THE EFFECT OF PARBOILING AND MILLING ON THE ANTINEURITIC VITAMIN (B_1) AND PHOSPHATE CONTENT OF RICE.

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In the course of some experiments on the vitamin B_1 (antineuritic) value of cereals, it was observed that a sample of highly milled "parboiled" rice contained a considerable amount of vitamin B_1, while a sample of raw milled rice, of similar origin and milled apparently to the same degree, appeared to be devoid of the vitamin. This was opposed to the usual idea that the vitamin B_1 potency of a rice sample depends on its degree of milling, and the matter seemed worthy of further investigation.

The parboiling of rice.

In the process of parboiling, unhusked rice (paddy) is soaked in water for 24–36 hours, subjected to steam at atmospheric pressure for 15–20 minutes, and subsequently dried in the sun. When steamed the soaked grain swells, and the hard woody husk splits longitudinally, with the result that husk and grain can be separated with comparative ease—the primary purpose of the operation. Homely methods, such as pounding, which are comparatively ineffective with raw rice, will remove the husk from parboiled rice.

As a rule, parboiled rice is eaten in a roughly milled state, and this is due to several causes. First, parboiling toughens the grain and makes the removal of the pericarp more difficult. Secondly, parboiling is employed to facilitate husking in primitive communities where efficient mills are not available. A further reason may be found in the fact that since in the process of parboiling the grain assumes a creamy colour and therefore can never be milled to quite the same degree of whiteness as raw rice, millers favour the raw variety. But though in practice parboiled rice is rarely subjected to a high degree of milling, it is nevertheless quite possible to mill, from rice so treated, a highly polished product, which can only with difficulty be distinguished, by its toughness and translucence, from the ordinary white rice of commerce. The difference, as regards colour, may be very small indeed.

Historical.

Braddon (1907), in the epidemiological study which first drew attention to the close connection between beriberi and the consumption of rice, recorded the observation that those who eat parboiled rice ("cured" rice) escape beriberi. He reconciled this with his theory of a toxic origin of beriberi by

suggesting that in the process of steaming the causative toxic substance was destroyed.

Fraser and Stanton (1910) made a systematic investigation of the relation between the degree of milling to which particular kinds of rice had been subjected, and their capacity to protect human beings from beriberi and birds from polyneuritis. They confirmed the observation of Eijkman (1897) and others, that the antineuritic vitamin of the rice grain resides chiefly in the germ and pericarp, and suggested that a convenient way to assess the vitamin B_1 content of a rice sample is to measure the amount of germ and pericarp present. Most of the phosphate present in rice is to be found in the embryo and integuments, and the phosphate content of rice (estimated as P_2O_5), dependent on its degree of milling, should therefore serve as a useful index of vitamin B_1 value. Table I, in which the P_2O_5 content of rices in various stages of millings is compared with their vitamin B_1 potency, is based on results given by Fraser and Stanton.

Table I. *The effect of feeding different kinds of rice, unmilled, roughly milled, and finely milled, containing different percentages of P_2O_5, on the development of polyneuritis in birds and beriberi in man. Based on the work of Fraser and Stanton* (1910).

Type of rice	*Percentage of P_2O_5	Effect on fowls	Association with human beriberi
Unmilled rice	0·54	No polyneuritis	Never associated
Parboiled rice	0·41	No polyneuritis	Never associated
Roughly milled rice (Malay)	0·38	Almost complete protection from polyneuritis	Occasionally associated
Polished rice (Rangoon) ...	0·32	Some birds developed polyneuritis	Often associated
Polished rice (Siam) ...	0·26	Almost all birds developed polyneuritis	Associated with severe outbreaks

* Average result of several estimations.

On the basis of these observations (Table I) Fraser and Stanton suggested that a rice containing less than 0·40 per cent. of P_2O_5 is liable to cause beriberi. The parboiled rices examined were all under-milled, and these workers associated the generally observed higher vitamin content of parboiled rice with toughening of the outer layers of the grain, which renders a highly milled product less easy to obtain.

