Nutrition And Food Science Journal

Review Article

Germinated Brown Rice, a Whole Grain with Health Benefits For Common Chronic Diseases

Xinchu Weng[1], Min Sun[1], Haiyan Gao[1], Zhanmin Liu[1], Junyi Huang[1], Xianyan Liao[1] and Garry X Shen[2*]

[1]School of Life Sciences, Shanghai University, China

[2]Departments of Internal Medicine, University of Manitoba, Canada

ARTICLE INFO

Received Date: September 12, 2019
Accepted Date: October 14, 2019
Published Date: October 15, 2019

KEYWORDS

Germinated brown rice
γ-Amino butyric acid
Fiber
Diabetes
Chronic metabolic disorders

Citation for this article: Xinchu Weng, Min Sun, Haiyan Gao, Zhanmin Liu, Junyi Huang, Xianyan Liao, and Garry X Shen. Germinated Brown Rice, a Whole Grain with Health Benefits for Common Chronic Diseases. Nutrition And Food Science Journal. 2019; 2(1):119

Corresponding author:
Garry X Shen,
Departments of Internal Medicine, University of Manitoba, Canada. Tel: 204-789-3816; Fax: 204-789-3987; Email: garry.shen@umanitoba.ca

ABSTRACT

Rice is the staple food for over 50% of people in the world. Increased contents of γ-Amino Butyric Acid (GABA), fiber, vitamins and phenolic acids, and reduced levels of starches were detected in Germinated Brown Rice (GBR). Administration of GBR attenuated blood lipids, glucose, hypertension, oxidative stress, inflammation, atherosclerosis, carcinogenesis and neurodegeneration compared to white or brown rice. Bioactive components in GBR and precise mechanism for the health benefits of GBR remain unclear. GABA and fiber play important roles in the multiple health benefits of GBR. The abundances of many components in GBR correlated with the condition of pre-germination. Increase in the consumption of GBR potentially prevents a number of common chronic diseases including diabetes, hyperlipidemia, hypertension and atherosclerotic cardiovascular disease, and potential beneficial effect on neurodegenerative diseases and cancers. This review summarized up-to-date literatures on the bioactive ingredients, pre-germination, health benefits and food products of GBR to promote the research, knowledge translation, production and consumption of GBR for improving the health of people at population level.

INTRODUCTION

Rice is one of the most popularly consumed grains by humans in the world [1]. A variety of rice has been planted in more than 100 countries. More than 90% of rice is consumed in Asia as main grain; however, rice is used as ingredient of salad, cereal or dessert in many other regions of the world [2]. The predominantly consumed type of rice product is refined white rice. Most nutrients and active gradients in the out-layer of brown rice are removed during the refining process. Brown rice has not become a type of staple grain mainly because of its rough mouth feeling and the requirement of prolonged cooking time. Germinated Brown Rice (GBR) was originally produced to improve the taste of brown rice. Pre-germination softens the bran of brown rice, shortens cooking time, and triggers the synthesis of new bioactive ingredients in the germ. A large battery of studies on the production and health benefits of various sprouted grains, including GBR, was summarized in a book published in 2018 [3]. The methods for the germination of brown rice varied. Most studies used the contents of γ-Amino Butyric Acid (GABA) in GBR as measurement of the intensity of pre-germination [3]. GBR has not been widely consumed in most areas possibly due to insufficient public awareness of its benefits and the lack of the variety of food products on market. In addition, the underlying mechanism and bioactive compounds for the health benefits of GBR remains unclear. Although other types of rice, including black, purple, red and wild rice, also have health benefits, this review focuses on up-to-date information regarding the bioactive components, potential products, the health benefits of GBR and underlying mechanism for common chronic diseases.

GROSS STRUCTURE AND COMPOSITION OF RICE GRAIN

Rough rice is coated by hard husk. Brown rice is obtained through de-hulling, and it is surrounded by fiber-rich bran. Rice bran is composed of several layers, including pericarp, seed cover, nuclear tissue and aleurone [4]. Brown rice contains germ, which can sprout when it is exposed to moisture at suitable temperature (Figure1). The germination increases the amounts of lipids, proteins, minerals, vitamins, enzymes, and GABA in the germ. During milling, both bran and germ are removed from brown rice and the remaining is endosperm or white rice, which is composed of starch and small amount of proteins and lipids [3]. Pre-germination increases nutrients compared to brown rice in addition to improve mouth feeling.


Rough rice

Brown rice

GBR (wet)

GBR (dry)

White rice

Figure 1: Images of different rice products: rough rice, brown rice and freshly wet Germinated Brown Rice (GBR), dry GBR and white rice.

PRE-GERMINATION OF BROWN RICE

GBR is germinated via soaking brown rice in warm water and then exposing to air at moist environment till sprouting. The conditions of pre-germination have been discussed in details in previous literature [1,3]. The temperature and time of soaking or aeration correlate with the extents of compositional changes in GBR [5]. Multiple patents have been issued for the protocols of the pre-germination [3], but the procedure of pre-germination of brown rice has not been standardized. Typically, brown rice is soaked in water between 28°C and 40°C for 8-72 h. After the removal of excess water, wet brown rice is exposed to air at 28°-35°C for 12-48 h, which allows germ to be sprouted to 0.5-1 mm in length. Hot air or microwave is used to stop the pre-germination. Dried GBR has similar shelf life as non-germinated rice [1]. Prolonged germination favors microbial growth; besides, some bioactive compounds may lose from GBR into water during steeping. The addition of 0.5% lactic acid solution during the soaking may reduce the growth of microorganisms [6]. The quality of the pre-germination of GBR is often assessed by the content of GABA in the whole grain.

BIOACTIVE COMPONENTS IN GBR

Pre-germination softens the hard coat of bran triggers the synthesis of multiple amino acids, proteins and bioactive micronutrients in germ and reduces the content of starch in endosperm, which improves the mouth feeling and taste of GBR [1]. The components in GBR and the conditions of germination have been compared to white rice, brown rice or the both (Table 1-3) [7-17].

Table 1: Comparison of the nutritional components of germinated brown rice, brown rice and white rice.

Author	Year	Source of rice and pre-germination condition	Nutrients	Germinated brown rice	Brown rice	White rice
Chu et al., [7]	2019	Baimahu Village, Jiangsu province, China. 10 min in 0.5% sodium hypo-chlorite; 30°C 5 h in water; 30°C 120 h in air	Free phenolics (mg/kg)	1483.81±119.29	1012.17±44.09	-
			Bound phenolics	617.11±32.00	318.79±27.57	-
			γ-aminobutyric acid (μg/g)	1465.21±81.00	75.82 ± 1.14	-
			Asp (μg/g)	681.15 ± 22.46	55.44±6.44	-
			Thr (μg/g)	922.84 ± 44.80	26.81 ± 2.02	-
			Ser (μg/g)	1624.97 ± 35.66	100.58 ± 3.47	-
			Glu (μg/g)	1703.43 ± 134.50	604.50 ± 26.98	-
			Gly (μg/g)	539.18 ± 68.10	14.24 ± 0.54	-
			Ala (μg/g)	2127.57 ± 106.76	85.58 ± 1.95	-
			Val (μg/g)	2227.74 ± 80.03	88.69 ± 2.20	-
			Cys (μg/g)	210.54 ± 9.01	16.06 ± 0.26	-
			Met (μg/g)	598.56 ± 37.40	10.65 ± 0.32	-
			Iso (μg/g)	1372.13 ± 49.83	9.45 ± 0.58	-
			Leu (μg/g)	2101.20 ± 123.57	32.49 ± 0.90	-
			Tyr (μg/g)	1617.93 ± 19.98	48.80 ± 3.22	-
			Phe (μg/g)	1470.15 ± 166.12	21.38 ± 0.32	-
			Lys (μg/g)	1654.34 ± 47.86	73.35 ± 4.40	-
			His (μg/g)	1495.53 ± 24.34	113.70 ± 13.68	-
			Arg (μg/g)	2899.51 ± 134.45	320.21 ± 17.24	-
			Pro (μg/g)	894.65 ± 28.92	5.04 ± 0.35	-
Techo et al., [8]	2019	Chaijalearn Limited Partnership (Supanburi province, Thailad). 35°C in water for 6, 12, 18 or 24 h respectively, put in a box for 42, 36, 30 or 24 h respectively in air.	Phenolics (mg/g)	0.88±0.02	0.24±0.00	
			γ-aminobutyric acid (mg/g)	0.50±0.01	0.03±0.00	
Zhao et al., [9]	2018	Nanjing YuanwangFuqi Agriculture Products Inc. (Nanjing, Jiangsu, China). 40°C 16 h in water; 30°C 24 h in air.	Moisture %	2.3	-	2.4
			Ash %	13.2	-	11.8
			Fiber %	1.8	-	0.8
			Protein %	7.9	-	6.3
			Lipids %	2.3	-	0.4
			Carbohydrate %	75.4	-	78.3
			Selenium %	0.29	-	0.04
			γ-aminobutyric acid %	0.024	-	0.002
			Oxygen radical absorbance capacity (μmol/100 g)	1617	-	754
			Total phenolic contents (mg/kg)	649.6±4.7	-	160.9±6.9
			p-Hydroxybenzoic acid (mg/kg)	16.8	-	9.6
			p-Hydroxybenzaldehyde (mg/kg)	12.3	-	10.3
			Vanillic acid (mg/kg)	21.0	-	N.D.
			Vanillin (mg/kg)	10.9	-	N.D.
			Syringic acid (mg/kg)	11.1	-	N.D.
			p-Coumaric acid (mg/kg)	114.8	-	15.7
			Ferulic acid (mg/kg)	328.7	-	66.6
Maksup et al., [10]	2018	KhaoDawk Mali 105 rice, Thailand. 6 h in water in dark; 10 min with air-blowing.	Total phenolic (g/kg)	0.27	0.25	-
			Monomeric anthocyanin (g/kg)	0.038	0.015	-
		Mali Daeng rice, Thailand. 6 h in water in dark; 10 min with air-blowing.	Total phenolic (g/kg)	0.48	0.65	-
			Monomeric anthocyanin (g/kg)	0.177	0.033	-
Wang et al., [11]	2016	Hangzhou China. 5 min in 0.5% sodium hypochlorite; 30°C 6 h in water in dark; 30°C 96 h in air.	δ-Tocotrienol (μg/g)	3.41±0.07	3.6±0.01	-
			γ-Tocotrienol (μg/g)	25.19±1.49	32.99±0.78	-
			α-Tocotrienol (μg/g)	13.05±0.04	11.35±0.18	-
			δ-Tocopherol (μg/g)	1.93±0.02	4.06±0.13	-
			γ-Tocopherol (μg/g)	19.63±1.57	5.13±0.11	-

