A Comprehensive Review on Functional Properties of Fermented Rice Bran

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ABSTRACT
A predominant by-product of rice processing is rice bran (RB). The phytochemical composition of the RB varied among the cultivars. RB is rich in oil, phenolic compounds, polysaccharides, proteins, and micronutrients along with more than 100 known antioxidants and bioactive phytonutrients. The crude and purified RB extracts were used in pharmacological, cosmeceuticals, and food industries. Fermentation process improved the phytochemical constituents and enhanced the bioactivity of RB. The fermented RB (FRB) has been reported for the enhanced antioxidant, anti-cancer, and anti-inflammatory bowel diseases, anti-diabetes activities, etc., FRB is used as potent animal feed, especially in poultry industries. RB bioactive principles were studied for their potential application in anti-aging treatments, and cosmetics. The current manuscript summarizes the changes in the phytochemical content of RB during the fermentation process and functional property of FRB.

Key words: Antioxidants, fermented rice bran, phytochemicals, rice bran

INTRODUCTION
Fermentation, a chemical process mediated by microbes that break down substances, is one of the ancient methods to preserve food with more than 6000 years of history.1 Fermentation is the critical process for making bread, cheese, and alcoholic beverages, etc., In addition to preservation, fermentation process enhances the availability of nutrients, texture, taste, and increases the flavor of foods. The microbes involved in fermentation produces inhibitory compounds, such as organic acids, ethanol, short-chain fatty acids (SCFAs), and bacteriocins, which prevent the growth of contaminating microorganisms.2 Several studies have focused on the health benefits of fermented foods, especially on gastrointestinal tract health and nutrient absorption. Recent studies proved that the supplementation of fermented foods improved the health status of type 2 diabetes, impaired glucose metabolism, obesity, irritable bowel syndrome, hyperlipidemia, hypertension, osteoporosis, etc.3-9

One of the amplest and treasured byproducts of rice processing is rice bran (RB). RB is governing natural source for several phytochemicals One of the predominant by-product of rice processing is rice bran (RB). The phytochemical composition of the RB varied among the cultivars. RB is rich in oil, phenolic compounds, polysaccharides, proteins, and micronutrients along with more than hundreds of known antioxidants and bioactive phytonutrients, such as γ-oryzanol, B Vitamins, tocotrienols, minerals, phytosterols, polyphenols, and trace minerals including zinc, selenium, magnesium, omega-3 fatty acids, and Vitamin E. Several studies have been proved that the phytochemicals in RB could enhance the immune system.10 The current review paper summarizes the changes in the phytochemical content of RB during the fermentation process and functional property of fermented RB (FRB).

CHANGES IN THE COMPOSITION OF RICE BRAN
RB accounts for 5%-8% of the total weight of rice grain. RB contains 11%-13% of crude protein, ~11.5% of fibers, and about ~20% of the oil.11,12 The RB oil contains fatty acids, waxes, monocacylglycerols, diacylglycerols, triacylglycerols, triterpene alcohols, tocotrienols, tocopherols, and sterols. About 31%-33% linoleic, 37%-42% oleic, and 21%-26% of palmitic acids are present in RB oil.11,13

Rhizopus oryzae mediated solid state fermentation altered the lipid content of RB. About 9% of the reduction in lipid content was recorded after 120 h of fermentation while phospholipids were found to be increased. There was no significant alternation in linoleic, oleic, and palmitic acids. About 20% reduction was observed in saturated fatty acids while unsaturated fatty acids were increased up to 5%.13 Another report proved that fermentation of RB with R. oryzae CTT 7560 enhanced the total phenolic compounds and free radical scavenging property. The protein recovery from RB was also increased after fermentation.14 R. oryzae CTT 1217, strain isolated from RB, has been used for the solid-state fermentation of RB and the phychochemical changes and antioxidant property were evaluated. The results showed that the fermentation of RB by R. oryzae CTT 1217 improved the total phenolic compounds, and free radical scavenging ability. Methanol and aqueous extract of FRB also showed the antioxidant property.15 The total phenolic content of RB was found to be increased after Monascus purpureus and Rhizopus oligosporus mediated fermentation. The phenolic acids such as 4-hydroxybenzoic,

