Mineral Metabolism on Rice Diets

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Over half the population of the world eats a diet in which rice predominates and such a diet usually has a low mineral content. This is certainly true for the diets consumed by most of the people of Ceylon (Nicholls, 1936; Nicholls & Nimalasuriya, 1939; Bibile, Cullumbine, Watson & Wickramanayake, 1949; Cullumbine, 1949a), and it is difficult to understand how these people can grow and maintain health on such low mineral intakes. The problem is further complicated by the fact that these diets, which are rich in cereals (50–60% at least of the total calories may be obtained from rice), have a relatively high content of phosphorus, and presumably of phytate phosphorus too. McCance & Widdowson (1942–3a) have shown that the phytic acid of bread interferes with the absorption from the gut of calcium and magnesium. Their results indicate that the greater the phytic-acid content of a diet rich in bread, that is, the higher the extraction rate of the flour from which the bread is made, the less is the absorption of these minerals from the intestine. Walker, Fox & Irving (1948) have confirmed these findings and they made the further interesting observation that subjects can adapt themselves to a lowered absorption of calcium or magnesium. This recalls the suggestion of Nicholls & Nimalasuriya (1939) who, when discussing the low dietary intake of calcium by the average Ceylonese, concluded that only a process of racial adaptation could explain the growth of Ceylonese without the occurrence of bony abnormalities.

Unpolished rice has a higher phytic-acid content than polished rice (McCance & Widdowson, 1935), and both types of rice are consumed in Ceylon. It seemed desirable, therefore, to determine whether there was any difference in the calcium and magnesium metabolism of subjects when eating diets first high in unpolished rice and then in polished rice. Further, it seemed necessary to see whether the suggestion of the occurrence of a process of adaptation has any experimental basis.

Methods

Subjects. The subjects were twelve male medical students who lived in a nearby medical students' hostel. One of us (T. W. W.) was Resident Warden at this hostel during the period of the experiments and this facilitated the control of the diet and the collection of specimens. T. W. W. supervised the preparation of all meals, the issuing of food and the consumption of food throughout the experiments. Arrangements were also made to collect specimens during the day at the Physiology Department, where all the students were working. The subjects were under observation for a con-
continuous period of at least 12 weeks. Three of the subjects were maintained on the particular diets for 31 weeks; it was not thought advisable to study the rest of the subjects for the prolonged period since this would have extended their experiment into an examination term. Five of the subjects were Ceylon Tamils and seven were Sinhalese. They were all normally active and healthy and within the age range 21–25 years. Their heights and weights are given in Table 1.

Table 1. Heights and weights of the subjects

<table>
<thead>
<tr>
<th>Subject no.</th>
<th>Height (cm.)</th>
<th>Weight (kg.)</th>
</tr>
</thead>
<tbody>
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<td>51.5</td>
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<td>7</td>
<td>138.5</td>
<td>50.0</td>
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<tr>
<td>8</td>
<td>157.0</td>
<td>46.5</td>
</tr>
<tr>
<td>9</td>
<td>138.5</td>
<td>53.0</td>
</tr>
<tr>
<td>10</td>
<td>154.5</td>
<td>58.5</td>
</tr>
<tr>
<td>11</td>
<td>163.0</td>
<td>64.0</td>
</tr>
<tr>
<td>12</td>
<td>160.0</td>
<td>64.5</td>
</tr>
</tbody>
</table>

*Diets.* The diet was adjusted so that each subject ate daily the equivalent of 9 oz. raw rice. Our dietary surveys have indicated that this is the average consumption of rice among the Ceylonese (Cullumbine, 1949b). This quantity of raw rice is equivalent to at least 27 oz. cooked rice, and this formed the main bulk of the diet. The rest of the diet was typically Ceylonese in character. On the average the daily diet was composed of: rice 9 oz., potatoes 1.5 oz., sugar 1 oz., dhal 3 oz., green vegetables 2 oz., vegetable fruits (bread-fruit, jack-fruit, ladies' fingers, brinjals) 2.5 oz., fresh fruit 4.5 oz., white bread 3.5 oz., beef 4 oz., fresh fish 1 oz., butter 0.5 oz. It was not supplemented with vitamin D or any other vitamin. It was varied from day to day but was repeated from week to week. On different sampling weeks the actual foodstuffs eaten by the subjects through each 7-day period were weighed. This allowed us to check the constancy of consumption by each individual and also enabled us to calculate the chemical composition of each subject's diet. The diet had, it was found, the following average calculated (see p. 110) daily composition:

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Calories</td>
<td>2005</td>
<td>9750 i.u.</td>
</tr>
<tr>
<td>Protein:</td>
<td>84.0 g.</td>
<td>16.5 mg.</td>
</tr>
<tr>
<td>total</td>
<td></td>
<td>Vitamin A*</td>
</tr>
<tr>
<td>animal</td>
<td>47.0 g.</td>
<td>Aneurin: polished rice 1.70 mg.</td>
</tr>
<tr>
<td>Fat</td>
<td>39.5 g.</td>
<td>unpolished rice 2.20 mg.</td>
</tr>
<tr>
<td>Carbohydrate</td>
<td>351 g.</td>
<td>Riboflavin 4.74 mg.</td>
</tr>
<tr>
<td>Calcium</td>
<td>575 mg.</td>
<td>Nicotinic acid 20.2 mg.</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>1485 mg.</td>
<td>Ascorbic acid 101.6 mg.</td>
</tr>
</tbody>
</table>

* Derived from preformed vitamin A and carotene, in the approximate proportions 1:2. The intake has been assessed using a conversion factor of 2 i.u. carotene as equivalent to 1 i.u. vitamin A.
The subjects took the different varieties of rice as follows.

Weeks 1–4 inclusive: ‘normal’ diet, i.e. a mixture of polished (Europe no. 2) and unpolished (Ceylon Country) rice in the proportions of 6:4 and a total of 9 oz. rice a day.

Weeks 5–7 inclusive: unpolished rice diet, i.e. 9 oz. unpolished (Ceylon Country) rice a day.

Weeks 8–10 inclusive: polished rice diet A, i.e. 9 oz. polished (Europe no. 2) rice a day.

Weeks 11–12 inclusive: polished rice diet B, i.e. 9 oz. polished (Small Mills Specials) a day.

Two types of polished rice diet were used because several varieties of rice are consumed in Ceylon, and analyses showed that these differed in mineral content (Table 2). The rice was prepared by boiling in water, after a preliminary washing, the water being drained off and discarded after the washing. This is the usual method of preparing rice in Ceylon. About one-third of Ceylon’s rice is grown locally (Country rice, unpolished and parboiled), and the rest is imported from various countries, including Burma, Egypt and Brazil. Most of the imports come from Burma as Milchard no. 2, which is a moderately highly milled parboiled rice, or as Small Mills Specials which is lightly milled and polished. Europe no. 2 is well milled and polished and Europe no. 1 very highly milled and polished. The rices used in the diets were Ceylon Country rice in the unpolished rice diet, Europe no. 2 in the polished rice diet A and Rangoon Small Mills Specials in the polished rice diet B. (It is, of course, more correct to speak of lightly milled and highly milled rices than of unpolished and polished rices, but the latter terms are in more general use.) It will be seen, therefore, from Table 2 that the unpolished rice diet should be intermediate in calcium content and highest in phytate-phosphorus content; polished rice diet A should be low in calcium and low in phytate-phosphorus content; and polished rice diet B should be high in calcium content and intermediate in phytate-phosphorus content. The average Ceylonese eats a mixture of country rice and polished rice and such a mixture formed our so-called normal diet.

The rice always supplied 40–50% (varying with individuals) of the total estimated calories.

Experimental and analytical procedure. The general experimental procedure and the analytical methods closely followed those described by McCance & Widdowson.
The foods, faeces and urines were analysed for calcium, magnesium, total phosphorus, phytate phosphorus, and iron. Duplicate samples were taken in parallel and the determination was repeated if good agreement was not obtained. The only difficulty found was in obtaining good duplicate determinations for iron in food. McCance & Widdowson (1942–3a) reported a similar inconsistency.

Sampling was done for 7 consecutive days, during each of weeks 2, 4, 7, 10 and 12. The first 2 weeks (2 and 4) of sampling enabled us to determine that each subject was in a maintained mineral balance, that the diet was satisfying and that the subjects understood the co-operative nature of their task. The subsequent sampling weeks were spaced so as to ensure that the subjects had time to adjust themselves to the new dietary conditions.

Following this 12-week period, three subjects were maintained on the unpolished rice diet for a further period of 18 consecutive weeks. Samples were collected for the 7 consecutive days of each 3rd week of this period. From this more prolonged experiment it was hoped to obtain evidence as to the reality of the process of adaptation.

RESULTS

The figures obtained for the two preliminary sampling periods, when the subjects were eating the normal diet, were so consistent that, for the sake of brevity, only the results for week 4 are given for this period.