			α-Tocopherol (μg/g)	8.43±0.45	8.36±0.82	-
			γ-aminobutyric acid (μg/g)	115.24±2.75	24.67±1.06	-
			Hydroxybenzoic acid (μg/g)	9.1	7.0	-
			p-Coumaric acid (μg/g)	371.6	97.8	-
			Ferulic acid (μg/g)	705.3	227.5	-
Imam et al., [12]	2014	PadiBeras Nasional factory, Malaysia. 30 min in 0.1% sodium hypochlorite; 6 h in 0.5% hydrogen peroxide; 37°C 18 h in air.	Crude protein %	8.25±0.09	8.33±0.14	7.32±0.20
			Crude fat %	2.29±0.01	2.27±0.11	0.95±0.10
			Carbohydrate %	77.52±0.25	77.41±0.17	91.24±0.31
			Ash %	1.22±0.02	1.20±0.01	0.45±0.04
Jayadeep&Malleshi [13]	2011	IR 64, National Seeds Corporation, India. 16 h in water; 12 h in air covered with moist jute sheet.	Moisture (g/kg)	78 + 6.1	112 + 2.5	113 + 4.4
			Protein (g/kg)	80 + 5.0	85 + 3.6	82 + 4.2
			Fat (g/kg)	17 + 2.6	36 + 3.1	6.0 + 0.6
			Ash (g/kg)	12.5 + 1.5	13.0 + 1.4	9.0 + 0.5
			Carbohydrate (g/kg)	810+2.0	750+1.3	790+3.2
			Free sugar (g/kg)	42+3.1	13+1.0	3.0+0.3
			Insoluble fibre (g/kg)	36.8+2.4	41.5+1.3	10.3+1.1
			Soluble fibre (g/kg)	7.7+0.4	4.5+0.5	N.D.
			Total fibre (g/kg)	44.5+2.6	46.0+0.9	10.3+1.1
			Palmitic acid (%)	19.0+1.0	21.0+1.7	20.0+1.8
			Oleic acid (%)	39.0+1.1	40.0+1.5	41.0+2.1
			Linoleic acid (%)	38.0+2.4	36.0+0.6	36.0+2.9
			γ-Tocotrienol (mg/kg)	23.1+0.7	20.2+1.0	6.4+0.2
			Total tocotrienols (mg/kg)	25.5+1.3	21.8+0.6	6.7+0.2
			γ-Tocopherol (mg/kg)	0.69+0.2	4.97+0.8	0.71+0.04
			α-Tocopherol (mg/kg)	2.20+0.2	2.54+0.5	0.39+0.006
			Total tocopherols (mg/kg)	2.90+0.02	7.61+0.5	1.10+0.1
			Total vitamin E (mg/kg)	28.4+1.5	29.4+0.8	7.8+0.2
			Oryzanol (mg/kg)	296+18.6	280+20.6	54.0+4.5
		BPT, National Seeds Corporation, India. 16 h in water; 12 h in air covered with moist jute sheet.	Moisture (g/kg)	66+6	125+4.7	124+4.2
			Protein (g/kg)	73+5.5	76+3.2	71+3.1
			Fat (g/kg)	15.7+2.5	30+3.2	5.7+1.5
			Ash (g/kg)	15.9+1.7	15+1.5	11.0+1.7
			Carbohydrate (g/kg)	830+11.6	750+8.3	790+3.6
			Free sugar (g/kg)	51+4.7	17+1.3	4.1+0.3
			Insoluble fibre (g/kg)	31.7+2.5	37.0+2.0	9.0+1.0
			Soluble fibre (g/kg)	5.9+0.2	3.5+0.2	N.D.
			Total fibre (g/kg)	37.6+2.7	40.5+2.2	9.0+1.0
			Palmitic acid (%)	22.0+0.6	22.0+2.2	23.0+1.0
			Oleic acid (%)	39.0+2.1	41.0+2.1	38.0+3.5
			Linoleic acid (%)	36.0+1.7	35.0+1.7	36.0+2.5
			γ-Tocotrienol (mg/kg)	28.0+0.9	18.4+0.8	6.8+0.3
			Total tocotrienols (mg/kg)	29.8+1.0	19.3+0.8	7.0+0.3
			γ-Tocopherol (mg/kg)	0.75+0.1	4.7+1.0	0.1+0.02
			α-Tocopherol (mg/kg)	4.7+0.02	2.5+0.2	0.86+0.04
			Total tocopherols (mg/kg)	5.5+0.3	7.20+1.1	0.97+0.06
			Total vitamin E (mg/kg)	35.3+1.3	26.5+1.8	7.97+0.3
			Oryzanol (mg/kg)	297+21.1	295+19.1	66+5.7
Shirai et al., [14]	2010	Hojo, Ibaraki prefecture, Japan. 30 min in 0.1% sodium hypochlorite; 30℃ 24 h in water; 96 h in air.	Starch (g/kg)	312.2	310.2	303.8
			Casine (g/kg)	183.6	184.4	186.8
			Palm oil (g/kg)	42.2	43.4	47.4
			γ-aminobutyric acid (mg/kg)	169.3	22.4	8.2
Usuki et al., [15]	2007	Commercial source without details (Japan) 37°C 24 h in water	Protein (g/100 g)	21.8	21.6	21.5
			Fat (g/100 g)	8.1	8.3	7.0
			Available carbohydrate (g/100 g)	50.4	50.0	53.4
			Dietary fiber (g/100 g)	6.7	6.5	5.6

			Total energy (kcal/100 g)	375.1	374.1	373.8
Komatsuzaki et al., [16]	2007	Oryza sativa L, ssp. Japonica: Haiminori, Oou 359, Koshihikari, Yumetsukushi, and Nipponbare. (Japan). 35°C 24 h in water.	Asp (mg/100 g)	1.2±0.22	6.6±1.04	-
			Thr (mg/100 g)	3.1±0.76	1.0±0.48	-
			Ser (mg/100 g)	2.0±0.75	3.5±0.29	-
			Asn (mg/100 g)	3.7±0.55	7.1±1.69	-
			Glu (mg/100 g)	4.5±0.41	12.4±3.06	-
			Pro (mg/100 g)	5.1±0.67	1.9±1.66	-
			Gly (mg/100 g)	4.3±0.82	1.5±0.89	-
			Ala (mg/100 g)	12.3±1.31	12.3±1.31	-
			Val (mg/100 g)	4.5±0.76	0.8±0.33	-
			Cys (mg/100 g)	1.9±1.41	1.4±0.51	-
			Met (mg/100 g)	2.2±0.52	0.4±0.40	-
			I-Leu (mg/100 g)	3.7±0.67	0.7±0.15	-
			Leu (mg/100 g)	6.4±0.97	0.9±0.17	-
			Tyr (mg/100 g)	4.1±0.37	1.4±0.39	-
			Phe (mg/100 g)	3.8±0.37	1.0±0.59	-
			γ-aminobutyric acid (mg/100 g)	10.1±1.36	7.3±2.05	-
			Lys (mg/100 g)	4.4±0.84	3.9±1.45	-
			His (mg/100 g)	2.4±0.79	1.0±0.30	-
			Arg (mg/100 g)	4.9±1.14	4.9±1.14	-
Seki et al., [17]	2005	Hokkaido, Japan. 30°C 24 h in water.	Protein (g/100 g)	14.6	-	7.3
			Fat (g/100 g)	24.8	-	1.5
			Ash (g/100 g)	9.8	-	0.4
			Dietary fiber (g/100 g)	30.5	-	N.D.
			Starch (g/100 g)	9.7	-	73.9
			γ-aminobutyric acid (mg/100 g)	61.1	-	3.3

Starch and sugar

The content of total carbohydrates in GBR is 15% less than white rice [12] (Table 1). The content of starch in GBR was lowered after pre-germination compared to brown rice [17-19]. Veluppillai et al., [20] found that the abundance of reducing sugar increased during pre-germination.

