

DOI: 10.16210/j.cnki.1007-7561.2020.05.007.en

Thailand Experience in Developing Wellness-driven Rice as the Key to Fight NCDs and Farmer Poverty

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Abstract: Prevalence of chronic noncommunicable diseases (NCDs) is rapidly increasing and has become a global problem in modern day. Over consumption of simple, processed carbohydrate foods is considered one of the main causes of NCD in young and elderly populations. Whole grain rice is an important source of a complex carbohydrate, dietary fiber, enriched with vitamins, minerals, and antioxidants. However, palatability of brown rice is the key success factor among white-rice-addicted communities. In the initial phase, we successfully breed rice strains with aromatic, soft-whole grain, white rice contains high grain-Fe/Zn density and intermediate glycemic index (GI). The most successful variety was uniquely soft-textured black purple rice named Riceberry, depicting rice enriched with blueberry nutritional characteristics. Product development for fiber-rich, high antioxidant has been extremely active from academia, real sectors, and SMEs. In total, 39 patent applications (18 granted patents), 12 international publications, and 18,700 Youtubes related to Riceberry. From 2017, Riceberry has become the most popular choice for product development surpassing Thai Hommali Rice. More than 200 food and non-food products were commercialized as dairy replacement, side dishes, meals, hot beverages, bakery, and breakfast cereals. In the second phase, we successfully breed low GI rice strains named Pink+4 equipped with farmers' preferred resistance to flash flooding, bacterial leaf blight, leaf blast, and devastating brown planthopper adapted to organic rice production. Innovative products combined of low GI rice flour with purple Riceberry have been the next trend for functional ingredients and foods. These healthy rice products have high potential globally as healthy foods, gluten-free, fiber-rich, complex carbohydrate, and nutrient-dense from sustainable organic farming.

Key words: whole-grain rice; non-communicable diseases (NCDs); glycemic Index (GI); riceberry; Thai Hommali Rice; organic farming; flash flooding; bacterial leaf blight; leaf blast; brown planthopper; gluten-free foods
Chinese Library Classification Number: TS201.4; S511

Documentary Identification Code: A Article ID: 1007-7561(2020)08-0057-07

Published time on CNKI: 2020-08-20 07:00:01

Published address on CNKI: <http://kns.cnki.net/kcms/detail/11.3863.TS.20200819.1615.001.html>

1. INTRODUCTION

Thailand has rapidly become an aging society.

Received Date: 2020-06-02

Supported by: National Research Council of Thailand (NRCT), Agricultural Research and Development Agency (ARDA), and National Center for Genetic Engineering and Biotechnology (BIOTEC), Thailand.

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As the world population is projected to increase exponentially to nearly 10 billion people in year 2050, the average age of the Thais will be 30 years older compared to 1975. As elderly population is increasing, it is anticipated that there will be more incidence of non-communicable diseases (NCDs) such as obesity, diabetes (T2D), cardiovascular disease (CVD). Particularly, the prevalence of T2D has increased rapidly from 6.5% in 2015 to 10.7% in 2030 with the largest increase was found among the elderly population (72%). In developing

countries, NCD has become the biggest burden among the poor elderly whose life depends on their children. There are strong links between consuming high glycemic index foods, sedentary lifestyle, and NCDs. If the world is going to need 56% more caloric foods to feed the future population in 2050, the grand challenge is to add more healthy functions into caloric foods to slow down the NCDs for the next 30 years.

Unfortunately, in the next 30 years, climate change will make the task even more challenging. Increasing average temperature and decreasing precipitation will limit productivity and acreage of rice production, particularly, in the net exporting countries like Thailand, India, Vietnam, and Myanmar. It is imminent that even before 2050, the world will face real food shortage and malnutrition if eating habit do not drastically changed.

