derson et al., 1969), the alkaline residue after one protein extraction presumably can be neutralized and extruded into breakfast food, snacks, or other textured convenience foods. This residue may also be used as a starch source for fermentation. Starch can also be produced according to Figure 1.

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Protein Quality of Wild Rice

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Protein quality of wild rice has been studied by rat assay method and amino acid composition. Wild rice has relatively high protein content (15.2–17.0%, dry basis) and protein efficiency ratio (1.77) for a cereal. Wild rice proteins consist of a very low proportion of alcohol-soluble prolamines and a high proportion of glutelins. They are relatively rich in essential amino acids, especially lysine and methionine. Neither the rice variety nor the fermentation step that is unique in wild rice processing affects the nutritional value of wild rice.

Wild rice (*Zizania aquatica*) is an annual aquatic grass that for many centuries has grown naturally in shallow lakes and marshes, especially in the upper Great Lakes region of the United States and Canada (Rossman et al., 1973). Historically, wild rice was a principal vegetative food of the American Indians who lived in an area where agriculture was limited. However, for the last 50 years or so, Indians have sold most of the wild rice they harvested, and the grain is now widely appreciated because of its unique color and flavor characteristics.

In recent years, wild rice fields or "paddies" have been built in the region where wild rice grows naturally. Today, about 12 000 to 13 000 acres of paddies are seeded with newly developed strains of wild rice having desirable growing characteristics, and mechanical devices have replaced the hand labor used by the native Americans to harvest and process the rice. The Indians, however, continue to harvest natural stands in traditional ways.

Wild rice freshly harvested is moist (35–50% moisture) and flexible, and it must be processed before marketing. The present methods of processing wild rice vary greatly among the processors. Generally, wild rice goes through the following steps before it appears on the market shelf: fermenting, parching, hulling, aspirating, grading, and packaging.

The literature contains relatively little information on the nutritional value of wild rice. Earlier investigators (Kennedy, 1924; Capen and LeClerc, 1948) found that wild rice has a higher content of protein and vitamin B_1 than many cereals, and it contains common minerals in amounts comparable to other cereals. Recent studies (Lindsay et al., 1975), in addition to confirming earlier findings, indicated that fermentation has little effect upon the protein and mineral content of the wild rice and that the amino acid composition of wild rice compares favorably with the FAO Provisional Pattern (FAO–WHO, 1973). They also found that the lipid content of wild rice is low compared to some cereal grains, but it contains high levels of linoleic and linolenic acids. These compositional qualities have recently been reviewed by Anderson (1976).

This study was undertaken to investigate the protein quality of wild rice by rat assay method and amino acid

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Table I. Proximate Composition of Wild Rice (dry basis)

Wild rice	Protein N × 6.25, %	Ether extract, %	Ash, %	Fiber, %	Carbohydrate, %
Laboratory processed, K_2 strain					
Unfermented	15.9	1.3	1.8	1.5	79.5
Fermented	15.2	1.4	1.9	2.0	79.5
Commercial, Johnson strain	17.0	1.8	2.0	1.5	77.7
Commercial, K_2 strain	15.7	1.2	1.8	1.2	80.1

analysis and also to evaluate the effects of fermentation on the protein quality of wild rice.

MATERIALS AND METHODS

Laboratory Processed Wild Rice Samples. To investigate the effect of fermentation, the combine-harvested paddy wild rice, K_2 strain, was transported to our laboratory in Peoria, Ill., from northern Minnesota within 24 h of harvest. The rice was immediately processed following current industry practices. About 50 kg of rice (50% moisture) was piled 50-cm high on the outside ground, turned, and watered three times daily for 10 days. This process is generally known as curing or fermenting. Inoculum is from the natural flora on the wild rice. The fermented rice was then dried in an oven at 90 °C with frequent stirring to prevent uneven drying. After drying to a desired moisture (less than 10%), the rice was removed from the oven, cooled, and dehulled by a rice huller. The drying process is actually a combination of steaming, drying, and roasting which helps to develop the characteristic flavor of wild rice, to darken its color, and also to gelatinize the starch center. Instead of opaque white starch center of freshly harvested kernels, the dried rice has a hard translucent gelatinized starch center.

Another 50 kg of freshly harvested rice was dried and dehulled in the same manner but without the 10-day fermentation on the outside ground.

