CHAPTER

22

Rice Bran: A Food Ingredient with Global Public Health Opportunities

Erica C. Borresen[*], *Elizabeth P. Ryan*[*,†]

[*]Colorado State University, Department of Environmental and Radiological Health Sciences, Fort Collins, Colorado, USA, [†]Colorado School of Public Health, Fort Collins, Colorado, USA

INTRODUCTION

Rice is an important staple food crop for human health because it provides the bulk of calories for more than half the world's population. Rice is currently grown in over 100 countries, and more than 1 billion people depend on it for their livelihood.[1] Of the 475 million tonnes of milled rice produced globally, 85% is used for human consumption and the remaining 15% is used for animal feed or is wasted. [2] In developing countries, rice provides roughly 30% of the population's daily diet, and consumption has grown in developed countries to ~27 pounds of rice per person per year.[3] Thus, in order to enhance our understanding of the connections between rice, nutrition, and human health, an overarching recognition of rice is needed in the context of global food security.

Rice is primarily consumed in the polished, white grain form. Unfortunately, the refined white grain has lost many nutritious components with the removal of the bran. The bran portion of the grain contains a rich source of lipids, protein, soluble and insoluble dietary fibers, iron, B vitamins, and a number of small molecules (e.g., phytosterols, phenolic acids, and antioxidants) that can aid in disease prevention, control, and treatment.[4] Figure 22.1 shows paddy rice processing of whole grain rice, and the estimated nutrient contents of the white rice and rice bran parts.

Consumption of the bran portion of whole grain rice is being investigated regarding health attributes relevant to both chronic and infectious diseases. The vast majority of research has focused on chronic disease prevention and control, whereby brown rice and rice bran have been shown to decrease risk of type 2 diabetes,[5,6] regulate lipid metabolism,[7–10] control metabolic syndrome and cardiovascular disease,[11–13] and exhibit anti-cancer activity.[14,15] The effects of rice bran components on the immune response and, more recently, in protection against enteric pathogens such as *Salmonella*,[16] represent areas of research relevant to infectious diseases.[17–19]

Given that many of the world's poorest children and adults eat white rice as their main source of calories, and do not receive the natural health-promoting components found in the bran, they also are at higher risk of malnutrition. Approximately 870 million individuals (or 1 in 8) are considered chronically undernourished in our world today.[20] These individuals can be classified as "food insecure," because they do not have adequate safe and nutritious food because of lack of availability, affordability, accessibility, or some combination of these factors. Although the global population of undernourished people has been steadily declining since the 1990s, there are still more than 2.5 million children under the age of 5 years that die from malnutrition-related complications every year.[20] Achieving food security has become a major global public health priority that relates to the first Millennium Development Goal (MDG) to halve the prevalence of hunger and malnourishment, and the UN Secretary General calling for a "Zero Hunger Challenge" by encouraging all nations to end hunger.[21]

At the same time, obesity has been increasing globally, with rates that have more than doubled since 1980; currently, over half a billion people (or 1 in 10) are obese.[22] The complexity of the obesity epidemic involves individual behaviors, physical inactivity, and dietary choices, as well as socioeconomic influences and psychological conditions apparent in both developed and developing countries. Evidence shows that individuals who have lower birth weights and childhood stunting are at risk for developing co-morbidities associated with

Wheat and Rice in Disease Prevention and Health
http://dx.doi.org/10.1016/B978-0-12-401716-0.00022-2

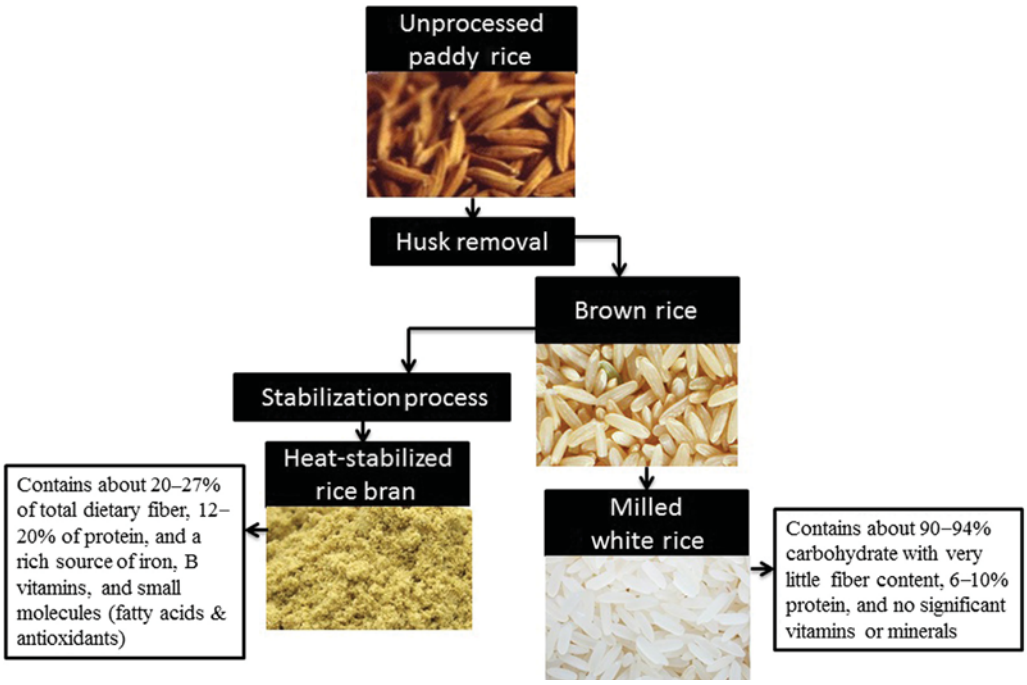

FIGURE 22.1 Whole grain rice processing and a summary of nutrient variations of white rice and rice bran end products.[10,57] See color plate at the back of the book.

abdominal obesity later in life.[23,24] This evolving paradox of malnourished and overweight/obese individuals further stresses the barriers to improve health in our global food system.

Addressing global food security with a multidisciplinary approach and diverse inputs across non-profits, non-governmental organizations (NGOs), academia, private sectors, governments, and even local, small shareholders is challenging. Given that there is an adequate amount of food grown in agriculture to feed the world's population,[25] how do we innovate the rice food system to address issues of hunger, malnutrition, and life-threatening diseases? Specifically, can we develop opportunities for dietary rice bran to simultaneously alleviate the complex problems of malnutrition and obesity-related diseases? The Green Revolution accomplished altering rice genes for improved rice varieties with increased yield to feed the growing population, and now we understand that the increased production of rice does not equate to better nutrition.[26] Tremendous attention has been paid to the development of Golden Rice to combat vitamin A deficiency,[27–29] yet with the rice genome sequenced and the varied cropping systems intact, there still remains a great opportunity to advance dietary rice bran intake as a sustainable solution for human health via improved post-harvest processing (e.g., safe collection and storage of rice bran for human consumption).[30] Furthermore, there continues to be a gap in our knowledge regarding how bran from genetically and geographically diverse rice varieties differs in health attributes.