To address the above challenges, increasing the consumption of whole grain rice is a sensible solution. As whole grain rice is the primary product of paddy rice processing, energy consumption is much less demanded than well-polished rice processing. Whole grain rice is shielded by a thin layer of cells called bran over the starchy cell portion called endosperm. It is found that whole grain rice accumulate non-caloric fibers, minerals, protein, amino acids, pigments, along with complex carbohydrate. Currently, there are social trends to promote consuming whole-grain pigmented rice including purple and red rice in Thailand as well as other around the world as it offers better health and nutritious benefits.

2. RICE FOR WELLBEING DEFINED

Rice is a primary energy food that provides approximately 50% of the energy needs for daily life. However, over consumption of refined high caloric foods is the major cause of obesity. Rice for wellbeing are confined within the functional properties of starch, dietary fiber, prebiotic, antioxidant, nutrients, and micronutrients that can lower the risk of NCDs. In comparison, the average available carbohydrate of the whole grain and polished rice are 73%~76% and 77%~78%, respectively, with 30%~50% more crude fiber and rich antioxidants in the whole grain rice^[1]. As such, whole grain rice in general meets a definition of rice for wellbeing.

2.1 Balancing the intake of nutrients and calories

Providing a well balance in caloric content with ample of dietary fiber, nutrients, and micronutrients such that consumers, for average adult male and female, can optimize their daily caloric intake (DCI) within the recommended DCI of 2 000~2 500

kcal and 1 800~2 000 kcal, respectively. The caloric content of three platefuls (80 g x 3) of cooked rice is about 840 kcal or approximately 40% of your DCI, living you only 60% for main courses, side dishes, and coffee/tea breaks. Because white rice is lack of essential nutrients, switching to whole grain rice providing you with more nutrients for the same DCI.

2.2 Providing fullness feeling and prolong hunger

In reality, most people can't stay with the recommended DCI. In fact, the global average DCI is 2 870 kcal, with cereals and sugar/fat together contributed 57% of the caloric intakes. Therefore, controlling high caloric foods such as starch, sugar, and fat, can help optimizing the DCI. More effective approach was discovered by Professor Yoshinori Ohsumi, the 2016 Nobel Prize Laureate in Medicine, who revealed the magic of intermittent fasting (IF) in activation of immunity and wellness. The most difficult part of IF is how to control your appetite and hunger, something called fullness factor. Consuming whole grain rice and cereal products provides enough dietary fiber to allow fasting by controlling your hunger. Glycemic index is another key factor controlling obesity and type-2 diabetes. Rice with low Glycemic index has high fullness factor than rice with high glycemic index.

2.3 Supporting probiotic growth

In gastrointestinal tract, growth and diversity of microbiota called probiotic can help reducing endotoxin, reducing insulin insensitivity, inflammation, and stimulate immune system. Nutrient properties of foods affecting gastrointestinal microbiota growth is called prebiotic. Comparing between whole and white rice, whole grain rice is prebiotic providing specific substrate for useful microbiota to grow such as dietary fiber and oligosaccharides.

2.4 Free of pesticides and heavy metal

Current rice production which requires high such production inputs as chemical herbicides, fertilizers, and pesticides, contained toxic residues and such heavy metal as Cd and As in rice grains. In addition, some soil types also contain Cd or As, in particular As in rice paddy. These heavy metals are carcinogenic and must be avoid in rice for wellbeing. On the other hand, no toxic pesticide residues and minimum As contamination were found in organic rice.

3. NUTRITIONAL VALUE OF WHOLE-GRAIN RICE

Genetic variation of carbohydrate contents among rice germplasm has only minor difference. Rice protein provides 4% of the essential amino

acid lysine, which is twice what is found in corn, and more threonine and methionine than in other cereals. Rice contains vitamins B1, 2 and 3 and is high in unsaturated fatty acids such as linoleic, which boosts the human immune system. Whole grain rice contains the mineral nutrients phosphorus, calcium, iron, zinc, manganese and iodine. Most of all, whole grain rice is the most important source of antioxidant providing The repeated polishing of rice causes approximately 30% chance of losing the most nutritious portion of the rice kernel. Thus, whole-grain rice or partially polished rice has more protein, four times more vitamin B1, and two times more calcium, magnesium and iron than polished rice. Therefore, mineral deficiency can be mitigated by consuming whole grain rice. Most of all, whole grain rice is the most important source of antioxidant providing well balance nutrient content for well-being.

