The component of protein in rice, at 7–9% by weight, is relatively low, but the total amount of rice protein potentially available is significant because the production of rice worldwide, at 380 million tons annually, is huge. Rice proteins are recognized as nutritional, hypoallergenic, and healthy for human consumption, and rice protein products have been in demand in recent years. However, because of difficulties in the processing, rice protein products, particularly high-protein content ones, have not been readily available. Two of the main sources of rice protein, rice bran and, to a lesser extent, broken rice kernels, have been under-used and under-priced. This report provides an update on the processing of these sources for rice proteins. Methods of protein processing are highlighted including the traditional alkaline extraction, enzyme-assisted extraction, and the novel uses of physical treatments prior to water extraction. Also discussed are effects of processing on the functional and nutritional properties of rice protein.

1 Introduction

Rice is one of the leading food crops in the world, and in recent years annual production of milled rice worldwide is about 380 million metric tons [1]. For about 50% of the world population, mostly in Asian countries, rice is the staple diet and provides 35–59% of energy consumed from foods [2]. The component of protein in rice, at 7–9% by weight, is relatively low, but it is a major source of protein for these rice-consuming people. Specifically, contribution of rice for protein in the diet is 69.2% in South Asia and 51.4% in Southeast Asia [2]. Plant proteins have been recognized to be nutritionally equal, if not superior, to animal proteins, and rice proteins have the added advantages of being hypoallergenic and healthy for human consumption [3]. Indeed, rice proteins have been in great demand for health-conscious consumers, and efforts are being made to develop new rice protein products to meet these needs.

High-protein rice products have become commercially available only recently, especially in traditionally low rice-consuming countries such as the United States. The reason for the lack of interest in these products in the past is that, in addition to being low in content, proteins in rice are extremely insoluble in water, which makes them difficult to separate during processing. As a result, the two main sources of rice protein, rice bran and broken rice kernels, have mostly been under-used and under-valued through the years. The industry used to process broken rice kernels or rice flour for its starch and consider the residual protein a co-product of little value and often a disposal concern [4, 5]. On the other hand, rice bran from the milling of rice, in spite of being relatively rich in protein, has mostly been ignored as a valuable resource because it contains little of the desirable starch. Only in recent years when plant proteins in general and rice proteins in particular were recognized to be exceptionally healthy and desirable for human consumption, did the processing of rice proteins begin to get attention from industry and rice research facilities.

Rice proteins consist of four traditionally classified fractions based on solubility: albumin (water-soluble), globulin (salt-soluble), glutelin (alkaline-soluble), and prolamin (alcohol-soluble). Globulin (about 12%) and glutelin (about 80%) are the major rice protein components. Water and alkaline solutions are, therefore, the solvents of choice for the processing of rice proteins. However, depending on the source of protein and the effect of solvent on the products, various processing designs and methods have been developed through the years. This review covers the development on the traditional alkaline extraction, enzyme-assisted extraction and novel physical treatments prior to the extraction. The emphasis is on recent processing trends, the production of high-protein rice products, and the processing effects on the functional and nutritional properties of the products.

2 Rice bran

2.1 Bran protein

Rice bran is a particularly attractive source of protein because it is protein-rich, plentiful, and low-cost. Rice bran comprises about 10% by weight of rough rice (Fig. 1), with an annual yield of about 50 million metric tons worldwide as a co-product from the milling of rice. It contains about 12% protein (Table 1) but is used primarily as animal feed. Efforts to add value to this co-product have not been totally successful because of difficulties in the processing of the protein component. Rice proteins are believed to be bonded strongly by disulfide linkages forming high-molecular-weight complexes,
Processing of high-protein rice products

which are extremely insoluble in water [6–9]. Furthermore, because of the presence of lipid, which is easily hydrolyzed by lipase or oxidized causing rancidity in rice, rice bran needs to be stabilized such as by heat or acid treatment to deactivate the lipase or by defatting to remove the lipid [10–12]. These treatments could cause protein denaturation or aggregation which reduces protein solubility and makes the processing of rice bran proteins even harder to achieve.

