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The influence of milling on the nutritive value of flour from cereal grains
4. Rice

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Abstract. Brown and milled rices were prepared from rough rice, and the nutritive value of the rices was studied by chemical analyses and in balance experiments with growing rats. The concentration of essential nutrients decreased with the degree of milling, but the energy density of brown and milled rices was similar. In the highly refined white rice the protein content was reduced to 86% and the mineral content to 23% of corresponding levels in brown rice. The zinc concentration was halved. The amino acid composition was rather unaffected by the degree of milling, but the lysine concentration was slightly lower in white rice than in brown rice. Milling was accompanied by an increase in true protein digestibility and a corresponding decrease in biological value. Thus net protein utilization of the different rices was remarkably uniform. A total of 33% of the utilizable protein and 22% of the digestible energy in brown rice was removed during milling.

Rats fed rough, brown and lightly milled rices were unable to maintain their femur zinc concentration; deposition of calcium and phosphorus also appeared to be affected. Factors present in the outer part of the rice kernel interfere strongly with zinc utilization. Phytate and/or fibre are not solely responsible for this effect. Unless rice was milled into highly refined white rice, zinc status of rats was adversely affected. The results suggest that zinc might be a limiting factor in rice-based diets.

Introduction

The rice grain, rough rice, consists of an edible portion, the rice caryopsis, and its covering structure, the fibrous husk, which constitutes approximately one fifth of the rough rice weight [13]. The rice is shelled to remove the husk, and then milled to remove most of the bran layers and germ. Usually 10% by weight of the brown rice is removed during milling [15].

A majority of the consumers prefer well-milled rice with little or no bran adhering to the endosperm, and in countries where rice is the principal food, the preference is generally for well-milled rice. It is well known that milling brings about changes in chemical composition, and the degree of milling determines the amount of nutrients in the residual milled rice. Protein, fat, vitamins and minerals are present in greater quantities in the bran removed than in the remaining endosperm [31]. On the other hand, the milling process remove a large proportion of the phytate, which might adversely affect the utilization of at least some of the minerals and trace elements,

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notably zinc [12]. Fibre, which might interfere with mineral [11] as well as protein utilization [33] is also removed [31].

Among cereals, rice has a comparatively high content of essential amino acids and a fairly low content of glutamic acid and other nonessential amino acids. However, lysine is still the first limiting amino acid followed by threonine [15]. The rather small decrease in lysine concentration associated with milling of rice does not severely affect protein utilization as determined in rats [7]. In children the retention of nitrogen from rice appears to be limited by a poor nitrogen digestibility [21].

Zinc is important in protein synthesis and growth, and zinc has been suggested as a limiting factor in cereal based diets [37]. The results of a study by Roxas et al. [32], in which preschool children were fed diets based on milled high-protein rice, indicate that zinc is a limiting factor. A very low availability to rats of zinc in brown rice has also been reported [9].

The purpose of the present study was to examine the effect of milling on the nutritive value of rice. N and zinc balances were performed in growing rats fed rough, brown and milled rices. Mineral status of the rats was assessed by analyses of mineral content in femurs and livers removed at the end of the experiment. Losses of protein and energy in the milling process was also determined.

Materials and methods

Rough rice harvested in Italy was used in the experiment. The rice was first cleaned (Schule, Mini Petkus), and then milled into different qualities of rice. Brown rice was prepared by passing cleaned rough rice through a Strong Scott Barley Pealer (Seedburo Equipment Comp.), the husk was removed by air sifting, and unshelled rough rice was separated from the brown rice by hand. The milling yield of brown rice was 82%. Undermilled rice was prepared from rough rice by removal of husk and part of the bran in a DVA decorticator (United Milling System), the milling yield was 77%. Milled and overmilled rices were prepared by abrasive milling of the undermilled rice (Scule, Vertical Abrasive Polisher). The milling yields, calculated as a percentage on basis of cleaned rough rice, were 72%, 68% and 64%, respectively. The rough, brown and milled rices were finally hammer-milled (Norris and Christy, Laboratory Mill).