In this chapter, our objective is to synthesize rice bran's global health opportunities for chronic and infectious disease control and prevention. To this end, we will discuss current challenges, provide an overview of dietary rice bran intake possibilities across the lifespan and address the need for further research on rice health traits and bioactive components from studies using traditional rice varieties.

COMMON TERMINOLOGY FOR DIETARY RICE BRAN AND PUBLIC HEALTH OPPORTUNITIES

There are multiple stakeholders involved in rice food systems that can influence our understanding of nutrition and health benefits. Here, we define a number of commonly used terms throughout the chapter for the purpose of enhancing the clarity of this conceptual framework.

Complementary foods: Foods other than breast milk or infant formula introduced to an infant to provide additional necessary nutrients for proper growth and development.
Chronic diseases: Diseases that progress slowly over time. Examples include obesity, cardiovascular disease, cancer, and type 2 diabetes.[31]
Enteric pathogen: Any bacteria that causes disease in the intestinal tract. Clinical symptoms include greater than or equal to three unformed stools

(diarrhea) in 1 day, and nutrient electrolyte absorption failure by the intestine.[32]
Food security: To attain adequate nutrition so that "… all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life".[33]
Food system: All activities, people, and resources utilized from production to consumption, including growing, harvesting, processing, packaging, transporting, marketing, consumption, and disposal.
Green Revolution: An increase in crop yields based on cultivation of high-response varieties of food grains, such as wheat, rice, maize, and millet, and including intensive use of fertilizers, pesticides, irrigation, and machinery.[34]
Gut microbiome: All microbes found in the human gut.[35]
Health: A state of complete physical, mental, and social well-being, and not merely the absence of disease or infirmity.[36]
Infectious diseases: Diseases that are caused by pathogenic microorganisms (e.g., bacteria, viruses, parasites, or fungi) that are spread directly or indirectly between individuals.[37]
Malnutrition: A broad term used to describe people whose food intake does not provide adequate calories and other essential nutrients for growth and health maintenance or when people are not able to fully utilize the food they eat due to illness. This term may also apply to people whose food intake provides more than enough calories, yet from nutrient-depleted sources.[38]
Micronutrients: Nutrients required by humans throughout life in small quantities to orchestrate a range of physiological functions.[39]
Phytochemicals: Chemical compounds found in plant sources that may have biological significance but are not established as essential nutrients.[40]
Public health nutrition: The art and science of promoting population health status via sustainable improvements in the food and nutrition system.[41]
Rice varieties: There are more than 100,000 varieties of rice (*Oryza sativa*), categorized into four major groups: Indica, Japonica, Aromatic, and Glutinous.[42]
Whole grain rice: Rice that contains 100% of the original grain (i.e., germ, endosperm, and bran), and is also known as brown rice.[43]

CURRENT CHALLENGES FOR DIETARY RICE BRAN

After rice is harvested from the field, it goes through a milling process where the hull and bran are removed mechanically, leaving refined white rice (68–70%), rice husk (20%), rice bran (5–10%), and rice germ (2%).[44] Based on current estimates of rice production, there are roughly 66 to 74 million tonnes of bran that can be made available for human consumption.[4] Rice bran contains essential micronutrients and non-essential phytochemicals, and is used as animal feed or becomes agricultural food waste. Consumption of the fully processed white rice grain provides calories that primarily stem from carbohydrates (Fig. 22.1), and white rice consumption as a staple food alone has been shown to lead to malnutrition.[45] Lack of daily intake of essential nutrients can lead to a broad spectrum of risk for infectious and chronic diseases. Individuals suffering from infectious or chronic diseases may experience persistent inflammation and reduced host immune competence, both of which now occur at alarming rates in impoverished and malnourished areas of the world.[46]

Figure 22.2 illustrates a conceptual framework for "rice bran opportunities" in global public health nutrition by means of interrupting the negative cycle between malnutrition and disease (both infectious and chronic). The inner circle displays challenges for achieving adequate nutrition and disease prevention. The rectangles within this circle list causal factors, including nutrient malabsorption, lack of food security, gastrointestinal damage and inflammation, and impaired immune defense.[47,48] The dotted lines outline environmental exposures and damaged gastrointestinal integrity that keep this negative cycle intact. Novel solutions using dietary rice bran include supplementation into culturally acceptable foods and implementation of diverse rice varieties with existing traits of agronomic importance. The outer red squares signify places in the cycle for these various interventions using dietary rice bran to improve nutritional status and decrease disease susceptibility (both infectious and chronic). All of these inputs can in turn reduce obesity, improve growth and cognitive capability, as well as help establish a healthy gut microbiome.

Although the rice bran solution appears conceptually simple, there are challenges to address before rice bran can be sustainably utilized. Post-harvest post-harvest technicalities include the need for heat stabilization (lipase inactivation), ensuring shelf-life and storage conditions in different climates, value-added benefits for rice farmers, cultural taste preferences, and verification of bran nutrient and phytochemical contents across rice varieties. Addressing and overcoming these challenges with innovation represents promising avenues for achieving food security and enhancing human health in global, diverse populations.

Rice Bran Heat Stabilization and Shelf-Life

The main reason why rice bran has been largely limited to animal feed is that it quickly becomes rancid after milling, caused by lipase-mediated oxidation of rice bran

