European Journal of Clinical Nutrition (2000) 54, 380–385

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# Glycaemic index of parboiled rice depends on the severity of processing: study in type 2 diabetic subjects

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**Objective:** To study the influence of parboiling and the severity of the process on glycaemic and insulinaemic responses to rice in type 2 diabetes. Moreover, to examine changes in starch structure related to parboiling, which may affect the metabolic responses and digestibility.
**Design:** Nine type 2 diabetic subjects ingested four test meals: white bread (WB) and three meals of cooked polished rice of the same variety being non-parboiled (NP), mildly traditionally parboiled (TP) and severely pressure parboiled (PP). The participants ingested the test meals (50 g available carbohydrates) on separate occasions after an overnight fast.
**Setting:** Outpatient clinic, Dept. Endocrinology and Metabolism, Aarhus University Hospital, Denmark.
**Results:** All three rice samples elicited lower postprandial plasma glucose response (NP: $335 \pm 43$; TP: $274 \pm 53$; PP: $231 \pm 37$ mmol/1*180 min.; means $\pm$ s.e.m.) than white bread ($626 \pm 80$; $P < 0.001$), within rice samples PP tended to be lower than NP ($P = 0.07$). The glycaemic indices were: NP: $55 \pm 5$, TP: $46 \pm 8$ and PP: $39 \pm 6$, and lower for PP than NP ($P < 0.05$). The insulin responses were similar for the three rice meals, which were all lower than that to white bread ($P < 0.001$). Differential scanning calorimetry showed the presence of amylose–lipid complexes in all rice samples and of retrograded amylopectin in PP. Amylose retrogradation was not detected in any of the rice samples.
**Conclusions:** All rice test meals were low-glycaemic in type 2 diabetic subjects. There was no effect of TP on glycaemic index, whereas PP reduced the glycaemic index by almost 30% compared to NP.
**Sponsorship:** The Royal Veterinary and Agricultural University, Aarhus University Hospital, Danish International Development Assistance (DANIDA), Ministry of Foreign Affairs and the 'Konsul Johannes Fogh-Nielsens og Fru Ella Fogh-Nielsens Legat' foundation.
**Descriptors:** Type 2 diabetes; glycaemic index; glucose; insulin; rice; parboiling; amylose-lipid; lipid complex
*European Journal of Clinical Nutrition* (2000) **54,** 380–385

## Introduction

The glycaemic response to cooked rice has been extensively investigated (O'Dea *et al*, 1980; Wolever *et al*, 1985; Brand Miller *et al*, 1992; Rasmussen *et al*, 1992; Casiraghi *et al*, 1993; Larsen *et al*, 1996), but large variations in the findings have led to disagreements as to whether rice should be considered a high or low glycaemic food. It is now increasingly accepted that the large differences in the glycaemic response to rice are in part due to variations in the physico-chemical properties of rice varieties as well as in the processing. Approximately 20% of the rice consumed worldwide is parboiled, and the market for this type of rice appears to be increasing, especially in the industrialized countries (Efferson, 1985). Parboiling is generally believed to lower the glycaemic response to rice. However, only a few studies have investigated this topic and the results were conflicting. Wolever *et al* (1986) were the first to bring attention to the subject. They investigated two commercially obtained rice samples and found a lower glycaemic response in the parboiled rice sample compared to the non-parboiled (Wolever *et al*, 1986). Later studies have compared parboiled and non-parboiled rice of the same variety. Casiraghi *et al* (1993) observed that parboiling lowered the glycaemic response to rice, whereas other studies showed no difference (Brand Miller *et al*, 1992; Larsen *et al*, 1996). Parboiling is a hydrothermal processing of paddy rice. The traditional method includes soaking of the rice until saturation, heat treatment until the starch is gelatinized, and then slow drying before the husk is removed. A variety of modernized processes have been developed, though, in which the processing time has been shortened by using warmer soaking temperatures and applying pressure during

