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Preface

The prevalence of obesity has doubled from 1975 to 2016 worldwide. Approximately 1.5 billion people worldwide are overweight or obese, which increases the risk of developing type 2 diabetes, cancer, inflammatory disturbances, and cardiovascular disease. Despite numerous efforts and major advancements made to control these metabolic disorders, significant deficiencies and gap for improvements remain. The plant is of particular interest because plant-derived components modulate oxidative stress and hence alter gene and protein expression. Rice is one of the vitally important staple foods for almost half of the population in the world. The demand for rice is expected to remain strong over the next few decades due to the rapid growth of the population. Hence, the rice industry will remain sustainable for a long time, and the production of rice by-products including rice husk, rice straw, broken rice, rice germ, rice bran, and brewers' rice will remain high. Empirical evidence suggests that rice by-products may possess beneficial effects against oxidative stress and may favor for the prevention of metabolic disorders. These beneficial effects have been associated with the phytochemicals of the rice by-products present, such as vitamin E, dietary fiber, γ-oryzanol, γ-aminobutyric acid (GABA), and phytosterols. Based on our knowledge, the literature pertaining to rice by-products and its derived components with their molecular mechanisms that modulate non-communicable diseases has not well been compiled in the form of brief/book. Indeed, this disintegrated information needs to be compiled together to deliver knowledge at one point. Therefore, this book attempts to discuss issues pertaining to rice by-products, namely rice demands and rice by-products production, phytonutrients and antioxidant properties of rice by-products, potential health benefits, application in food products, and future prospects. By summarizing all the information in the lucid and comprehensive manner in one brief/book, it would provide a cohesive representation of the literature on the underlying mode of action involved in the pharmacological effect of these bioactive constituents that present in the rice by-products as well as plausible means for the prevention of metabolic ailments for the allied stakeholders and readers.

Serdang, Selangor, Malaysia — Bee Ling Tan

Abbreviations

5-LOX	5-Lipoxygenase
ABC-A	ATP-binding cassette
ACF	Aberrant crypt foci
AGEs	Advanced glycosylation end products
$AlCl_3$	Aluminum chloride
AOM	Azoxymethane
APC	Adenomatous polyposis coli
AR	Aldose reductase
ATP	Adenosine triphosphate
BHA	Butylated hydroxyanisole
BHT	Butylated hydroxytoluene
BMI	Body mass index
BOP	*N*-Nitrosobis(2-oxopropyl)amine
CE	Catechin equivalents
CEHC	γ-Carboxyethyl hydroxychroman
CK1	Casein kinase 1
COX	Cyclooxygenase
COX-2	Cyclooxygenase-2
CRP	C-Reactive protein
CVD	Cardiovascular disease
DBP	Diastolic blood pressure
DC-STAMP	Dendritic cell-specific transmembrane protein
DPPH	1,1-Diphenyl-2-picryl-hydrazyl
DPP IV	Dipeptidyl peptidase IV
ERK	Extracellular regulated protein kinases
FAO	Food and Agriculture Organization
FRAP	Ferric reducing antioxidant power
GABA	γ-Aminobutyric acid
GAD	Glutamate decarboxylase
GAE	Gallic acid equivalents
GSK3β	Glycogen synthase kinase 3β

