ure 2); for soaking at high temperatures will favor increased bran embedding because of the high surface-moisture content (*2*), and also the penetration of the husk pigment because of bursting of the grain (*2*). The greater effect of soaking temperature in RC is significant in this context, because this paddy shows greater moisture gradient and quicker splitting during soaking (*2*). It also has a dark reddish husk, whereas the husk of BS is golden.

An effect of pH of the soaking medium on the color of parboiled rice has been demonstrated more recently by Jayanarayanan (*6*); discoloration increased on either side of pH 4.5. The pH could have a direct influence on the browning reaction besides modifying the color of the bran pigment at higher ranges, for the pigment is an acid-base indicator (*13*) and changes color (intensifies) in the approximate range of pH 7 to 9. The relative contribution of these two effects in Jayanarayanan's results has to be evaluated, because color was measured by him apparently on brown rice without further milling. The observed color-inducing effect of pH below 4.5 has to be further investigated.

Further work on the quality factors of parboiled rice and the physicochemical aspects of parboiling is being planned.

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RICE

Effect of Parboiling on Thiamine Content of Rice

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Parboiling destroys a part of the total thiamine content of paddy while protecting the remaining vitamin from milling loss. Soaking *per se* does not lead to loss, but much thiamine is leached out if paddy splits during soaking; soaking at high pH also may reduce it. Steaming destroys the thiamine partly. The thiamine is protected against milling loss by mere high temperature soaking of paddy (70° C. or above) or by soaking and steaming, but not by soaking alone at lower temperatures. This protection thus appears to be caused by embedding of the inner bran and scutellum layers in the endosperm, consequent on gelatinization, rather than by inward diffusion of the vitamin. Presence of more bran pigments in milled parboiled rice than in raw rice and their greater adhesion to the endosperm support this hypothesis.

Numerous workers have demonstrated that milled parboiled rice contains more thiamine than milled raw rice (*1, 3, 4, 7–14, 17–20, 24*). However, it is not clear, despite a few studies (*8, 10, 11*), how different parboiling treatments would affect the vitamin content of the rice. Initial attempts to elucidate this aspect showed fairly large differences in the B_1 content of different parboiled samples; but no clear correlation with the processing history of the samples could be established. Followup of the vitamin content in paddy (rough rice) after each step of processing (soaking and steaming) as well as in the rice milled at each step, under a variety of processing conditions, led to a clearer understanding of the situation and also threw light on the mechanism of vitamin retention by parboiling. These results are given here.

Materials and Methods

Parboiled Paddy and Rice. Samples of parboiled and semiparboiled paddy and rice employed, in the two varieties of Bangara Sanna (BS) and Ratna Chudi (RC), have been described (*5*); they are referred to here by their code numbers.

Estimation of Thiamine. Thiamine was estimated in paddy and rice (5 grams) by the usual thiochrome method (*2*) with some modifications. (In the case of paddy, a little more than 5 grams of the sample were ground in a hand mill and the entire amount was weighed for extraction to avoid the difficulty of proper sampling from a nonuniform mixture of husk and powdered endosperm.) Extraction was carried out with 100 ml. of 0.1*N* sulfuric acid by standing overnight at room temperature, and the filtrate was directly taken for oxidation. It was ascertained from a few preliminary experiments that neither the cold extraction nor the absence of enzyme treatment lowered the results of B_1 assay. The husk in the paddy did not interfere with the analysis, as evidenced by low blanks and good recovery.

Extracts were oxidized in the usual way (*2*), except that a larger quantity of the extract (10 ml.) and higher concentrations of the reagents (3 ml. of 40% sodium hydroxide and 3 drops of 1% potassium ferricyanide) and of standard B_1 (2.5 μg.) were employed. This was necessary because the fluorometer employed (Klett) had only a narrow tube as the cuvette and so needed a higher concentration of thiochrome for accurate readings. The results were generally highly reproducible, so that while oxidation was done always in duplicate, extraction was replicated only when in doubt.