2.2 Alkaline extraction

High-protein rice products can most conveniently be obtained from rice bran by alkaline extraction followed by precipitation at the isoelectric pH of the protein. Typically, Connor et al. [13] extracted full-fat rice bran with dilute sodium hydroxide at 24 °C, followed by separation of the fibrous residue with acid and heat, and produced protein concentrates containing 33–38% protein by weight. Prakash and Ramanatham [14] reported that, under optimum conditions of extraction at pH 11 and the follow-up acid separation at pH 4, contents of protein concentrations obtained from untreated rice bran and acid stabilized rice bran were in the range of 71–73% whereas protein concentrates from heat stabilized rice bran and parboiled rice bran had lower protein contents of 39.5% and 54.5%, respectively. Similarly, commercially available unstabilized and heat-stabilized rice bran were extracted in a slurry at pH 9.5 for 30 min resulting in protein concentrates with protein content of 71.5% and 50.9%, respectively [15]. Invariably, heat stabilization not only impaired the extractability of the protein in bran but also changed the amino acid composition and electrophoretic profile for the extracted protein products [14, 15]. Generally, alkaline conditions are effective in solubilizing and extracting protein from rice bran, but alkaline extraction has its shortcomings. High pH alkaline conditions could lead to undesirable protein modifications including molecular cross-linking and rearrangements resulting in the formation of toxic compounds such as lysinoalanine [16, 17]. Molecular denaturation and degradation often occur, which reduce the food-use functional property and nutritional quality of the protein [14, 18, 19].

2.3 Enzymatic methods

For food-use purposes, high-protein products from rice bran are often and preferably produced by enzymatic methods. Enzyme-assisted water-extraction of protein from rice bran has been studied using various food grade enzymes [20]. In general, proteases were reported to be more effective than carbohydrases in enhancing the protein extractability, but the proteins recovered by proteolysis were protein hydrolysates that might not maintain their original structural and functional properties. In a similar study, Hamada [21] reported a procedure for the preparation of rice protein isolate using alkaline protease. However, at low degrees of hydrolysis (<2%) when protein degradation was insignificant, the improvement in protein extractability remained low. On the other hand, at high degrees of hydrolysis when >90% protein was extractable, the functional and nutritional properties of the extracted protein may be adversely affected. More general processes involve the use of carbohydrate-hydrolyzing enzymes such as cellulase, pectinase, hemicellulase, and xylanase to remove the cell wall tissues and thus enhance the extractability of the entrapped protein components [22–24]. Pretreatment of rice bran with commercially available carbohydrases was shown to enhance the nitrogen extractability up to 57% [22]. In a particularly successful extraction, as shown in Fig. 2, rice bran protein isolate containing about 92% protein was prepared from unstabi-

Table 1. Proximate protein content of rough rice and its milling fractions

<table>
<thead>
<tr>
<th>Rice fraction</th>
<th>Crude protein (g N × 5.95)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rough rice</td>
<td>5.6–7.7</td>
</tr>
<tr>
<td>Brown rice</td>
<td>7.1–8.3</td>
</tr>
<tr>
<td>Milled rice</td>
<td>6.3–7.1</td>
</tr>
<tr>
<td>Rice bran</td>
<td>11.3–14.9</td>
</tr>
<tr>
<td>Rice hull</td>
<td>2.0–2.8</td>
</tr>
</tbody>
</table>

From [27]
lized and defatted rice bran using phytase and xylanase [23]. However, prior to the recovery of the protein, the enzymes were deactivated by adjusting the reaction mixture to pH 10. Therefore, in addition to the enzyme function, the treatment under alkaline conditions may also contribute to the enhancement of the protein extractability.

2.4 Physical methods

Physical methods are often more desirable than chemical or enzymatic methods in the processing of food, because they normally induce less unnatural alterations in food and cause less health concerns. Anderson and Guraya [25] used high-speed high-shear milling prior to water extraction in the processing of rice bran and reported moderate successes in the separation of rice proteins. For full fat rice bran, the protein content of the supernatant increased from 21.8 to 33.0% after the high-speed high-shear colloid milling, and to 38.2% with a further homogenization treatment. For defatted rice bran, the numbers were much lower after similar treatments, increasing from 13.9 to 14.7% and to18.7%, respectively.