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*Contributors:* HNL led the project and was involved in all parts of the study including conception of the hypothesis, data collection, statistical analyses, interpretation of the results and writing of the paper. OWR took part in patient management, data collection and interpretation of the results. KKAl took part in patient management and data collection. PHR performed the DSC analyses and interpretated these data. SKB was responsible for the selection of rice varieties, physico-chemical analyses on the rice and for the traditional parboiling process. IT, SHT and KH were involved in the project design and interpretation of results. All contributed to the preparation of the manuscript.
*Guarantor:* Hanne Nygaard Larsen.
Received 14 July 1999; revised 4 December 1999; accepted 14 December 1999

the heat treatment. Parboiling leads to profound changes in the rice kernels, including alterations in the starch fraction, which may affect the rate of digestion and absorption as well as the overall digestibility. Moreover, it appears that the type and degree of these alterations depend on the severity of the method applied (Biliaderis *et al*, 1993; Ong & Blanshard, 1995). We hypothesized that the effect of parboiling on the glycaemic response to rice would depend on the severity of the parboiling process. Thus, the use of parboiling processes of different severity might be an explanatory factor for the discrepancies found in the effect of parboiling on glycaemic response to rice.

The aim of the present study was to investigate the effect of parboiling per se as well as the severity of the parboiling process on the glycaemic and insulinaemic responses to rice in type 2 diabetic subjects. Determination of the resistant starch content and examination of the rice by differential scanning calorimetry (DSC) were included to elucidate the possible changes in the starch structure, which might affect the rate of digestion and absorption as well as the digestibility.

## Methods

*Subjects*

Nine type 2 diabetic subjects were included in the study. The participants were selected from the out-patient clinic. Two subjects suffered from micro albuminuria and one from proteinuria, otherwise the subjects showed no signs of late diabetic complications apart from simplex retinopathy. Exclusion criteria included insulin requirement, $HbA_{1c}$ values above 10% and fasting plasma glucose concentrations above 13 mmol/l. Twelve type 2 diabetic subjects were originally assigned to the study. However, in two subjects fasting glucose concentrations exceeded the exclusion criterion, and a third subject got remission of his diabetes. The clinical characteristics of the nine included participants are given in Table 1. All participants were treated with diet, five patients received sulphonyluric hypoglycaemic agents, which they took at the beginning of the test meal. One patient received metformin and took this after the end of the test period of 180 min. The study was approved by the Regional Scientific-Ethical Committee of the county of Aarhus, and participants gave their written consent after being fully informed about the experimental nature of the study.

*Study design*

The study was performed on an out-patient basis. Participants were served four different test meals in random order on separate days within $4 \pm 1$ weeks (mean $\pm$ s.d.). The participants were instructed to eat carbohydrate rich foods on the days prior to a trial. Upon arrival, an intravenous cannula was inserted into a superficial vein in the forearm, and blood samples were collected 15 min and immediately before the test meal serving and 15, 30, 45, 60, 90, 120, 150 and 180 min after. The participants were served the test meal at 08:30 h after an overnight fast and consumed the meal within 15 min. They were requested to micturate before meal intake, and urine was collected during the test period (0–180 min) to measure a possible glucose excretion.

**Table 1** Clinical characteristics of nine Type 2 diabetic subjects (six males and three females)

| | *Age (ys)* | *BMI ($kg/m^2$)* | *Diabetes history (ys)* | *$HbA_{1c}$ (%)* | *FPG (mmol/l)* |
|---|---|---|---|---|---|
| Mean | 60 | 26.6 | 3 | 6.6 | 8.1 |
| s.e.m. | 2 | 1.3 | 0.8 | 0.2 | 0.4 |
| Range | 50–68 | 20.6–31.2 | 0.5–8 | 5.2–7.3 | 6.6–10.4 |

BMI: Body mass index; $HbA_{1c}$: Haemoglobin $A_{1c}$; FPG: Fasting plasma glucose.