Calcium metabolism. McCance & Widdowson (1942–3a) discussed their results on the basis of the estimated amount of calcium absorbed, the assumption being made that all the faecal calcium was obtained from unabsorbed food calcium. Steggerda & Mitchell (1946b) have shown that this assumption may not be true, so that we have here considered the calcium balance (total intake less total excretion) rather than the absorption (Table 3).

All twelve subjects showed a positive calcium balance during the 4 preliminary weeks that they were eating a normal diet. In every instance substitution of unpolished, country rice for the normal mixture of rice resulted in a substantial decrease in this metabolic balance and, in six subjects, the balance actually became negative. This occurred despite the fact that the intake of calcium on the unpolished rice diet was in many subjects higher than on the normal, mixed-rice diet. The decrease in the calcium balance was due to the increased excretion of calcium in the faeces, the faecal calcium being greater in all subjects when they were eating the unpolished rice diet.

Consumption of polished rice instead of the unpolished rice altered the balance again. In all subjects the balance became more positive or changed from a negative to a positive one, although the actual intake of calcium was uniformly less on this diet of polished rice than when unpolished rice was consumed. This change in the calcium metabolism was due to the lessened excretion of calcium in faeces. The urinary excretion of calcium was, in nine subjects, greater on the polished rice diet.

Increasing the calcium intake, by the substitution of polished rice diet B for diet A, still further increased the calcium balance. The increase in amount of calcium retained in the body was roughly proportional, but not equal, to the increase in intake, and both the faecal and urinary calcium excretions also were increased.
<table>
<thead>
<tr>
<th>Subject no.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<th>9</th>
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<tbody>
<tr>
<td>Ingested Feces</td>
<td>10.5</td>
<td>11.2</td>
<td>9.8</td>
<td>10.7</td>
<td>11.4</td>
<td>10.1</td>
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<td>10.9</td>
<td>11.6</td>
<td>10.3</td>
<td>11.0</td>
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<tr>
<td>Urine Feces</td>
<td>8.0</td>
<td>8.6</td>
<td>7.2</td>
<td>8.4</td>
<td>9.1</td>
<td>7.8</td>
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<td>11.2</td>
<td>10.0</td>
<td>10.5</td>
</tr>
<tr>
<td>Urine Feces</td>
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<td>8.3</td>
<td>7.0</td>
<td>7.9</td>
<td>8.7</td>
<td>7.4</td>
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<td>9.6</td>
<td>8.8</td>
<td>9.2</td>
</tr>
<tr>
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<td>10.9</td>
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<td>10.2</td>
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<tr>
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<td>8.6</td>
<td>7.4</td>
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<tr>
<td>Zero Balance</td>
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<td>9.7</td>
<td>8.7</td>
<td>8.8</td>
<td>9.5</td>
<td>9.3</td>
<td>9.6</td>
<td>10.0</td>
<td>8.6</td>
<td>9.3</td>
<td>8.5</td>
<td>9.0</td>
</tr>
</tbody>
</table>

Note: All measurements are in mg/day. 

Table 3: Daily intake, excretion and retention of calcium, magnesium, total phosphorus and iron from diets containing unpolished and polished rice.
It is obvious, therefore, that the greater calcium retentions were obtained on the polished rice diet B. With unpolished rice the calcium balance tended to become negative. This obviously suggests that, from the point of view of calcium metabolism, polished rice is to be preferred. The less highly milled rice, Small Mills Specials, had a higher calcium content than the highly milled Europe no. 2 rice and our results suggest that the former, 62 % extraction rice, is the rice of choice for inducing calcium retention.

**Magnesium metabolism.** Very similar conclusions are obtained from a study of the magnesium balance on the various types of diet (Table 3).

The results are not so consistent as with calcium, but the same general tendency is to be noted.

**Total phosphorus metabolism** (Table 3). The intake of total phosphorus was greater on the unpolished rice diet but so was the excretion of phosphorus in the faeces. There was, however, a definite tendency for the retention of phosphorus to be greater on the diet of unpolished rice. McCance & Widdowson (1942-3a) reported the same phosphorus balance with diets containing bread made from high and low extraction flours. Walker *et al.* (1948) found the retention of phosphorus to be somewhat greater on a white bread diet than on a brown bread diet. Our figures suggest that the phosphorus retention is proportional to the amount absorbed. Increased absorption is accompanied by increased urinary excretion, but it is also accompanied by increased utilization or storage. Therefore, because of the greater phosphorus content, a diet containing unpolished rice will be more likely to provide a positive phosphorus balance than a diet of polished rice. On all types of diet, however, positive balances were obtained and all the diets were probably adequate from the standpoint of the phosphorus metabolism.