Animals and diets

The experimental procedure has been described by Eggum [4]. Six groups of five Wistar male rats (Møllegaard's Breeding Centre) weighing 70 ± 2 (S.D.)g were used in balance experiments with a preliminary period of 4 days and a collection period of 5 days. The rats were weighed at the beginning of the experiment and divided into groups of five so that the average weights of the groups differed by no more than 0.5 g. The rats were housed individually in plexiglass cages with stainless steel mesh-bottoms in a controlled environment. Temperature and relative humidity were held at 25 °C and 50%, respectively. Lighting was controlled by alternating 12-hour periods of light and darkness. Each animal received 10 g dry matter daily. Distilled water was supplied ad libitum. Body weight and dietary intake were recorded. Urine and faeces were collected separately during the balance period. The faeces were lyophilized and ground into a fine powder prior to analyses. True protein digestibility (TD), biological value (BV), net protein utilization (NPU = TD x BV), utilizable protein (UP = Protein % x NPU) and digestible energy were measured. TD was determined by correcting for endogenous excretion of nitrogen. A constant factor of 76 mg N/rat/5 days was used. Estimation of digestible energy was based on analysis of diets and faeces. Apparent absorption and retention of zinc were also determined in the balance experiments. Femurs and livers were removed at the end of the experiment; zinc, calcium and phosphorus were determined in the femurs and zinc, copper and iron in the livers. With one exception the nitrogen content of the test diets was not adjusted to the customary 1.5% because the rices contained less nitrogen. To the brown rice test diet a minor amount of N-free mixture consisting mainly of autoclaved potato starch [28] was added. The vitamin and mineral mixtures added have been described previously [19] but zinc and copper were omitted, and the rices were the sole source of dietary protein, zinc and copper. Composition and mineral content of the test diets are shown in Table 4.

Analytical methods

AOAC methods [1] were used for determination of dry matter (No. 14.063), ash (No. 14.064) and nitrogen (No. 14.069). Energy was determined by an JKA-Calorimeter Type C 400 (Janke and Kunkel). Starch + sugar were determined according to MacRae and Armstrong [22] and fat after Stoldt [34]. The rices were also analysed for tannin [6], phytate [39] and amino acids [23]. Zinc, copper, iron and calcium were determined by atomic absorption spectophotometry and phosphorus by the colorimetric method of Stuffins [35]. The data were subjected to one-way analysis of variance and Tukey's HSD test [10]. The minimum level of statistical significance accepted was $P < 0.05$.

Results

Milling of rice into refined white rice resulted in a marked decrease in the concentration of nutrients except starch + sugar in the residual kernels (Table 1), the energy content was, however, only slightly reduced. In the most refined rice the content of minerals was reduced to 23% of that in brown rice. The protein content was reduced to 86%, but the amino acid composition was quite unaffected by the degree of milling (Table 2). The concentration of lysine, the first limiting amino acid in rice protein, was only slightly lower in the milled rices compared to the brown and rough

Table 1. Chemical composition (% dry basis) of rough, brown and milled rices

Rice materials:	Rough	Brown	Under-milled	Milled	Overmilled	
Milling yields (%):	100	82	77	72	68	64
Ash	2.9	1.3	0.8	0.6	0.4	0.3
Protein (N × 6.25)	8.6	9.9	9.3	9.2	8.8	8.5
Fat	2.5	3.0	1.5	1.2	1.1	1.0
Starch + sugar	69.1	85.8	92.2	92.5	92.5	92.6
Crude fibre	12.2	0.9	0.2	0.1	0.3	0.1
Tannin	0.5	0.4	0.4	0.3	0.3	0.3
Energy kJ/g	18.4	18.3	18.1	18.1	18.1	17.9

Table 2. Amino acid content (g/16 g N) of rough, brown and milled rices

Rice materials:	Rough	Brown	Under-milled	Milled	Overmilled	
Milling yields (%):	100	82	77	72	68	64
Alanine	5.24	5.21	5.33	5.18	5.24	5.10
Arginine	7.61	8.15	8.39	8.15	8.03	7.97
Aspartic acid	8.66	8.67	8.88	8.59	8.69	8.42
Cystine	2.08	2.22	2.20	2.12	2.11	2.06
Glutamic acid	16.48	17.23	18.09	17.51	17.88	17.19
Glycine	4.30	4.26	4.32	4.15	4.14	4.09
Histidine	2.09	2.25	2.24	2.13	2.15	2.07
Isoleucine	3.93	4.03	4.18	4.05	4.14	4.00
Leucine	7.56	7.64	8.04	7.74	7.92	7.63
Lysine	3.53	3.52	3.49	3.29	3.37	3.27
Methionine	2.31	2.46	2.51	2.57	2.54	2.50
Phenylalanine	4.95	4.84	5.16	4.90	5.15	4.75
Proline	4.05	4.08	4.31	3.73	3.91	3.63
Serine	4.94	5.04	5.29	5.05	5.08	4.96
Threonine	3.32	3.24	3.31	3.20	3.25	3.12
Tyrosine	4.24	4.54	4.89	4.64	4.80	4.44
Valine	5.06	5.22	5.41	5.16	5.21	5.10

