Rice (*Oryza sativa*) is one of the most important cereal crops in the world. It is a dietary staple that provides the bulk of daily calories for many companion animals and humans. The bran fraction of rice is a nutrient-rich by-product that has been primarily used as a low-cost feed for livestock and a fiber source in pet food. This review highlights areas of research related to evaluating the health and dietary value for the inclusion of rice bran in food, in feeds, and as nutritional products for livestock, companion animals, and humans. Diverse rice varieties, as characterized by genetics, landraces, and morphology, are cultivated around the world. Although rice varieties have been extensively studied for distinct agronomic traits such as yield, many have not yet been thoroughly examined for differences in nutrient composition and bioavailability. Thus, our understanding of the differences in phytochemical contents of the bran among diverse rice varieties is limited. The purpose of the information reported here is to describe the bioactive components and health properties of rice bran that may differ among varieties and to indicate opportunities for development of rice bran as a value-added food ingredient and functional food for disease prevention and enhancement of animal health.

**Overview of Rice Processing**

By-products from processing of rice can include rice hulls, rice bran, rice polishings, and broken rice grains. Rice is harvested from fields in the form of paddy rice in which each kernel is fully enveloped by a tough, fibrous hull. After the rice is dried, the first stage of the milling process is removal of the hull, which yields brown rice. Next, the outer layer is removed from the brown rice kernels to yield white rice. The separated outer (brown) layer is designated as rice bran. More than 600 million metric tons (approx 661 million tons) of paddy rice is milled each year worldwide, which yields approximately 382 million metric tons (421 million tons) of brown rice that is further processed to yield approximately 337 million metric tons (372 million tons) of white rice for consumption by humans. This results in global production of approximately 60 to 68 million metric tons (66 to 74 million tons) of rice bran available for use in animal feed, pet food, or human food or that is discarded as waste (Figure 1). Rice mill feed is a mixture of all the by-products obtained from the milling of rice and contains approximately 60% hulls, 35% bran, and 5% polishings. When compared with the nutrient content of other cereal grains, rice bran provides a nutritious mixture of protein, lipids, energy, and minerals. However, a heat-stabilization step is required to prevent rice bran from spoiling. If the rice bran is not heat stabilized, a large fraction of it will be lost to oxidative rancidity.

Nutrition for companion animals has been driven by a fast-growing pet food industry that has typically paid attention to rice bran as a whole ingredient rather than through its contribution of phytochemicals. Rice bran is primarily used as a source of fiber and...
fat and may comprise up to 40% of dietary intake for pigs, cows, poultry, and dogs.3-7 Emerging research is devoted to bran extraction and enrichment for chemical constituents (eg, antioxidants and sterols) other than fat and fiber content.10 Because the rice genome has been sequenced,11,12 the extent to which genetically diverse rice cultivars can be evaluated for differences in bran chemical and nutrient composition (and thus their subsequent health implications) has expanded and may be used for integration into rice breeding programs.13 Studies of dietary rice bran intake in animals are limited and have not included an understanding of how genetic diversity might impact the nutritional value. Crop varietal differences in bioactive compounds from staple foods and the opportunity to improve crops for animal and human health have been recently described as biomedical agriculture.14 This emerging concept of assessing differences in nutrient content of rice varieties and their subsequent effects on health quality can also be applied to other food crops (eg, corn, wheat, and potatoes).15,16

**Paradigm Shift for Use of Rice Bran in Agriculture and Health Products**

Rice bran has a long history of use in livestock feed. The use of rice bran in chicken feed dates back to the early 1900s. Prior to the discovery of vitamins, it was recognized that laboratory chickens became ill when their feed was changed from unpolished brown rice to polished white rice.15 The potential of rice bran for improving companion animal and human health has been slow to evolve, and the development of rice bran as a medicinal food or dietary supplement is in its infancy. One factor that has contributed to the delayed development of rice bran as a major ingredient in human food is its short shelf life because of rancidity. Rice bran may undergo hydrolytic rancidity as a result of a lipase enzyme that resides on the seed coat and oxidation of the unsaturated fatty acids liberated from glycerol that are extremely susceptible to oxidation. These chemical reactions result in undesirable odors and flavors. However, exposure to high heat soon after the rice polishing process stabilizes the rice bran for dietary use.18