Commercial Wild Rice Samples. The two commercial samples used in this study were purchased directly from two processors. One of the samples is K_2 strain and the other is Johnson strain. The commercial processing usually includes 7–14 days of fermentation.

Biological Evaluation of Protein Quality. Protein was evaluated according to AOAC "Official Methods of Analysis" (1975). Each sample to be evaluated was ground into powder with a hammer mill and then incorporated into a basal diet to provide 10% of protein. On the basis of proximate analysis, the diets were equalized with respect to moisture, fat, ash, and crude fiber. All diets were supplemented with vitamins and minerals known to be adequate for the rat. Groups of five male weanling rats of the Sprague-Dawley strain were fed the appropriate diet and water ad libitum for 28 days. Casein was used as a reference for comparison. Digestibility data were obtained from the 14th through the 21st days of test.

Analytical Methods. Protein content (nitrogen × 6.25) was determined by micro-Kjeldahl nitrogen analysis. Fat, fiber, and ash were analyzed by procedures described in approved methods of the AACC (1962).

Amino Acid Analysis. Each sample was hydrolyzed for 24 h by refluxing in 6 N hydrochloric acid, evaporated to dryness, and then dissolved in citrate buffer at pH 2.2. A portion of the hydrolysate solution was analyzed in a Beckman Spinco Model 121 amino acid analyzer, and data were computed automatically (Cavins and Friedman, 1968).

Fractionation of Protein. Rice proteins were separated into four fractions based on their solubilities. Ground air-dried wild rice sample (3 g) was mixed with 50 mL of H_2O, mechanically shaken for 30 min, and then centrifuged for 15 min at 3500*g*. The extraction was repeated two more times, and the supernatants were combined and designated as albumins. After water-soluble proteins had been removed, the residues were next extracted with 1 M NaCl in the same manner as with water. This fraction was reported as globulins. The alcohol-soluble fraction or prolamines was the fraction obtained next by extracting the residues with 70% ethyl alcohol. After water-soluble, salt-soluble, and alcohol-soluble proteins had been removed, the residue was denoted as glutelins. A portion of each fraction was analyzed for nitrogen by a micro-Kjeldahl method.

RESULTS AND DISCUSSION

Composition. The proximate analyses of the four wild rice samples are shown in Table I. Quantitatively, starch is the most important food material in wild rice just as in other cereal grains. Wild rice, however, has a higher protein content than many of the common cereals. The wild rice samples used in this study contained from 15.2 to 17.0% of protein (nitrogen × 6.25), dry basis, whereas rice has a protein content of 7.6%, wheat, 14.1%, and corn, 10.3%, calculated on dry basis (Anderson, 1976). The fermentation step, which is unique in wild rice processing, did not significantly affect the proximate composition. Data also indicate that Johnson strain had a higher protein content than K_2 strain. However, another analysis of 34 commercial wild rice samples conducted in this laboratory (unpublished data) did not reveal varietal variation in protein content. The present data on proximate composition generally agree with the published results (Anderson, 1976) that wild rice is relatively low in lipid compared to the other cereals.

Protein Efficiency Ratio (PER) of Wild Rice. Data on rat fed diets containing commercially processed rice and laboratory processed rice with or without fermentation are summarized in Table II. There were no significant differences in PER among the four rice samples tested, which indicates that the PER value of wild rice was not affected by fermentation nor did it vary with strain. The adjusted PER of the laboratory processed samples was 1.78 without fermentation and 1.82 with fermentation, and that of the two commercial samples was 1.76 and 1.72. Thus, the PER of wild rice averages 1.77 as compared to 2.50 of casein. The apparent digestibility was also similar for the four rice samples, but was somewhat less than that of casein. Recent data of Juliano (1977) indicated that cooking reduces true digestibility of milled rice protein from 99.7 to 88.6% in growing rats. Furthermore, one of the reviewers informed us that parboiling which is similar to parching reduced true digestibility of IR480-5-9 milled rice protein from 100.4 to 94.7%. Thus, the lower apparent digestibility of wild rice protein as compared to casein may be due in part to the parching process.