Proteins and amino acids

Germination moderately increased the amount of proteins in GBR (up to 25% compared to brown rice [9,12,13,15] and white rice (up 100%) [13,15,17] (Table1). Moongngarm et al., [21] demonstrated that germination elevated protein contents in brown rice in a time-dependent manner. The content of water-soluble proteins in brown rice decreased first and then increased during pre-germination. The content of free amino acids in brown rice gradually increased during pre-germination [22]. Proteomic analysis demonstrated that germination enhanced the proteins responsible to the synthesis of phenolic acids against oxidative stress [10] Komatsuzaki et al., [16] reported that pre-germination for 24 h reduced the contents of glutamine. Ohtsubo et al., [23] demonstrated that GBR contains significantly more alanine, glycine and aspartic acid than brown rice after a 72 h of germination. Relationship between the health benefits of and the changes in protein and most amino acids in GBR have not been well documented.

Lipids

The content of total lipids in GBR are similar as brown rice [14,24] but higher than that in white rice [9,15] (Table 1). A trend of decrease in the abundance of oleic acid was detected in GBR during the germination, while the contents of palmitic acid and linoleic acid were increased [25].

GABA

GABA is a non-protein free amino acid biosynthesized from glutamate catalyzed by glutamate decarboxylase, and is the mostly studied type of amino acid in GBR. The formation of GABA requires pyridoxal phosphate (vitamin B6) as a co-factor [26]. GABA in mammalians functions as an inhibitory neurotransmitter in brain cortex and it is metabolized through GABA transaminase. GABA is also produced in plants, especially in sprout during germination, which may contribute to intracellular signaling for the germination [27]. The abundance of GABA in GBR was 18.5-20.6-folds of that in white rice [9,14,17] and 1.4-19.3-folds of that in brown rice

[7,8,11,14,16]. GABA promotes pancreatic β-cell proliferation, the restoration of β-cell mass, insulin secretion and glucose lowering in diabetic rats [28,29]. Maternal exposure to GABA reduced high fat diet-induced insulin resistance in rat offspring [30]. GABA also inhibits cancer cell proliferation, hypertension, hypercholesterolemia, and prevents alcohol-related diseases [1]. The contents of GABA in GBR correlate with the temperature and duration of soaking and aeration, and varied among different species of rice, but the generation of GABA was reduced in too high temperature or prolonged steeping [31]. Pre-treatment with 0.5% hypochlorite for 5-10 min substantially increased the content of GABA in GBR [7,11]. A recent study by Zhang et al., [32] demonstrated that cellulose spray before germination enhanced the content of GABA in GBR. It remains unclear whether the increase of GABA during pre-germination is limited to germ or is also altered in other parts of GBR.

Phytic acid and elements

Phytic acid is a reservoir of phosphorus in plants. It helps to chelate trace metal elements, and prevents metal elements to be absorbed. Pre-germination significantly reduced the content of phytic acid in brown rice [33]. Mineral elements are essential components of the body and are important for maintaining physiological activities. GBR contains 7-times higher selenium compared to white rice [9]. The contents of elements, such as selenium and magnesium, in rice bran or germ are absorbed from soil. Human body excretes certain amount of physiologically important elements, so those elements need to be absorbed from diet to meet daily requirements [34].While the content of phytic acid in brown rice was reduced after germination, the absorption rate of zinc did not increase, which suggests that zinc in GBR may also bind to other components in the body [33].

Fiber

The abundances of total, soluble and insoluble fiber in GBR are varied according to the methods of germination and laboratories. Jayadeep & Malleshi demonstrated that the amounts of total and insoluble fiber in GBR and brown rice were comparable, but were 3-4-times of those in white rice [13]. Pre-germination increased the soluble fiber in brown rice by 70%. In addition, pre-germination decreases the contents of xylose, mannose and glucose, and increases in rhamnose and arabinose in brown rice [35]. Seki et al. did not find detectable amount of fiber in white rice, and the amount of fiber in GBR was 30 g/100g [17]. Usuki et al., [15] reported that the amounts of total fiber in GBR and brown rice were 16-20% higher than white rice. A recent study demonstrated that fiber-rich diet reduced fasting blood glucose in T2D patients, which was associated with increases in the abundances of Short Chain Fatty Acids (SCFA) in fecal samples from the patients [36].

Phenolic acids

Major phenolic acids in brown rice are ferulic acid and p-coumaric acid, which are potent antioxidants. Imam et al., [37] found that GBR has better antioxidant capacity than white rice or brown rice because of the higher content of phenolic compounds. Anaerobic treatment after germination increased phenolic acids in GBR, and the increases in phenolic acids and antioxidant capacity were more evident in germinated red or black rice than from brown rice [38]. Tianet al., [39] showed that the contents of free ferulic acid, coumaric acid and sinapic acid in GBR were significantly higher than those in brown rice. Ohtsubo et al., [23] reported that the content of ferulic acid increased by 26% after a 72 h of germination. Zhao et al., [9] demonstrated that the contents of vanillic acid, vanillin, syringic acid in addition to coumaric acid and ferulic acid were higher in GBR compared to white rice (Table 1).

γ-Oryzanol

γ-oryzanol is a mixture of phytosterols hydroxycinnamate esters, which are abundant in grains [3]. The content of γ-oryzanol is increased in GBR [40]. The amount of γ-oryzanol was 71-times higher than that of vitamin E in GBR [21]. The administration of oryzanol-rich extract reduced the levels of lipids, glucose and insulin in rats [41].

Vitamins

GBR has abundant vitamin E. Vitamin E family is composed of tocopherols and tocotrienols, each of them contains α,β,δ and γ types of isoforms. The abundance of γ-tocotrienols was higher than other vitamin E family members in GBR in a report [14] (Table 1). GBR contains more vitamin B1 than in brown rice, and it is well known that vitamin B1-deficiency is the cause of beriberi characterized by neuropathy and heart failure [42]. It appears that pre-germination substantially alters a number of macro- and micro-nutrients in GBR compared to brown rice. The impact of most of the compositional changes in GBR on health remains unclear.

IMPACT OF GBR ON COMMON CHRONIC DISEASES

Results of experimental and clinical studies demonstrated that GBR has hypoglycemic, hypolipidemic, hypotensive, anti-obesity, anti-atherosclerosis and anti-inflammatory properties, and potentially reduces the risk of Alzheimer's disease and carcinogens is (Figure 2). (Table 2) [30,37,41,43-55] and (Table 3) [9,14,40,48,56-63] categorized the effects of GBR on the common chronic diseases from selective in vivo studies.

Hypoglycemic effect

GBR or germinated waxy black rice reduced blood glucose in diabetic rats induced by streptozotocin or high fat diet compared to white rice [37,43,50]. GBR administration in diabetic rats lowed the levels of blood glucose compared to white rice, and that was associated with decreases in the levels of tumor necrosis factor-α (TNF-α), Plasminogen Activator Inhibitor-1 (PAI-1), two inflammatory mediators, and an increase in the level of adiponectin, a negative regular of chronic inflammation and obesity, in plasma [48]. Germinated pigmented rice lowered glucose, insulin levels and the enzymatic activity of hepatic phosphoenolpyruvate carboxykinase and glucose-6-phosphatase in overiectomized rats [51]. Treatment with germinated black Thai rice reduced oxidative stress, fasting plasma glucose, lipids and insulin resistance in rats in similar extents as metformin [64]. Treatment of pregnant rats with GBR or oryzanol-rich extract in addition to high fat diet reduced the levels of glucose and insulin in the blood circulation of their offspring compared to those exposed to high fat diet alone in utero [41]. GBR consumption reduced fasting plasma glucose in women with glucose intolerance compared to white rice [49]. In a randomized controlled trial with crossover design, GBR reduced fasting blood glucose in diabetic patients [46] (Table 2). The glucose lowering effect of high fiber diet in T2D patients was associated with increases of SCFA-generating bacteria in gut [36]. However, the results on the glucose lowering effect of GBR in healthy subjects were inconsistent [44,45].