McCarrison and Norris (1924) made an extensive research into the antineuritic value of raw and parboiled rice. They noted that various samples of parboiled rice, even when milled and polished, protected pigeons from polyneuritis. Two samples of similar origin, one raw, the other parboiled, were highly milled and polished, and fed to birds as the sole source of vitamin B_1, with the result that those receiving the raw specimen developed polyneuritis, while those fed on the parboiled specimen did not. All the samples of parboiled rice tested by McCarrison and Norris, however, though stated to be highly milled and polished, contained a percentage of P_2O_5 of 0·35 or over, while the

P_2O_5 content of the raw, milled, and polished rices was in general below that figure. The possibility therefore existed that, owing to the greater mechanical difficulties of producing a finely milled parboiled rice, the parboiled rice samples tested by them retained in fact more pericarp than the raw.

The literature, then, in general, records that the vitamin B_1 value of parboiled rice is higher than that of raw rice, the explanation offered being that the pericarp of parboiled rice is more difficult to remove completely in milling. This explanation, however, could not apply to the sample of highly milled parboiled rice referred to in the opening paragraph of this paper which, although containing a demonstrable amount of vitamin B_1 retained no pericarp visible to the naked eye or by the microscope. To elucidate the problem the following study was undertaken of the vitamin B_1 value of raw and parboiled rice.

Technique of vitamin B_1 estimation.

The method of Chick and Roscoe (1929) was employed, in which the growth of young rats is the criterion. Young rats, a few days after weaning, about 40–50 grm. in weight, were given a diet (F.L.) composed of:

Light white casein British Drug Houses	20 parts
Rice starch	60 „
Arachis oil	15 „
Salt mixture	5 „
Water	100–120 „

[The diet is cooked in a steamer for 3 hours at 100° C.]

The rats were fed on this diet without supplement for 1 week, after which they received a daily addition of 0·05–0·01 grm. of cod-liver oil to supply vitamins A and D. Vitamin B_2, the second constituent of the vitamin B complex, was supplied by daily doses (equivalent to 0·5 grm. of dry yeast) of an extract made from washed brewer's yeast with 0·01 per cent. acetic acid. The extract was autoclaved for 5 hours at 120° (*p*H ca. 5·0) to destroy the antineuritic vitamin.

After the addition to the diet of the autoclaved yeast extract the rats increased in weight for 2–3 weeks, after which growth ceased. When the weight had been stationary for about 1 week the test material was fed either in the form of separate daily additions to the basal diet, or else the basal diet was modified to include a definite proportion of the substance under examination in the manner described in a previous publication (Aykroyd, 1930). The increase in weight was observed over a further test period of 4 weeks, and the vitamin B_1 value of different rice samples estimated and compared by observing the average weekly growth (increase in weight) corresponding respectively to various daily doses or percentages in the basal diet.

On certain of these diets the animals showed, in addition to failure of growth, the condition of ataxia and paralysis usually called "polyneuritis," and this was recorded as further evidence of the poverty of the regime in vitamin B_1. The power of some of the test substances to cure the condition was also investigated.

MATERIALS TESTED.

As a preliminary experiment (Table II) the vitamin B_1 content of a number of rice samples, raw and parboiled, milled to various degrees, was tested, each sample being fed as 65 per cent. of the basal diet. Most of the samples marked (x) came from the same rice farm in British Guiana. One specimen of highly milled and polished parboiled rice (y) was also grown in British Guiana, but not on the same farm. In addition a sample of milled raw rice of Burmese origin (z) was tested.

Table II. *Average weekly growth increments of rats receiving* (*a*) *samples of raw rice, unmilled and milled, and* (*b*) *samples of parboiled rice, unmilled and milled, all fed as* 65 *per cent. of a purified diet deficient in vitamin* B_1. *The* P_2O_5* *content of the rices is also given.*

(*Vitamin* B_2 *supplied by daily doses of an autoclaved yeast extract.*)

Substance tested	P_2O_5 content %	No. of rats	Average weekly increase in weight during test period of 4 weeks (g.)	Evidence of vitamin B_1 deficiency shown by rapid decline and "polyneuritis"
(*a*) Raw rice:				
Unmilled (x)	0·493	3	19	—
Milled (x)	0·223	2	Lost weight	Both developed "polyneuritis" in 3–4 weeks
Milled (z)	0·233	5	Lost weight	All developed "polyneuritis" or died without nervous symptoms in 3–6 weeks
(*b*) Parboiled rice:				
Unmilled (x)	0·499	2	19	—
Milled (x)	0·271	4	19	—
Milled (y)	0·216	4	18·5	—

* The phosphate estimations (expressed as P_2O_5) were made in duplicate by a modified Briggs method.

