, 151, 152, 154, 156, 158,
159, 163, 164, 190, 197, 198, 199, 204,
208, 209, 210, 211, 212, 213, 267, 268,
269, 274, 275, 276, 280, 283, 284, 291,
293, 294
therapeutic, 51, 73, 85, 95, 129, 140, 150,
151, 152, 155, 162, 164, 209, 283
thermal degradation, 220, 227, 228, 235,
238, 244, 245, 247, 257
thermal insulation, 101, 112, 113

Thibbun Nabawi, 92
total phenolic content, 16, 17, 21
toxin-free, 150
traceability, 310, 321, 323, 333
traceability systems, 321
traditional, vii, 1, 2, 3, 7, 8, 9, 10, 13, 14,
33, 35, 37, 43, 47, 53, 57, 64, 67, 81, 82,
83, 85, 94, 95, 98, 100, 126, 151, 155,
165, 189, 190, 191, 193, 194, 195, 196,
197, 198, 199, 200, 201, 202, 203, 205,
206, 207, 208, 209, 210, 211, 212, 214,
220, 222, 224, 225, 226, 227, 230, 231,
232, 233, 234, 235, 236, 239, 241, 244,
250, 252, 253, 256, 258, 260, 267, 270,
275, 276, 277, 278, 279, 280, 283, 285,
287, 288, 289, 298, 302, 303, 304, 305,
312, 316, 318, 328, 329, 337, 338
traditional craft, 151, 207, 211
traditional knowledge, vii, 81, 189, 191,
198, 199, 207, 208, 209, 210, 270
traditional Malay vegetable, 81, 94
traditional vegetables, 82, 98, 201, 210
Tristimulus values, 27
tropical species, 9

U

Ulam. *See* traditional Malay vegetable, 81,
82, 84, 85, 86, 87, 88, 89, 90, 91, 92, 94,
95, 96, 98, 100, 200, 201, 210, 212, 214
ultrasonication, 158
ultrasound-assisted extraction (UAE), 1,
14, 36, 40, 158, 220, 228, 229, 230, 231,
232, 240, 241, 243, 245, 251, 259, 260,
278, 279, 289, 293, 302, 315
ultraviolet, 56, 63, 77, 95, 131, 150
undertone (dM), 1, 16, 26, 27, 28, 29, 30,
31
UV protection, 160

V

vegan cheese, 312, 318, 329
vegan products, 300

vegetable(s), 43, 49, 50, 51, 59, 67, 69, 70,
72, 77, 78, 81, 82, 86, 90, 91, 94, 97,
100, 153, 154, 156, 200, 201, 214, 215,
216, 220, 221, 222, 229, 230, 231, 235,
237, 241, 242, 243, 244, 245, 246, 248,
250, 253, 254, 255, 259, 261, 262, 264,
265, 272, 274, 282, 303
vibrant colors, 169, 181
vibrant colours, 157, 270, 284
virus, 96
visual appeal, 26, 197, 303, 306, 312
visual health, 154
vitamin A, 55, 67, 90, 97, 98, 130, 133,
137, 201, 209, 212, 213, 215, 216, 218,
219, 221, 256, 272
vitamin C, 141, 285, 293

W

wash-fastness, 1, 34
waste reduction, 35
water consumption, 2, 33
water management, 33
water pollution, 32, 159
water-soluble pigment, 140, 154, 270
wavelength, 16, 18, 21, 23, 105, 130, 132,
133, 139

weight management, 304

X

xanthones, 152
xanthophyll, 58, 86

Y

yeast, 132, 167, 222, 224, 243, 254, 263,
275, 288
yeast biomass, 222, 224, 243, 254
yellow, 9, 15, 23, 28, 43, 48, 50, 51, 52, 56,
57, 62, 84, 86, 105, 110, 118, 127, 128,
130, 153, 156, 198, 200, 202, 203, 216,
271, 274, 282
yellow-orange betaxanthin, 156
yield, 6, 11, 12, 13, 43, 56, 103, 114, 144,
149, 153, 157, 189, 199, 216, 218, 232,
233, 238, 239, 240, 244, 253, 260, 267,
278, 280, 285, 289, 309

Z

zeaxanthin, 43, 48, 49, 50, 51, 54, 56, 61,
66, 86, 87, 88, 89, 90, 105, 123, 131,
141, 153, 202, 273

NATURAL PIGMENTS

Sources, Properties, and Health Benefits

Rashidi Othman, PhD

Qurratu Aini Mat Ali, PhD

Razanah Ramya, PhD

Farah Ayuni Mohd Hatta, PhD

Wan Syibrah Hanisah Wan Sulaiman, PhD

Nur Hanie Mohd Latiff, PhD

nova
science publishers

www.novapublishers.com

Contributor Copy

ISBN 979-8-901341-19-3



9 798901 341193