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caffeic, syringic, ferulic, vanillic, and sinapic acids were increased in the methanol extract of FRB. The antioxidant capacity of RB has also been enhanced by fungal fermentation.\textsuperscript{[16]} M. purpureus strain F0061 mediated fermentation has not significantly altered the total phenolic content, whereas antioxidant capacity was increased considerably. The phenolic acids such as caffeic, syringic, ferulic, vanillic, and sinapic acids were increased dramatically after the fermentation of RB with M. purpureus.\textsuperscript{[21]}

Separate fermentation of RB with Aspergillus oryzae and R. oligosporus enhanced the total phenolic content from 1.66 ± 0.61 to 7.96 ± 0.18, and 7.22 ± 0.28 mg gallic acid equivalent/g of the sample, respectively. A. oryzae mediated fermentation increased the concentration of caffeic, syringic, ferulic, protocatechuic, and sinapic acids in RB after 12 days of fermentation. Similarly, R. oligosporus mediated fermentation increased the level of 4-hydroxybenzoic and caffeic acids in RB. Both, A. oryzae and R. oligosporus mediated fermentation of RB showed greater antioxidant capacity in ferric reducing/antioxidant power (FRAP) assay.\textsuperscript{[18]} R. oryzae mediated fermentation decreased the reducing sugars (60%), and phytic acid (50%), fat (40%) content of RB while increasing the proteins (40%) and fibers (50%) content.\textsuperscript{[10]} Jung et al.\textsuperscript{[20]} evaluated the changes in total phenolic content, β-glucan, and γ-oryzanol, of FRB of 21 different Korean rice varieties, and found that fermented (Lentinula edodes mediated fermentation) RB of the cultivar Haedam showed increased total phenolic content with bioactivity improvement. Migwang RB exhibited the highest γ-oryzanol content after fermentation with L. edodes.

Lactic acid bacteria (Lactococcus lactis, Pediococcus pentosaceus, and Pediococcus acidilactici) mediated solid state fermentation of RB improved α-tocopherol content. P. acidilactici mediated simultaneous saccharification and fermentation (SSF) of RB increased the γ-oryzanol content. The total phenolic content of FRB was also altered compared to unFRB, and ferulic acid concentration was found to be increased in P. acidilactici mediated SSF of RB. During fermentation, increased level of organic acids was observed due to lactic acid bacteria mediated fermentation. Authors also observed the improvement in the antioxidant capacity of RB after fermentation for 48 h. \textsuperscript{[21]} Heat-stabilized defatted RB (HSDRB) has been reported as a possible source of bioactive phenolic compounds with several claimed health benefits. The fermentation of HSDRB by Bacillus subtilis subspecies subtilis release 26.8 mg (ferulic acid equivalents/g of sample) of phenolic compounds. About 96 h of fermentation process significantly improved the total phenolic content (–)-epicatechin, caffeic, syringic, ferulic, gentistic, sinapic, benzoic, and p-coumaric acids) and free radical scavenging activity.\textsuperscript{[22]}

Preussia aemulans mediated fermentation of RB displayed a significant increase in nucleoside, protein, amino acid, and phenolic contents.\textsuperscript{[23]} Fermentation of RB with M. pilosus KCCM660084 increased the total flavonoid content up to 4.58-fold.\textsuperscript{[24]}