Studies indicate that rice bran is an important grain component that has several health benefits. As white rice is considered the major product for mass markets locally and globally. As such, rice bran was normally considered left-over product used as animal feed or raw material for edible bran oil for household consumption and export in some countries. Rice bran contains complete nutrients, not only healthy fatty acids, protein, carbohydrates, fiber, vitamins and minerals but also 'nutraceuticals' comprising lipids and water soluble active ingredients that have strong health benefits. The lipid soluble nutraceuticals are phytosterols, gamma oryzanol, carotenoids, and vitamin E as tocopherol and tocotrienol. For pigmented rice, anthocyanin, polyphenol, etc., are water-soluble active ingredients. These strong antioxidants can inhibit free-radical-generating oxidative reactions resulting in reducing oxidative stresses. In addition, rice bran contains a substance called squalene and ceramide that, when combined with nutrients and nutraceuticals, can nourish skin. Thus, important ingredients in rice bran are important in alleviating NCDs by reducing oxidative stresses such as atherosclerosis, cancers and diabetes. Identifying the health benefits of rice bran continues to be a popular research topic.

4. WHY IS PIGMENTED RICE SO NUTRITIOUS

Rice is rich in natural colors or pigments. Pigmented rice is a set of exotic germplasm which accumulates specific forms of anthocyanin in rice bran, leaf blade, and leaf sheath, varying from red, blue, to dark purple. Actually, the two ancestors of cultivated rice, *Oryza rufipogon* and *Oryza nivara*,

have red and dark purple seeds, respectively. Anthocyanin acts like a natural UV shield to protect UV sensitive nutrients such as carotenoids. As a consequence, pigmented rice lines are richer in antioxidants than white rice. In addition to anthocyanin, varieties of flavonoids, carotenoids, and phenolic compounds combined significantly contribute to even higher antioxidants in rice bran. Most importantly, whole grain pigmented rice contains significant amount of micronutrients Fe, Zn, Se, Mn, amino acid and protein as compared to non-pigmented whole grain rice. These microelements have long been known to have positive effects on human health. As the richest nutrient content, whole grain rice is considered to have high potential in as functional food ingredients and cosmeceutical applications. Therefore, whole grain rice is an ideal solution for sustainable and innovative foods alike that can effectively address global food security challenge. At the same time, with its highly nutritious nature, it could be considered as a great source of protective food that could mitigate non-communicable diseases in the future.

5. DIETARY FIBER AS THE KEY FOR WELLBEING

Fiber, or dietary fiber, is a large complex carbohydrate present in the edible portions of plants such as roots, leaves, the stems of vegetables, the peelings and rinds of fruit and fruit fresh, the seed coats of cereals or rice bran from whole-grains. Polished rice without its bran has much less fiber. Fiber, being undigested in the digestive system, does not contribute energy but helps the secreting system, reducing blood cholesterol and controlling blood glucose. Food fiber can be divided into two types, 'soluble' and 'insoluble' fibers, based on their solubility.

5.1 Insoluble dietary fiber

These fibers are cellulose, hemicellulose and lignin present in the cell walls of whole rice kernels and bran. This type of fiber is not soluble but absorbs water and swells like a sponge inside your stomach. This makes a person feel full and satisfaction. Inside the large intestine, because insoluble fiber is not digested by bacteria, it adds bulk to soften stools and ease their excretion. By easing constipation and promoting probiotic growth in large intestine, insoluble fiber helps reduce the risk of colon cancer. Toxic substances may have more chance of being absorbed via the intestinal lining into the blood stream when one is constipated. Accumulated toxic substances in the blood stream affect skin radiance, muscle pain, ulcers and

pimples. Low dietary fiber foods combined with risky eating habits such as a diet containing high fat, more meat, barbecued meat, little fiber, alcohol and smoking, can lead to intestinal cancers.