The results shown in Table II indicated that unmilled raw rice, and both unmilled and milled parboiled rice, could induce rapid increase in weight when fed as 65 per cent. of the purified diet free from vitamin B_1. The animals on the diet containing milled raw rice showed a speedy decline. Although one sample of milled parboiled rice (y) had a lower P_2O_5 content than the two samples of raw milled rice examined (x and z) (and therefore, on the Fraser and Stanton hypothesis, retained less pericarp) rapid growth ensued when the former was fed, and paralysis and death in the case of the latter. It was, however, possible that the different origins of x, y and z samples might explain their difference in vitamin B_1 content. The milled parboiled rice (x) contained a very slightly higher percentage of P_2O_5 than the raw milled rice of exactly similar origin (x) and might therefore be somewhat richer in pericarp. It was conceivable that a very small amount of vitamin B_1 in the test material, when such large amounts were being fed, might support growth. It was therefore decided to procure specimens of raw and parboiled rice of which the degree of milling should be identical.

EXPERIMENTS WITH A HAND RICE MILL.

A small machine used for milling samples of rice was borrowed from a firm of rice merchants. The machine consists of a grindstone inside a metal drum whose circumference is of finely meshed wire. Grindstone and drum are made to rotate in different directions and are separated by a space of about $\frac{1}{2}$ in., into which about 20 grm. of rice can be placed. As the machine rotates the outer layers of the grain are rubbed off between the two rough surfaces of wire and stone, and the millings fall through the wire mesh into a receptacle beneath the drum. The milled rice is separately removed. The millings can be collected and weighed, and it is possible to remove a desired percentage weight of millings from a given amount of unmilled rice. After a little practice with the machine it is easy to mill rice to any required degree.

Table III. *Average weekly growth increments of rats on a purified diet deficient in vitamin (B_1) supplemented with daily doses of various rice products.*

(*Vitamin B_2 supplied by daily doses of an autoclaved yeast extract.*)

Substance tested	Percentage of original weight removed as millings	P_2O_5 %	Amount given daily (g.)	No. of rats	Average weekly increase in weight for 4 weeks (g.)	Evidence of vitamin B_1 deficiency as shown by rapid decline and polyneuritis
(*a*) Raw rice:						
Unmilled	—	0·493	1	4	6	—
			2	3	15	—
			3	3	17	—
Roughly milled (some pericarp visible)	11	0·276	2	3	Lost weight	All developed polyneuritis in 2 weeks
			3	3	4 (2 rats)*	1 rat developed polyneuritis
Highly milled	15	0·169	3	3	Lost weight	All developed polyneuritis
Millings	—	2·299	0·25	3	11	—
			0·5	3	15	—
(*b*) Parboiled rice:						
Unmilled	—	0·499	1	4	7	—
			2	3	17	—
			3	3	20	—
Highly milled	15	0·256	1	4	5	—
			2	3	13	—
			3	3	20	—
Highly milled (*y*)	—	0·216	2	3	12	—
			3	2	16	—
Millings	—	2·046	0·5	3	9	—

* One rat lost weight.

Two samples of unhusked rice (paddy) from the same rice farm in British Guiana, one raw (*a*), the other parboiled (*b*), were husked in the machine. The resulting unmilled rices, whose P_2O_5 content was similar, were then milled until about 15 per cent. of their weight was rubbed off from the outer layers of the grain—a high degree of milling. The resulting samples of highly milled raw and highly milled parboiled endosperm, and the millings removed from each, were

respectively tested for content of vitamin B_1. Another sample of less thoroughly milled raw rice (11 per cent. of original weight removed), of the same origin, was also examined.