rices. The concentration of minerals was highest in the peripheral layers and decreased as the centre of the kernel was approached, the steepness of the gradient, however, varied greatly for the different minerals (Table 3). While only 28% of the amount of phosphorus and iron in brown rice was retained in the overmilled rice; zinc, calcium and especially copper were more evenly distributed through the kernel. The husk appeared to be high in iron and calcium but low in zinc. Phytate phosphorus made up 69% of the total phosphorus content in both rough and brown rice. In the milled rices only traces of phytate phosphorus were left; and the phytate:zinc molar ratio ranged from 31 in the rough rice and 24 in the brown rice to 1 in the refined rices.

The true protein digestibility increased from 95% in brown rice to 100% in the milled rices. In rough rice the protein digestibility was 88% (Table 5). The biological value, however, decreased by milling, and NPU of the different

Table 3. Mineral content (dry basis) in rough, brown and milled rices

Rice materials:	Rough	Brown	Under-milled	Milled	Overmilled	
Milling yields (%):	100	82	77	72	68	64
Calcium (mg/g)	0.31	0.12	0.10	0.08	0.07	0.07
Phosphorus (mg/g)	3.1	3.2	2.0	1.5	1.0	0.9
Phytate-P (mg/g)	2.1	2.2	0.7	0.2	0.1	0.1
Zinc (ppm)	24	33	20	18	17	16
Copper (ppm)	2.8	2.7	2.6	2.2	1.9	1.8
Iron (ppm)	38	8.8	7.0	4.1	2.2	2.4
Phytate : zinc[a]	31	24	11	4	1	1

[a]Molar ratio. Phytic acid is assumed to contain 28.2% of phosphorus.

Table 4. Composition and mineral content (dry basis) of the six experimental diets

Rice materials:	Rough	Brown	Under-milled	Milled	Overmilled	
Milling yields (%):	100	82	77	72	68	64
Rice flour %	95.2	94.4	95.2	95.2	95.2	95.2
N-free mixture %	–	0.8	–	–	–	–
Mineral mixture %	3.2	3.2	3.2	3.2	3.2	3.2
Vitamin mixture %	1.6	1.6	1.6	1.6	1.6	1.6
Dietary minerals						
Zinc ppm	23	31	20	18	16	15
Copper ppm	2.7	2.8	2.6	2.4	2.3	1.9
Iron ppm	120	100	80	87	80	88
Calcium mg/g	4.1	3.7	3.8	3.8	3.8	3.5
Phosphorus mg/g	5.5	5.2	4.2	3.8	3.6	3.3

Table 5. Food intake (dry basis), weight gain and protein utilization (dry basis) in rats fed rough, brown and milled rices

Rice materials:	Rough	Brown	Under-milled	Milled	Overmilled	
Milling yields (%):	100	82	77	72	68	64
Food intake per 9 days (g)	88.9	88.7	88.8	86.7	85.8	85.2
Weight gain per 9 days (g)	11.8[a]	16.5[bc]	16.1[bc]	16.8[c]	14.2[abc]	13.1[ab]
True protein digestibility	87.8[a]	95.0[b]	98.8[c]	99.3[c]	100.0[c]	100.6[c]
Biological value	72.6[a]	66.1[ab]	64.6[b]	64.4[b]	64.9[b]	63.3[b]
Net protein utilization	63.7	62.8	63.8	63.9	64.9	63.7
Utilizable protein (g/100 g rice)	5.5[a]	6.2[b]	5.9[ab]	5.9[ab]	5.7[ab]	5.4[a]
Utilizable protein (g/100 g rough rice)	5.5[a]	5.1[a]	4.5[b]	4.2[bc]	3.9[cd]	3.4[d]

[a–d]Mean values with unlike superscript letters in the same row were significantly ($P < 0.05$) different. SD_{pooled}: Food intake = 2.2, Weight gain = 1.7, TD = 1.5, BV = 3.4, NPU = 3.9, UP (g/100 g rice) = 0.4, UP (g/100 g rough rice) = 0.3.