5.2 Soluble dietary fiber

There are different types of resistant starch such as oligosaccharide, pectin and gum. These dietary fibers are present in prunes, apples, blueberries, bananas and strawberries and in dried beans, oats, rye and sorghum. Soluble dietary fiber, when diluted with water, thickens and can prolong digestion, delaying the absorption of glucose and fat across the intestinal lining. Whole grain rice contains functional soluble fibers such as beta-glucan and pectin.

5.3 Soluble and insoluble dietary fiber

Both types of dietary fiber escape digestion and become 'prebiotic' as nutrients for resident microbiota living inside the large intestine called 'probiotic'. Therefore, the large intestine can be considered the garbage truck of the human body because it can accumulate waste that must be excreted. The large intestine generally harbors various types of bacteria, including probiotics and infectious bacteria. When the body is weak, infectious bacteria may become overgrown and cause diseases. By promoting probiotic growth in the large intestine, short-chain fatty acids are increased, and the acidified large intestine can control infectious bacteria. In addition, short-chain fatty acids can stimulate small and large intestinal lining cells to avoid wilting, stimulate the immune system, and help adjust glucose and fat metabolism (Institute of Liver Diseases and Digestive Tract). In addition to short-chain fatty acids, probiotics can produce special nutrients for the human body such as essential amino acids, vitamin B and vitamin K to help the metabolism and produce natural antibacterial agents that help prevent malignant cell growth and eradicate some carcinogens.

5.4 Resistant starch

Research on resistant starch from whole-grain rice was reported in Thai rice cultivars. Resistant starch is a complex carbohydrate that functions similarly as dietary fiber. Isolated resistant starch promotes probiotics in human large intestine than polished rice. A study of mice observed that bran from black non-sticky or sticky rice contains flavonoid substances that can suppress malignant cell growth^[2]. Comparing the fiber content of whole-grain rice to fruits and vegetables, whole-grain rice contains 3 g per 100 g whereas fruits and vegetables contain 2 g per 100 g. In general,

humans require from 20~25 g of dietary fiber per day, one-half from whole-grain rice and cereals and the other half from fruits and vegetables. When dietary fiber is moved along the intestinal tract, the fiber continues to absorb extra glucose and fatty acids to prevent absorption into the blood stream. Consuming sufficient dietary fiber, then, may help control blood glucose and fatty acids. To benefit from dietary fiber over the long term, we must change our habits to consume brown rice daily. However, consuming edible fiber above the optimum level prevents the absorption of minerals such as Ca, Mg, Fe, Cu and Zn, causing an acid stomach and stomach bubbles.

6. ANTI-NUTRITIONAL FACTORS

Anti-nutritional factors are compounds found in foods that interfere with the absorption of beneficial nutrients and minerals. Anti-nutritional factors are present in different food substances in varying amounts, depending on the kind of food. Such anti-nutrients as phytate, polyphenol, tannin, etc. are present in many grains^[3]. Anti-nutrients in plant foods are responsible for low bioavailability of nutrients and micronutrients. However, some anti-nutrients may exert beneficial health effects at low concentrations. For example, phytic acid, lectins, tannins, saponins, amylase inhibitors and protease inhibitors have been shown to reduce the availability of nutrients and cause growth inhibition. However, when used at low levels phytate, lectin, tannins, amylase inhibitors and saponins have also been shown to reduce the blood glucose and insulin responses to starchy foods and/or the plasma cholesterol and triglyceride^[3]. Low phytic acid rice varieties have been identified.