HDL-C	High-density lipoprotein cholesterol
HEBR	Hydrolysates produced by limited enzymatic broken rice
HepG2	Hepatocellular carcinoma
HO-1	Heme oxygenase-1
HOMA-IR	Homeostasis model assessment-insulin resistance
HPA	Hypothalamic pituitary adrenal
HPLC	High-performance liquid chromatography
HT-29	Colon cancer cell lines
Hs	High-sensitivity
ICR	Imprinting control region
IFN-γ	Interferon-gamma
IgA	Immunoglobulin A
IL-1β	Interleukin-1beta
IL-6	Interleukin-6
iNOS	Inducible nitric oxide synthase
IP6	Inositol hexaphosphate
IRRI	International Rice Research Institute
JNK	c-Jun *N*-terminal kinase
LDL	Low-density lipoprotein
LDL-C	Low-density lipoprotein cholesterol
LPS	Lipopolysaccharides
LRP6	Low-density lipoprotein receptor-related protein 6
MAP	Mean arterial pressure
MAPK	Mitogen-activated protein kinase
MCF-7	Breast carcinoma
MDA	Malondialdehyde
NFATc1	Nuclear factor of activated T-cells, cytoplasmic 1
NF-κB	Nuclear factor-kappa B
NK	Natural killer
NMRI	Naval Medical Research Institute
NO	Nitric oxide
Nrf2	NF-E2-related factor 2
PC-3	Prostate cancer cell
PG	Prostaglandin
PGC1α	Peroxisome proliferator-activated receptor gamma coactivator 1-alpha
PGE_2	Prostaglandin E2
PGH_2	Prostaglandin H_2
PKC	Protein kinase C
PPARγ	Peroxisome proliferator-activated receptor-γ
PTH	Parathyroid hormone
PUFA	Polyunsaturated fatty acids
RANKL	Receptor activator of nuclear factor κB ligand
RBO	Rice bran oil
RNS	Reactive nitrogen species

ROS	Reactive oxygen species
SBP	Systolic blood pressure
SCFA	Short-chain fatty acids
SiO_2	Silica
SOD	Superoxide dismutase
SREBPs	Sterol regulatory element-binding proteins
TBHQ	tert-Butylhydroquinone
TC	Total cholesterol
TEAC	Trolox equivalent antioxidant capacity
TG	Triglycerides
TLR	Toll-like receptors
TMR	Total mixed rations
TNF-α	Tumor necrosis factor-alpha
USDA	United States Department of Agriculture
XOS	Xylooligosaccharides

Contents

Chapter 1
Introduction and Background

Abstract Rice is a staple food for nearly half of the global population. Irrigated rice contributes to nearly 55% of the global harvested area, which is about 75% of global rice production (410 million tonnes of rice per year), which is 100 times more productive compared to upland rice. The yields of rice production depend on water supply, herbicides, and fertilizers. They are several rice by-products produced during the rice milling process including rice bran, rice husk, brewers' rice, and rice straw. However, most of the rice by-products were used as animal feed and some of them were not efficiently utilized. Unused rice by-products are usually burnt in the field and thus leading to a serious environmental problem. Substantial evidence shows that rice by-products contain a high amount of bioactive compounds, for instance, pigmented compounds, γ-oryzanol, vitamin E, flavonoids, and phenolic acids that possess potential health benefits such as anticancer, antimutagenic, and antioxidative activity. Therefore, this book attempts to discuss issues related to rice by-products, including rice demands and rice by-products production, phytonutrients and antioxidant properties of rice by-products, potential health benefits, application in food products, and future prospects.

Keywords Irrigated rice · Rice by-products · Upland rice

Rice (*Oryza sativa* L.) supports a large number of populations over millennia compared to other crops as it was domesticated from 8,000 to 10,000 years ago (Greenland 1997). Currently, rice is one of the important cereal crops in Asia consumed by nearly half of the world's population as their daily staple food (Ali 2018). The rice is cultivated in more than 110 countries (Sharif et al. 2014). According to rice production quality data (2016) estimated by FAO, nearly 740 million tonnes of rice is harvested globally and about 670 million tonnes, which is 90% is consumed and produced in Asia, particularly eastern, southern, and south-eastern regions (Peanparkdee and Iwamoto 2019). Rice contributes up to 40% of caloric intake in tropical Asia but some countries can achieve more than 65% (Fairhurst and Dobermann 2002). Table 1.1 shows the rice production, area, and yield.