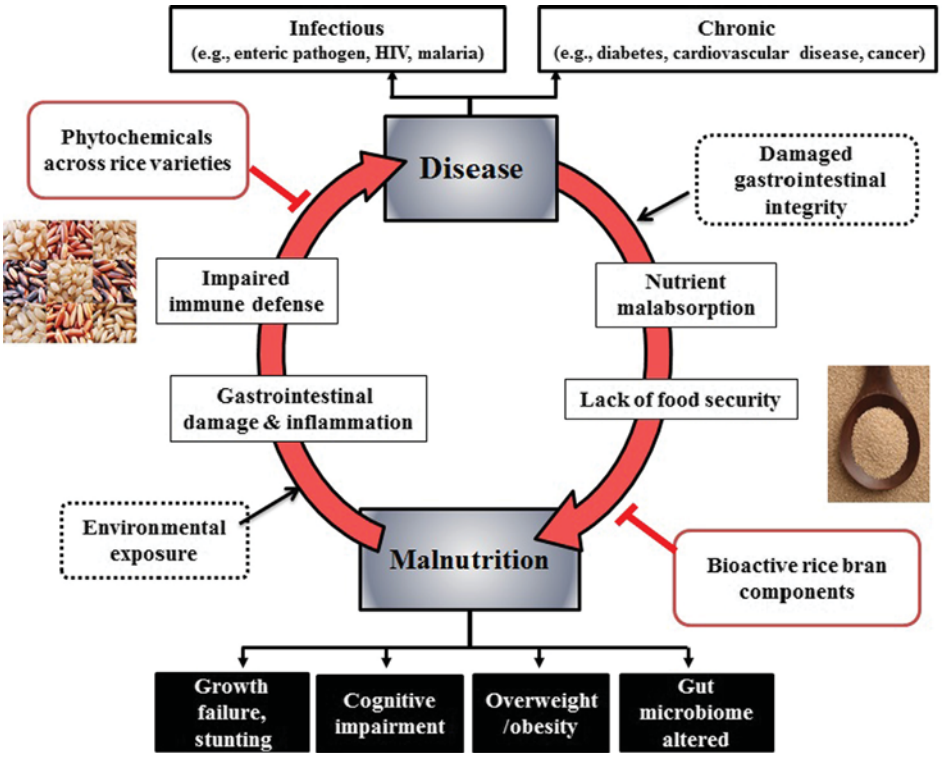

FIGURE 22.2 Conceptual framework for rice bran opportunities in global public health. See color plate at the back of the book. *Adapted from Preidis* et al.[89]

lipids.[49] Milling technology advances have now allowed for stabilized rice bran via cold storage, sun-drying, steaming, and expelling.[50] Countries such as India, Thailand, and the United States have also started to use these stabilization processes to create rice bran oil. Although stabilization is a promising attribute for rice bran products, most of the rice-producing countries do not have this type of technology or current infrastructure. Thus, the immediate challenge is to develop rice bran stabilization methods in areas experiencing food insecurity, malnutrition, and high rates of mortality under the age of 5 years, such as many parts of Sub-Saharan Africa and Asia.

Rice bran has a shorter shelf-life compared to refined white rice due to increases in free fatty lipids during storage.[51] If proper packaging and storage recommendations are followed, white rice can be stored for decades, compared to only about 1 year for the bran fraction. Advancing technology through extrusion cooking (a process of heating the food product under high pressure that results in reduced moisture content and a cooked and dried food product) has allowed for an extended shelf-life of rice bran.[52] Another rice processing technique is parboiling, which deactivates the lipase and allows some minerals and water-soluble vitamins to leak from the bran to the endosperm, which increases the nutrient composition. However, antioxidants are also destroyed in this process, causing the nutrient profile to differ from that of heat-stabilized rice bran.[4] The creation of technology that allows adequate stabilization will result in a longer shelf-life and create an opportunity to develop a market that utilizes rice bran as a common ingredient for human consumption.

Cultural Preferences Regarding Brown Rice or Rice Bran

As traditional diets shift towards convenience around the world, perceptions regarding healthy foods begin to waver and food decisions are based on cost, ease, and preferences. These are important considerations for incorporating rice bran into meals and snacks, and may influence current beliefs or existing knowledge of whole grain, brown rice preferences. For example, individuals in Tanzania are primarily unaware of brown rice; however, when they are familiar with it, they assume brown rice is a part of a diabetic diet.[53] Additionally, participants in a focus group study in southern India commented that eating rice that is not white in color is considered to be inferior.[54]

There is continuing growth in the demand for brown rice by health conscious people in developed countries.[55] Additionally, food scientists and health researchers are aware of the important bioactive compounds in rice bran, yet there continues to be a lack of global consumer awareness regarding the importance of rice bran for chronic disease control and prevention. Limited information has been collected to show the amount of brown rice consumed throughout the world, and most epidemiological research has to define what exactly a whole grain is, in order to complete analysis on whole

grain rice consumption.[5,56] We suggest that collection of data and statistics regarding the dietary intake of brown rice and rice bran (in addition to white rice) is critical for evaluating health properties at a population scale, and for drawing accurate associations between the amounts of brown rice or rice bran intake needed to affect chronic or infectious disease outcomes. As more areas start to face a "double burden of disease", where countries have problems with both infectious and chronic diseases, increased education and lay knowledge regarding the healthy content of brown rice and rice bran may be beneficial for changing nutrition–food behaviors, cultural preferences, and taste perceptions.

Whole Grain Rice Contents of Health Importance

There are some current myths and misconceptions regarding rice bran components that merit clarification and continued investigation. One concern is the level of antinutritional compounds, such as trypsin inhibitors, hemagglutinin (lectin), oryzacystatin, and phytic acid, which can decrease the bioavailability of other nutrients and thus may lead to deficiencies and malnutrition.[57] These compounds are found in rice bran, yet hemagglutinin and oryzacystatin antinutrient activities are inhibited by high heat exposure (such as heat stabilization). Phytic acid, although considered an antinutrient in foods, is a candidate nutraceutical for chemoprevention.[58,59] Continued education from cancer chemoprevention research regarding phytic acid has been helpful, and may be particularly important to areas with minimal access to medicines and healthcare.

Other potential concerns for rice bran that also exist for many other staple food crops include aflatoxin, pesticide residues, and arsenic.[60,61] Recent evaluation of the occurrence and distribution of pesticide residues in brown rice, white rice, and rice bran under controlled field-growing conditions suggests that the lipid content of rice bran may make it more susceptible to uptake of lipophilic pesticides such as difenoconazole and the strobilurins.[62] Greater knowledge of these potential exposures and continued research in this area is necessary not only for raw rice products, but also in combination with water contaminants and cooking conditions. Rice bran arsenic levels appear to be dependent on soil concentrations in specific geographic regions,[63–65] and further research is needed to assess the maximum allowable intake levels from rice, and to accurately differentiate between total, organic, and inorganic forms.