7. NATIONAL STANDARD OF PIGMENT RICE

As the global demand of pigmented rice is expanding, Thailand is the only country who establish official pigmented rice standard to control product quality for local and export markets. With high in dietary fiber, vitamin, proteins, minerals, and antioxidants, whole-grain pigmented rice with good after-taste has high public perception as rice for better and healthy wellbeing. It is worth noting that Thailand is one of the top rice exporters in the world and, if the project is successful, the country could play critical role in ensuring global supply of nutrient-rich, low glycemic whole grain rice.

8. EMERGING RICEBERRY

Developing palatability of whole grain rice is the most sensible aspect of breeding whole grain

rice to get consumer acceptance and mitigating NCDs. Soft and palatability of whole grain rice is the key trait for consumer preference. Breeding new rice varieties for superb cooking quality of whole grain have been undertaken by optimizing amylose: amylopectin ratio, gelatinization temperature, the quality of dietary fiber, and grain aroma. In addition, anthocyanin pigments provides not only high antioxidant but also distinctive appearance and recognition. Purple rice is considered the most palatable with perfect fragrance quality. In ancient time, purple rice is used in making varieties of sweet dishes as spiritual foods to pay respect to gods and spirit. In China, the world renowned purple rice was used to cook special dishes for the emperor called “Forbidden Rice”. Rich in varieties of anthocyanin and lack of breeding emphasis for high yielding, purple rice is the richest sources of nutritional qualities. Most of all, purple rice is the most palatable with unique aromatic quality providing the excellent resources for breeding whole grain quality.

Riceberry a newly developed purple rice by crossing between the world-renowned white Jasmine and purple short-stature, non-photoperiod insensitive JHN purple rice (see in Fig. 1). Riceberry is set the most successful whole grain rice breeding to disrupt normal white rice eating habit. Consumers know Riceberry by distinctive appearance, nutritional value, and perception that not only fill our stomach but also fill our heart. Inducing consumers to accept the nutritional benefit of whole grains is the major change of mindset about rice consumption. The beauty of purple color and the indulgence of soft and tasty are the second mindset changing consumers understanding about the health benefit of natural pigments.



Fig.1 Riceberry grain

9. MINING NATURAL CHEMOPROTECTIVES FROM RICEBERRY BRAN

Rice bran contains different flavonoid pigments for light brown (leucoanthocyanin), red (cyanidin-3-

glucoside anthocyanin), and navy blue (delphinidin-3-glucoside anthocyanin) in various compositions. From thin cell layers wrapping around the endosperm became research topics for discovering new biologically active compounds in rice. Riceberry bran is rich in soluble dietary fiber, proteins, fatty acids, phytosterols, vitamins, minerals, antioxidants, anthocyanin, and polyphenols.

9.1 Bioactive compounds

Extracting biologically active compounds can be done using solvents^[4], ultrasonic^[5], and enzymes^[6]. By using dichloromethane (DC) and methanol (ME), chemoprotective compounds were identified. Riceberry bran accumulates beta-carotene and lutein in 185 and 224 $\mu\text{g}/100\text{g}$, respectively, which do not normally found in white rice. Also, chemoprotective compounds such as polyphenol, tannin, and catechin were 3~10 times of that found in normal brown rice. Furthermore, vitamin B1, B2, B3, and B9 were also found in high amount, particularly, in dark purple Riceberry contains in 48 $\mu\text{g}/100\text{g}$ of folate (B9).

9.2 Chemoprotective compounds

Flavones like apigenin, phytosterols, and triterpenes like lupeol are capable of preventing cancer cells such as colon Caco-2, breast MCF-7, and white blood LD-60^[4,7]. Gramisterol, bioactive compounds from Riceberry bran prevented acute myelogenous leukemia^[8].