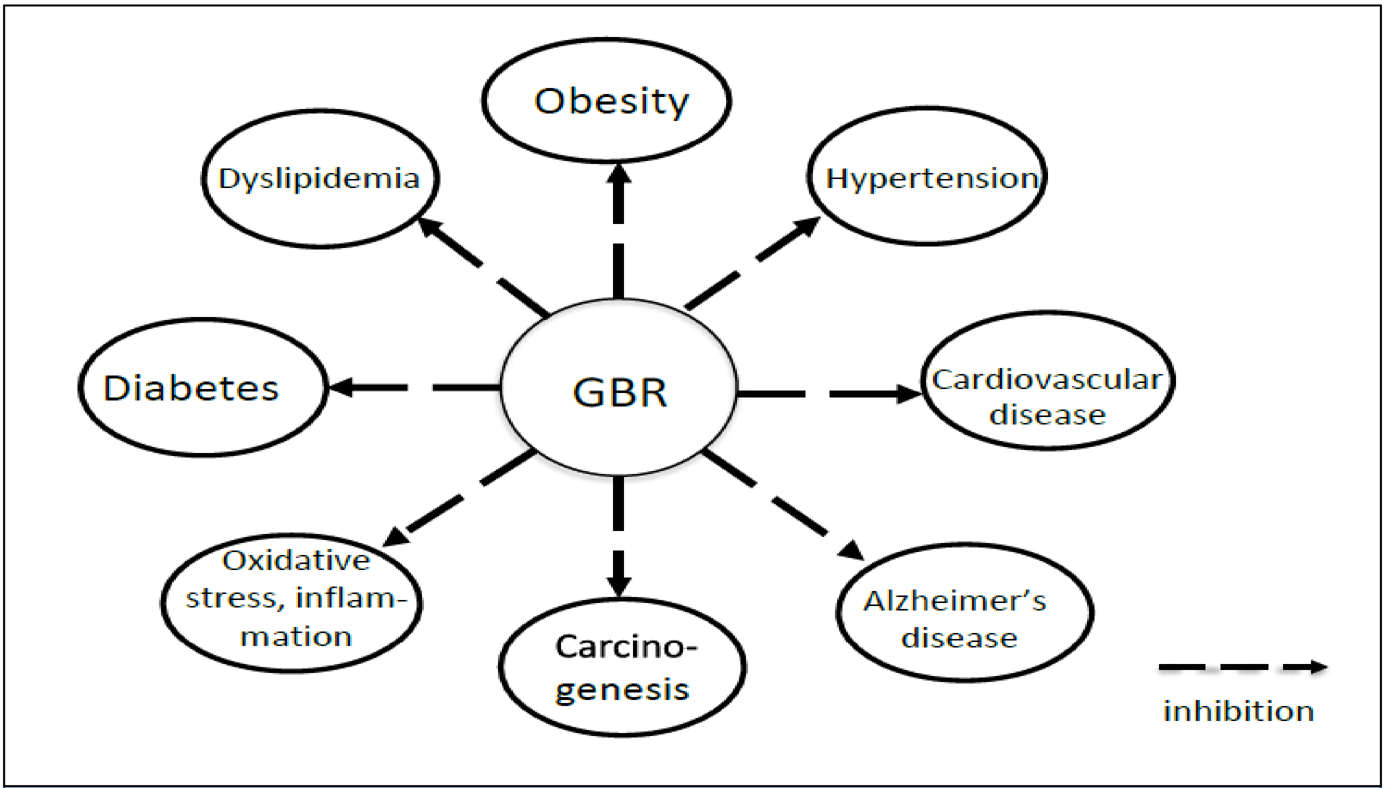

Figure 2: Health benefits of Germinated Brown Rice (GBR).

Table 2: Effects of Germinated Brown Rice (GBR), Brown Rice (BR) Versus White Rice (WR) on diabetes, obesity and hyperlipidemia.

Beneficial effects	Author (reference)	Year	Source of rice and pre-germination condition	Experimental model	Nutritional interventions	Major effects of GBR or BR
Anti-diabetes	Hagiwara et al., [43]	2004	WR and GBR, FANCL Co., Kanagawa, Japan	Streptozotocin-induced diabetic male Wistar rats	AIN-93G; WR or GBR substitution for corn starch in AIN-93G	GBR ↓glucose,↓PAI-1,↓lipid peroxide concentration vs WR
	Morita et al., [44]	2004	No details provided	67 healthy volunteers (aged 71 ±8)	WR and GBR + WR (1: 1, w/w) over 11–13 months	BR+WR↓HbA1c, ↔BMI, ↔blood pressure, ↔lipid profile, ↔kidney and liver functions, ↔blood glucose, ↔insulin response vs WR
	Ito et al., [45]	2005	A short grain variety, Hokkaido, Japan Pre-germination condition not described	Healthy subjects	Cooked WR, BR, GBR, mixed GBR and WR; for 120 min	BR and GBR ↓blood glucose,↓insulin response vs WR
	Hsu et al., [46]	2008	Japonica rice, Hoshinoyume, Hokkaido, Japan Pre-germination condition not described	11 Diabetic subjects (fasting blood glucose > 110 mg/dL)	6 weeks of feeding with 180g/time, 3times/d of GBR or WR and a 2 week-washout, medications were maintained (1 on insulin, 10 on oral hypoglycemics) during the dietary intervention	GBR ↓glucose,↓triglycerides,↓TC, ↓TG,↓FBG,↓fructosaminelevel,↑HDL cholesterol vs WR
	Shallan et al., [47]	2010	Crops Research Institute, Agric. Research Center, Giza, Egypt 37°C 24 h in water	Diabetic albino rats	WR, BR, GBR for 5 weeks	GBR and BR ↓weight, ↓glucose, ↓cholesterol vs WR
	Torimitsu et al., [48]	2010	WR and GBR, FANCL Co., Kanagawa, Japan Pre-germination condition not described	Male OLEFT rats (model of type 2 diabetes)	AIN-93G; WR or GBR substitution for corn starch in AIN-93G	GBR ↓blood glucose vs WR
	Imam et al., [37]	2012b	PadiBeras Nasional factory, Malaysia 30 min in 0.1% sodium hypochlorite; 6 h in 0.5% hydrogen peroxide; 37°C 18 h in air	Diabetic rats (fasting blood glucose of >250 mg/dL)	High-fat diet for 6 weeks to induce obesity, then adding WR, BR or GBR for 28 days	GBR or BR ↓glucose, ↑antioxidant status, ↑hydroxyl radical scavenging capacities of liver and kidneys, ↑expression of superoxide dismutase gene vs WR
	Bui et al., [49]	2014	Tam Rice Company of Hai Hau, Nam Dinh Province, Vietnam 30°C 24 h in water	Vietnamese women with impaired glucose tolerance	The first 2 weeks, WR was replaced by 50% GBR, 75% GBR for 2 weeks and finally 100% GBR for 1 month	GBR ↓glucose level vs BR
	Adamu et al., [41]	2017	AdiBeras Nasional Berhad, Selangor, Malaysia 30 min in 0.1% sodium hypochlorite; 37°C6 h in 0.5% hydrogen peroxide; 37°C 18 h in water	High fat diet-induced insulin resistance in F1 generation of rats	high fat die alone, high fat die + GBR or high fat die + oryzanol-rich extract (100 or 200 mg/kg/day) for 4 weeks and 8 weeks	GBR and oryzanol-rich ↓weight gain, ↓glycemic response, ↓fasting insulin, ↓retinol binding protein 4, ↑adiponectin levels vs high fat die group
Anti-obesity	Shallan et al., [47]	2010	Crops Research Institute, Agric. Research Center, Giza, Egypt 37°C 24 h in water	Diabetic albino rats	WR, BR, GBR for 5 weeks	GBR and BR ↓weight, vs WR
	Torimitsu et al., [48]	2010	WR and GBR, FANCL Co., Kanagawa, Japan Pre-germination condition not described	Male OLEFT rats (model of type 2 diabetes)	AIN-93G; WR or GBR substitution for corn starch in AIN-93G	GBR ↑adiponectin vs WR
	Bui et al., [49]	2014	Tam Rice Company of Hai Hau, Nam Dinh Province, Vietnam 30°C24 h in water	Vietnamese women with impaired glucose tolerance	The first 2 weeks, WR was replaced by 50% PGBR, 75% GBR for 2 weeks and finally 100% GBR for 1 month	GBR ↓weight vs BR
	Adamu et al., [30]	2017a	AdiBeras Nasional Berhad, Selangor, Malaysia 30 min in 0.1% sodium hypochlorite; 37°C6 h in 0.5% hydrogen peroxide; 37°C 18 h in water	High fat diet-induced insulin resistance in F1 generation of rats	High-fat diet, high-fat die + GBR, or high fat die +γ-aminobutyric acid for 4 weeks and 8 weeks	GBR, γ-aminobutyric acid and their offspring↑adiponectin levels, ↑hepatic mRNA levels, ↓insulin, ↓homeostasis model assessment of insulin resistance, leptin, ↓oxidative stress, ↓retinol binding protein-4

	Adamu et al., [41]	2017b	AdiBeras Nasional Berhad, Selangor, Malaysia 30 min in 0.1% sodium hypochlorite; 37°C6 h in 0.5% hydrogen peroxide; 37°C 18 h in water	High fat diet-induced insulin resistance in F1 generation of rats	High-fat die alone, high fat die + GBR or high fat die + oryzanol-rich extract (100 or 200 mg/kg/day) for 4 weeks and 8 weeks	GBR and oryzanol-rich ↓weight gain, ↓glycemic response, ↓fasting insulin, ↓retinol binding protein-4, ↑adiponectin levels vs high fat die group
Hypolipidemic effect	Kawana et al., 52]	2003	FANCL Co., Japan Pre-germination condition not described	20 females, age 20.5±1,, body mass index 21.0±1.8, body fat rate 26.3±3.5%	WR 200 g/d, PGBR 200g/d for 68 days	PGBR ↓TC, ↓HDL cholesterol, ↓LDL cholesterol, ↓TG
	Miura et al., [53]	2006	No description on rice source. 30°C 24 h in water	Hypercholesterolemia in hepatoma bearing rats	AIN-93G; WR, BR, or GBR substitution for cornstarch in AIN-93G	BR and GBR ↓TBARS, ↓TC, ↓AI, ↑HDL cholesterol, ↑fecal steroid excretion, ↑hepatic cholesterol 7a-hydroxylase activity vs WR
	Roohinejad et al., [54]	2010	An aromatic variety, MRQ74, Malaysia 30 min in 0.1% sodium hypochlorite; 30°C 24/48 h in water	Diet-induced hypercholesterolemic rats	GBR pre-germinated for 24 h, or 48 h for 6 weeks	48 h GBR ↓TC, ↓LDL cholesterol, ↑HDL cholesterol vs 24 h GBR
	Bui et al., [49]	2014	Tam Rice Company of Hai Hau, Nam Dinh Province, Vietnam 30°C 24 h in water	Vietnamese women with impaired glucose tolerance	The first 2 weeks, WR was replaced by 50% PGBR, 75% PGBR for 2 weeks and finally 100% PGBR for 1 month	GBR ↓lipid level vs BR
	Yen et al., [55]	2017	Asia RICE Biotech, Inc, Taipei, Taiwan Pre-germination condition not described	Normal six-week-old mice fed high-fat diet	After 16 weeks, the source of carbohydrates in high-fat diet was replaced with GBR for 4 weeks	GBR ↓systolic blood pressure, ↓blood glucose, ↓blood lipids, ↓adipocytokines level, ↑fecal TG, ↑TC, ↑bile acid levels vs high-fat diet group

AI: Atherogenic Index; AIN: American Institute of Nutrition; BMI: body mass index; FBG: Fasting Blood Glucose; HbA1c: Hemoglobin; A1C; HDL: High-Density Lipoprotein; ICR: Institute of Cancer Research; LDL: Low-Density Lipoprotein; TBARS: Thiobarbituric Acid-Reactive Substances; TC: Total Cholesterol; TG: Triglyceride.