Whole grain consumption across cereal grains has shown promising outcomes for chronic disease prevention, and has been mainly attributed to dietary fiber. In brief, soluble fiber aids in lowering cholesterol, and insoluble fiber helps to decrease gastrointestinal transit time and increase short-chain fatty acid production.[66] Total dietary fiber makes up about 20% of rice bran, while only 2–3% is soluble fiber.[57] Even though rice bran has generally lower amounts of soluble fiber compared to other brans (such as wheat, corn, or oat brans), it has more compelling cholesterol lowering properties due to its unique lipids.[7–12,67] Mechanisms of action from other bioactive nutrients and compounds (e.g. y-oryzanol) may also be major driving factors in the disease-fighting activity. Table 22.1 highlights the biological activity associated with some bioactive rice bran components that may also be important for decreasing malnutrition and protection against disease. Although these compounds have been reviewed for health promotion and disease prevention, our work and that of others suggest that whole food approaches may be more beneficial for health when compared to single-agent dietary supplements.[14,68]

DIETARY RICE BRAN OPPORTUNITIES THROUGHOUT THE LIFESPAN

Addressing the challenges and embracing the opportunities discussed for rice bran in the previous sections is achievable through continued research, public–private partnerships, and global health collaborations. Fortunately, progress has been made through nutrient supplementation programs, breastfeeding promotion, and culturally targeted nutritional education programs. However, focused efforts are still needed for concerns such as iron deficiency and anemia, which continue to be increasingly prevalent in rice-consuming countries.[55] Iron deficiency can be particularly troubling for growing children and for women during pregnancy. Iron and other micronutrients (e.g., potassium, zinc, and magnesium) are detected in the rice grain; however, the amounts vary across varieties.[45] Thus, the untapped resource of rice bran may lead to additional global health achievements for children and adults in rice nutrient enrichment programs, in particular where varieties that contain higher amounts of these essential micronutrients are used.

Rice and health related scientific research that is performed without industry bias is necessary to convey the importance of rice bran for health across the lifespan. Consumers need greater access to knowledge and awareness of rice bran nutritional properties, even though this food rarely reaches our plates. Taste and texture are also important attributes that merit further study for acceptance by consumers, as these features alone have been cited as reasons why brown rice has not been widely accepted.[54] Introduction of rice bran into existing meals is a promising solution that allows individuals to continue eating their preferred foods, while delivering the important bioactive nutrients and phytochemicals. There is an opportunity to enhance health and nutrition

TABLE 22.1 Selected Rice Bran Bioactive Components and Biologic Activity for Human Health

Rice Bran Bioactive Food Components	Examples	Biologic Activity	Reference(s)
Non-saponifiable lipid (i.e., γ-oryzanol)	Combination of ferulic acid, esters of sterol, and triterpene alcohols	Antibacterial Antioxidant Reduces cholesterol absorption Cancer chemoprevention	Cicero and Gaddi[8], Ghoneum *et al.*[90], Rong *et al.*9, Seetharamaiah and Chandrasekhara[91]
Vitamin E	α-Tocopherol, γ-tocopherol, tocotrienols	Cancer chemoprevention Antioxidant Antibacterial Reduces cholesterol absorption	Kawakami *et al.*[92], Minhajuddin *et al.*[93], Miyazawa *et al.*[94], Sen *et al.*[95], Sun *et al.*[96], Morel *et al.*[97], Boxer[98], Iqbal *et al.*[99], Nakashima *et al.*[100]
Polyphenols	Ferulic acid, α-lipoic acid, caffeic acid, salicylic acid	Antioxidant Antiproliferative effect on cancer Antibacterial Anti-inflammatory	Mori *et al.*[58], Taniguchi *et al.*[101], Srinivasan *et al.*[102]
Phytosterols	β-Sitosterol, campesterol, stigmasterol	Reduces cholesterol absorption Anti-inflammatory Antioxidant Stimulates lymphocyte proliferation Cancer chemoprevention	Basker *et al.*[103]
Amino acids	Lysine	Growth and development Hypoallergenicity	Khan *et al.*[70]

across the lifespan with the use of dietary rice bran, and this is explained in greater detail below.

Addition of Rice Bran to Complementary Foods

For the first 6 months of life, it is recommended that infants be exclusively breastfed for proper growth and development.[69] After this period, complementary foods are introduced to an infant's diet; these may include food products based on staples, as well as fruits and vegetables, in liquid to semisolid forms. Acceptable weaning foods may also include higher amounts of protein and fats to continue healthy development into the toddler years, including animal-based sources such as meat, milk, and eggs. However, in areas that lack food security these options may not be available to young members of the family. This can lead to inadequate nutrient uptake and underdevelopment of infants' and toddlers' immune systems, making them more susceptible to diseases such as viral and bacterial associated pneumonia and diarrhea (see Fig. 22.2).[48]

The introduction of rice bran into weaning foods is a tremendous opportunity, because of its exceptional fat and protein content, high digestibility, and hypoallergenic assets.[70] Rice bran lipids can deliver energy needs adjusted based on age. The protein quality of rice bran is more suitable compared to other cereal brans, as it contains a substantial amount of lysine and the amino acid content meets the requirements of growing children.[71] Adding rice bran to complementary foods is a promising approach to improve overall nutritional quality, and food scientists have been working on creating these rice bran-added products. A recently developed rice bran enriched biscuit included 10% of a rice bran protein concentrate, and was shown to be similarly acceptable when compared to a non-rice bran biscuit.[72] Khan *et al.* developed a rice bran protein isolate-based formulation that can be used in complementary foods and was tested for acceptability in weaning infants via taste satisfaction.[70] These studies provide compelling evidence for the feasibility of adding rice bran to complementary foods in culturally and socially acceptable ways.

Various strategies, such as micronutrient supplementation, food fortification, and educating mothers about appropriate complementary foods, have proven to be effective in many countries,[20] yet alarming rates of child malnutrition and disease continue. Promising results from a recent Cochrane Review found that those infected with enteric pathogens, have improved outcomes with rice-based medications, such as oral rehydration solutions.[73] Additionally, Intermark Partners Strategic Management, LLC was recently awarded a Patent for Humanity for the development of Nutra-Iso™, a technology that extracts edible protein and other nutrients from rice bran.[74] This product can be used as a nutritional supplement for children and pregnant women. This increasing evidence indicates that practical solutions involving low-cost, energy-rich, and high-nutrition infant products can be developed and implemented in malnourished areas.

Preventing and Treating Malnutrition in Children

In addition to delivering a combination of important nutrients, rice bran has also been shown to improve gut health in animal, *in vitro*, and human studies. Henderson *et al.* found that 10% rice bran consumption modulated mucosal immunity by increasing immunoglobin A concentrations and native gut *Lactobacillus* spp. in a mouse model.[19] Martins *et al.* reported improved colon development in malnourished rats with 5% rice bran supplementation.[75] *In vitro* studies have also shown that rice bran can augment phagocytosis and enhance intracellular killing of microbes by human phagocytic cells.[17,18] Additionally, the human gut microbiome has shown to be altered, with immunological benefits, through consumption of whole grains, including brown rice.[76] These studies indicate that rice bran has bioactive properties that modify metabolic properties of the gut microbiome with long-term health improvements that can include, but may not be limited to, improved immune development through proper absorption of nutrients, and protection against enteric infections (Fig. 22.2). The healthcare infrastructure is unstable in many parts of the world and access to medications and medical care may be difficult to obtain; thus, novel, safe and low-cost dietary interventions are crucial to improve global health alongside food security.