**Iron metabolism.** The consumption of unpolished rice did not affect the amount of iron retained by each subject (Table 3). Walker *et al.* (1948) similarly found that the iron balance did not vary as their subjects changed from white to brown bread diets, although Widdowson & McCance (1942) found a greater iron absorption from white bread diets than from brown bread diets. Our experimental periods may have been too short to reveal significant differences with such small metabolic balances.

**Phytic-acid phosphorus.** Unpolished rice contains more phytic acid than polished rice and, in conformity with this, we found the phytic-acid phosphorus contents of the unpolished rice diets higher than those of the polished rice diets. The differences, however, were not as great as would be expected from our analytical figures for raw rice. If each subject consumed daily an average of about 9 oz. of rice we should expect the diets with unpolished rice to contain 270-430 mg. more phytic-acid phosphorus than the polished rice diets; the average estimated difference was only 117 mg./day (Table 4). A probable explanation of this is that the phytic-acid phosphorus of rice cooked by Ceylonese methods is less than that of raw rice. Some preliminary estimations that we have made on various Ceylonese rice dishes suggest that about two-thirds of the phytate may be hydrolysed or broken down during the process of cooking. The difference in phytic-acid phosphorus content does not explain the marked differences in the total phosphorus content of the two types of diet. Unpolished rice contains more of other types of phosphorus too. Presumably our results on the
influence of various types of rice on mineral metabolism can be explained on the basis of the greater phytic-acid content of unpolished rice, though whether there is sufficient phytic acid present quantitatively to account for the noted differences in calcium and magnesium balances we cannot say. We may assume that inorganic phosphorus does not interfere with calcium absorption, since McCance & Widdowson (1942–3a) have shown that fortification of bread with calcium phosphate improves the absorption of calcium.

The proportion of phytate hydrolysed did not vary with the type of diet consumed (Table 4).

*Adaptation.* Walker et al. (1948) thought that their results indicated that subjects could gradually adjust their metabolism so as to obtain positive calcium balances on diets poor in calcium, but rich in phytate phosphorus, and that the smaller the difference between the experimental calcium intake and the normal calcium intake the quicker this adjustment occurred. McCance & Widdowson (1942–3a) could find no evidence for such an adjustment in their subjects, but their periods of observation (at least for calcium) were probably too short for this to become evident.

The calcium intakes on our experimental unpolished rice diet were very similar to, and indeed slightly greater than, the subjects’ normal intakes. We should expect, therefore, that if an adjustment were to occur it would occur quickly. Different subjects may vary in their response and it may be argued that those subjects whom we found

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**Table 4. Daily intake, excretion and retention of phytate phosphorus on unpolished and polished rice diets**

<table>
<thead>
<tr>
<th>Subject no.</th>
<th>Diet</th>
<th>Intake (mg.)</th>
<th>Excretion in faeces (mg.)</th>
<th>Phytate hydrolysed (percentage of intake)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Unpolished rice</td>
<td>346</td>
<td>39</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>Polished rice A</td>
<td>260</td>
<td>32</td>
<td>88</td>
</tr>
<tr>
<td>2</td>
<td>Unpolished rice</td>
<td>367</td>
<td>62</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td>Polished rice A</td>
<td>321</td>
<td>42</td>
<td>87</td>
</tr>
<tr>
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<td>Unpolished rice</td>
<td>399</td>
<td>44</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>Polished rice A</td>
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</tr>
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<td></td>
<td>Polished rice A</td>
<td>247</td>
<td>42</td>
<td>83</td>
</tr>
</tbody>
</table>
to have a positive calcium balance during the 3rd week of the unpolished rice period had already adjusted themselves to the new dietary conditions.

To obtain further evidence on this important aspect, three subjects consumed the experimental unpolished rice diet continuously for 18 weeks. Two of these subjects (nos. 2 and 9) had previously had negative calcium and magnesium balances on this diet; the third (no. 1) was almost in equilibrium for both calcium and magnesium (Tables 2 and 3). Analyses done on the samples for every 3rd week of this period gave the results shown in Table 5.

It is evident that the calcium and magnesium balances improved for each subject so that, for example, originally negative balances in time became positive. This is definite evidence of an adaptation on the part of the organism to adverse dietary conditions. That this adaptation may not be entirely sufficient is suggested by the figures for the 19th week of the experiment, when polished rice diet A (lower calcium and phytic-acid contents) was consumed. This change in diet was accompanied by an immediate increase in the amounts of calcium and magnesium retained.