Gas chromatography-mass spectrometry analysis revealed that galactose, palmitic acid, and α-linolenic acid content was reduced, and xylitol, alanine, phosphoric acid, and 1,2,3-propanetricarboxylamic acid content were increased in Saccharomyces boulardii FRB of Neptune rice cultivars (PI 655959), while glucitol was detected only after fermentation. Likely, palmitic acid was detected in the RB of Red Wells cultivar after the fermentation by S. boulardii. The results indicated that the fermentation process could introduce new active principle in the FRB, which could enhance the protective nature of the RB phytochemicals.\textsuperscript{[23]} Yeast fermentation improved protein content (up to 6.77%), and total amino acid content of the RB (cultivar MR 219).\textsuperscript{[26]} However, Saccharomyces cerevisiae mediated fermentation did not significantly alter the phytochemical content of Thai black RB, whereas the free radical scavenging activity was augmented slightly.\textsuperscript{[27]} Thus, the significant positive changes in chemical composition RB desperately depends on the strain used for fermentation.

The phenolic acids such as gallic, protocatechuic, chlorogenic, p-hydroxybenzoic, caffeic, syringic, vanillic, and ferulic acid content were found to be changed in RB after R. oryzae mediated fermentation. More significantly, gallic (2.6 ± 0.8–154.5 ± 6.0 mg/g of dry weight) and ferulic acid (33.3 ± 2.3–764.7 ± 32.0 mg/g of dry weight) content was found to be increased after 120 h of fermentation.\textsuperscript{[28]} A. oryzae and R. oryzae mediated FRB showed an increase in ferulic acid (43.2 ± 4.9 μg/ml), and organic acid, especially citric acid (214.6 ± 12.1 mg/g) content.\textsuperscript{[59]}

**FUNCTIONAL PROPERTIES OF FERMENTED RICE BRAN**

**Antioxidant property**

Grifola frondosa mediated fermented defatted RB water extract (GFDRBE) (1 mg/ml) exhibited a significant increase in hydroxyl radical scavenging activity, which is comparable to ascorbic acid (positive control). Nine fermented extracts displayed reduced effective concentration (EC\textsubscript{50}) value of 0.31 mg/ml when compared to unfermented samples (EC\textsubscript{50} = 0.38 mg/ml). About 87.85% of 2,2-diphenyl-1-picrylhydrazyl (DPPH) scavenging ratio was attained at 2.0 mg/ml of GFDRBE whereas unfermented sample exhibited only 56.2% of DPPH scavenging activity. Similarly, the EC\textsubscript{50} value of GFDRBE (0.6 mg/ml) in DPPH was significantly reduced when compared to unfermented sample (1.17 mg/ml). Nitric oxide (NO) production was also significantly decreased by GFDRBE at low concentration (50–100 μg/ml) while increasing the NO production at high concentration (200–400 μg/ml) of GFDRBE. The concentration-dependent regulation of NO production by GFDRBE could be used to activate the macrophages or to neutralize the over production of NO.\textsuperscript{[10]}

R. oryzae FRB showed <50% of inhibition of DPPH free radical at the concentration of 0.1 mg/ml. The EC\textsubscript{50} value of the FRB extract (250 ± 4 mg of antioxidant per gram of DPPH) was slightly similar to the value of ferulic acid (235 ± 4 mg of antioxidant per gram of DPPH) and unFRB extract (213 ± 10 mg of antioxidant per gram of DPPH), whereas the EC\textsubscript{50} values were lower than the reported EC\textsubscript{50} values for white RB extract, onion, and cardamom extracts. Whereas, R. oryzae FRB exhibited potent peroxidase enzyme inhibition activity.\textsuperscript{[28]}

M. purpureus, R. oligosporus, M. purpureus + R. oligosporus FRB showed a significant increase in antioxidant activity (FRAP assay). The water extract of unfermented, M. purpureus, R. oligosporus, M. purpureus + R. oligosporus FRB showed the antioxidant activity of 30.22 ± 9.57, 61.21 ± 4.50, 116.33 ± 4.74, and 144.03 ± 10.12 mg ascorbic acid equivalent (AAE) per gram of sample, respectively. The methanol extract of unfermented, M. purpureus, R. oligosporus, M. purpureus + R. oligosporus FRB showed the antioxidant activity of 30.93 ± 3.80, 80.68 ± 1.07, 61.44 ± 0.98, and 74.75 ± 1.18 mg AAE/g sample, respectively. Whereas, the percentage of radical scavenging activities (DPPH) of water and methanol extracts of FRB was not altered significantly.\textsuperscript{[14]}