Anti-obesity effect

Both GBR and brown rice reduced body weights in rats compared to white rice [47]. Prenatal intake of GBR extract, oryzanol or GBR along with high fat diet in female rats reduced body weights of mothers [41,22]. GBR administration decreased more body weights in women with glucose intolerance than brown rice [49]. GBR contains more soluble fiber than white or brown rice [15] (Table 1). Soluble dietary fiber increases the production of gut hormones causing satiety and weight loss [65].

Hypolipidemic effect

GBR administration for 10 weeks reduced the content of total cholesterol and Low-Density Lipoprotein-Cholesterol (LDL-C) in female college students [52]. GBR increased High-Density Lipoprotein-Cholesterol (HDL-C) levels in hyperlipidemia rabbits [54]. GBR improved high fat diet-induced hyperlipidemia in mice [55]. Lipid lowering effect of GBR was detected in women with glucose intolerance compared to white rice [49] (Table 2). The lipid lowering effects of GBR may result from multiple components, including oryzanol, fiber or vitamin E [66,67]. Both GBR and brown rice increased the activity of hepatic cholesterol 7α-hydroxylasein hepatoma bearing rats compared to white rice, which may promote the fecal secretion of bile acid and reduce blood cholesterol [53]. A more recent study demonstrated that GBR reduced lipogenesis and hepatic adipocyte accumulation, and increased lipolysis in overiectomized rats [68].

Hypotensive effect

GBR lowered blood pressure in Spontaneously Hypertension Rats (SHR) with or without the intake of NaCl [14,56,57]. Yen et al., [55] reported that GBR reduced blood pressure in mice fed with high fat diet. Bui et al., [49] observed a significant hypotensive effect of GBR in people compared to those receiving white rice. Ferulic acid lowered blood pressure in hyperlipidemic and diabetic rats [69]. Rice bran extracts have more pronounced anti-hypertensive effect than that of ferulic acid alone in stroke-prone SHR, which suggests that rice bran contains other anti-hypertensive component beside ferulic acid [70]. Watanabe et al., [71] proposed to use GBR as a dietary adjuvant treatment for hypertension.

Cardioprotective effects

GBR reduces multiple important risks for cardiovascular disease, including diabetes, hyperlipidemia, obesity and hypertension. Mohd Esa et al., [40] reported that GBR and brown rice decreased atherosclerotic index compared to white rice in hypercholesterolemic rabbits, which was associated with reductions in total cholesterol, LDL-C, lipid oxidation, and an increase in HDL-C. Zhao et al., [9] demonstrated that GBR attenuated aortic atherosclerotic lesions in LDL receptor-knockout mice, and that was associated with a reduction in the tendency of vascular inflammation including monocyte adhesion and the abundances of PAI-1, TNF-α and multiple oxidative stress regulators in cardiovascular tissue (Table 3). Oxidative stress and inflammation play critical roles in atherogenesis [72,73]. GBR contains abundant antioxidants, including phenolics and vitamin E family members. GBR significantly reduced oxidative stress and increased the activities of antioxidant enzymes in mice receiving high fat diet [58]. The responsible components and mechanism for the anti-atherosclerotic and anti-inflammatory effect of GBR remains unclear. The cardioprotective effect of GBR detected in experimental studies should be verified in clinical trials.

Table 3: Effects of Germinated Brown Rice (GBR), Brown Rice (BR) Versus White Rice (WR) on hypertension, cardiovascular disease, cancer and neurologic disorders.

Beneficial effects	Author	Year	Source of rice and pre-germination condition	Experimental model	Nutritional interventions	Major effects of GBR or BR
Antihypertensive effect	Choi et al., [56]	2006	IcheonNonghyup Rice Rice Processing Plant, Korea 30° 24 h in water	Spontaneously hypertensive rats	AIN-76; BR (50% diet), or GBR (50% diet) substitution in AIN-76	BR and GBR ↓FER, ↓SBP, ↓TG vs control diet
	Hiroko et al., [57]	2009	GBR, FANCL Co., Kagawa Prefecture, Japan Pre-germination condition not described	Spontaneously hypertensive rats	40% GBR diet for 8 weeks	GBR ↓TC, ↓blood pressure vs no GBR
	Torimitsu et al., [48]	2010	WR and GBR, FANCL Co., Kanagawa, Japan Pre-germination condition not described	Male OLETF rats (model of type 2 diabetes)	AIN-93G; WR or GBR substitution for corn starch in AIN-93G	GBR ↓blood glucose, ↓TNF, ↓PAI-1, ↑adiponectin vs WR
	Shirai et al., [13]	2010	Hojo district of castle prefecture, Japan 30 min in 0.1% sodium hypochlorite; 30°C 24, 48, 72, 96 h in water	spontaneously hypertensive rats	Polished rice, BR and GBR add 0.26% NaCl respectively. Feed is formulated according to nutrients, for 13 weeks	GBR ↓blood glucose, ↓insulin level, ↓adiponectin, ↓triacylglycerol, ↓leptin,
Cardioprotective effect	MohdEsa et al., [40]	2011	O. sativa L. variety MR220, Malaysia 30 min in 0.1% sodium hypochlorite; 30°C 24 h in water	Diet-induced hypercholesterolemic rabbits	AIN-93G diet without or with cholesterol (0.5 g/100 g), cholesterol diet with WR (19.8%), with BR (19.0%), with GBR (19.5%) for 10 weeks	GBR and BR↓TC, ↓LDL cholesterol, ↓atherogenic index, ↓MDA, ↑HDL cholesterol vs WR
	Zhao et al., [9]	2018	Nanjing Yuanwang Fuqi Agriculture Products Inc. (Nanjing, Jiangsu, China) 40°C 16 h in water; 30°C 24 h in air	Male LDL receptor-knockout mice	WR and GBR (60%+control diet) for 20 weeks	GBR ↓monocyte adhesion to aortas, ↓PAI-1, ↓MCP-1, ↓TNF-α vs WR

	Chung et al., [58]	2018	Keunnunjami rice, Department of Agriculture Science, Korea National Open University	4-week-old male C57BL/6N mice	AIN-93G; high-fat diet group with ethanol (0.25%) extracts of BR, GBR, Keunnunjami rice, and germinated Keunnunjami rice for 4 weeks.	GBR and germinated Keunnunjami rice ↓weight, ↓plasma TBARS, ↓erythrocyte TBARS, epididymal, perirenal, inguinal ↑GSH-Px, ↑CAT, ↑PON vs BR and Keunnunjami rice respectively
Anti-carcinogenesis	Kawabata et al., [59]	1999	Oryza Oil and Fat Chemical Co. Ichinomiya, Japan Pre-germination condition not described	Azoxymethane-induced colon carcinogenesis in rats	Basal diet, 2.5% defatted rice-germ, 2.5% γ-aminobutyric acid-enriched defatted rice-germ, 2.5% rice-germ for 5 weeks	γ-aminobutyric acid-enriched defatted rice-germ and rice-germ ↓frequency of colonic adenocarcinoma, ↓incidence of colonic adenocarcinoma
	Park et al., [60]	2017	Cell Activation Research Institute, Kyungji-Do, Korea Pre-germination condition not described	Human-derived colon carcinoma cell lines SW 480, HT 29, and tumor-xenografted mouse model	Treatment with *Phellinus linteus* on GBR extract	GBR↑sensitivity and apoptosis of colon cancer cells and tumor- xenografted mouse model to cetuximab
	Saki et al., [61]	2017	Malaysian local rice (*Oryza sativa*), Selangor, Malaysia 28°C 48 h in water, dried at 50°C until 10% moisture content	Human colon cancer cells HT-29	Incubation with germinated rough rice crude extract for 24, 48, and 72 h, add MTT 3 h	Germinated rough rice ↓weight of kidney, liver, heart, lung, spleen and colon, ↓HCT, ↓RBC ↑WBR, ↑MCH, ↑MCHC
Anti-neurologic disorders	Mamiya et al., [62]	2004	WR and GBR, from Hokkaido, Japan 30°C 24 h in water	Male ICR mice	AIN-93G; WR or GBR substitution for corn starch in AIN-93G	GBR, but not WR, prevented β-amyloid protein-induced impairment of memory capacity (Y maze test) in mice
	Mamiya et al., [63]	2007	WR and GBR, from Hokkaido, Japan 30°C 24 h in water	Male ICR mice	AIN-93G; WR or GBR substitution for corn starch in AIN-93G	GBR ↑learning capacity and 5-HT (frontal cortex) vs control diet

AIN: American Institute of Nutrition; CAT: Catalase; FER: Food Efficiency Ratio; GSH-Px: Glutathione Peroxidase; HCT: Hematocrit; HDL: High-Density Lipoprotein; 5-HT: 5-Hydroxytryptamine; ICR: Institute of Cancer Research; LDL: Low-Density Lipoprotein; MCH: Mean Corpuscular Haemoglobin; MCHC: Mean Corpuscular Haemoglobin Concentration; MDA: Malondialdehyde; MTT: 3-(4,5-dimethylthiazol-2-Yl)-2,5-Diphenyltetrazo-Lium Bromide; OLETF: Otsuka Long-Evans Tokushima Fatty Rat; PAI-1: type-1 Plasminogen Activator Inhibitor; PON: Paraoxonase; RBC: Red Blood Cell; SBP: Systolic Blood Pressure; TBARS: Thiobarbituric Acid Reactive Substance; TC: Total Cholesterol; TG: Triglyceride; TNF-α,: Tumor Necrosis Factor- α; WBC: White Blood Cell.