According to the USDA, crude rice bran contains 12% to 13% oil and 4.3% highly unsaponifiable components.1 White rice, brown rice, and rice bran are major ingredients in foods formulated for dogs; however, differences in nutrient and chemical contents among rice varieties and the importance to overall nutritional value for canine health are unknown. For example, investigators in 1 study1 assessed the effect of stabilized (full-fat) rice bran at 12% of a dry extruded dog food and reported that the diet was more palatable than a diet that included defatted rice bran. This study1 also supports that the inclusion of stabilized rice bran in diets with differing fat sources has no adverse effect on nutrient digestibility and does not change inflammatory immune mediators or fecal characteristics in healthy dogs. However, dietary rice bran fed to cats at 26% of the total diet reduced plasma and whole blood taurine concentrations.18 Because of possible differences in the rice variety and bran contents used in these studies, continued research on rice bran is warranted to produce dietary intake information that can be used by veterinary nutritionists and to inform pet food manufacturers. In addition to nutritional and chemical composition, the impact of the rice bran dose that is minimally required and maximally tolerated for sustaining or promoting optimal health in companion animals remains to be determined.

Rice bran is distinct from other cereal grains in its content of tocotrienols-tocopherols, γ-oryzanol, and β-sitosterol. This is important because there is an emerging body of evidence that indicates these constituents may contribute to decreased concentrations of total plasma cholesterol, triglycerides, and low-density lipoproteins as well as increased concentrations of high-density lipoproteins.20,21 Rice bran also contains soluble dietary fibers (eg, β-glucan, pectin, and gum) and ferulic acid from nonlignified cell walls. The USDA nutrient database values for crude rice bran are routinely used when formulating diets for animals; however, care should be exercised because these values may not account for differences across rice varieties.10,22 Furthermore, the USDA nutrient database does not provide information regarding phytochemical components (eg, antioxidants and fatty acids) that may have bioactivity for health promotion and disease prevention.

The unique combinations of lipids (eg, γ-oryzanol and tocopherols) and ratios of minerals (eg, calcium and phosphorus) found in rice bran have led companies to produce stabilized rice bran and rice bran oil nutritional products that are marketed to enhance health of humans and other animals. Animal health products may include stabilized rice bran or rice bran oil that are advertised to enhance energy and muscle condition or improve skin, coat, and digestion for horses. Health claims of rice bran nutritional supplements for humans are largely related to reports of lipid-lowering effects and cardiovascular benefits.21-25 Continued investigation of the effects of rice bran in animal species is warranted to substantiate the long-standing historical use of rice bran for animal health as well as the more recent claims for human health and disease prevention.

A company3 that manufactures rice bran nutritional products entered the market in 2004 with a proprietary technology for stabilizing rice bran. That company produces rice bran foods and dietary supplements for humans and nutritional products for animals, converting several million tons of what was once agricultural waste rice bran into new products. As few as 10 years ago, this rice bran was sold for minimal value for use as animal feed or it was discarded as waste. Use of rice bran foods and nutritional products should continue to grow as additional information is gained on the effects of these products on the health of humans and animals.

**Terms Associated with Use of Dietary Rice Bran**

The ability to effectively communicate scientific evidence that supports health claims and properties of rice bran can sometimes be misleading because of the wide range of applications for dietary consumption by humans and domestic animals. Specific activities of rice bran with biomedical importance may...
not be tested for a particular disease or health status; therefore, terms can be imprecisely applied. The language used to summarize nutritional intervention studies of rice bran for health may have a powerful influence on the interpretation of effects and outcomes. Therefore, the following terms and their definitions are important:

- **Ingredient**: a substance that forms part of a mixture.
- **Animal feed**: compound-commercial pelleted food produced in a feed mill and fed to domestic livestock or fodder-food (including plant material cut or removed) provided to domestic livestock.
- **Nutrient**: food or chemicals that an organism needs to live and grow or a substance used in an organism’s metabolism that must be taken in from its environment. Organic nutrients include carbohydrates, fats, proteins (or their building blocks [i.e., amino acids]), and vitamins. Inorganic chemical compounds include minerals. Water and oxygen may also be considered as nutrients. A nutrient is essential to an organism if it cannot be synthesized by the organism in sufficient quantities and must be obtained from an external source.
- **Food**: any substance or material eaten to provide nutritional support for the body or for pleasure that consists of plant or animal origin and is ingested and assimilated by an organism to produce energy, stimulate growth, and maintain life.
- **Functional food or medicinal food**: any food claimed to have a health-promoting or disease-preventing property beyond the basic function of supplying nutrients. This category applies to both humans and other animals. It may include processed foods, foods fortified with additives (e.g., vitamin-enriched foods), and fermented foods with live cultures. The term was first used in the 1980s in Japan, where there is a government approval process for Foods for Specified Health Use.
- **Dietary food–nutritional supplement**: a preparation intended to supplement the diet and provide nutrients, such as vitamins, minerals, fiber, fatty acids, or amino acids, that may be missing or may not be consumed in sufficient quantity in a person’s diet.
- **Neutraceutical**: a combination of the words nutrition or pharmaceutical, a neutraceutical is a food or a product isolated from food or purified from food that provides health and medical benefits, including the prevention and treatment of disease. Products may range from isolated nutrients, dietary supplement–type products, and specific diets to genetically engineered foods, herbal products, and processed foods.
- **Phytochemicals**: chemical compounds that naturally occur in plants.
- **Cultivar**: a cultivated variety of a plant that has been deliberately selected for specific desirable characteristics (e.g., form of flower, yield of crop, or disease resistance).

### Compounds in Rice Bran for Prevention of Chronic Disease

Major challenges exist for drawing conclusions and associations between certain compounds found in rice bran and health because of the limited number of studies that have been conducted and because of the substantial variability among studies relative to rice processing (e.g., the degree of milling), storage (e.g., heat, moisture, and containers), and the rice cultivar or variety. Bioactive food components in rice bran may include, but are not limited to, γ-oryzanol, tocopherols, tocotrienols, polyphenols (ferulic acid and α-lipoic acid), phytosterols (β-sitosterol, campesterol, and stigmasterol), and carotenoids (α-carotene, β-carotene, lycopene, lutein, and zeaxanthin). Rice bran also contains essential amino acids (tryptophan, histidine, methionine, cysteine, and arginine) and micronutrients (e.g., magnesium, calcium, phosphorous, manganese, and B-vitamins), all of which may work together for health promotion. Selected compounds from rice bran have been investigated for prevention and control of chronic disease via multiple mechanisms (Table 1).

**Rice bran oil**—Three major stages in the production of rice bran oil are extraction, refinement, and quality-control processing. Recent trends for processing rice bran oil have been reviewed elsewhere, and the quality control of the final product is primarily focused on the γ-oryzanol and tocotrienol content. Processing can influence total antioxidant capacity of the rice bran oil and should be taken into consideration when evaluating its biological activity. A few controlled studies have been conducted on the use of rice bran oil in horses, but to the author’s knowl-

### Table 1—Selected bioactive compounds in rice bran evaluated for their properties with regard to prevention of chronic disease.

<table>
<thead>
<tr>
<th>Rice bran compound</th>
<th>Disease prevention activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferulic acid</td>
<td>Antioxidant, chemopreventive, anti-inflammatory, and lipid-lowering effects</td>
</tr>
<tr>
<td>γ-Oryzanol</td>
<td>Antioxidant, chemopreventive, anti-inflammatory, and lipid-lowering effects</td>
</tr>
<tr>
<td>γ-oryzanol hexaphosphate</td>
<td>Blocks cancer growth and signaling</td>
</tr>
<tr>
<td>Campesterol</td>
<td>Antiangiogenic</td>
</tr>
<tr>
<td>β-Sitosterol</td>
<td>Blocks cholesterol</td>
</tr>
<tr>
<td>Linoleic acid</td>
<td>Anti-inflammatory</td>
</tr>
<tr>
<td>α-Tocopherol</td>
<td>Inhibits lipid peroxidation and intracellular signaling</td>
</tr>
<tr>
<td>Tocotrienol</td>
<td>Inhibits lipid peroxidation and intracellular signaling</td>
</tr>
<tr>
<td>Salicylic acid</td>
<td>Anti-inflammatory</td>
</tr>
<tr>
<td>Caffeic acid</td>
<td>Gastrointestinal microbe interactions</td>
</tr>
<tr>
<td>Coumaric acid</td>
<td>Antimutagenic, inhibits the cell cycle, antioxidant, and chemopreventive</td>
</tr>
<tr>
<td>Tricin</td>
<td>Antimutagenic, inhibits the cell cycle, antioxidant, and chemopreventive</td>
</tr>
</tbody>
</table>
edge, there have been no controlled trials reported on the benefits of rice bran oil as a nutritional product for dogs or cats. Most of the studies conducted to evaluate health benefits of rice bran oil have involved the use of rodents and human clinical studies. Rice bran oil is approximately equal to other vegetable oils with regard to provision of fatty acids; however, there was marked variation in amounts of fatty acids and phytosterols extracted from rice bran oil for 6 rice varieties grown in Madagascar in 1 report. Little is known regarding whether this variability in content translates to species-specific differences in bioavailability and health benefit. Rice bran oil from diverse genotypes represents a promising area for research for diets of companion animals.