An active radical scavenging property on the DPPH radical was observed in P. acidilactici FRB. The DPPH radical scavenging activity of RB was reported to be 82.6% after fermentation with P. acidilactici, whereas, RB fermented with P. pentosaceus and L. lactis exhibited 71.5% and 77.2% of activity, respectively.\textsuperscript{[21]}

A mixture of RB, Actinidia deliciosa (kiwifruit) and Laminaria Japonica (seaweed) were fermented by effective microbes showed an incredible increase in antioxidant activity determined by FRAP assay.\textsuperscript{[31]} The fermentation of RB with R. oryzae exhibited 87% of DPPH...
radical scavenging property. The solid-state fermentation of RB with *M. pilosus* KCCM60084 showed 38%, 80%, and 60% increase in ABTS + radical scavenging activity, iron chelating activity, and reducing power, respectively. RB fermented with *R. oryzae* CTT 1217 has been kinetically analyzed for the improvement of the antioxidant property. 96 h FRB exhibited about 50% of DPPH radical scavenging activity after 15 min of reaction. The methanol extract of FRB was incubated with olive oil to determine the peroxidase activity. About 60% of peroxidase inhibition was observed after 21 days of incubation, whereas 30 days of incubation showed only 34%. Naturally FRB protein concentrate (NFRBPC), yeast-FRB protein concentrate (YFRBPC), and unFRB concentrate (UFRBPC) exhibited 55.29%, 58.62%, and 47.14% of DPPH radical scavenging activity, respectively. The ferric reducing ability of NFRBPC, YFRBPC, and UFRBPC were 0.58, 0.73, and 0.41 mmol Trolox equivalent per gram of sample, respectively. Jung et al. reported the changes in the antioxidant capacity of *L. edodes* mediated FRB of 21 different rice cultivars of Korea. FRB of cultivars *Segeyjinmi, Chindeul, Seolgaeng, Sunpum, Heonpum, Haedam, Chujum, Wolbaek, O. sativa cv. Haepum, Danmi, Gooami2, Dasan1, Misomi, Ilpum, Migwang, Jungsanggold, and Haai* displayed improvement in DPPH radical scavenging activity and the FRB of all 21 Korean cultivars exhibited increased oxygen radical absorbance capacity. *B. subtilis* fermented HSDRB showed an increase in antioxidant activity after 96 h of the fermentation process when compared to that of the unfermented control sample. Authors claimed that the improvement of antioxidant activity was attributed to an enzyme produced by the fermenting organism. Oxidative inhibition rate was reduced sharply during the 1st 50 h of fermentation. The aqueous extract of *Issatchenkia orientalis* MFST1 mediated FRB was reported to be effective against high glucose and hydrogen peroxide-induced oxidative stress in 3T3-L1 adipocytes. FRB exposure significantly suppressed the reactive oxygen species formation and induced adiponectin and peroxisome proliferator-activated receptor gamma expression. The results revealed that FRB exposure diminishes the oxidative stress-induced insulin resistance. ANTI-CANCER AND ANTI-INFLAMMATORY BOWEL DISEASES PROPERTIES A series of studies on the anti-cancer property of brown rice and RB fermented by *A. oryzae* has been published. *A. oryzae* mediated fermented brown rice, and RB (AFBRRB) significantly suppressed the azoxymethane mediated aberrant crypt foci formation in the rat. About 5% of AFBRRB reduced the incidence and inhibit the cell proliferation in colon adenocarcinomas. AFBRRB has also been reported for the protective effect against diethylnitrosamine and phenobarbital induced hepatocarcinogenesis in male F344 rats. N-nitrosomethylbenzylamine-induced esophageal tumorigenesis development was inhibited by AFBRRB supplementation. The incidence and multiplicity of dysplasia were significantly decreased by AFBRRB (10%) supplementation. Another study with AFBRRB revealed that the protective effects of AFBRRB against inflammation-related carcinogenesis in mice were through inhibition of inflammatory cell infiltration. N-nitrosobis (2-oxopropyl) amine-induced pancreatic tumorigenesis in hamsters has also been suppressed by AFBRRB (10%) supplementation via reduction of proliferation rate of tumor cells. The anti-carcinogenesis effect of AFBRRB was demonstrated using transgenic rat for adenocarcinoma of the prostate (TRAP). TRAP model was fed with AFBRRB for 15 weeks. AFBRRB