Carcinogenesis

Yasukawa et al., [74] reported that oryzanol from rice bran inhibited the proliferation of mouse skin cancer cells. Hudson et al., [75] found that extracts from brown rice or rice bran suppressed the proliferation of breast or colon cancer cells. Rice germ inhibited the growth of oxidized azomethane-induced colon cancer in rats [59]. Phellinus linteus on GBR (PBR) extract increased the sensitivity of colon cancer cells and tumor-xenografted mouse model to cetuximab, and promoted the apoptosis of cancer cells [60]. Ethanol extract of germinated rough rice prevented azoxymethane-induced colorectal cancer in rats [61]. GBR in combination with L. acidophilus and/or B. Animal is subsp. Lactis inhibited colorectal carcinogenesis by enhancing anti oxidative capacity and apoptosis in rats [76]. The potential anticancer effects of the components or derivatives of GBR observed in experimental studies should be further investigated.

Neurodegenerative and Alzheimer's diseases

Alzheimer's disease is a common geriatric neurodegenerative disorder without an effective treatment and is characterized by the deposition of β-amyloid protein in brain. Mamiyaet al., [62] reported that GBR improved β-amyloid protein-induced learning and memory deficit in mice. GBR also improved depression-like behavior in mice, which was associated with an increase of 5-hydroxytryptaminein brain cortex of mice [62]. Azmi et al., [77] reported that GBR altered the aggregation of Aβ protein and modulated genes related Alzheimer's disease in SH-SY5Y neuroblastoma cells. GABA plays a vital role in the memory process, such as improving brain function, improving nerve function, and promoting long-term memory [78].

Antioxidants in GBR may reduce the toxicity of oxidative stress to brain cells. Ethyl acetate extract of GBR inhibited hydroperoxide-induced oxidative stress and apoptosis in neuroblastoma cells [79]. Ferulic acid improves memory and prevents trimethyltin-induced learning and memory impairment in mice [80]. The above preliminary findings from experimental studies suggest that GBR may help to prevent or manage Alzheimer's disease or other neurodegenerative disorders. Clinical studies are required to verify the hypothesis generated from animal studies.

Other chronic diseases

GBR also inhibits sobering [81], regulates mood [82], and improves skin condition [83] in experimental or human studies.

FOOD PRODUCTS OF GBR

GBR may be developed into various food products [3] in addition to steam rice, which are potentially accepted as staple foods by both rice eaters and non-rice eaters. Several of GBR food products may enhance the consumption of GBR as described below.

GBR flour

GBR flour is processed by hydrolyzing GBR with xylanase, further dried and milled into powder [84]. GBR powder has a porous network structure after extrusion due to protein cleavage. The gelatinization of GBR powder can reach almost 100%, which improves the nutritional value of GBR [85]. The extrusion reduces the dispersion of GBR flour. The addition of 15% maldextrin, 0.12% sucrose ester and 0.55% monoglycerides to GBR flour helps to solve the issue of the lack of dispersion [86]. GBR flour mixed with wheat flour, transglutaminase and gluten can enhance its gas-hold ability and water retention, which improves the quality of bread [87]. Rice flour is often used as a component of gluten-free bread for people with gluten-sensitivity, such as celiac disease [88]. Since the flour of white rice is low in nutrients, GBR flour may be a suitable replacement of white rice flour for gluten-free foods [3].

GBR beverage

GBR beverage has enjoyable flavor. Extrusion recombination technology was applied in the production of GBR-green tea beverage. GBR-milk beverage is fermented by lactic acid bacteria, and hydrolyzed with α-amylase [89]. GBR tea was obtained by baking GBR, and then mixed with other ingredients. The optimal formulation allows the content of poly phenol to reach 309 mg/kg, and that of GABA to 427 μg/dL in GBR tea [90].

GBR enzymes

GBR enzymes are composed of a mixed biological enzyme system. They are generated from GBR fermented by lactic acid bacteria and yeast. During the fermentation process, dozens of new enzymes are generated, which enhances the nutritional value of GBR [91]. GBR is used as a substrate to generate the enzymes. The protease activity and the content of GABA are often used as indicators to assess the efficacy of the generation of the enzymes [92].

GBR wine

GBR wine is prepared through the fermentation of GBR with yeast, known as koji. The content of glutathione in GBR wine is often used to monitor the fermentation. A new kind of low-alcohol GBR wine with high nutritional value was prepared by using bilateral fermentation method in combination with the saccharification process of beer and the fermentation technology for yellow rice wine, which is a popular beverage in southern China [93]. The quality of GBR wine, as estimated by the abundance of aroma components, was improved significantly after the germination [94].

Healthy snacks

Sprouted grains are often used in healthy snacks, such as bar, muffin, cookie, oatmeal, granola and cake, due to their soft texture and high values of nutrition [95]. GBR can be a good candidate as an ingredient of those healthy snacks.

LIMITATIONS AND FUTURE DIRECTION

Precise mechanism for the health benefits and the nature of responsible bioactive compounds in GBR remain unclear. GABA, fiber, antioxidant vitamins and phenolic acids enriched in GBR possibly contribute to a number of the health benefits of GBR on the common metabolic disorders. Molecular mechanism and interactions of bioactive compounds for the beneficial effects of GBR remains largely unclear. The process of pre-germination and the evaluation system of GBR production may be optimized for targeted purpose and populations. Based on the definition of whole grains from the American Association of Cereal Chemists, a qualitative and quantitative monitor system for GBR and its food products need to be established. At the same time, public education on the health benefits of GBR food products should be enhanced. Researchers, consumers, food industries, farmers, government departments, health organizations, education and social media may work in a cooperative way to promote the production and consumption of GBR. In order to encourage the consumption of GBR, diversified GBR products need to be developed to meet the requirements of different subgroups of consumers, such as elders, children, pregnant women and individuals with risks for various chronic metabolic disorders.

CONCLUSION

GBR can be homemade or obtained commercially. GBR is a natural source for GABA, fiber, proteins, phenolic acids, vitamins, antioxidants and trace elements. Available results suggest that GBR has many potential beneficial health effects for common chronic diseases. Regular consumption of GBR is cost-effective for the prevention or management of the common chronic diseases. If more people consume GBR as staple food, immeasurable health impact is expected to achieve at population level.

ACKNOWLEDGEMENTS

The authors thank Mr. Min Shun Zhou, Ms. Chen Liu and Mr. Zhen Guo Liu for photographing, and supports from Shanghai University Research Matching Fund, and operating grant from Diabetes Canada to G.X.S (NOD_OG-3-15-4889-GS).

CONFLICT INTERESTS

All authors have none conflict interest to the contents of this review.

REFERENCES

1. Cho DH, Lim ST. (2016). Germinated brown rice and its bio-functional compounds. Food Chem. 196: 259-271.
2. Wu F, Yang N, Toure A, Jin Z, Xu X. (2013). Germinated brown rice and its role in human health. Crit Rev Food Sci Nutr. 53: 451-463.
3. Feng H, Nemzer B, DeVris JW. (2018). Sprouted grains: Nutritional value, production and applications. Woodhead Publishing. Elsevier.
4. Yu X, Zhou L, Xiong F, Wang Z. (2014). Structural and histochemical characterization of developing rice caryopsis. Rice Sci. 21: 142-149.
5. Guo X, Zhu Y. (2003). Application of response surface methodology (RSM) in the study of germinated brown rice. Cereal Feed Industr (Chinese). 11: 11-12.
6. Thitinunsomboon S, Keeratipibul S, Boonsiriwit A. (2013). Enhancing gamma-aminobutyric acid content in germinated brown rice by repeated treatment of soaking and incubation. Food Sci Technol Internat. 19: 25-33.
7. Chu C, Yan N, Du Y, Liu X, Chu M, et al. (2019). iTRAQ-based proteomic analysis reveals the accumulation of bioactive compounds in Chinese wild rice (Zizania latifolia) during germination. Food Chem. 289: 635-644.
8. Techo J, Soponronnarit S, Devahastin S, Wattanasiritham LS, Thuwapanichayanan R, et al. (2019). Effects of heating method and temperature in combination with hypoxic treatment on γ-aminobutyric acid, phenolics content and antioxidant activity of germinated rice. Int J Food Sci Tech. 54: 1330-1341.
9. Zhao R, Ghazzawi N, Wu J, Le K, Li C, et al. (2018). Germinated brown rice attenuates atherosclerosis and vascular inflammation in low-density lipoprotein receptor-knockout mice. J Agri Food Chem. 66: 4512-4520.
10. Maksup S, Pongpakpian S, Roytrakul S, Cha-Um S, Supaibulwatana, K. (2018). Comparative proteomics and protein profile related to phenolic compounds and antioxidant activity in germinated Oryza sativa 'KDML105' and Thai brown rice 'Mali Daeng' for better nutritional value. J Sci Food Agric. 98: 566-573.
11. Wang Y, Li M, Xu F, Chai L, Bao J, et al. (2016). Variation in polyphenols, tocols, γ-aminobutyric acid, and antioxidant properties in whole grain rice (Oryza sativa L.) as affected by different germination time. Cereal Chem. 93: 268-274.
12. Imam MU, Ishaka A, Ooi DJ, Zamri ND, Sarega N, et al. (2014). Germinated brown rice regulates hepatic cholesterol metabolism and cardiovascular disease risk in hypercholesterolaemic rats. J Functional Foods. 8: 193-203.
13. Jayadeep A, Malleshi NG. (2011). Nutrients, composition of tocotrienols, tocopherols, and γ-oryzanol, and antioxidant activity in brown rice before and after biotransformation. CyTA - J Food. 9: 82-87.
14. Shirai N, Suzuki H, Suzuki K, Ohtsubo K. (2010). Effect of extruded polished, brown, and germinated brown rice on the behavior and plasma parameters of icr mice. Food Sci

Tech Res. 16: 621-626.