Although the PER of wild rice is lower than that of casein, the value is high for a cereal grain. The PER of

Table II. Protein Efficiency Ratio and Digestibility of Wild Rice

Protein source	Weight gain,[c] g	Feed consumption,[c] g	PER[a] Actual[c]	PER[a] Adjusted	Apparent digestibility[b] Diet, %	Apparent digestibility[b] Nitrogen, %
Casein (ANRC)	141 ± 6[1]	417 ± 29[1]	3.37 ± 0.09[1]	2.50	93	90
Laboratory rice						
Unfermented (K_2)	80 ± 6[2]	332 ± 33[2]	2.40 ± 0.05[2]	1.78	91	80
Fermented	76 ± 2[2]	306 ± 4[2]	2.45 ± 0.03[2]	1.82	90	78
Commercial rice A						
Fermented (Johnson strain)	77 ± 5[2]	323 ± 12[2]	2.37 ± 0.06[2]	1.76	91	80
Commercial rice B						
Fermented (K_2 strain)	68 ± 5[2]	292 ± 18[2]	2.32 ± 0.05[2]	1.72	92	82

[a] PER = g of weight gain/g of protein consumed. [b] Digestibility: diet = (feed intake-fecal weight)/feed intake × 100. Nitrogen = (N intake − fecal N)/N intake × 100. [c] Mean ± standard error. Means without a superscript number in common are significantly different, $p < 0.05$ (Duncan, 1955).

Table III. Protein Fractions in Wild Rice as Compared to Other Cereal Grains

Crop	% of total nitrogen: Albumins (water-soluble)	Globulins (salt-soluble)	Prolamines (alcohol-soluble)	Glutelins (alcohol-insoluble)
Wild rice	10	10	1	79
Rice[a]	5	10	5	80
Oats[a]	1	78	16	5
Barley[a]	18	14	46	22
Corn[a]	4	2	55	39
Wheat[a]	5	10	69	16

[a] From Pomeranz (1974).

wild rice is comparable to oats, 1.8 (Pomeranz, 1974), and rice, 1.8 (Juliano, 1972), but it is higher than the PER of barley, 1.6; corn, 1.4; rye, 1.3; and wheat, 0.9 (Pomeranz, 1974). The low PER of cereal protein is generally recognized to be partly the result of the high proportion of alcohol-soluble prolamines, which are low in lysine; therefore, the relatively high PER of wild rice among the cereals could be the consequence of low prolamines.

Protein Fractions. Table III presents data on the averaged relative amounts of albumins, globulins, prolamines, and glutelins in wild rice. For the purpose of comparison, protein fractions of other regular cereals are also included. The data indicate that wild rice protein resembled common rice in that it had an unusually high proportion of glutelins and was low in prolamines when compared with other cereal proteins. Glutelins, which contain more lysine than the prolamines but do not have as balanced an amino acid composition as albumins or globulins, perhaps dictate the PER of wild rice. Therefore, an increase in the proportion of albumins or possibly globulins at the expense of glutelin could be reflected in an improved nutritive value of wild rice.

Amino Acid Composition. The amino acid composition of the four wild rice samples is given in Table IV. The data were calculated to 100% nitrogen recovery and expressed in g of amino acid/16 g of nitrogen recovered. The four rice samples showed very little variation in amino acid composition, which suggests that there was no varietal difference and also that the fermentation step had no effect on the amino acid composition.

In the commercial processing of wild rice, the blackish pericarp is partially removed (scarification) to shorten the cooking time. The scarification, however, was omitted in the laboratory processed rice. Thus, our data suggest that partial removal of pericarp did not affect the amino acid composition of wild rice. Lindsay et al. (1975) observed only a slight decrease in the level of arginine and histidine when the pericarp was totally removed. They also reported no significant fermentation effect on amino acid composition. The amino acid composition of wild rice found in this study is also in agreement with that reported by Oelke et al. (1973). Although variations in amino acid composition of wild rice can be expected due to strains, growing conditions, and harvest maturity as shown in other grains, thus far no significant difference in amino acid composition of wild rice due to these factors has been reported.