Paddy rice production has been sustained for a longer period of time and thus is considered as one of the world's most productive and sustainable farming systems (Horgan et al. 2016). Based on the annual basis, irrigated rice is 100 times more

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Table 1.1 Rice production, area, and yield (Food and Agriculture Organization of the United Nations (FAOSTAT) 2019a)

	1990			2017		
Countries	Production (tonnes)	Area harvested (hg/ha)	Yield (ha)	Production (tonnes)	Area harvested (hg/ha)	Yield (ha)
Asia	477,693,369	132,426,521	36,072	692,590,948	145,539,189	47,588
India	111,517,408	42,686,608	26,125	168,500,000	43,789,000	38,480
China	191,614,680	33,518,971	57,166	214,430,049	31,035,082	69,093
Malaysia	1,884,984	680,647	27,694	2,901,894	689,268	42,101
Africa	12,697,110	6,034,413	21,041	36,560,295	14,959,657	24,439
Europe	4,570,432	1,063,346	42,982	4,051,459	642,982	63,010
World	518,568,653	146,960,085	35,286	769,657,791	167,249,103	46,019

productive compared to upland rice, about 5 times more productive than rainfed rice, and more than 12 times productive than deep-water rice (Fairhurst and Dobermann 2002). Irrigated rice contributes to nearly 55% of the global harvested area, accounting for about 410 million tonnes (75%) of global rice production annually (Dobermann and Fairhurst 2000). It is predominantly centered in regions of tropic and humid subtropical climate (Satapathy et al. 2015; Bayer et al. 2015). Intensified paddy rice system accounts for large population density as well as rich cultures that have been developed along with the major river systems in Asia (Hossain et al. 2016; Talhelm and Oishi 2018). Therefore, rice culture has been recognized as the cornerstone for the development of economic, cultural, and social in Asia (Spangenberg et al. 2018).

In the middle of the last century, the yields of rice production have increased steadily when several methods were developed to control the water supply. The farmer also used the varieties adapted to specific agro-ecological conditions (Vo et al. 2018). In general, rice was adapted to fit a broad spectrum of growing conditions, from deep-water swamps to the uplands and from the equatorial tropics to the high altitudes of Japan. Therefore, this could be explained why it is possible to collect up to 80,000 local varieties over the last 35 years, which stored at the International Rice Research Institute (IRRI) germplasm (Fairhurst and Dobermann 2002).

Several factors have changed on the demands of rice including per capita incomes, changes in the price of rice relative to substitute crops, and population growth (Dang et al. 2019). In the early 1960s, it was witnessed a steady increase in Asia's per capita rice production from 132,560 tonnes in the early 1960s to nearly 449,399 tonnes in 2013 (Food and Agriculture Organization of the United Nations (FAOSTAT) 2019b). These data indicate that the rising per capita production is more than doubled during this period, implied the high demands of rice in Asian countries. According to IRRI senior economist Dr. Samarendu Mohanty, rice consumption and their needs are expected to increase to an additional 116 million tonnes by 2035 to feed the global population (Subramanian 2013). Increasing rice consumption was driven primarily by population growth in Africa, Latin America, and Asia (Muthayya et al. 2014).

Before the introduction of herbicides, tall rice plants have a greater likelihood to have a competitive advantage compared to weeds. Furthermore, tall varieties were preferred because farmers often used rice straw for other purposes such as mulch, animal bedding, and fuel. Furthermore, tall varieties are easy to harvest (Fairhurst and Dobermann 2002). In the late 1950s, advancements in nitrogen fertilizer manufacturing technology led to a reduction of nitrogen cost. However, tall rice plants were less responsive to nitrogen fertilizer due to their susceptibility to lodging (Fairhurst and Dobermann 2002). Improvements in water control, herbicides, and crop protection as well as combined with the cost-effective nitrogen fertilizer, and thus leading the breeders to select plants with stiff and short straw that were less prone to lodging and produced high harvest index (Fairhurst and Dobermann 2002).