15. Usuki S, Ito Y, Morikawa K, Kise M, Ariga T, et al. (2007). Effect of pre-germinated brown rice intake on diabetic neuropathy in streptozotocin-induced diabetic rats. Nutr Metab. 4: 25.
16. Komatsuzaki N, Tsukahara K, Toyoshima H, Suzuki T, Shimizu N, et al. (2007). Effect of soaking and gaseous treatment on GABA content in germinated brown rice. J Food Engineer. 78: 556-560.
17. Seki T, Nagase R, Torimitsu M, Yanagi M, Ito Y, et al. (2005). Insoluble fiber is a major constituent responsible for lowering the post-prandial blood glucose concentration in the pre-germinated brown rice. Biol Pharmaceut Bul. 28: 1539-1541.
18. Charoenthaikij P, Jangchud K, Jangchud A, Piyachomkwan K, Tungtrakul P, et al. (2009). Germination conditions affect physicochemical properties of germinated brown rice flour. J Food Science. 74: C658-C665.
19. Li C, Oh SG, Lee DH, Baik HW, Chung HJ. (2017). Effect of germination on the structures and physicochemical properties of starches from brown rice, oat, sorghum, and millet. Int J Biol Macromol. 105: 931-939.
20. Veluppillai S, Nithyanantharajah K, Vasantharuba S, Balakumar S, Arasaratnam V. (2009). Biochemical changes associated with germinating rice grains and germination improvement. Rice Science. 16: 240-242.
21. Moongngarm A, SaetungN. (2010). Comparison of chemical compositions and bioactive compounds of germinated rough rice and brown rice. Food Chem. 122: 782-788.
22. Ayernor GS, Ocloo FC. (2007). Physico-chemical changes and diastatic activity associated with germinating paddy rice (PSB.Rc 34). Afric J Food Sci. 1: 37-41.
23. Ohtsubo K, Suzuki K, Yasui Y, Kasumi T. (2005). Bio-functional components in the processed pre-germinated brown rice by a twin-screw extruder. J Food Compos Analysis. 18: 303-316.
24. Imam MU, Azmi NH, Bhanger MI, Ismail N, Ismail M. (2012). Antidiabetic properties of germinated brown rice: a systematic review. Evidence-Based Complemen Alternat Med. 2012: 816501.
25. Choi I, Suh SJ, Kim JH, Kim SL. (2009). Effects of germination on fatty acid and free amino acid profiles of brown rice ‘Keunnun’. Food Sci Biotechnol. 18: 799-802.
26. Petroff OA. (2002). GABA and glutamate in the human brain. Neuroscientist. 8: 562-573.
27. Roberts MR. (2007). Does GABA act as a signal in plants?: Hints from molecular studies. Plant Signaling Behav. 2: 408-409.
28. Purwana I, Zheng J, Li X, Deurloo M, Son DO, et al. (2014). GABA promotes human β-cell proliferation and modulates glucose homeostasis. Diabetes. 63: 4197-4205.
29. Wang Q, Ren L, Wan Y, Prudhomme GJ. (2019). GABAergic regulation of pancreatic islet cells: Physiology and antidiabetic effects. J Cell Physiol. 234: 14432-14444.
30. Adamu HA, Imam MU, Der-Jiun O, Ismail M. (2017). In utero exposure to germinated brown rice and its GABA extract attenuates high-fat-diet-induced insulin resistance in rat offspring. J Nutrigenet Nutrigenomics. 10: 19-31.
31. Banchuen J, Thammarutwasik P, Ooraikul B, Wuttijumnong P, Sirivongpaisal P. (2009). Effect of germinating processes on bioactive component of sangyod muang phatthalung rice. Thai J Agri Sci. 42: 191-199.
32. Zhang Q, Liu N, Wang S, Liu Y, Lan H. (2019). Effects of cyclic cellulase conditioning and germination treatment on the γ-aminobutyric acid content and the cooking and taste qualities of germinated brown rice. Food Chem. 289: 232-239.
33. Liang J, Han BZ, Nout MJ, Hamer RJ. (2008). Effects of soaking, germination and fermentation on phytic acid, total and in vitro soluble zinc in brown rice. Food Chem. 110: 821-828.
34. Marr KM, Batten GD, Blakeney AB. (2010). Relationships between minerals in Australian brown rice. J Sci Food Agri. 68: 285-291.
35. Rao RSP, Muralikrishna G. (2004). Non-starch polysaccharide–phenolic acid complexes from native and germinated cereals and millet. Food Chem. 84: 527-531.
36. Zhao L, ZhangF, Ding X, Wu G, Lam YY, et al. (2018). Gut bacteria selectively promoted by dietary fibers alleviate type 2 diabetes. Science. 359: 1151-1156.
37. Imam MU, Musa SNA, Azmi NH, Ismail M. (2012). Effects of white rice, brown rice and germinated brown rice on

antioxidant status of type 2 diabetic rats. Int J Mol Sci. 13: 12952-12969.

38. Shen S, Wang Y, Li M, Xu F, Chai L, et al. (2015). The effect of anaerobic treatment on polyphenols, antioxidant properties, tocols and free amino acids in white, red, and black germinated rice (Oryza sativa L.). J Functional Foods. 19: 641-648.
39. Tian S, Nakamura K, Kayahara H. (2004). Analysis of phenolic compounds in white rice, brown rice, and germinated brown rice. J Agri Food Chem. 52: 4808-4813.
40. Mohd Esa NM, Kadir KK A, Amom Z, Azlan A. (2011). Improving the lipid profile in hypercholesterolemia-induced rabbit by supplementation of germinated brown rice. J Agri Food Chem. 59: 7985-7991.
41. Adamu HA, Imam MU, Ooi DJ, Esa NM, Rosli R, et al. (2017). In utero exposure to germinated brown rice and its oryzanol-rich extract attenuated high fat diet-induced insulin resistance in F1 generation of rats. BMC Complement Altern Med. 17: 67.
42. Watchararparpaiboon W, Laohakunjit N, Kerdchoechuen O. (2010). An improved process for high quality and nutrition of brown rice production. Food Sci Technol Internat. 16: 147-158.
43. Hagiwara H, Seki T, Ariga T. (2004). The effect of pre-germinated brown rice intake on blood glucose and PAI-1 levels in streptozotocin-induced diabetic rats. Biosci Biotechnol Biochem. 68: 444-447.
44. Morita H, Uno Y, Umemoto T, Sugiyama C, Matsumoto M, et al. (2004). Effect of gamma-aminobutyric acid-rich germinated brown rice on indexes of life-style related diseases. Nihon Ronen Igakkai Zasshi (Japanese). 41: 211-216.
45. Ito Y, Mizukuchi A, Kise M, Aoto H, Yamamoto S, et al. (2005). Postprandial blood glucose and insulin responses to pre-germinated brown rice in healthy subjects. J Med Invest. 52: 159-164.
46. Hsu TF, Kise M, Wang MF, Ito Y, Yang MD, et al. (2008). Effects of pre-germinated brown rice on blood glucose and lipid levels in free-living patients with impaired fasting glucose or type 2 diabetes. J Nutr Sci Vitaminol (Tokyo). 54: 163-168.
47. Shallan MA, Elbeltagi HS, Mona AM, Amera TM, Sohir NA. (2010). Effect of amylose content and pre-germinated brown rice on serum blood glucose and lipids in experimental animal. Austr J Basic Applied Sci.4: 114-121.
48. Torimitsu M, Nagase R, Yanagi M, Homma M, Sasai Y, et al. (2010). Replacing white rice with pre-germinated brown rice mildly ameliorates hyperglycemia and imbalance of adipocytokine levels in type 2 diabetes model rats. J Nutr Sci Vitaminol. 56: 287-292.
49. Bui TN, Le TH, Nguyen DH, Tran QB, Nguyen TL, et al. (2014). Pre-germinated brown rice reduced both blood glucose concentration and body weight in Vietnamese women with impaired glucose tolerance. J Nutr Sci Vitaminol. 60: 183-187.
50. Kang HW, Lim WC, Lee JK, Ho JN, Lim EJ, et al. (2017). Germinated waxy black rice ameliorates hyperglycemia and dyslipidemia in streptozotocin-induced diabetic rats. Biol Pharm Bull. 40: 1846-1855.
51. Chung SI, Jin X, Kang MY. (2019). Enhancement of glucose and bone metabolism in ovariectomized rats fed with germinated pigmented rice with giant embryo (Oryza sativa L. cv. Keunnunjami). Food Nutr Res. 63.
52. Kawana H, Ihara M, Sato M, Masumi H, Arita M. (2003). Effect on lipid and fatty acid composition in serum of female university students dieting pregerminated brown rice. Bul Tokyo Kasei Univ. 43: 33-37.
53. Miura D, Ito Y, Mizukuchi A, Kise M, Aoto H, et al. (2006). Hypocholesterolemic action of pre-germinated brown rice in hepatoma-bearing rats. Life Sciences. 79: 259-264.
54. Roohinejad S, Omidizadeh A, Mirhosseini H, Saari N, Mustafa S, et al. (2010). Effect of pre-germination time of brown rice on serum cholesterol levels of hypercholesterolaemic rats. J Sci Food Agri. 90: 245-251.
55. Yen HW, Lin HL, Hao CL, Chen FC, Chen CY, et al. (2017). Effects of pre-germinated brown rice treatment high-fat diet-induced metabolic syndrome in C57BL/6J mice. Biosci Biotechnol Biochem. 81: 979-986.
56. Choi HD, Kim YS, Choi IW, Park YK, Park YD. (2006). Hypotensive effect of germinated brown rice on spontaneously hypertensive rats. Korean J Food Sci Technol (Korean). 38: 448-451.