Calculation of Per Cent Thiamine Retention. For facilitating the comparison of results, the B_1 analysis data in paddy and rice obtained after different steps of processing were expressed as per cent of the vitamin present in the original paddy (or in the corresponding paddy when evaluating the milling loss of B_1). Per cent retention in paddy after any treatment was calculated directly on the basis of equal weight. But in calculating per cent retention of B_1 in milled rice in terms of paddy, the amounts of vitamin in equal numbers of grains rather than in equal weights of paddy and rice had to be compared—i.e., the weight loss during milling had to be taken into account. This was achieved by multiplying the result by the total milling yield (*5*) as in the following formula:

$$\% \ B_1 \text{ retention in milled rice} = \frac{R}{P} \times f$$

where

R = B_1 in milled rice, μg./g.
P = B_1 in paddy, μg./g.
f = total milling yield of rice, %

Actual 100-grain-weight analysis of the corresponding paddy and rice in a few samples gave factors close to those based on milling yields.

Analysis of Bran Content. Bran in milled rice was analyzed by extracting 2 grams of the ground rice (in duplicate) with 12 ml. of alkaline methanol (1 to 1 mixture of 2% aqueous sodium carbonate and methanol) for 3 hours with occasional vigorous shaking, and reading the yellow solution in a Klett-Summerson photoelectric colorimeter at 420 mμ (*21*). [To make sure that the product of browning reaction in parboiled rice would not interfere with this analysis, a sample of parboiled rice was heated in a closed tube in the oven (18 hours at 100° C.) to a deep amber color; this rice, on extraction, gave the same color reading as the unheated control.] Relative firmness of the adhesion of bran to the endosperm in raw and parboiled rice was tested by extracting replicate aliquots (2 grams) of the whole grains for different lengths of time and comparing with the color reading obtained by complete extraction from the powdered material.

Results

Loss of Thiamine during Parboiling. Evaluation of the retention of thiamine in paddy at different stages of parboiling (Table I) showed that parboiling resulted in some loss of thiamine under certain conditions of soaking and steaming. Soaking at temperatures of up to 60° C. did not lead to loss. [There was a moderate loss of the vitamin in R-60-c, which is characteristic of the quicker splitting of RC during soaking (*5*); BS showed little loss at this stage.] But soaking, especially oversoaking, at 70° and 80° C. resulted in progressive and considerable loss of the vitamin. The data of Done (*8*) also show similar losses at high temperatures of soaking. Considering that the paddy under these conditions underwent progressive bursting (*5*), it appeared very likely that this loss was due to leaching of the vitamin into the soak water. A preliminary experiment showed this to be true (Table II), and additionally brought out

Table I. Retention of Thiamine in Paddy after Soaking and Steaming

Sample[a]	Retention of B_1, % of Original Paddy,[b] Consecutively after: BS Soaking	BS Steaming	RC Soaking	RC Steaming
Unsoaked paddy		95 (95)[c]		90 (90)[c]
RT-a-10_0	97	—	100	—
b-10_0	94	—	101	—
c-10_0	89	—	99	—
50-a-10_0	101	96 (95)	100	90 (90)
b-10_0	101	97 (96)	99	—
c-10_0	102	95 (93)	97	89 (92)
60-a-10_0	100	—	101	—
b-10_0	99	—	94	—
c-10_0	94	—	84	—
70-a-10_0	96	—	97	—
b- 2_0	91	—	94	91 (97)
5_0		—		91 (97)
10_0		84 (92)		90 (96)
20_0		—		85 (90)
40_0				81 (86)
60_0				76 (81)
10_5				84 (89)
10_{10}				80 (85)
10_{20}				68 (72)
c-10_0	73	—	63	—
60_0				—
80-a-10_0	83	—	87	—
b-10_0	61	58 (95)	83	81 (98)
c-10_0	42	—	69	—

[a] First letter (omitted in this table because it is a common list) refers to paddy variety (B for BS, R for RC); second item gives temp. of soaking; lower case third letter gives soaking time (in general terms, a undersoaking, b optimal soaking, and c oversoaking); and last figure indicates time (min.), and its subscript, pressure (p.s.i.g.), of steaming. For details, see (*5*).
[b] Thiamine content of original paddy was: BS 274 and RC 287 μg./100 g.
[c] Data in parentheses give percentage retention of B_1 in steamed paddy in terms of corresponding soaked paddy.