The rice samples were fed as additions of from 1–3 grm. daily to the basal diet, except one sample of milled raw rice, very deficient in vitamin B_1, of which 65 per cent. (> 3 grm. daily calculated from total consumed) was included in the diet. In the tests of the rice polishings, the daily dose was smaller: 0·25–0·5 grm. The percentage of P_2O_5 present in all the products was estimated. The results are given in Table III, in which the vitamin B_1 assay of a commercial sample of highly milled and polished parboiled rice (*y*) is also included.

A number of interesting points arise from the results set out in Table III. The samples of unmilled raw (*a*) and unmilled parboiled (*b*) rice contained an equal percentage of P_2O_5 and were about equal in vitamin B_1 value. 2 grm. of either sufficed for a weight increase of 15–17 grm. weekly. The milled products of these rices, however, showed great differences of vitamin B_1 content. The two specimens of raw milled rice (P_2O_5, 0·169 and 0·276 per cent.) were extremely deficient in the vitamin; the animals receiving 2–3 grm. daily failed to grow and in many cases developed polyneuritis. The milled parboiled sample of similar origin (P_2O_5, 0·256 per cent.) was only a little poorer in vitamin B_1 than the original rice in the unmilled state. When 2 or 1 grm. daily was given a slight inferiority to the unmilled rice was manifest, but with 3 grm. daily growth was excellent (20 grm. weekly). Parboiled rice polishings, on the other hand, were found to have a lower vitamin B_1 and phosphate content than polishings from raw rice. 0·5 grm. of the former produced poorer growth than half that quantity of the latter.

Curative tests. All rats which, on being fed additions of raw milled rice, developed polyneuritis, were cured, and resumed rapid growth, when given 2 grm. daily of parboiled milled rice.

THE RELATION BETWEEN THE P_2O_5 CONTENT OF RAW AND PARBOILED RICE AND THEIR DEGREE OF MILLING.

When 15 per cent. by weight of polishings was removed from the unmilled raw rice sample, the P_2O_5 content of the resulting product was 0·169 per cent. With parboiled, unmilled rice, on the other hand, the milling away of the same percentage of its weight produced a specimen with $P_2O_5 = 0·256$ per cent. The roughly milled raw rice, with a P_2O_5 content (0·276 per cent.) about equal to this figure, was obtained from unmilled rice by the removal of only 11 per cent. by weight of polishings.

DISCUSSION.

These results, at first sight puzzling, can be simply explained. When soaked unhusked rice is steamed, it absorbs water and swells, and in this process the water-soluble vitamins contained originally in the germ and pericarp diffuse

through the endosperm. The phosphate contained in the integuments, much of which, as McCarrison and Norris (1924) have shown, is water-soluble, tends also to be diffused throughout the grain in the same way. Comparison under the microscope of raw and parboiled rice grains lends support to the theory. In the parboiled grain, unlike the raw, the starch granules are irregular in shape, their distribution is disorderly, and the fibrous partitions of the endosperm are broken down.

When rice is parboiled the endosperm thus absorbs vitamin B_1 at the expense of the germ and pericarp, and milling does not remove the vitamin. Phosphorus compounds probably diffuse through the grain in a similar fashion, and a sample of milled parboiled rice will tend to contain more P_2O_5 than raw rice milled to the same extent.

For this reason parboiled rice polishings contain considerably less vitamin B_1 and phosphate than raw rice polishings (Table III).

The importance of steaming in the parboiling process.

Parboiling consists of three processes: soaking, steaming, and drying. The relative importance of these processes in altering the distribution of vitamin B_1 in the grain was investigated in the following manner. A specimen of raw paddy (unhusked rice) was soaked in water for 36 hours after which half of it (*b*) was steamed at atmospheric pressure for about 30 minutes. Both steamed and unsteamed portions were subsequently dried at 37° C. 11 per cent. by weight of polishings was subsequently milled from the soaked and dried sample (*a*) and 17 per cent. from the soaked, *steamed* and dried sample (*b*). These milled rices were tested for vitamin B_1 in the same way as the other samples (Table IV).