One of the most momentous histories of rice production was the crossing of the Indonesian variety Peta and Taiwanese variety Dee-geo-woogen to produce IR8, and thus began the Green Revolution. Therefore, they have been remarkably increased in grain yields. Local governments with the support from international lending agencies have made tremendous efforts and investments to enhance the water control in irrigated rice systems and thereby increase the area planted to rice and improve the cropping intensity (crops/ha/year) (Fairhurst and Dobermann 2002). Collectively, the combination of these systems has allowed the rice production to keep pace with the demand driven by the increase of growth in world population over the last few decades (Fairhurst and Dobermann 2002).

In addition to the nitrogen fertilizer, phosphorus fertilizer was also needed before a substantial response to nitrogen. In general, a country with a high deposit of natural gas and oil is used to manufacture nitrogen fertilizers. Manufactured phosphorus fertilizer is either produced or imported from local or oversea phosphorus rock, phosphoric acid, and sulphuric acid (Fairhurst and Dobermann 2002). In addition to phosphorus and nitrogen fertilizers, potassium fertilizer has been used sparingly in Asia's rice fields. However, potassium fertilizer could be served as an important production factor in the area, for instance, past soil mining and rice straw removal field (Fairhurst and Dobermann 2002). Emerging evidence highlights the importance of potassium fertilizer in the relation of pest resistance and plant health (Shi et al. 2018).

Several by-products are produced during the rice milling process including rice bran (combined with germ), rice husk, brewers' rice, and rice straw. In general, about 1,100 tonnes of straw can be obtained from the paddy field per year. Furthermore, rice processing also generates low-value by-product such as bran and husk, contributes for about 10 and 20% of the total weight of rice, respectively (Butsat and Siriamornpun 2010). In general, the rice milling by-products are utilized as an ingredient for animal feed (Sharif et al. 2014) as well as other purposes such as bedding material. Indeed, some of them were not efficiently utilized (Rafe and Sadeghian 2017). The disposal of this rice by-product has led to an adverse outcome (Daifullah et al. 2003). The previous finding has found that unused rice by-products are usually burnt in the fields and thus leading to the economic waste and environmental problems for instance loss of soil moisture, smog formation, and air pollution (Chaudhary et al. 2016). Intriguingly, substantial evidence highlights that rice by-products consist of numerous bioactive constituents, for instance, pigmented compounds, γ-oryzanol, vitamin E, flavonoids, and phenolic acids, which exerts potential health benefits (Peanparkdee et al. 2018; Kim et al. 2019; Liu et al. 2019). For example, rice bran contains several beneficial compounds such as phenolic compounds, tocotrienols, tocopherols, γ-oryzanol, and sterols (Peanparkdee and Iwamoto 2019). Notably, some of the phenolic acids found in rice bran, for example, diferulate, ferulic, and p-coumaric acids are not present in a significant amount in vegetables and fruits (Adom and Liu 2002). In addition to γ-oryzanol, a mixture of lipophilic phytosterols composed of sterols or triterpene alcohols with ferulic acid ester, shows cholesterol-lowering and antioxidant activity (Daou and Zhang 2014; Rungratanawanich et al. 2018). Several phenolic compounds, tocotrienols, and tocopherols in rice by-products have potentially beneficial effects, such as anticancer, antimutagenic, and antioxidative activity that play a vital role in promoting health (Hall et al. 2019). Research evidence has demonstrated that the bioactive compounds do not uniformly present in a cereal grain but are mainly concentrated in the bran and husk layers (Gao et al. 2018; Castanho et al. 2019). Therefore, dietary intake of whole grain in regular meals is strongly recommended to maintain desirable health benefits beyond basic nutrition as well as decrease the risk of numerous metabolic ailments (Gong et al. 2018).

According to the best of authors' knowledge, the literature pertaining to rice by-products and its derived components with their molecular mechanisms that modulate non-communicable diseases has not well been compiled in the form of brief/book. Indeed, this disintegrated knowledge needs to be combined together to deliver maximum information at one point. Therefore, this book attempts to discuss issues related to rice by-products, including rice demands and rice by-products production, phytonutrients and antioxidant properties of rice by-products, potential health benefits, application in food products, and future prospects.

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