It is not possible to say what is the essential nature of this process of adaptation. It is achieved, apparently, by decreasing the quantities of calcium and magnesium in the faeces. This may be due to an alteration in the intestinal flora producing increased breakdown of phytate, or to altered rates of absorption. The urinary excretion, it will be noted, tended to increase and all our figures suggest, as McCance & Widdowson (1942–3b) have shown, that the urinary calcium, at least, tends to follow the absorption.

**DISCUSSION**

**Calcium requirements.** Most of the dietary requirements are still disputed. The optimum requirements are usually defined as those necessary to produce normal growth and full health but there is considerable confusion over the standards of growth and health at which to aim. The Ceylonese are, on the average, smaller than Europeans. This may be due to multiple deficiencies in the diet, but it must also be remembered that even the upper classes are still relatively small in stature (Cullumbine, 1949c). Therefore, it seems reasonable to assume that each race has its own growth standards and, therefore, possibly its own dietary requirements.

The minimum daily requirement of calcium is usually taken as the amount that will just maintain a positive metabolic balance and, on this basis, it seems that about 10 mg./kg. body-weight is this requirement for western people (Steggerda & Mitchell, 1939, 1941, 1946a; Leitch, 1937; Holmes, 1945). The results reported in this paper suggest that the calcium requirement varies also with the type of cereal in the diet, and that the process of adaptation may enable subjects to maintain a positive balance even on low intakes of available calcium. For these reasons it is difficult to make a dogmatic statement about the minimum requirements for adult Ceylonese. All that we can usefully say, at present, is that 10 mg./kg./day would seem to be an ample allowance of calcium for these subjects. The average weight of our group was 60.2 kg.; the average weight of adult male Ceylonese is 50 kg. There are, however, considerable individual variations in the metabolism of calcium. Thus, on the unpolished rice diet subject no. 6
Table 5. *Daily intake, excretion and retention of calcium and magnesium on a diet of unpolished rice*

<table>
<thead>
<tr>
<th>Subject no.</th>
<th>Week</th>
<th>Intake (mg./day)</th>
<th>Faeces (mg./day)</th>
<th>Urine (mg./day)</th>
<th>Total (mg./day)</th>
<th>Balance (mg./day)</th>
<th>Intake (mg./day)</th>
<th>Faeces (mg./day)</th>
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* In the 19th week a polished rice diet was consumed.
had a positive balance of 109 mg. with an intake of 465 mg., whereas subject no. 9 had a negative balance of 10 mg. on an intake of 883 mg.

Basu and his co-workers have studied the problem of calcium metabolism in Indian subjects consuming different types of diet. They have calculated the maintenance calcium requirement as 432 mg./man-value (Basu, Basak & De, 1941); this is less than the 10 mg./kg. recommended for occidental peoples. They have made no direct comparison of the effects of different varieties of rice on the calcium balance but they reached the significant conclusion that the replacement of a portion of the rice of a diet by an equal weight of sago, which contained the same percentage of calcium as the rice but much less phosphorus, improved the calcium balance (Basu, Basak & Rai Sircar, 1939). In their experiments the diets were changed every 6 days, so that any process of adaptation would not have been revealed.

Calculated composition of the diets. There is always some doubt, in assessing the data of a dietary survey, about the accuracy of the calculated chemical composition of the diets. During our own nutritional surveys in Ceylon we have used the tables compiled by Platt (1945), McCance & Widdowson (1946), and Joachim & Pandittesekere (1938), with, in addition, some figures obtained in our own laboratories from analyses on some of the common cooked dishes of Ceylon. This investigation gave us the opportunity to check the reliability of our calculations against the actual estimations for calcium, phosphorus and iron. One such comparison for the unpolished rice diet is shown in Table 6. The agreement in most instances is remarkably close.

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**SUMMARY**

1. The metabolism of calcium, magnesium, phosphorus, phytate phosphorus and iron was studied in twelve healthy Ceylonese male medical students for periods lasting from 12 to 31 consecutive weeks. Each subject consumed daily 9 oz. rice and the type of rice was varied from time to time.

2. Consumption of polished rice gave a better calcium and magnesium balance than the consumption of unpolished rice. A moderately polished rice with a high calcium content and a moderate phytic-acid content gave the best balances.
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3. Three of the subjects consumed an unpolished rice diet for a continuous period of 18 weeks and during this period the calcium and magnesium balances improved. This is taken as definite evidence of a process of adaptation.

4. The metabolism of iron was not consistently influenced by the type of rice consumed.

5. Unpolished rice diets resulted in greater excretions of phosphorus in faeces and urine and in greater phosphorus retentions than the polished rice diets.

REFERENCES