Table II. Loss of Thiamine during Soaking of Paddy

[15 grams of paddy (BS) were soaked in 45 ml. of soaking medium in wide boiling tubes immersed in an appropriate water bath. After soaking, the soak water was filtered through wire mesh, and the paddy was dried in an oven at 75° C. for 1 hr. followed by overnight exposure to the atmosphere. B_1 was estimated in each after acid extraction.]

Medium	Soaking Conditions: Approx. pH[a]	Approx. temp., ° C.	Time, hr.	B_1, % of Original Paddy, in: Soaked paddy	Soak water	Total
Dist. water	6.1–6.4	60	3	96	1	97
			8	94	2	96
		80	1	96	1	97
			2.5	81	12	93
			3.5	74	17	91
Tap water	6.9–7.1	80	2.5	79	6	85
0.5% NaH_2PO_4	5.6	80	2.5	87	8	95
0.5% $NaHCO_3$	8.0–9.0	80	2.5	77	0	77

[a] Tested with pH papers. Wherever range has been given, pH tended to rise during soaking from lower to higher value.

the effect of pH of the soaking medium. Relatively higher pH values reduced the B_1 in the paddy slightly; however, their chief effect was in destroying the vitamin already leached out into the soaking medium. Thermal destruction of B_1 within the grain during soaking did not appear to be very significant.

Steaming resulted in some additional destruction of the thiamine, but on the whole to a small extent (R-70-b series, Table I). Under normal conditions of steaming (10 minutes at 0 p.s.i.g.), 5 to 10% of the vitamin was lost. A point not investigated, but which appears possible from the data of Table II, is that if paddy is soaked at relatively higher pH, the destructive effect of the subsequent steaming may be enhanced.

Sun drying of parboiled paddy (tested in a sample of BS, B-60-b-10_0, not shown here), as contrasted to shade drying, did not affect its B_1 content. From this it is difficult to understand the implication of the results of Mazumder *et al.* (*15*), who found that rice from mechanically dried parboiled paddy contained more thiamine than that obtained by drying in the sun.

Loss of Thiamine during Milling. Milling of raw paddy resulted in drastic loss of its thiamine content, which was largely prevented by parboiling (Table III). However, the milling retention of B_1 increased strikingly on mere soaking of paddy at a temperature near or above the gelatinization point; below this point, the retention remained low or increased only marginally even on prolonged soaking. (The moderate increases in R-50 and R-60 were again characteristic of RC; BS showed less increase at these stages.) On steaming following soaking, however, the milling retention of the vitamin was always high, irrespective of the condition of soaking (even undersoaking) and steaming. Simple steaming of raw paddy, as is generally known (*11*, *17*), also increased the retention of the vitamin.

Quantitatively, the milling loss of B_1 in parboiled paddy was nearly independent of the processing condition, amounting (for full polish) to about one fourth of what was retained in the paddy after soaking and steaming. The loss was a little more after processing by room-temperature soaking or undersoaking at 50° C.

Thiamine Content of Milled Rice. There were fairly large variations in the thiamine contents of different milled rice samples, both parboiled (soaked and steamed) and semiparboiled (only soaked) (Table IV). This was expected because the final retention of B_1 in the finished rice was the resultant of the losses during soaking, steaming, and milling, which themselves varied widely depending on the processing conditions. In parboiled rice, the percentage milling loss was fairly constant (Table III), so that the retention was determined chiefly by the variable losses during soaking and steaming. But in rice obtained from merely soaked paddy, the widely variable milling loss was the main determining factor.