Table 6. Digestible energy (dry basis) in rats fed rough, brown and milled rices

Rice materials:	Rough	Brown	Under-milled	Milled	Overmilled	
Milling yields (%):	100	82	77	72	68	64
Digestible energy (%)	80.1^{a}	96.0^{b}	97.8^{c}	98.2^{c}	98.2^{c}	98.5^{c}
Digestible energy (kJ/g rice)	14.7^{a}	17.5^{b}	17.7^{b}	17.7^{b}	17.7^{b}	17.6^{b}
Digestible energy (kJ/g rough rice)	14.7^{a}	14.3^{b}	13.6^{c}	12.8^{d}	12.1^{e}	11.2^{f}

[a–f]Mean values with unlike superscript letters in the same row were significantly ($P < 0.05$) different. SD_{pooled}: DE % = 0.7, DE (kJ/g rice) = 0.1, DE (kJ/g rough rice) = 0.1.

Table 7. Zinc balance (μg zinc per 5 days) in rats fed rough, brown and milled rices

Rice materials:	Rough	Brown	Under-milled	Milled	Overmilled	
Milling yields:	100	82	77	72	68	64
Intake (μg)	1121^{a}	1528^{b}	970^{c}	878^{d}	815^{e}	751^{f}
Faeces (μg)	875^{b}	1313^{a}	748^{bc}	684^{cd}	573^{d}	564^{d}
Urine (μg)	26^{a}	43^{ab}	66^{c}	55^{bc}	74^{c}	64^{c}
App. absorption (μg)	246	215	222	194	241	187
App. absorption (%)	22	14	23	22	30	25
App. retention (μg)	219	172	157	139	167	123
App. retention (%)	20	11	16	16	21	16

[a–f]Mean values with unlike superscript letters in the same row were significantly ($P < 0.05$) different. SD_{pooled}: I = 19, F = 68, U = 11, App.abs. (μg) = 66, App. abs. (%) = 7, App. ret. (μg) = 66, App. ret. (%) = 7.

rices was remarkably uniform. Since the protein content of the residual kernels was reduced by milling, the amount of utilizable protein decreased from 6.2 g per 100 g in the brown rice to 5.4 in the most refined rice. When the protein lost in the milling process was taken into consideration, UP, calculated on basis of rough rice, was reduced from 5.5 to 3.4 g per 100 g.

The digestibility of energy was high, 98%, in the milled rices and only slightly lower in the brown rice, 96% (Table 6). In the rough rice the digestibility of energy was only 80%. The energy density was similar in brown and milled rices; but a considerable amount of energy was removed in the milling process.

Data concerning zinc balances are shown in Table 7. Rats fed the brown and the rough rice had a higher intake and a higher faecal excretion of zinc than rats fed the milled rices. The urinary zinc excretion was lowest in rats fed the rough rice. The apparent absorption and retention of zinc did not differ significantly between groups.

Mineral content in the femurs are given in Table 8. The content of zinc in the femurs increased with the degree of milling; in rats fed rough and brown rice, femur zinc concentration was significantly reduced. Rats killed

Table 8. Mineral content in the femur of rats fed rough, brown and milled rices

Rice materials:	Rough	Brown	Under-milled	Milled	Overmilled	
Milling yields (%):	100	82	77	72	68	64
Dry weight of femur (mg)	149	151	150	152	145	151
Zinc (ppm)	163^{c}	171^{bc}	188^{ab}	194^{a}	201^{a}	206^{a}
Calcium (mg/g)	171	173	177	174	174	170
Phosphorus (mg/g)	90.6	92.6	93.2	91.7	91.5	88.9
Ca:P	1.88^{bc}	1.87^{c}	1.90^{ab}	1.90^{ab}	1.91^{ab}	1.92^{a}

a—c Mean values with unlike superscript letters in the same row were significantly ($P < 0.05$) different. SD_{pooled}: Dry weight = 7, Zn = 12, Ca = 7, P = 2.6, Ca:P = 0.01.