Crude rice bran oil contains approximately 1.5% \( \gamma \)-oryzanol, which is a component unique to rice bran. \( \gamma \)-Oryzanol consists of a group of ferulate esters of triterpene alcohols and phytosterols. The antioxidant properties of \( \gamma \)-oryzanol were the basis for its development as a nutritional product. Because of these properties, \( \gamma \)-oryzanol is marketed with health claims for enhancing energy, improving muscle condition, and healing athletic stress in dogs. Some of the reported physiologic effects related to \( \gamma \)-oryzanol and other components of rice bran oil include the ability to reduce cholesterol absorption and decrease early atherosclerosis, inhibit platelet aggregation, and increase excretion of fecal bile acids. Rice bran oil is also the only readily available oil, other than palm oil, that contains substantial amounts (approx 500 ppm) of tocotrienols. Tocotrienols are similar to the tocopherols in chemical structure and are found in at least 4 forms. They belong to the vitamin E family and are powerful natural antioxidants, and their ability to prevent chronic disease is comparable to that of \( \gamma \)-oryzanol.

Phenols—The ability of rice bran phenols, such as ferulic, salicylic, caffeic, and coumaric acids and \( \alpha \)-tocopherol (a methylated phenol), to scavenge free radicals, alter enzymes, affect biochemical pathways, and interfere with gene expression has attracted the attention of researchers in search of cancer-fighting agents. The efficacy of ferulic acid, which remains in the bloodstream longer than other known antioxidants and therefore may provide more protection, is dependent on its bioavailability and the dosage. Plant phenols are often found in a biologically unavailable form (ie, ester-linked to cell wall polysaccharides); therefore, the optimal dose of rice bran required to achieve disease-fighting amounts of ferulic acid may be dependent on other dietary components. Humans and rats have gastrointestinal esterases in the large and small intestines that can liberate diferulic acid from bran fiber, which may enhance bioavailability. Whether these enzymes come from the intestines or from gastrointestinal microbiota is uncertain and represents another potential source of variability and a promising area for investigation. Although the bioavailability of ferulic acid has been described in the literature, bioavailability of other phenolic compounds from rice bran has not been reported.

Phytic acid—Inositol hexaphosphate (ie, phytic acid) is the major nutritionally relevant form of inositol found in nature. The primary functions of phytic acid in rice seeds are for storage of phosphates as energy sources and as antioxidants during germination. Phytic acid found in rice has been considered as an antinutrient because of its propensity to bind with minerals, which results in deficiencies in human populations that rely on these food sources as their primary form of nutrition. Although numerous in vitro studies have confirmed that phytic acid has cancer preventive actions, absorption of phytic acid in the small intestines of humans is low and dependent on plasma concentrations. Nonetheless, the ability of rice bran phytic acid to inhibit abnormal cell proliferation and prevent metastasis holds much promise.

Detailed discussion of each bioactive component in rice bran is beyond the scope of this article. Substantial gaps in knowledge exist regarding dietary rice bran bioavailability and bioactivity when compared with those of isolated components. Consumption of whole rice bran is recognized as being important for providing comprehensive protection against cancerous cells, compared with protection provided by consumption of isolated constituents. Evidence supports the fact that 1 in 4 dogs will develop cancer. One can easily speculate that the bioavailability of the aforementioned selected rice bran components will be important for determining their disease prevention properties in healthy dogs and the potential for medicinal food application in dogs with cancer.

Considerable challenges exist for making substantiated health claims for dietary inclusion of rice bran in pets and humans. However, there are noteworthy research opportunities for improving development of rice bran as a functional food ingredient that could cause a delay in tumor progression or prevent tumor development in humans and pets. Prospective research directions that will help substantiate health claims for rice bran may include investigation of muscle conditioning and development, physical performance or improvement in stamina, inhibition of UV light absorption, improvement of the coat of horses and dogs, enhancement of immunity, and control and prevention of chronic diseases (obesity, diabetes mellitus, heart disease, and cancer).