Highest retention of thiamine in milled parboiled rice was obtained after optimal soaking at 50°, 60°, and 70° C., followed by minimal steaming. The vitamin content was markedly reduced whenever the paddy was soaked under conditions leading to bursting (70-c, 80-b, c), or severely steamed (R-70-b series), or both (R-70-c-60_0). However, even when produced by the

Table III. Effect of Processing on Retention of Thiamine and Bran on Milling of Paddy

Sample	B_1 Retained in Rice Milled, % of Corresponding Paddy				Bran Pigments in Rice Milled, Klett Reading	
	BS		RC		RC	
	Before steaming	After steaming[a]	Before steaming	After steaming[a]	Before steaming	After steaming
Unsoaked paddy	7	24	10	36	72	—
RT-a-10_0	5	64	7	65	65	300
b-10_0	5	64	7	66	58	260
c-10_0	6	68	7	68	58	240
50-a-10_0	9	66	15	70	108	240
b-10_0	12	73	20	75	153	244
c-10_0	14	74	24	77	200	244
60-a-10_0	11	74	18	77	150	245
b-10_0	19	78	31	81	210	250
c-10_0	21	79	32	76	210	260
70-a-10_0	38	—	40	77	—	—
b- 2_0	47	—	54	74	230	234
5_0		—		75		260
10_0		74		76		259
20_0		—		—		325
40_0				—		400
60_0				75		355
10_5				—		305
10_{10}				75		330
10_{20}				71		450
c-10_0	75	—	69	73	—	—
80-a-10_0	66	76	67	71	232	280
b-10_0	—	76	66	70	325	355
c-10_0	—	—	68	70	550	530

[a] In calculating this percentage, average loss of 7.5% of thiamine during steaming for 10 min. at 0 p.s.i.g. assumed wherever B_1 data for such steamed paddy were not available (cf. Table I).

Table IV. Thiamine Content of Milled Semiparboiled and Parboiled Rice

Sample	B_1 in Rice, μg./100 G., Milled			
	Before Steaming		After Steaming	
	BS	RC	BS	RC
Steamed paddy	30 (7)[a]	35 (10)[a]	97 (24)[a]	131 (32)[a]
RT-a-10_0	20 (5)	30 (7)	221 (57)	233 (60)
b-10_0	21 (5)	29 (7)	218 (56)	240 (62)
c-10_0	22 (5)	30 (7)	220 (56)	240 (62)
50-a-10_0	36 (9)	61 (15)	243 (62)	252 (65)
b-10_0	48 (12)	80 (20)	267 (68)	265 (68)
c-10_0	55 (14)	91 (23)	274 (70)	267 (69)
60-a-10_0	45 (11)	73 (18)	269 (69)	277 (71)
b-10_0	75 (19)	117 (29)	280 (72)	273 (70)
c-10_0	81 (20)	110 (27)	272 (69)	228 (59)
70-a-10_0	146 (37)	155 (39)	—	268 (69)
b- 2_0	173 (43)	204 (51)	—	262 (68)
5_0			—	262 (68)
10_0			259 (66)	264 (68)
20_0			—	—
40_0				—
60_0				222 (57)
10_5				—
10_{10}				233 (60)
10_{20}				186 (48)
c-10_0	217 (55)	174 (44)	—	165 (42)
60_0				136 (35)
80-a-10_0	220 (55)	226 (58)	228 (58)	223 (58)
b-10_0	143 (36)	209 (53)	168 (43)	205 (53)
c-10_0	79 (20)	185 (47)	—	173 (45)

[a] Data in parentheses express B_1 content as % of that present in original paddy.

most adverse conditions, the vitamin content of milled parboiled rice was considerably more than that of the corresponding milled raw rice. The high thiamine content of rice milled from paddy merely soaked at 70° C. and above is also significant.