Table 9. Mineral content in the liver of rats red rough, brown and milled rices

Rice materials:	Rough	Brown	Under-milled	Milled	Overmilled	
Milling yields (%):	100	82	77	72	68	64
Dry weight of liver (g)	0.95^{b}	1.23^{a}	1.10^{ab}	1.14^{ab}	1.23^{a}	1.07^{ab}
Zinc (ppm)	76^{b}	55^{a}	70^{ab}	63^{ab}	60^{ab}	68^{ab}
Copper (ppm)	17.2	11.4	13.8	13.7	14.2	14.7
Iron (ppm)	548	470	485	457	414	467

a—b Mean values with unlike superscript letters in the same row were significantly ($P < 0.05$) different. SD_{pooled}: Dry weight = 0.09, Zn = 8, Cu = 3.1, Fe = 108.

at the beginning of the experiment had a femur zinc concentration of 203 ppm, thus, only rats fed the milled rices were able to maintain their femur zinc concentration during the experimental period. The Ca:P ratio was also slightly lower in rats consuming rough and brown rice. The dry weight of the liver was higher in rats fed brown rice compared to rats fed rough rice, and the concentration of zinc was lower (Table 9). The content of copper and iron was not significantly affected by the degree of milling. There was no significant difference in food intake between groups. The weight gain was lowest in rats fed rough rice (Table 5).

Discussion

In agreement with previous work [31], the degree of milling has a marked effect on the concentration of nutrients in the residual kernels. The content of non-starch constituents decreased as the center of the kernel was approached, and the content of nutrients was markedly lower in milled rice than in brown rice. The level of crude fibre was very low in the milled rices, and fibre as well as phytate were effectively removed in the milling process. The husk made up 18% by weight of the rough rice, which is in agreement with the values reported by Houston [13]. The fibrous husk is low in protein and fat [13], and the protein and fat content was higher in brown rice than in rough rice.

N balance results are in close agreement with values published previously [5, 7]. Milling resulted in an increase in TD and a corresponding decrease in BV. The resulting NPU's were rather unaffected by the degree of milling. The amino acid composition was quite similar in the various rices, in accordance with the results of Kennedy and Schelstraete [18]. The small reduction in lysine concentration brought about by milling correspond with the slightly lower BV of white rice compared to brown rice. However, BV of rough rice was considerably higher than BV of brown rice, despite a quite similar amino acid pattern. TD, on the other hand, was significantly lower in rough rice than in the brown and milled rices. Calculated on basis of N content of rough and brown rice, the husk contained 2.7% protein, which is in accordance with the 3% reported by Houston [13]. The digestibility of the husk protein is probably low [2], but even if it is assumed to be completely indigestible, this does not account for the reduction in TD of rough rice compared to brown rice. Fibre in the husk is probably, at least in part, responsible for the depressed protein digestibility of rough rice; fibre affects protein utilization, digestibility and endogenous faecal excretion [33]. The N balance results reflect a shift towards increased faecal N excretion and decreased urinary excretion, when brown and especially rough rice were fed compared to white rice. A similar change in N excretion pattern in rats fed various types of fibre and starch has been described by Beames and Eggum [3], and explained by a movement of urea from the blood to the intestine. Trends towards decreased urinary N excretion and increased faecal N excretion have also been found in humans consuming rice bran supplemented diets [14].

In rats cooking of milled rice results in an appreciable reduction in protein digestibility and a corresponding increase in biological value [8]. This adverse effect of cooking on digestibility of rice protein might in part explain the much lower protein digestibility found in children, where a poor nitrogen digestibility appears to limit the retention of nitrogen from rice [21]. As a result of the reduction in protein content by milling, UP was 13% lower in the most refined rice. In total, 38% of the amount of utilizable protein in rough rice and 33% of that in brown rice was removed by milling.

There was no difference in the energy density of brown and milled rices. As in children [21], the overall digestibility of rice is very high. Digestibility of energy in the husk is extremely low, as in barley husk [2], and the energy density in rough rice is only 84% of that in brown and milled rices. This probably explains the lower weight gain in rats fed rough rice compared to rats fed the other rices. The lysine requirement is especially high during growth, however, it is unlikely that the rather small differences in weight gain have significantly affected the N-balance results. The amount of digestible energy (kJ/g rough rice) decreased with the degree of milling. A total of 24% of the digestible energy in rough rice and 22% of that in brown rice was lost in the milling process.