supplementation reduced the rate of adenocarcinoma in the lateral prostate, and also reduced the development of prostate carcinogenesis. It is observed that the AFBRRB supplementation induces the cell death and inhibit the proliferation of cells. The suppression of tumor growth depends on the phospho-adenosine monophosphate-activated kinase regulation by AFBRRB. The chemoprotective effect of AFBRRB through the suppression of cell proliferation was reported against 4-nitroquinoline 1-oxide-induced oral carcinogenesis, N-methyl-N'-nitro-N-nitrosoguanidine-induced gastric carcinogenesis, and regulation of inflammatory system was reported against azoxymethane-induced colorectal carcinogenesis in rat models. The aqueous extract of AFBRRB powder was evaluated for its anti-cancer activity in human acute lymphoblastic leukemia Jurkat cells. AFBRRB extract reduced the viability of leukemia, which is attributed to DNA fragmentation. The cleavage of caspase-8, -9, and -3 was accelerated by AFBRRB extract exposure and also reduced the B-cell lymphoma-2 (Bcl-2) expression while inducing the Death receptor-5 (DR5), Fas (tumor necrosis factor receptor) and pro-apoptotic protein (Bid) expression. The results suggested that AFBRRB extract activates the death receptor-mediated pathway to suppress the multiplication of human acute lymphoblastic leukemia cells. A. oryzae, *L. rhamnosus*, and *S. cervisiae* mediated FRB, and its aqueous extract FRB extract (FRBE) were evaluated for melanoma inhibition property. Fermentation process reduces the cytotoxicity of RB. FRBE suppressed the α-melanocyte stimulating hormone-induced melanin synthesis in B16F1 cells and also reduced the intracellular tyrosinase activity. Microphthalmia-associated transcription factor expression was significantly diminished by FRBE. Thereby, FRBE suppresses the development of melanoma. Exo-biopolymer isolated from *Lentinus edodes* FRB showed anti-cancer activity in B16/B16 melanoma transplanted mice via natural killer cell activation. RB was fermented by *S. cervisiae* Misaki-1 and *L. plantarum* Sanriki-SU8 for 2 days at 30°C, and then FRB was subjected to aqueous extraction. The protective effect of FRB extract was evaluated using sodium sulfate-induced inflammatory bowel disease model mice. The spleen enlargement, structure of the crypt, and submucosa of colon tissues were reduced in FRB extract treated group when compared to control. The fermentation process improved the anti-inflammatory property of RB. Heating process diminishes the bioactivity of FRB extract. The anti-colitis property of *Aspergillus kawachii*, *L. brevis*, *L. rhamnosus*, and *Enterococcus faecium* FRB was assessed using dextran sodium sulfate-induced colitis mice model. Colitis-induced mice were supplemented with FRB, and the changes in body mass, disease activity index (DAI), histopathology score, myeloperoxidase (MPO) activity, the expression pattern of cytokine and chemokines, and the production of SCFAs and mucin were evaluated. FRB supplementation improved the weight gaining process and reduced the DAI. The total inflammation, crypt cell damage, epithelial loss, and infiltration of inflammatory cells was significantly reduced in FRB supplemented mice when compared to that of the control, and raw RB supplemented group. MPO activity and thiobarbituric acid reactive substance were reduced on FRB treatment in colitis-induced mice. The mRNA analysis revealed that FRB supplementation suppresses the expression of pro-inflammatory cytokines (Tnf-α, Il-6, and Il-1 β), chemokines (Ccl2 and Cxcl1), and its receptor gene (Ccr3). The feces SCFAs level was increased in FRB treated group. ANTI-DIABETIC PROPERTY Lim and Lee prepared *Bacillus* sp. KS-25, *B. circulans* KS-80, *B. licheniformis* KS-30, *B. sonorenensis* KS-33, and *B. subtilis* KS-29 fermented materials (FM) that mainly contains RB, soybean powder, and the anti-diabetic property of FM was evaluated in type 2 diabetes mice.
model. The experimental animals fed with FM for 10 weeks showed a reduction in serum glucose, triglyceride, and HbA1c level. The glucose uptake was raised up to 60% after the treatment using ethanol extract of FM in C2C12 cells, and also activates insulin signaling process by