Rice Bran for Chronic Disease Prevention and Control

Chronic diseases are increasing in incidence and prevalence in both developed and developing countries. Food quality and eating habits have been implicated in the etiology of these diseases, and whole foods are now being advocated to replace easy-to-distribute, ready-made nutrient-deprived food products that lead to higher caloric intakes. Increased energy intake coupled with sedentary lifestyles contributes to obesity and an increased risk of developing chronic diseases.[77] Numerous *in vitro*, animal, and epidemiological evidences suggest that consuming whole grain rice may be protective against these chronic diseases via unique bioactive nutrients and phytochemicals (e.g., γ-oryzanol and tocotrienols).[55] Vitamin E complex contents in rice bran, which can range from 179–389 mg/kg, are almost three-fourths α- and δ-tocotrienols.[78] Rice bran is also high in fatty acids (oleic, linoleic, and α-linoleic acids) compared with other grains, and includes a vast amount of various compounds such as phytosterols, tocopherols, and γ-oryzanol.[14] These components found in rice bran oil were shown to reduce total cholesterol, low density lipoproteins, and triglycerides, for further protection from cardiovascular disease.[10]

Despite the health advantages and increasing availability of whole grain rice, particularly in developed countries, switching white rice consumers to eating whole grain rice does not seem likely, given cultural connections and taste preferences for white rice. Developing food options with the addition of rice bran allows the populations of rice-consuming countries to continue eating rice in their traditional way but still receive the healthy benefits of eating bran. Our laboratory has completed a placebo-controlled, single-blinded pilot dietary rice bran intervention study in healthy adults with and without a history of colorectal cancer. We developed seven meals and six snacks that include rice bran as a main ingredient. Interim analysis has shown feasibility of consuming 30 g of rice bran daily without complications (data not published). The ability to incorporate rice bran into common meals, such as casseroles, soups, and crackers, indicates an opportunity for the food industry to modify current food products with rice bran, with tremendous potential to result in greater consumer acceptance of these meals and snack foods.[66] Further research on increasing dietary rice bran for health-promoting capabilities will be helpful to endorse these food products.

GLOBAL RICE GENETIC VARIATION

Increased rice yield as a result of the Green Revolution provided substantially more food for a growing global population. These modified rice crops were minimally evaluated for changes in the levels of essential and non-essential nutrients (e.g., certain amino acids, minerals, vitamins, and fatty acids).[79] The grain quantity-over-quality debate (also referred to as the "breeders dilemma") merits continued discussion because rice breeders currently do not include nutritional or health importance as an integrated quantitative trait for crop improvement.[80] With over 100,000 varieties of rice grown throughout the world, substantial opportunities exist to better understand the health importance of and traits associated with bran. Alongside the development and expansion of genetically modified rice to include β-carotene (i.e., Golden Rice), there is still much to learn about traditional rice varieties and how their nutrient profiles, especially regarding the bran component, can address the prevention of malnourishment and disease.

A recent review showed that nutrient make-up of rice varieties differs significantly, and that the varieties with higher nutritional values are used less frequently due to their lower grain yields.[81] The mineral content of 274 rice genotypes has also shown variations,[45] indicating that certain rice varieties should be further evaluated for higher amounts of micronutrients. Rice has been used for medicinal purposes too; for instance, there is a

specific variety of rice with red bran that is used to control hypertension and diabetes.[82] Moreover, a medicinal Indian rice variety traditionally used in Ayurveda, called Njavara, has also been scientifically examined.[83–86]

With increasing evidence that rice varieties do not share similar chemical and nutrient compositions,[87] and that the bran component is the most important for delivery of nutrients found in whole grain rice, it is crucial to conduct research on rice varieties for their mechanisms of action to improve a range of health outcomes in people. Studying changes in the human metabolome and gut microbiome will be helpful in this endeavor, as researchers will be able to understand the gut microbial metabolic mechanisms involved and may recommend which rice varieties are optimal for health outcomes in children and adults. Interestingly, different rice varieties were fed to mice and evaluated for modulation of gut microbiome, allergic reactions, and immune responses.[88] As knowledge continues to increase regarding the connections between rice in the diet, gut microbes, and the human metabolome, there is a strong need to make sure that rice bran is not neglected as a key player, and may serve a major role in food security and global health promotion.

CONCLUSION

This chapter explains how an underutilized food ingredient, namely rice bran, could become the next simple, yet significant, opportunity in global health, nutrition, and food security. Even though challenges are apparent to increase dietary rice bran in the global food market, they merit attention and scientific as well as technological innovation. Additional research and global funding opportunities are necessary to tackle issues of hunger and nutrition-related disease through dietary rice bran interventions. Multidisciplinary, global collaborations are necessary to make sure these solutions are developed in a sustainable, culturally appropriate, and economically sound way. This untapped food source may shed light on how we can feed the world through adequate delivery of nutrients, with an overarching goal of disease prevention and thriving health via health promotion.