Bran in Milled Rice. Analysis of bran pigments in the different samples (RC) demonstrated a pattern broadly similar to that of the retention of thiamine (Table III). In particular, steaming following soaking invariably led, as in the case of B_1, to an increase in the bran content up to a soaking temperature of 60° C. but not beyond that point (if sufficiently soaked). Figure 1 shows a much firmer adhesion of the bran to the endosperm in parboiled rice than in raw rice.

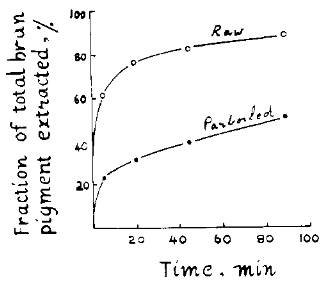

Figure 1. Rate of extraction of bran pigments from whole grains of raw (RC) and parboiled (R-60-b-10$_0$) rice

Color reading obtained by extracting ground rice for 3 hr. considered as 100%

Discussion

Although parboiling as a whole increases the thiamine content of milled rice, the present work shows that it also results in some loss of total thiamine in the grain during soaking and steaming. Its second, and more important, role is to protect the thiamine remaining in the paddy from being lost during milling.

Mechanism of Reduction in Thiamine Milling Loss after Parboiling. This is very commonly ascribed to a diffusion of the vitamin from the outer layers into the endosperm during soaking (and steaming). Direct experimental evidence in support of this theory has been furnished by only two workers (*9, 17*). But a careful study of their results does not indicate the evidence as conclusive. [The photomicrographs of Simpson (*17*), for instance, show only a general diffusedness of the previously sharp thiamine layer after parboiling, but little sign of actual penetration. The experimental conditions of Hinton (*9*) were such that as much as 50% of the vitamin was always lost; his data therefore need re-evaluation.] Our data appear to be irreconcilable with this theory. A slight inward diffusion of the vitamin during soaking probably occurs. The trend of the data of the milling retention of the vitamin (Table III), increasing slightly from RT-a-10$_0$ through 60-b-10$_0$ (as well as in the corresponding unsteamed samples), suggests this. But any such diffusion appears to be only marginal and without much influence on the milling loss of thiamine, for even prolonged soaking below the gelatinization temperature did not appreciably improve the retention of the vitamin after milling.

The present results strongly implicate the gelatinization of the grain in the protection of B_1 against milling loss. Presumably the inner bran and scutellum layers (with their thiamine content) get embedded into the surface of the endosperm during gelatinization, and are thus prevented from being removed during milling. Indeed, this had been suggested earlier (*16, 18, 19, 22*), although without much experimental evidence. Presence of greater amounts of bran pigments in the milled grain following gelatinization (Table III), and their firmer adhesion to the endosperm in parboiled rice compared to raw rice (Figure 1), support this hypothesis. The fact that the washing loss of thiamine from rice is markedly reduced by parboiling (*4, 14, 23, 24*) is also indicative of a firm adhesion. However, the bran and the B_1 values in Table III are not strictly proportional. Part of the cause of this discrepancy may lie in an inherent error in the method adopted for the estimation of bran: If any husk pigment is absorbed by the endosperm during soaking (*6*), it will wrongly increase the bran value in this method.

Conditions for Maximal Retention of Thiamine by Parboiling. One of the chief considerations for parboiling of rice is its nutritional importance resulting from higher retention of vitamins, especially thiamine. Since the B_1 retention is largely dependent on the processing conditions, it is important to select conditions where maximum vitamin retention, consistent with other favorable characteristics, is achieved. Best results are obtained when the paddy is soaked under conditions not leading to its bursting and then subjected to minimum of steaming. Soaking at very high temperatures (favoring bursting) or severe steaming leads to marked reduction in the vitamin content. Soaking at high pH may also reduce it. The drying condition appears to have no effect.

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