Table IV.

Rice	P_2O_5	Percentage of original weight removed as millings	Dose (g.)	No. of rats	Average weekly increase in weight
(*a*) Soaked and dried at 37° C.	0·278	11	3	3	2 (2 rats)*
(*b*) Soaked, *steamed* and dried at 37° C.	0·237	17	3	3	15

* One rat lost weight.

The soaked and dried sample did not, when milled, differ in appearance or vitamin B_1 value from other specimens of raw milled rice tested. The steamed sample, however, was found to have retained its vitamin B_1 after milling. This indicates that it is the application of steam which changes the structure of the grain and the distribution of the vitamin, and thus renders the removal of vitamin B_1 in milling impossible.

GENERAL DISCUSSION.

The fact that it is possible to produce a highly milled and polished variety of rice which nevertheless contains vitamin B_1 may be of some practical importance. A good sample of milled parboiled rice can scarcely be distinguished in taste and appearance from ordinary commercial rice when made into a milk pudding, though parboiled rice is somewhat tougher and may require longer cooking. It is often difficult to persuade communities liable to beriberi to discard the more attractive and more palatable polished rice in favour of an undermilled variety; prejudice might, however, be overcome by the substitution instead of milled rice, of good quality, previously parboiled, which is pleasing to the eye and palate, and may contain enough vitamin B_1 to prevent beriberi. It would be worth while to investigate, from the practical and clinical sides, the advantages and disadvantages of highly-milled parboiled rice as a staple cereal.

Estimation of P_2O_5 content seems to serve as an index of the vitamin B_1 value of raw rice, and the present investigation supports the suggestion of Fraser and Stanton that raw rice containing less than 0·40 per cent. of P_2O_5 is liable to be low in vitamin B_1 and give rise to beriberi. The phosphate content of parboiled rice, however, is no guide to its vitamin B_1 value, since percentages as low as 0·22–0·28 may be present in samples which contain abundance of the vitamin.

From the present observations, and those of McCarrison and Norris (1924), it appears that water readily removes vitamin B_1 from rice germ and pericarp. In parboiling, the antineuritic vitamin is, as it were, washed in, and so not lost to the grain, but when unmilled rice is washed in the ordinary way the vitamin diffuses into the surrounding water. Many communities have the sensible custom of drinking the water used for washing rice and thus avoid loss of the vitamin. A point worth noting is that the first stage of the parboiling process, viz. soaking, does not remove the vitamin from *unhusked* raw rice.

Milled parboiled rice readily loses vitamin B_1 when soaked in water. In one experiment it was found that after being soaked for 36 hours with one change of water a sample of milled parboiled rice retained very little antineuritic vitamin, but this could be recovered from the water. A sample of milled parboiled rice covered with water for 5 minutes lost most of its vitamin. Undermilled rice of poor quality is often subjected to washing before consumption, and it is important that it should be generally realised how easily this may weaken its original vitamin potency. Probably, as McCarrison has suggested, the occasional occurrence of beriberi among populations eating undermilled rice may be explained by loss of vitamin B_1 when the rice is washed.

SUMMARY.

1. Highly milled parboiled rice was found to be rich in the antineuritic vitamin B_1, while roughly milled raw rice was deficient. In estimating the content of vitamin B_1 the method of Chick and Roscoe was used.

2. Exact comparison was made of the vitamin B_1 potency of two samples of rice, the one raw, the other parboiled, after similar degrees of milling. The vitamin value of the unmilled samples was equal, but when each was highly milled to an equal degree, as judged by weight of polishings removed in a hand rice mill, the parboiled sample retained the vitamin while the raw sample did not.

3. Polishings from parboiled rice were found to contain less vitamin B_1 than those from raw rice.

4. Parboiled rice contains more P_2O_5 than raw rice milled to the same degree.

5. It is probable that when rice is steamed in the process of parboiling, the vitamin B_1 and some of the phosphate contained in the germ and pericarp diffuse through the endosperm.

6. The P_2O_5 content of raw rice is a good index of vitamin B_1 value, but in parboiled rice a low percentage of phosphate is compatible with the presence of the vitamin.

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