### Table 1: Other functional properties of fermented rice bran

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<th>Interventions and dose</th>
<th>Microbes used for fermentation</th>
<th>Observed results</th>
<th>General claimed property</th>
<th>Reference</th>
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<tr>
<td>EM-YU (fermented mixture of RB, seaweed, and kiwifruit)</td>
<td>Effective microbes (strains details not available)</td>
<td>Fermented RB broth showed antibacterial activity against <em>P. aeruginosa</em> PAO1, and <em>E. coli</em> O157:H7 and exhibited tyrosinase inhibition activities. Ethyl acetate extract of EM-YU showed anti-biofilm activity against <em>E. coli</em> O157:H7</td>
<td>Antibacterial, tyrosinase inhibition, and anti-biofilm property</td>
<td>[31]</td>
</tr>
<tr>
<td>Aqueous extracts of FRB; 1.5 and 3 g/kg at day 7 and 21.</td>
<td><em>Issatchenka orientalis</em> MFST1</td>
<td>Inhibit the formation of thiobarbituric acid reacting substance. The results suggested that FCSRE could prevent atherosclerosis</td>
<td>Anti-atherogenic effects</td>
<td>[57]</td>
</tr>
<tr>
<td>Hot water extract of FRB</td>
<td><em>S. cerevisiae</em></td>
<td></td>
<td></td>
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<tr>
<td>FRB extract with plants (A. gigantis Radix, A. princeps, C. sinensis, and C. officinale)</td>
<td><em>L. rhamnosus</em>, <em>P. deserticola</em></td>
<td>FRB withdrew collagen-induced platelet aggregation and attenuates the formation of thrombus</td>
<td>Anti-thrombotic activity</td>
<td>[61]</td>
</tr>
<tr>
<td>FRB; 0.4% of FRB in normal diet for 8 weeks.</td>
<td><em>Bacillus</em> sp. (KCTC11351BP), <em>B. circulans</em> (KCTC11355BP), <em>B. sonorensis</em> (KCTC11354BP), and <em>B. subtilis</em> (KCTC11352BP)</td>
<td>FRB blocked the intracellular calcium mobilization and inhibits the stimuli-responsive kinase 1/2, p38-mitogen-activated protein kinases and c-Jun N-terminal kinase phosphorylation</td>
<td>Hepatoprotective property</td>
<td>[62]</td>
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<tr>
<td>FRB with <em>A. princeps</em>, <em>A. gigantis</em>, <em>C. sinensis</em>, and <em>C. officinale</em></td>
<td><em>L. rhamnosus</em> and <em>P. deserticola</em></td>
<td>Reduced the skin lesions in 1-chloro-2,4-dinitrobenzene-induced atopic dermatitis and serum IgE, and WBC count. FRB treatment significantly nullified the toxin-induced consequences of atopic dermatitis</td>
<td>Prevents atopic dermatitis</td>
<td>[63]</td>
</tr>
<tr>
<td>FRB; 100 mg per kg for 5 days</td>
<td><em>L. plantarum</em> NCIMB 8826</td>
<td>FRB supplementation showed 30% toxic incidence, 10% of mortality, and 40% of gastrointestinal mucosal pathology, while nonfermented RB showed 50%, 30%, and 50% of incidence, death, and mucosal pathology, respectively</td>
<td>Chemoproteective effect on doxorubicin-induced toxicity. Aid therapy for cancer treatment. Cytotoxic activities</td>
<td>[64]</td>
</tr>
<tr>
<td>Fermented black rice bran</td>
<td><em>B. subtilis</em> KU3</td>
<td>68.07% and 71.65% of cytotoxicity were observed against HeLa and MCF-7 cells, respectively</td>
<td>Protects liver from acute hepatitis</td>
<td>[65]</td>
</tr>
<tr>
<td>FRB; 5%-10% of FRB in diet</td>
<td><em>A. oryzae</em></td>
<td>The incidence of hepatitis was reduced. Survival period of the rat was extended</td>
<td></td>
<td>[66]</td>
</tr>
<tr>
<td>A mixture of FRB and <em>S. cerevisiae</em>; 20 g per kg per day for 7 days</td>
<td><em>S. cerevisiae</em>, <em>Bacillus</em> spp</td>
<td>No significant changes in serum Ca level Activates the macrophage and regulate IL-6 production, and increase the proliferation of bone marrow cells</td>
<td>Immune enhancer</td>
<td>[67]</td>
</tr>
<tr>
<td>FRB (Rice bran exo-biopolymer, RBEP); Six capsules per day for 8 weeks to healthy human subjects</td>
<td><em>Lentinus edodes</em></td>
<td>Increased the production of IFN-γ NK cell activity and TNF-α, IL-12, IL-4, IL-10, and IL-2 levels were not affected by FRB intervention</td>
<td>Immune enhancer</td>
<td>[68]</td>
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phosphorylating Akt (glucose transporter modulator). FM extract does not affect the insulin-independent signaling process while suppressing the negative signaling to the insulin pathway. The results suggested that FM extract increase glucose uptake through the activation of PI3kinase/Akt pathways.