57. Hiroko E, Mika I, Masanobu A. (2006). Antihypertensive effect of pre-germinated brown rice in spontaneously hypertensive rats. J Soc Brewing Jap. 100: 581-587.

58. Chung SI, Lee SC, Yi SJ, Kang MY. (2018). Antioxidative and antiproliferative activities of ethanol extracts from pigmented giant embryo rice (Oryza sativa L. cv. Keunnunjami) before and after germination. Nutr Res Pract. 12: 365-370.

59. Kawabata K, Tanaka T, Murakami T, Okada T, Murai H, et al. (1999). Dietary prevention of azoxymethane-induced colon carcinogenesis with rice-germ in F344 rats. Carcinogenesis. 49: 2109-2115.

60. Park HJ, Park JB, Lee SJ, Song M. (2017). Phellinus linteus grown on germinated brown rice increases cetuximab sensitivity of KRAS-Mutated colon cancer. Internat J Mol Sci. 18: 1746.

61. Saki E, Yazan LS, Ali RM, Ahmad Z. (2017). Chemopreventive effects of germinated rough rice crude extract in inhibiting azoxymethane-induced aberrant crypt foci formation in Sprague-Dawley rats. Biomed Res Int. 2017: 1-8.

62. Mamiya T, Asanuma T, Kise M, ItoY, Mizukuchi A, et al. (2004). Effects of pre-germinated brown rice on beta-amyloid protein-induced learning and memory deficits in mice. Biol Pharm Bull. 27: 1041-1045.

63. Mamiya T, Kise M, Morikawa K, Aoto H, Ukai M, et al. (2007). Effects of pre-germinated brown rice on depression-like behavior in mice. Pharmacol Biochem Behav. 86: 62-67.

64. Chaiyasut C, Sivamaruthi BS, Pengkumsri N, Keapai W, Kesika P, et al. (2017). Germinated Thai black rice extract protects experimental diabetic rats from oxidative stress and other diabetes-related consequences. Pharmaceuticals (Basel). 10: 3.

65. Lattimer JM, Haub MD. (2010). Effects of dietary fiber and its components on metabolic health. Nutrients. 2: 1266-1289.

66. Rong N, Ausman LM, Nicolosi RJ. (1997). Oryzanol decreases cholesterol absorption and aortic fatty streaks in hamsters. Lipids. 32: 303-309.

67. Chau CF, Huang YL, Lin CY. (2004). Investigation of the cholesterol-lowering action of insoluble fibre derived from the peel of Citrus sinensis L. cv. Liucheng. Food Chem. 87: 361-366.

68. Lo LMP, Kang MY, Yi SJ, Chung SI. (2016). Dietary supplementation of germinated pigmented rice (Oryza sativa L.) lowers dyslipidemia risk in ovariectomized Sprague–Dawley rats. Food Nutr Res. 60: 30092.

69. Sri BM, Rukkumani R, Menon VP. (2003). Protective effects of ferulic acid on hyperlipidemic diabetic rats. Acta Diabetolo. 40: 118-122.

70. Ardiansyah, Shirakawa H, Koseki T, Ohinata K, Hashizume K, et al. (2006). Rice bran fractions improve blood pressure, lipid profile, and glucose metabolism in stroke-prone spontaneously hypertensive rats. J Agri Food Chem. 54: 1914-1920.

71. Watanabe S, HirakawaA, Nishijima C, Ohtsubo KI, Nakamura K, et al. (2016). Food as medicine: the new concept of “Medical Rice”. Adv Food Sci Tech. 2: 38-50.

72. Diaz MN, Frei B, Vita JA, Keaney JF. (1997). Antioxidants and atherosclerotic heart disease. N Eng J Med. 337: 408-416.

73. Geovanini GR, Libby P. (2018). Atherosclerosis and inflammation: overview and updates. Clin Sci (Lond). 132: 1243-1252.

74. Yasukawa K, Akihisa T, Kimura Y, Tamura T, Takido M. (1998). Inhibitory effect of cycloartenol ferulate, a component of rice bran, on tumor promotion in two-stage carcinogenesis in mouse skin. Biol Pharmaceut Bul. 21: 1072-1076.

75. Hudson EA, Dinh PA, Kokubun T, Simmonds MS, Gescher A. (2000). Characterization of potentially chemopreventive phenols in extracts of brown rice that inhibit the growth of human breast and colon cancer cells. Cancer Epidemiol Biomarkers Prevent. 9: 1163-1170.

76. Lin PY, Li SC, Lin HP, Shih CK. (2018). Germinated brown rice combined with Lactobacillus acidophilus and Bifidobacterium animalis subsp. lactis inhibits colorectal carcinogenesis in rats. Food Sci Nutr. 7: 216–224.

77. Azmi NH, Ismail M, Ismail N, Imam MU, AlitheenNBM, et al. (2015). Germinated brown rice alters Aβ(1-42) aggregation and modulates Alzheimer’s disease-related genes in differentiated human SH-SY5Y cells. Evidence-based Complementary Alternative Medicine. 2015: 1-12.

78. Huang YH, Bergles DE. (2004). Glutamate transporters bring competition to the synapse. Curr Opin Neurobiol. 14: 346-352.
79. Azmi N H, Ismail N, Imam MU, Ismail M. (2013). Ethyl acetate extract of germinated brown rice attenuates hydrogen peroxide-induced oxidative stress in human SH-SY5Y neuroblastoma cells: role of anti-apoptotic, pro-survival and antioxidant genes. BMC Complement Altern Med. 13: 177.
80. Kim MJ, Choi SJ, Lim ST, Kim HK, Heo HJ, et al. (2007). Ferulic acid supplementation prevents trimethyltin-induced cognitive deficits in mice. Biosci Biotechnol Biochem. 71: 1063-1068.
81. Kurita O, Nakabayashi T, Fukukawa M, Tsubouchi K. (2004). High alcohol sake production tests with the use of roasted germinated brown rice. J Soc Brewing Jap. 99: 474-480.
82. Sakamoto S, Hayashi T, Hayashi K, Murai F, Hori M, et al. (2007). Pre-germinated brown rice could enhance maternal mental health and immunity during lactation. Eur J Nutr. 46: 391-396.
83. Kawana H, Ihara M, Itoh Y, MizukuchiA, Ohnishi M, et al. (2005). Effects of pre-germinated brown rice diet on skin condition in female university students. J Integrated Study Dietary Habits.16: 108-113.
84. Hu X, LiuY, Liu J, Li Y. (2012). Effect of enzyme on cortex structure of germinated brown rice. Cereal Feed Indust (Chinese). 8: 30-32.
85. Han Y, Liu G, Shi X, Liu J, Li B, et al. (2010). Effect of extrusion on physicochemical properties of germinated brown rice. J Chin Cereals Oils Assoc (Chinese). 25: 1-5.
86. Ma T, Lu J. (2012). Improving the dispensability of extrusion brown rice powder. Food Industr Technol (Chinese). 33: 277-279.
87. Yu S, He Y, Ma L. (2012). Processing technology of germinated brown rice bread. Acad Periodic Farm Prod Process. 2: 34-38.
88. Casper JL, Atwell WA. (2014). Gluten-Free Baked Products. AACC International Inc. St. Paul. MN.
89. Liu K, Wang J, Yu X, Zhang Z. (2013). Research on lactobacillus beverage of germinated brown rice. Cereal Feed Industry (Chinese). 3: 30-33.
90. Sun J, Liu K, Ning XU, Han L, Bai Y, et al. (2016). Development of compound beverage of germinated brown rice with green tea. Cereal Feed Industr (Chinese). 12: 51-54.
91. Wang L, Duan W, Qian HF, Zhang H, Xi-Guang QI. (2016). Research status and development trend of brown rice food. Food Ferment Industr (Chinese). 42: 236-243.
92. Hou LJ, Qiu ZC, Wang JL, Tang FL, Liu D, et al. (2016). Research on brown rice enzyme produced by saccharomycetes fermentation. Heilongjiang Sci (Chinese). 7: 6-7.
93. Xiao L, Yan J, Wu D. (2007). Study on the production of germinated brown rice wine by bilateral fermentation. Food Industr Technol (Chinese). 28: 153-155.
94. Wei J. (2012). Fermentation technology and product index analysis of wine fermented by brown rice and sprout brown rice (Thesis, Chinese). Northeast Agricultural University. Helongjiang, China.
95. Kaukovirta-Norja A, Wilhelmson A, Poutanen, K. (2004). Germination: a means to improve the functionality of oat. Agri Food Sci. 13: 100-112.