Phytochemical Teamwork

Rice bran is a rich source of phytochemicals that may be working both synergistically and in parallel with each other to promote health and fight disease. Rice bran is much richer in phytoneutrients and antioxidants than are corn, wheat, or oat bran. Variation has been detected in the amounts and types of phytochemicals in rice bran with respect to cultivars, growing conditions, bran separation, and kernel thickness. Rice bran fractionation of various cultivars has revealed that both the inner and outer portion of the bran layer contains phenols with anticancer properties; the outer portion contains the highest concentration. Another recent study revealed that significant phytochemical diversity was detected among a set of rice varieties. This analysis revealed a link between genetic regulation of differences in phenolic and vitamin E contents of
cooked brown rice and suggests that genetic variation can control global metabolite diversity.13

A shift from evaluation of single rice bran components to evaluation of rice bran metabolite profiles that have disease-fighting activity holds great promise for determining the complex interactions of rice bran compounds with intestinal microbiota and mammalian cells.63,68 It is challenging to extrapolate results of

Figure 2—Photographic images depicting rice varieties with regard to visual differences in grain size and pigment during each stage of processing (A) and principal components analysis of cooked rice metabolites as detected by ultra performance liquid chromatography–mass spectrometry (B). Nipponbare (red symbols), Dular (green symbols), and IR64 (black symbols) rice varieties were chosen as examples of varieties with notable phenotypic and metabolite variation. LTH = Lijiangxintuanheigu.
research on rice bran conducted in rodents, chickens, pigs, cows, horses, dogs, and humans without inclusion and appreciation for the microbiome. Use of -omic technologies (eg, genomics, transcriptomics, proteomics, and metabolomics) for rice and advances in pyrosequencing techniques for assessing dietary changes in the canine microbiome will be useful for advancing our knowledge of plant chemical–bacteria interactions that participate in health and disease. Systems-level integration of these approaches with robust experimental designs will be essential for elucidating the health benefits of rice bran across species. Improving our understanding of the role for microbial rice bran metabolism will be critical for linking rice bran phytochemical interactions with mechanisms for health and disease prevention across species.

Because differences in health attributes among varieties of the same food type are often an underappreciated source of variability in the study of phytochemicals, scientific reports should provide the rice variety, growing location, and storage conditions (if known) to maximize the ability of other investigators to reproduce the study findings and validate results. Rice varieties have visual, morphological, and phenotypic differences (Figure 2). Varietal separation of metabolite profiles from methanol-extracted rice bran can be detected by use of liquid chromatography–mass spectrometry. Principal components analysis revealed a > 20% difference for separating rice phytochemical profiles among 3 varieties and provided novel insights into the relationship between phenotypic differences. Dietary investigation of rice bran varieties points toward a new conceptual framework for studying phytochemical teamwork and provides tremendous opportunities for long-term, sustainable improvements in rice quality for animal and human health.

Genetic Diversity of Cultivated Rice and Implications for Identification of Health Traits

Genotype is an important factor used to characterize a rice variety, and it is strongly associated with identification of traits. Significant differences between and within cultivated rice varieties regarding nutrients and health-promoting value are becoming more appreciated as a result of the sequencing of the rice genome. Evaluation of all rice varieties (> 100,000) for nutritional contents is unwieldy; therefore, the use of varieties that have already been selected by the rice research community for diverse agronomic traits provides a sustainable approach. Collaborations with rice breeders have allowed nutritionists and biomedical scientists to investigate commercially viable rice varieties, but the conceivable investigation of health properties in combinations with traits of agronomic importance has not been fully realized.

More information on how the genetic diversity among cultivated rice varieties influences health and nutritional quality of the bran is needed to enhance the value of rice bran as a functional food for promoting health in humans and other animals. Comprehensive data, ranging from gene expression to metabolites that are currently available for rice cultivars, can be used for exploration of health quality and disease prevention traits. This unique research approach would test the hypothesis that cultivar-specific differences in rice bran chemical contents and health effects from studies in animals can be used for the identification of novel health traits in rice. Rice is an important staple food for domestic animals and humans around the world. A sustainable plan to advance the utility of rice bran as a functional food ingredient or nutritional, medicinal food product for disease-fighting and health-promoting properties must involve strategies for improvement of the rice crop. Although the discovery and identification of health traits in the bran fraction of rice will require substantial coordination among plant and biomedical scientists, this approach represents a unique and promising opportunity for translating food quality and health benefits observed in the laboratory into the clinic and marketplace.

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