RB was fermented with A. kawachii, and a blend of lactic acid bacteria (L. brevis, L. rhamnosus, and E. faecium) and the FRB was supplemented to stroke-prone spontaneously hypertensive SHRSP/1zm rats. The oral administration of 5% FRB for 4 weeks reduced the systolic and diastolic blood pressure and enhanced the serum adiponectin level. Besides, FRB intervention amended serum insulin levels, insulin sensitivity, glucose tolerance, and lipid profiles. The results suggested that the dietary supplementation of FRB may reduce hyperglycemia and complications of metabolic syndrome. A. oryzae fermented soybean, brown rice, brown rice and RB paste, and brown rice-red ginseng marc was investigated for the influence of glucose metabolism in high-fat diet mice model. The high fat-induced hyperglycemic condition was reduced with the supplementation of fermented paste. The hepatic glucose-regulating enzyme activities were altered by the fermented paste. Even though fermented brown rice and RB showed anti-hyperglycemic property, the fermented brown rice-red ginseng marc exhibited improved hypoglycemic and antioxidative activities.

**COSMETICS**

RB was fermented with A. oryzae, R. oryzae, and R. oligosporus separately. Then the fermented samples were extracted with an aqueous solution. The phytochemical content and enzyme inhibitory activity of the fermented extracts were evaluated. Tyrosinase (tyrosinase inhibition prevents the hyperpigmentation in the skin) and elastase inhibition activities (helps to claim the anti-aging property of the extract) were examined to assess the skincare properties of extracts. A. oryzae FRB showed about 56, and 60% of tyrosinase, and elastase inhibition, respectively. Researchers appealed that the FRB could be a potent cosmeceutical ingredient for skincare products.

RB fermented with S. cerevisiae, and L. rhamnosus has been studied for anti-photoaging properties. FRB showed inhibition of melanin synthesis in B16F1 melanoma cells. Ultraviolet (UV)-B irradiated human fibroblasts were exposed to different concentration of FRB and found that FRB supplementation increase the type I collagen synthesis, reduced the matrix metalloproteinase-1 expression, and inhibited the IL-1β production. The results suggested that the FRB could protect the UV-B mediated skin damages.

**ANIMAL FEED**

The naturally FRB was microbiologically evaluated, and the active strains, R. oligosporus, and S. cerevisiae were selected for specific fermentation. The fermentation of RB has enhanced the nutritional value, especially protein content, and digestibility of fiber. The FRB has been claimed as a health feed for the rabbit. RB fermented with A. niger for 72 h was enriched with dry matter, crude protein, organic matter, and nitrogen retention, which can be used as poultry feed. RB used in phytase production has been extracted, and the crude used RB was supplemented to the broiler