3 Endosperm proteins

3.1 Alkaline extraction

Rice flour from milled rice or broken kernels contains endosperm storage proteins, about 7% by weight, and these proteins appear to be more readily available for extraction than the proteins in rice bran. As expected, alkaline solvent is effective in facilitating the extraction of the endosperm proteins. Up to 97% of the protein, mostly in the form of gluten, can be extracted by using 0.1 N sodium hydroxide or potassium hydroxide [6, 8]. However, in practice, the alkaline treatment of rice flour is seldom used for protein processing, but serves instead to remove the endosperm proteins for starch production. Similarly, alkaline protease digestion of endosperm protein has also been used for the recovery of the starch [26]. Protein in the effluent is normally discarded or recovered for use in feeds [27].

3.2 Enzymatic methods

Because the major component in rice flour is starch, starch-hydrolyzing enzymes such as α-amylase, glucoamylase, and pullulanase are often used to separate the protein in rice flour by solubilizing and removing the starch. Depending on the processing conditions in the production of the rice flour and the enzymatic treatment, protein content of the resulting products ranges from slightly enriched (25% protein) to highly enriched (>90% protein). They are commonly referred to as rice protein concentrates, except when the protein content is higher than 90%, and then they are called rice protein isolates. High protein rice flours with protein contents in the range of protein concentrate have been produced for early childhood feeding by destarching treatments of rice flour or broken rice with α-amylase, glucoamylase or glucose isomerase [28–31]. Morita and Kiriya [32] achieved the processing of protein isolate by treating rice flour with heat-stable α-amylase at 97°C for 2 h. As starting material, the flour was obtained at 70% milling. The product, after washing off the solubles with boiling water, was recovered with a protein content >90%.

Because milled rice and rice flour are sold at premium prices and they contain only a small amount of protein, it is possible, but not practical, to produce rice isolate with >90% protein from milled rice or regular rice flour. An alternative is to use as starting material protein-rich co-products from the processing of rice ingredients, such as in syrup manufacturing. After removing the hydrolyzed starch as syrup, the insoluble residue contains up to 50% protein and is a low-cost industrial co-product [30, 33]. Shih and Daigle [34] reported that treatment of this co-product with α-amylase and glucoamylase resulted in a product containing 85% protein. Follow-up treatment with a mixture of cellulase and xylanase raised the protein content to 92%. Inorganic impurities, particularly the metal manganese that was present at an undesirably high level of 47 mg/kg in the starting rice flour, were also removed from the protein product.

3.3 Physical methods

Physical methods have been reported for the endosperm protein separation. When slurry of rice flour was emulsified in the presence of sodium stearoyl lactylate, the emulsion that was formed separated into two layer fractions on centrifugation [35]. The upper fraction contained 48.5% protein on dry basis, and the lower fraction contained only 1.6% protein. Air classification and electrostatic separation have been investigated for rice protein preparation [36]. Rice flour containing up to 17.5% protein was obtained by recovering protein-rich particles with size around 40 µm during the air classification of regular rice flour. Electrostatic separation was effective in processing coarse rice flour (over 100 µm), in which the negatively charged protein-rich coarse flour was attracted to the positive electrode under the potential around 2.5 kV.

4 Processing on functional properties

Compared with other plant proteins, rice protein has relatively poor food-use functional properties [37]. Rice proteins are extremely insoluble because of intermolecular disulfide linkages and high molecular weights of the major protein glutenins [6–9]. The solubility and other food-use functional properties are further reduced during processing, particularly by modifications such as heat treatment for bran stabilization [18, 38–40]. Functional properties can also be influenced by the
Table 3. Mean nutritional properties of various raw and processed rices

<table>
<thead>
<tr>
<th>Rice type</th>
<th>Crude protein (%) N × 6.25</th>
<th>Lysine (g/16 g N)</th>
<th>True digestibility (% of N intake)</th>
<th>Biological value (% of digested N)</th>
<th>Net protein utilization (% of intake)</th>
<th>Lysine digestibility (% of intake)</th>
<th>Cysteine digestibility (% of intake)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw(^\text{a})</td>
<td>8.9</td>
<td>3.6</td>
<td>99.7</td>
<td>67.7</td>
<td>96.8</td>
<td>99.9</td>
<td>99.5</td>
</tr>
<tr>
<td>Processed(^\text{b})</td>
<td>9.0</td>
<td>3.5</td>
<td>88.6</td>
<td>78.2</td>
<td>95.4</td>
<td>99.4</td>
<td>82.0</td>
</tr>
<tr>
<td>Raw(^\text{c})</td>
<td>11.8</td>
<td>3.5</td>
<td>99.1</td>
<td>68.8</td>
<td>97.0</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Processed(^\text{d})</td>
<td>12.7</td>
<td>3.5</td>
<td>85.8</td>
<td>73.7</td>
<td>92.5</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