As a cereal, the wild rice proteins were relatively rich in essential amino acids, especially lysine and methionine. Of the other amino acids, wild rice proteins contained less

Table IV. Amino Acid Composition of Wild Rice Protein (g/16 g of N)

Amino acid	Laboratory unfermented K_2 strain	Laboratory, fermented K_2 strain	Commercial, Johnson strain	Commercial, K_2 strain	Av
Aspartic acid	9.6	9.7	10.0	10.2	9.9
Threonine	3.6	3.7	3.5	3.6	3.6
Serine	5.6	5.7	5.7	5.8	5.7
Glutamic acid	17.1	17.3	17.9	18.0	17.6
Proline	3.6	3.5	3.5	3.5	3.5
Glycine	4.9	4.8	4.8	4.6	4.8
Alanine	5.6	5.7	5.8	5.7	5.7
Cystine	1.3	1.3	1.2	1.2	1.2
Valine	5.9	5.9	6.0	6.0	6.0
Methionine	3.4	3.3	3.2	3.2	3.2
Isoleucine	4.4	4.3	4.4	4.5	4.4
Leucine	7.2	7.2	7.3	7.3	7.3
Tyrosine	5.0	4.9	4.7	5.0	4.9
Phenylalanine	5.1	5.3	5.3	5.3	5.3
Histidine	2.6	2.9	2.8	2.6	2.7
Lysine	4.6	4.6	4.4	4.4	4.5
Arginine	8.0	7.9	8.4	8.2	8.2

Table V. Amino Acid Score of Wild Rice Protein

Amino acid	FAO pattern, mg/g of N	Wild rice, mg/g of N	Amino acid score, wild rice[a]
Isoleucine	250	275	110
Leucine	440	456	104
Lysine	340	281	82
Methionine + cystine	220	275	125
Phenylalanine + tyrosine	380	637	167
Threonine	250	225	90
Valine	310	375	120
Tryptophan	60	ND[b]	

[a] Calculated as amino acid in wild rice protein divided by amino acid in reference pattern and multiplied by 100 (FAO-WHO, 1973). [b] ND, not determined.

glutamic acid and proline and more arginine and aspartic acid than many of the cereal grains. The lysine content of wild rice was comparable to that of high-lysine corn (Wu and Sexson, 1976). Table V shows the amino acid scores of wild rice protein calculated based on the FAO pattern (FAO-WHO, 1973). Of the essential amino acids analyzed, lysine yielded the lowest score, 82. With the exception of lysine and threonine, the amount of each of the other essential acids matched or exceeded the FAO pattern.

Cereal grains are regarded primarily as energy sources rather than as sources of proteins. However, both the magnitude of protein malnutrition and the food consumption patterns have stimulated research effort to utilize cereals to help satisfy human protein needs. Insofar as PER and amino acid composition are concerned, wild rice has much to offer as a potentially excellent source of high-quality cereal protein.

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Comparative Nutritive Value, Amino Acid Content, Chemical Composition, and Digestibility in Vitro of Vegetable- and Grain-Type Soybeans

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Four vegetable-type and six grain-type varieties have been analyzed for their nutritive value, i.e., PER (protein efficiency ratio), NPR (net protein retention), chemical composition, and in vitro digestion. The protein quality index based on PER at 10% protein level was found to be highest in vegetable-type varieties Coker Stuart, 28-1-2, and Coker-240. Grain-type varieties were generally rich in crude fat, whereas vegetable-type varieties showed superiority over grain type in respect of iron content. A chemical score based on the essential amino acid content of egg protein and FAO pattern (1973) has indicated the level of first limiting amino acid methionine and cysteine (sulfur amino acids) in vegetable- and grain-type varieties of soybean. The EAAI (essential amino acid index) and BV (biological value) were calculated and found to be well correlated to PER values in the case of vegetable- and grain-type varieties. The study on in vitro digestion using trypsin enzyme revealed wide variation in different varieties. The high nutritive value, i.e., PER and NPR, obtained in the case of vegetable and some of the grain varieties is due to low trypsin inhibitor activity in the raw seeds and also to the inactivation of trypsin inhibitor on autoclaving.

Soybean and soybean products have been consumed over the years both separately and in food blends to increase protein intake and amino acid balance in the diet of man and animals in many oriental countries, but numerous attempts to introduce it in India have not succeeded very well because of an unpleasant beany flavor and difficulty in cooking (Kanthamani, 1970; Rathod and Williams, 1973). However, the vegetable varieties have been found to be superior to grain-type varieties in flavor, texture, and cooking (Morse, 1950).

The amino acid composition of a protein seldom gives its true nutritional value (Eggum, 1970). The nutritive value depends upon the presence of inhibitors of digestive enzymes, digestibility and absorption, toxic factors, and

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