chickens, and the impacts were evaluated. Chicken fed with RB does not show any significant difference in body mass, growth rate, and feed intake. The supplementation of by-product (used RB) of phytase production did not cause any adverse effects to broiler chicken, and it can be used as an alternative feed for poultry. Bacillus amyloliquefaciens mediated fermentation of RB with hemic substances condensed crude fiber content of RB, and one-day-old chicks were fed with different concentrations (0%–20%) of FRB along with the normal feed. Supplementation of FRB (15%) in the regular diet for chicks improved the feed conversion ratio, and weight gain, significantly.

Hot water extract of S. cerevisiae and Bacillus sp. mediated FRB was supplemented as feed additives to rats and found that the FRB supplementation improved the immune system and reduced the stress level. Supplementation of FRB improved the total free amino acid content, taste, flavor, aroma, and juiciness of the pork.

**OTHER FUNCTIONAL PROPERTIES**

FRB prepared with various microbial action were reported for several health promoting and chemoprotective properties such as anti-atherogenic, anti-allergic, anti-stress, anti-fatigue, anti-thrombotic, hepatoprotective, antibacterial, anti-biofilm, tyrosinase inhibition, prevents atop dermatitis, chemoprotective on doxorubicin-induced toxicity, cytotoxic activities on cancer cells, protects liver from acute hepatitis, and immune enhancer. FRB has also been reported as a potent prebiotic. Detailed information on the preparation of FRB, intervention, and observed results are listed in Table 1.

**CONCLUSION AND FUTURE PROSPECTUS**

The fermentation processes improved the phytochemical content and bioactivity of RB, especially the improvement in the antioxidant property. The microbes used in the fermentation processes played a critical role in the quality enhancement of RB. Bacillus strain (B. subtilis KU3) isolated from Kimchi, a traditional Korean food, decreased the anthocyanin and phenolic content of RB after fermentation. Moreover, DPPH radical scavenging activity and FRAP were reduced in FRB compared to non-FRB. Isolation and identification of compelling starter culture would extend the use of FRB. Further, in-depth studies are required to

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<td>FRB supplementation (21 g per day for two weeks and then for 12 weeks intermission and again 2 weeks ingestion) to healthy human subjects</td>
<td>A. oryzae</td>
<td>Showed prebiotic property in healthy adults, and FRB is safe for human consumption</td>
<td>Prebiotic effects</td>
<td>[69]</td>
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**Table 1: Contd..**
extract and characterize the active principles from the FRB that may provide the valuable active candidates for pharmacological and cosmetic applications.

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