\(^{a}\) Cooked and freeze-dried after being milled  
\(^{b}\) Low-protein rices (IR29, IR32, IR450-5-9)  
\(^{c}\) High-protein rices (IR58)  
From [27]

5 Processing on nutritional properties

Processing of rice proteins involves various physical and chemical treatments, which could affect, often adversely, the nutritional value of the protein. Most thermal processes cause decomposition of lysine and/or cysteine to various extents [51, 52]. In general, rice protein, like most cereal proteins, is deficient in the essential amino acid lysine, but has excess of the essential sulfur-containing amino acids, cystine and methionine. The lysine contents of home-prepared baby foods were damaged to a greater extent at 150–160°C compared with 100–110°C [52]. On the other hand, all the breakfast cereals processed commercially had levels of lysine reduced by 35–76% and arginine by 10–41%. Extrusion cooking of milled rice batter at 15% moisture and 120–150°C reduced total lysine content 11–13% and cysteine 14–29% but had no effect on tryptophan or cystine.

Heat processing of food affects the digestibility of the protein component in different ways. It modifies the tertiary and secondary protein structure causing denaturation, thus increasing protein digestibility. It also cross-links the protein molecules, inhibiting digestive enzyme reactions, thus lessening the digestibility of the protein. Based on in vitro enzymatic essay, thermal processing of foods, such as boiling, parboiling, and extrusion, increases the digestibility of rice proteins [53]. In in vivo essay for protein digestibility, food is fed to rats under various conditions, and the digestibility is measured by formulas in terms of nitrogen intake and output. True digestibility (TD) is calculated, taking into consideration of the nitrogen output due to non-protein components such as fibers that are involved in the diet [54]. Also calculated is the net protein utilization (NPU), a combined measure of digestibility and the efficiency of the utilization of the absorbed amino acids. Heat treatment has been reported to reduce the true digestibility of rice protein in rats by 10–15% (Table 3) [55]. However, the treatment improves the biological value of the protein such that NPU in rats is not reduced. Parboiling also reduces TD but increases biological value correspondingly without any adverse effect on NPU. The poorly digested protein, which passes out of the alimentary system as fecal protein particles, represents the lipid-rich core proteins that are poor in lysine but rich in cysteine [56, 57].

In addition to amino acids, processing could also alter or remove other protein subunits and polypeptides, resulting in changes in nutritional properties. As discussed earlier, high-pH treatment in alkaline extraction of protein could alter and convert protein ingredients into toxic compounds such as lysinoalanine [16, 17]. On the other hand, processing may enhance or improve rice protein to eliminate anti-nutritional factors. Watanabe et al. [58] treated milled rice with a surfactant and enzyme mixture to prepare a hypoallergenic milled rice grain. In clinical tests, this hypoallergenic rice can dramatically improve rice-associated atopic dermatitis [59]. However, the enzyme treatment is expensive and not suitable for mass production. Alternative approaches have been reported including simple alkaline extraction to remove the antigens [60] and genetic modification to achieve the hypoallergenization [61].

6 Concluding remarks

In spite of their limited food-use functional properties, rice proteins have been successfully utilized in foods. For years, with rice proteins as a key ingredient, rice flour or rice bran has been incorporated in foodstuffs such as bread, beverages, pasta, and confections [12, 62, 63]. As high-protein rice products become more available, the use of rice protein in foods...
surges. It has been used in infant foods [29], breakfast cereal [64], snack foods [65], hypoallergenic protein products [59], and edible films [66]. However, as shown in the above review, even though much has been achieved in processing rice proteins, fully effective processing methods, particularly on the extraction of rice bran proteins remain to be developed. More work needs to be done to improve on what has been accomplished, better understand the chemistry of rice protein, and meet the challenge of fully utilizing the unique product of rice proteins.

7 References