Unless the rice was milled into highly refined white rice the rats were unable to maintain their femur zinc concentration. According to House et al. [12] bone might be regarded as a sink in which zinc is deposited and largely retained during subsequent bone turnover. Therefore, the deposition of zinc in bone might represent an irreversible loss of zinc from the system. Morris and Ellis [25] showed that the requirement for growth takes precedence over deposition in bone in competing for the available zinc; and femur zinc concentration is probably a very sensitive indicator of zinc status [26]. However, femur zinc concentration as well as zinc absorption are influenced by the protein content of the diet [30]. The test diets in the present study were not isonitrogenous, but the differences in protein content were probably too small to significantly affect zinc absorption and deposition in bones. Thus, the zinc status of rats fed rices, which were not highly milled, were probably poor; and as the dietary zinc content far exceeded the minimum requirement, 12 ppm, zinc utilization must have been adversely affected by components present in the outer part of the kernel.

The results are in accordance with those of Franz et al. [9], who used weight gain of rats to determine the relative availability of zinc from brown and milled rice. The availability of zinc from brown rice was so low compared to that from white rice, that the higher content of zinc in brown rice were unable to offset the reduced availability. A remarkably lowered tibia zinc concentration has also been reported in chicks fed rice bran supplemented diets [36].

Although phytate may contribute to the reduced utilization of zinc from rough and brown rice, the level of phytate is probably too low to significantly affect zinc utilization from milled rice [40]. The phytate:zinc molar ratio has been suggested as an indicator of zinc availability from phytate containing diets, and ratios of less than 10 are usually associated with adequate zinc availability [26]. The lower femur zinc concentration in rats fed rough rice compared to rats fed brown rice might be attributed to the lower zinc content and subsequently the higher phytate:zinc molar ratio in rough rice than in brown rice. However, zinc utilization in rough rice might also have been further depressed by the high content of fibre [11]. The content of fibre in milled rice is low, and does probably not affect zinc utilization. In similar studies with rye [27] and wheat [28], no adverse effect on mineral utilization was observed in rats fed whole grain flours, in spite of just as high phytate:zinc ratios and similar levels of dietary zinc as those found in the present study. Consequently, phytate and fibre may not be solely responsible for the depressed utilization of zinc from rice.

A very high content of silicon in rice has been reported [13, 15]. The level in milled rice is considerably lower than in brown and rough rice, but even within the milled kernel the variation is remarkable, and the concentration of silicon can be greatly reduced by overmilling of milled rice [17]. Whether silicon affects availability as suggested by Kennedy [16] is not known. In rats fed barley zinc utilization was adversely affected unless the barley was highly refined [29]. The content of silicon in barley is also very high whereas rye and wheat have much lower contents [20].

It is surprising that the apparent absorption and retention of zinc were just as high or higher from rough and brown rice as from the overmilled rices. In rats fed unrefined rice, absorbed zinc might not have been fully available. The zinc distribution and the requirement might also have been affected. Several parameters of zinc metabolism appears to be influenced by dietary phytate and possibly fibre [11, 12]. The zinc balance results correspond with those obtained in a similar study with barley [29]. In rats fed unrefined barley flours rich in phytate and fibre, femur zinc concentration was severely depressed, but the apparent zinc absorption and retention were significantly higher than in rats fed refined barley flours. Whether or not the balance results reflect a homeostatic adaptation to low intake of available zinc cannot be determined from our study. The reduced urinary excretion of zinc in rats fed rough rice was rather unexpected, as the urinary zinc excretion generally is about equal to the inevitable renal zinc losses [38]. Contaminations might have affected the results, as urine are easily contaminated. However, Harmuth-Hoene [11] suggested that rats were able to compensate for increased faecal losses resulting from high intakes of fibre by decreasing the urinary excretion.

The slightly reduced Ca:P ratio in the femur of rats fed rough and brown rice indicate an effect on calcium and/or phosphorus metabolism probably caused by phytate [24]. The concentration of copper and iron in the liver, however, was unaffected by the degree of milling.

Our data suggest that zinc might be a limiting factor when rice constitutes a large portion of the diet. According to Franz et al. [9] cooking reduces availability of zinc from brown rice as well as milled rice, an effect which might be associated with the effect of cooking on protein digestibility. The results of Roxas et al. [32] obtained in a study with pre-school children also indicate that zinc is limiting in diets based on milled high-protein rice. A high degree of milling ensured adequate zinc status of rats in our study, however, highly refined white rice has a reduced protein content and is deficient in vitamins [16].

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