References

1. *Rice Almanac: source book for the most important economic activity on Earth*. Wallingford, United Kingdom: CABI Publishing; 2002.
2. FAO. *Rice Market Monitor. 4*. Rome: FAO; 2012.
3. *Rice in the global economy: strategic research and policy issues for food security*. Los Banos, Philippines: International Rice Research Institute; 2010.
4. Kahlon TS. Rice Bran: Production, Composition, Functionality and Food Applications, Physiological Benefits. In: Choo SS PS, editor. *Fiber ingredients: food applications and health benefits*. Boca Raton, FL: Taylor & Francis Group LLC; 2009. p. 305–21.
5. de Munter JS, Hu FB, Spiegelman D, Franz M, van Dam RM. Whole grain, bran, and germ intake and risk of type 2 diabetes: a prospective cohort study and systematic review. *PLoS Med* 2007;**4**(8):e261.
6. Cheng HH, Huang HY, Chen YY, Huang CL, Chang CJ, Chen HL, et al. Ameliorative effects of stabilized rice bran on type 2 diabetes patients. *Ann Nutr Metab* 2010;**56**(1):45–51.
7. Most MM, Tulley R, Morales S, Lefevre M. Rice bran oil, not fiber, lowers cholesterol in humans. *Am J Clin Nutr* 2005;**81**(1):64–8.
8. Cicero AF, Gaddi A. Rice bran oil and gamma-oryzanol in the treatment of hyperlipoproteinaemias and other conditions. *Phytother Res: PTR* 2001;**15**(4):277–89.
9. Gerhardt AL, Gallo NB. Full-fat rice bran and oat bran similarly reduce hypercholesterolemia in humans. *J Nutr* 1998;**128**(5):865–9.
10. Kahlon TS, Chow FI, Chiu MM, Hudson CA, Sayre RN. Cholesterol-lowering by rice bran and rice bran oil unsaponifiable matter in hamsters. *Cereal Chem* 1996;**73**(1):69–74.
11. Cicero AF, Derosa G. Rice bran and its main components: potential role in the management of coronary risk factors. *Curr Top Nutr Res* 2005;**3**(1):29–46.
12. Jariwalla RJ. Rice-bran products: Phytonutrients with potential applications in preventive and clinical medicine. *Drugs ExpClin Res* 2001;**27**(1):17–26.
13. Kim TH, Kim EK, Lee MS, Lee HK, Hwang WS, Choe SJ, et al. Intake of brown rice lees reduces waist circumference and improves metabolic parameters in type 2 diabetes. *Nutr Res* 2011;**31**(2):131–8.
14. Henderson AJ, Ollila CA, Kumar A, Borresen EC, Raina K, Agarwal R, et al. Chemopreventive Properties of Dietary Rice Bran: Current Status and Future Prospects. *Adv Nutr* 2012;**3**(5):643–53.
15. Mai HB, Tran VR, Nguyen TT, Le HS, Trinh TD, Le VT, et al. Arabinoxylan Rice Bran (MGN-3) Enhances the Effects of Interventional Therapies for the Treatment of Hepatocellular Carcinoma: A Three-year Randomized Clinical Trial. *Anticancer Res* 2010;**30**(12):5145–51.
16. Kumar A, Henderson AJ, Forster GM, Goodyear AW, Weir TL, Leach JE, et al. Dietary rice bran promotes resistance to Salmonella enterica serovar Typhimurium colonization in mice. *Bmc Microbiol* 2012:12.
17. Ghoneum M, Matsuura M. Augmentation of macrophage phagocytosis by modified arabinoxylan rice bran (MGN-3/Biobran). *Int J Immunopath Ph* 2004;**17**(3):283–92.
18. Ghoneum M, Matsuura M, Gollapudi S. Modified arabinoxylan rice bran (MGN-3/Biobran) enhances intracellular killing of microbes by human phagocytic cells *in vitro*. *Int J Immunopath Ph* 2008;**21**(1):87–95.
19. Henderson AJ, Kumar A, Barnett B, Dow SW, Ryan EP. Consumption of Rice Bran Increases Mucosal Immunoglobulin A Concentrations and Numbers of Intestinal *Lactobacillus* spp. *J Med Food* 2012;**15**(5):469–75.
20. FAO, WFP, IFAD. *The State of Food Insecurity in the World 2012 Economic growth is necessary, but not sufficient to accelerate reduction of hunger and malnutrition*. Rome: FAO; 2012.
21. *United Nations. UN Secretary-General Challenges All Nations To Acheive Zero Hunger*. Rio de Janeiro: United Nations; 2012.
22. Finucane MM, Stevens GA, Cowan MJ, Danaei G, Lin JK, Paciorek CJ, et al. National, regional, and global trends in body-mass index since 1980: systematic analysis of health examination surveys and epidemiological studies with 960 country-years and 9.1 million participants. *Lancet* 2011;**377**(9765):557–67.
23. James PT, Leach R, Kalamara E, Shayeghi M. The worldwide obesity epidemic. *Obesity Res* 2001;**9**:228S–33S.