9.3 Type II diabetes (T2D)

T2D caused by degeneration of pancreatic B cells causing insulin resistance preventing insulin from conducting serum glucose into myocytes. Moreover, T2D prevents liver cells from the conversion of unused serum glucose into glycogen causing hyperglycemia. In experimentally induced T1D and T2D rat populations, supplementing Riceberry bran in 1.5%~9% body weight for one month, mitigated hyperglycemia, improved liver and pancreatic activities, and avoided insulin tolerance by enhancing antioxidants, reducing apoptosis of B cells, and significantly improving functions of liver and pancreas^[9].

9.4 Attenuation of drug side-effects

Powerful antioxidants from Riceberry bran attenuated gentamicin, an effective gram-negative bacteria antibiotic, from induction of hepatotoxicity and nephrotoxicity causing renal dysfunction, the side-effects of gentamicin^[10-11].

9.5 Replacing bad with good cholesterol from Riceberry

Although rice bran contains only 8%~10% oil,

non-solvent oil pressing technology preserving chemoprotective compounds such as gramisterol, gamma oryzanol, vitamin E, beta-carotene, and lutein. As such, rice bran oil is the source of high lipid-soluble antioxidants. Patients with hyperlipidemia have a high chance for heart diseases. In short and long-term (8-week) studies using Riceberry bran oil, patients treated with Riceberry bran oil showed high antioxidant lipids, lower LDL, the bad cholesterol, and higher HDL, the good cholesterol, than the control group^[12]. Also, treating induced-Thalassemia rat with Riceberry bran oil preventing oxidative stress while improving antioxidant and CoQ10 prolong life-span of such Thalassemia rats.

10. ORGANIC RICEBERRY VALLEY

Developing health concern products requires not only good processing but also traceability to the original organic paddy field. Figure 2 shows the Organic Rice Research Farming Station, Kasetsart University, Kamphangsaeen Campus, Thailand. In order to expand from small to large organic field, the concept of Riceberry valley was established on 12 focus areas around the north and northeast of Thailand where the weather is permissive to high-quality rice. At present, approximately 20 000 Rai of the organic-cultivated area was registered on various types of organic certification programs including transitional, Organic Thailand, IFOAM, EU, COR, and USDA. The return to investment on farmland was estimated at 6,500 Thai Baht (THB) per Rai with an average benefit of 32 500 B/family/season (1 354 \$ per hectare)^[13].



Fig.2 Organic Rice Research Farming Station, Kasetsart University, Kamphangsaeen Campus, Thailand

The return to research investment of the Riceberry breeding, nutritional, and clinical researches were also calculated. From the total research fund of 30 million Baht, Riceberry generated almost 600 million Baht in return, 89% to farmers, 0.3% to miller, ~2% to food industries, and ~9% to consumers (Figure 3) with 50% internal rate of

return (IRR) (Table 1). Therefore, investment of medicinal rice has strong socio-economic return to farmers on the condition that consumers's acceptance is also high.

Table 1 Summary of economic impact in Thai Baht of the research project on development of Riceberry ex-post evaluation from 2000—2020.

Economic Return Indicators	Maximum Benefit (Thai Bath)
Net Present Value (NPV, Baht)	599,190,971
Benefit to Cost Ratio (BCR)	16.38
Internal Rate of Return (IRR)	50%

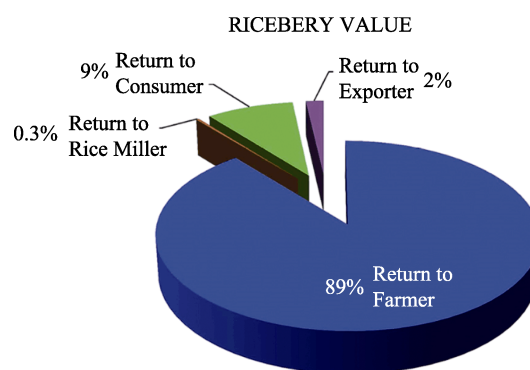


Fig.3 Socio-economic return to investment of research on Riceberry to different economic sectors. (see attached figure)