24. Tanumihardjo SA, Anderson C, Kaufer-Horwitz M, Bode L, Emenaker NJ, Haqq AM, et al. Poverty, obesity, and malnutrition: an international perspective recognizing the paradox. *J Am Diet Assoc* 2007;**107**(11):1966–72.
25. Holt-Gimenez E, Shattuck A, Altieri M, Herren H, Gliessman S. We Already Grow Enough Food for 10 Billion People … and Still Can't End Hunger. *J Sustainable Agric* 2012;**36**(6):595–8.
26. Schneeman BO. Linking agricultural production and human nutrition. *J Sci Food Agric* 2001;**81**(1):3–9.
27. Tang GW, Qin J, Dolnikowski GG, Russell RM, Grusak MA. Golden Rice is an effective source of vitamin A. *Am J Clin Nutr* 2009;**89**(6):1776–83.
28. Stein AJ, Sachdev HPS, Qaim M. Genetic engineering for the poor: Golden Rice and public health in India. *World Development* 2008;**36**(1):144–58.
29. Mayer JE. Delivering Golden Rice to developing countries. *J Aoac Int* 2007;**90**(5):1445–9.
30. International Rice Genome Sequencing P. The map-based sequence of the rice genome. *Nature* 2005;**436**(7052):793–800.
31. WHO. *Chronic Diseases*. Available at: http://www.who.int/topics/chronic_diseases/en/; 2013. (last accessed 22.02.2013).
32. Kolling G, Wu M, Guerrant RL. Enterica pathogens through life stages. *Front Cell Infect Micobiol* 2012;**2**:114.
33. FAO. *Rome Declaration on World Food Security and World Food Summit Plan of Action*. Rome: World Food Summit; 1996.
34. *Glossary of Environment Statistics, Studies in Methods*. New York, NY: United Nations; 1997.
35. Dave M, Higgins PD, Middha S, Rioux KP. The human gut microbiome: current knowledge, challenges, and future directions. *Transl Res* 2012;**160**(4):246–57.
36. Preamble to the Constitution of the World Health Organization as adopted by the International Health Conference. New York, NY; 1946.
37. WHO. *Infectious diseases*. Available at: http://www.who.int/topics/infectious_diseases/en/; 2013. (last accessed 22.02.2013).
38. UNICEF. *Tracking progress on child and maternal nutrition*. New York, NY: A survival and development priority; 2009.
39. UNICEF Canada Committee. Global Child Survival and Health, 2006. UNICEF.
40. FDA. *Guidance for Industry: Evidence-Based Review System for the Scientific Evaluation of Health Claims*. Rockville, MD, FDA; 2009.
41. Hughes R, Somerset S. Definitions and conceptual frameworks for public health and community nutrition: a discussion paper. *Aust J NutrDiet* 1997;**54**:40–5.
42. Hamilton RS. How many rice varieties are there? *Rice Today* 2006:50.
43. Whole Grains Council Definition of whole grains: Oldways Preservation Trust/Whole Grains Council, Boston, MA, 2012.
44. Saunders RM. The properties of rice bran as a foodstuff. *Cereal Foods World* 1990;**35**:632.
45. Jiang SL, Wu JG, Thang NB, Feng Y, Yang XE, Shi CH. Genotypic variation of mineral elements contents in rice (Oryza sativa L.). *Eur Food ResTechnol* 2008;**228**(1):115–22.
46. Boutayeb A. The double burden of communicable and non-communicable diseases in developing countries. *Trans R Soc Trop Med Hyg* 2006;**100**(3):191–9.
47. DeBoer MD, Lima AAM, Oria RB, Scharf RJ, Moore SR, Luna MA, et al. Early childhood growth failure and the developmental origins of adult disease: do enteric infections and malnutrition increase risk for the metabolic syndrome? *Nutr Rev* 2012;**70**(11):642–53.
48. Guerrant RL, Oria RB, Moore SR, Oria MOB, Lima AAM. Malnutrition as an enteric infectious disease with long-term effects on child development. *Nutr Rev* 2008;**66**(9):487–505.
49. Enochian RV, Saunders RM, Schultz WG, Beagle EC, Crowley PR. *Stabilization of rice bran with extrusion cookers, and recovery of edible oil: a preliminary analuysis of operational and financial feasbility*. Washington, DC: USDA/OICD; 1980.
50. Nagendra Prasad MN, Sanjay KR, Shravya Khatokar M, Vismaya MN, Nanjunda Swamy S. Health Benefits of Rice Bran – A Review. *J Nutr Food Sci* 2011;**1**:108.
51. Dhaliwal YS, Sekhon KS, Nagi HPS. Enzymatic-Activities and Rheological Properties of Stored Rice. *Cereal Chem* 1991;**68**(1):18–21.
52. Mujahid A, ul Haq I, Asif M, Gilani AH. Effect of various processing techniques and different levels of antioxidant on stability of rice bran during storage. *J Sci Food Agric* 2005;**85**(5):847–52.
53. Muhihi AJ, Shemaghembe E, Njelekela MA, Gimbi D, Mwambene K, Malik VS, et al. Perceptions, Facilitators, and Barriers to Consumption of Whole Grain Staple Foods among Overweight and Obese Tanzanian Adults: A Focus Group Study. *Int Scholarly Res Netw Public Health* 2012:1–7.
54. Kumar S, Mohanraj R, Sudha V, Wedick NM, Malik V, Hu FB, et al. Perceptions about Varieties of Brown Rice: A Qualitative Study from Southern India. *J Am Diet Assoc* 2011;**111**(10):1517–22.
55. Dipti SS, Bergman C, Indrasari SD, Herath T, Hall R, Lee H, et al. The potential of rice to offer solutions for malnutrition and chronic diseases. *Rice* 2012;**5**:1–18.
56. Sun Q, Spiegelman D, van Dam RM, Holmes MD, Malik VS, Willett WC, et al. White rice, brown rice, and risk of type 2 diabetes in US men and women. *Archintern Med* 2010;**170**(11):961–9.
57. Juliano BO. *Rice Chemistry & Quality. Philippines: Philippine Rice Research Institute (PhilRice)* 2007.
58. Mori H, Kawabata K, Yoshimi N, Tanaka T, Murakami T, Okada T, et al. Chemopreventive effects of ferulic acid on oral and rice germ on large bowel carcinogenesis. *Anticancer Res* 1999;**19**(5A):3775–8.
59. Norazalina S, Norhaizan ME, Hairuszah I, Norashareena MS. Anticarcinogenic efficacy of phytic acid extracted from rice bran on azoxymethane-induced colon carcinogenesis in rats. *Exp Toxicol Pathol* 2010;**62**(3):259–68.
60. Trucksess MW, Abbas HK, Weaver CM, Shier WT. Distribution of aflatoxins in shelling and milling fractions of naturally contaminated rice. *Food Addit Contam A* 2011;**28**(8):1076–82.
61. Bhattacharjee S, Fakhruddin ANM, Chowdhury MAZ, Rahman MA, Alam MK. Monitoring of Selected Pesticides Residue Levels in Water Samples of Paddy Fields and Removal of Cypermethrin and Chlorpyrifos Residues from Water Using Rice Bran. *Bull Environ Contam Toxicol* 2012;**89**(2):348–53.
62. Pareja L, Colazzo M, Perez-Parada A, Besil N, Heinzen H, Bocking B, et al. Occurrence and distribution study of residues from pesticides applied under controlled conditions in the field during rice processing. *J Agric Food Chem* 2012;**60**(18):4440–8.
63. Norton GJ, Islam MR, Deacon CM, Zhao FJ, Stroud JL, McGrath SP, et al. Identification of Low Inorganic and Total Grain Arsenic Rice Cultivars from Bangladesh. *Environ Sci Technol* 2009;**43**(15):6070–5.
64. Ruangwises S, Saipan P, Tengjaroenkul B, Ruangwises N. Total and Inorganic Arsenic in Rice and Rice Bran Purchased in Thailand. *J Food Prot* 2012;**75**(4):771–4.
65. Lombi E, Scheckel KG, Pallon J, Carey AM, Zhu YG, Meharg AA. Speciation and distribution of arsenic and localization of nutrients in rice grains. *New Phytol* 2009;**184**(1):193–201.
66. Alan PA, Ofelia RS, Patricia T, Maribel RSR. Cereal bran and wholegrain as a source of dietary fibre: technological and health aspects. *Int J Food Sci Nutr* 2012;**63**(7):882–92.
67. Bednar GE, Patil AR, Murray SM, Grieshop CM, Merchen NR, Fahey GC. Starch and fiber fractions in selected food and feed ingredients affect their small intestinal digestibility and fermentability and their large bowel fermentability *in vitro* in a canine model. *J Nutr* 2001;**131**(2):276–86.
68. Ryan EP. Bioactive food components and health properties of rice bran. *J Am Vet Med Assoc* 2011;**238**(5):593–600.

69. WHO. *Global Strategy for Infant and Young Child Feeding*. Geneva, Switzerland: WHO; 2003.
70. Khan SH, Butt MS, Anjum FM, Sameen A. Quality evaluation of rice bran protein isolate-based weaning food for preschoolers. *Int J Food Sci Nutr* 2011;**62**(3):280–8.
71. WHO/FAO/UNU. *Protein and Amino Acid Requirment in Human Nutrition: Report of Joint WHO/FAO/UNU Expert Consultation*. Albany, NY: WHO technical report series; 2007.
72. Yadav RB, Yadav BS, Chaudhary D. Extraction, characterization and utilization of rice bran protein concentrate for biscuit making. *Brit Food J* 2011;**113**(8-9):1173–82.
73. Gregorio GV, Gonzales MLM, Dans LF, Martinez EG. Polymer-based oral rehydration solution for treating acute watery diarrhoea. *Cochrane Database Syst Rev* 2009 (2).
74. U.S. Department of Commerce 2013. *U.S. Department of Commerce Announces Patents for Humanity Winners*. [press release] Retrieved from http://www.uspto.gov/news/pr/2013/13-17.jsp.
75. Martins MSF, Dores EFGC, Aguilar-Nascimento JE, Oyama LM, Latorraca MQ, Gomes-da-Silva MH, et al. Rice bran supplementation during nutritional recovery period of malnourished rats improves colon development. *Nutr Hosp* 2007;**22**(6):648–53.
76. Martinez I, Lattimer J, Hubac K, Case KL, Yang JY, Weber CG, et al. Gut microbiome composition is linked to whole grain-induced immunological improvements. *ISME Journal* 2013;**7**:269–98.
77. Astrup A, Dyerberg J, Selleck M, Stender S. Nutrition transition and its relationship to the development of obesity and related chronic diseases. *Obes Rev* 2008;**9**:48–52.
78. Bergman CJ, Xu Z. Genotype and environment effects on tocopherol, tocotrienol, and gamma-oryzanol contents of Southern US rice. *Cereal Chem* 2003;**80**(4):446–9.
79. Anandan A, Rajiv G, Eswaran R, Prakash M. Genotypic Variation and Relationships between Quality Traits and Trace Elements in Traditional and Improved Rice (Oryza sativa L.) Genotypes. *J Food Sci* 2011;**76**(4) H122–HH30.
80. Sands DC, Morris CE, Dratz EA, Pilgeram A. Elevating optimal human nutrition to a central goal of plant breeding and production of plant-based foods. *Plant Sci Int J Exp Plant Biol* 2009;**177**(5):377–89.
81. Kennedy G, Burlingame B. Analysis of food composition data on rice from a plant genetic resources perspective. *Food Chem* 2003;**80**(4):589–96.
82. Ahuja U, Ahuja SC, Thakrar R, Singh RK. Rice – A Nutraceutical. *Asian Agri-History* 2008;**12**(2):93–108.
83. Mohanlal S, Parvathy R, Shalini V, Helen A, Jayalekshmy A. Isolation, Characterization and Quantification of Tricin and Flavonolignans in the Medicinal Rice Njavara (*Oryza sativa* L.), as Compared to Staple Varieties. *Plant Foods Hum Nutr* 2011;**66**(1):91–6.
84. Shalini V, Bhaskar S, Kumar KS, Mohanlal S, Jayalekshmy A, Helen A. Molecular mechanisms of anti-inflammatory action of the flavonoid, tricin from Njavara rice (*Oryza sativa* L.) in human peripheral blood mononuclear cells: Possible role in the inflammatory signaling. *Int Immunopharmacol* 2012;**14**(1):32–8.
85. Deepa G, Singh V, Naidu KA. Nutrient composition and physicochemical properties of Indian medicinal rice – Njavara. *Food Chem* 2008;**106**(1):165–71.
86. Rao A, Reddy SG, Babu PP, Reddy AR. The antioxidant and antiproliferative activities of methanolic extracts from Njavara rice bran. *Bmc Complement Altern Med* 2010:10.
87. Forster GM, Raina K, Kumar A, Kumar S, Agarwal R, Chen M, et al. Rice varietal differences in bioactive bran components for inhibition of colorectal cancer cell growth. *Food Chem* 2013;**141**(2):1545–52.
88. Sonoyama K, Ogasawara T, Goto H, Yoshida T, Takemura N, Fujiwara R, et al. Comparison of gut microbiota and allergic reactions in BALB/c mice fed different cultivars of rice. *Br J Nutr* 2010;**103**(2):218–26.
89. Preidis GA, Hill C, Guerrant RL, Ramakrishna BS, Tannock GW, Versalovic J. Probiotics, Enteric and Diarrheal Diseases, and Global Health. *Gastroenterology* 2011;**140**(1) 8-+.
90. Rong N, Ausman LM, Nicolosi RJ. Oryzanol decreases cholesterol absorption and aortic fatty streaks in hamsters. *Lipids* 1997;**32**(3):303–9.
91. Seetharamaiah GS, Chandrasekhara N. Studies on hypocholesterolemic activity of rice bran oil. *Atherosclerosis* 1989;**78**(2-3):219–23.
92. Kawakami Y, Tsuzuki T, Nakagawa K, Miyazawa T. Distribution of tocotrienols in rats fed a rice bran tocotrienol concentrate. *Biosci Biotechnol Biochem* 2007;**71**(2):464–71.
93. Minhajuddin M, Beg ZH, Iqbal J. Hypolipidemic and antioxidant properties of tocotrienol rich fraction isolated from rice bran oil in experimentally induced hyperlipidemic rats. *Food Chem Toxicol* 2005;**43**(5):747–53.
94. Miyazawa T, Shibata A, Nakagawa K, Tsuzuki T. Anti-angiogenic function of tocotrienol. *Asia Pac J Clin Nutr* 2008;**17**(Suppl. 1):253–6.
95. Sen CK, Khanna S, Roy S. Tocotrienols in health and disease: the other half of the natural vitamin E family. *Mol Aspects Med* 2007;**28**(5-6):692–728.
96. Sun W, Xu W, Liu H, Liu J, Wang Q, Zhou J, et al. gamma-Tocotrienol induces mitochondria-mediated apoptosis in human gastric adenocarcinoma SGC-7901 cells. *Journal Nutr Biochem* 2009;**20**(4):276–84.
97. Morel S, Didierlaurent A, Bourguignon P, Delhaye S, Baras B, Jacob V, et al. Adjuvant System AS03 containing alpha-tocopherol modulates innate immune response and leads to improved adaptive immunity. *Vaccine* 2011;**29**(13):2461–73.
98. Boxer LA. Regulation of phagocyte function by alpha-tocopherol. *Pro Nutr Soc* 1986;**45**(3):333–44.
99. Iqbal J, Minhajuddin M, Beg ZH. Suppression of 7,12-dimethylbenz[alpha]anthracene-induced carcinogenesis and hypercholesterolaemia in rats by tocotrienol-rich fraction isolated from rice bran oil. *Eur J Cancer Pre* 2003;**12**(6):447–53.
100. Nakashima K, Virgona N, Miyazawa M, Watanabe T, Yano T. The tocotrienol-rich fraction from rice bran enhances cisplatin-induced cytotoxicity in human mesothelioma H28 cells. *Phytother Res* 2010;**24**(9):1317–21.
101. Taniguchi H, Hosoda A, Tsuno T, Maruta Y, Nomura E. Preparation of ferulic acid and its application for the synthesis of cancer chemopreventive agents. *Anticancer Res* 1999;**19**(5A):3757–61.
102. Srinivasan M, Sudheer AR, Menon VP. Ferulic acid: Therapeutic potential through its antioxidant property. *J Clin Biochem Nutr* 2007;**40**(2):92–100.
103. Baskar AA, Ignacimuthu S, Paulraj GM. Al Numair KS. Chemopreventive potential of beta-Sitosterol in experimental colon cancer model – an *in vitro* and *in vivo* study. *BMC Complement Altern Med* 2010;**10**:24.