11. THE POPULARITY OF RICEBERRY PRODUCTS

Riceberry doesn't require commercial rice milling but is sold in its whole grain form. It is very popular among farmers to produce whole-grain vacuum-packed rice from over-produced paddies using small-scale milling and packaging. Direct sales to consumers, farmers gained additional 10~20 B per kg than the wholesale of paddies to commercial rice milling. In the mainstream market, there were no less than 108 brands of 1-kg vacuum packed Riceberry on supermarket shelves. With smaller acreage than Thai Hommali Rice (THM), Riceberry has been popularly used for at least 66 products. Because of the lack of mixture ratio, production cost, sale price, and amount of sale, economic value addition was not accurately estimated. Searching between 2013—2018 for registered products from the Global New Product Database www.gnpd.com revealed interesting outcomes. From THM, red rice, and other purple rice, Riceberry products were increasing popular yearly since 2013 and outperformed THM as of 2018. Such successful product development may not only stem from its appealing and taste but also more research and development using Riceberry has been so popular as well. In summary, 65 research projects were focused on R & D of Riceberry while 39 patents were applied and 18 patents were endorsed <<http://patentsearch>.

iphailand.go.th/DIP2013/simplesearch. php>.

12. INTELLECTUAL PROPERTY PROTECTION ON RICEBERRY

Protecting intellectual properties, Riceberry was endorsed under plant variety protection (PVP) law since 2017. Also, Riceberry trademarks were successfully registered locally and internationally under the Department of Intellectual Properties since 2011. For products made out of Riceberry (Figure 4).



Fig.4 Part of Riceberry trademarks registered

Both IPs were owned by public institutes and can be licensed to use for product competitiveness in the global market.

13. CONCLUSION

Rice for well-being is a sensible goal to be integrated into current breeding program to avoid and mitigate non-communicable diseases in rice consumers' world. Such a project was initiated in Thailand since 2000 with consistent progress towards medicinal rice. Riceberry has become the most successful whole grain pigmented rice variety in Thailand for its soft and tasty cooked rice packed with antioxidants^[13]. Low glycemic index (Low GI) was developed for white, polished rice consumers who have problems with obesity and type-2-diabetes. Also, improvement for adaptation to climate change is on its way to sustain the production of nutrient-rich rice into the future.

REFERENCES:

See in the Chinese version before.

Author Profile



Apichart Vanavichit:

the Professor of Plant Breeding and Genomics, who devotes himself as a pioneer in rice molecular breeding. He gained his Ph.D. in Crop Science from Oregon State University, USA, and become the director of Rice Gene Discovery and Rice Science Center, Faculty of Agriculture Kamphaengsaen, Kasetsart University, Thailand. He was the lead Thai scientists in the team that sequenced the rice genome with 9 other nations. Significant outcomes from his centers are new nutrient-dense, environmental- friendly rice varieties for organic farming. His centers have led in the discovery of and owning patents on genes controlling 2-acetyl-1-pyrroline (aromatic gene) in Thai Jasmine rice. Later on, the gene was identified on all aromatic rice around the world.

The center has strong commitment to continue improving aromatic rice for multiplex resistance to flash flooding (F), bacterial leaf blight (B), leaf-neck blast(B), and brown planthopper (B) signified as FBBB. Jasmine plus 4 was one of the new varieties of Jasmine rice with multiplex resistant FBBB. Another strong commitment is to develop aromatic rice with low glycemic index (GI) to combat obesity, type II diabetes (T2D).

The center has successfully generated Low GI white rice, high yielding, and multiplex resistance to FBBB. His popular debut is new soft, tasty, high antioxidant purple rice namely Riceberry to the market. It is the breakthrough in changing consumer habit for whole grain rice. His final research debut on future food is called Rainbow rice where people can consume the whole plant to feed high nutritious rice to 9 billion people in 2050.

(Organized by TAN Hongzhuo; Translated it into Chinese: WU Nana and TAN Hongzhuo)