*Test meals*

The study included four test meals: white bread as reference food and non-parboiled (NP), traditionally parboiled (TP) and pressure parboiled (PP) rice of the same variety. All test meals contained 50 g available carbohydrates and were served with 50 g tomato sauce (prepared from canned peeled tomatoes, water, stock cubes, salt and pepper for palatability; 55 kJ/50 g and 2.2 g carbohydrates/50 g tomato sauce; DANKOST 2.0, Danish Catering Center A/S, Herlev, Denmark) and 250 ml tap water. Characteristics of the test meals are given in Table 2. The white bread was sliced, portioned and stored frozen (portion size of 109 g) until the trial day, when it was removed from the freezer 45 min before serving and thawed at room temperature. Rice was cooked in excess water and drained after cooking (water content: 600% of rice weight). A small amount of salt (approx. 0.6% based on rice weight) was added for palatability. The non-parboiled and traditionally parboiled rice samples were cooked to the pre-determined minimum cooking time (17.5 and 21.0 min, respectively), i.e. the time when $\geq 90\%$ of the kernels have fully cooked centres. The two parboiled rice samples were cooked for the same length of time. The test meals were served $16 \pm 6$ min after the end of cooking.

*Physico-chemical characteristics and parboiling of rice samples*

The rice samples were obtained from Bangladesh Rice Research Institute (BRRI), Bangladesh. All three samples were of the same indica rice variety (BR16) and originated from the same batch. The selected rice was a long grain variety (length/breadth ratio, 3.0) with a high apparent amylose content of 27% determined by the iodine-blue colorimetric method (Juliano *et al*, 1991). One rice sample was not parboiled (NP). The second sample (TP) was parboiled at BRRI by a mild traditional method, which

**Table 2** Characteristics of test meals (means $\pm$ s.d.)[a]

| | *White bread* | *Rice NP* | *Rice TP* | *Rice PP* |
|---|---|---|---|---|
| Dry matter (%)[b] | 65.3 | 89.5 | 88.8 | 90.4 |
| Available CHO (%)[b] | 45.9 | 78.3 | 77.0 | 78.1 |
| Protein (%)[b] | 8.2[c] | 7.3 | 8.5 | 8.3 |
| Portion size (g) | | | | |
| raw | | 64 | 65 | 64 |
| as served | 109 | $193 \pm 8$ | $196 \pm 4$ | $182 \pm 2$ |
| Cooking time (min) | | 17.5 | 21.0 | 21.0 |
| Freshly cooked rice: | | | | |
| dry matter (%): | | 27.7 | 27.8 | 31.6 |
| resistant starch (%): | | $0.8 \pm 0.1$ | $0.2 \pm 0.4$ | $1.6 \pm 0.2$ |

NP: Non-parboiled; TP: traditionally parboiled; PP: pressure parboiled; CHO: carbohydrates.
[a]Tomato sauce not included.
[b]For rice: determined on raw milled rice.
[c]Value from previous analysis of white bread baked from the same recipe (Larsen *et al*, 1996).

implies soaking at ambient water temperature (28–30°C) for approximately 36 h, steaming of the soaked rice at atmospheric pressure for 25–30 min, followed by drying at ambient temperature. The third rice sample (PP) was pressure parboiled at a pilot plant (Bühler GmbH, Germany) according to industrialized conditions. Pressure parboiling is a more severe type of processing. Thus, this rice sample was soaked at 70–75°C for 4 h, followed by steaming at 120°C and 1.5 bar ($1.5 * 10^5$ Pa) for 12 min and then pre-dried at 100°C for 3 min before final drying at room temperature. All three rice samples were milled to the same degree (90% of brown rice weight).

*Chemical composition of test meals*
The chemical composition of the test meals was determined in duplicate at the Danish Institute of Agricultural Sciences, Tjele, Denmark. Dry matter content was determined by oven drying at 105°C for 20 h. Protein content was determined as N * 5.70 for white bread and N * 5.95 for rice using a Kjell–Foss 16200 Autoanalyser. The content of available carbohydrates was determined enzymatically and included starch, breakdown products of starch and glucose (Bach Knudsen, 1997). Resistant starch was analysed in triplicate according to the method of Englyst *et al* (1992) with minor modifications.

*Chemical analyses of blood and urine samples*
$HbA_{1c}$-values were determined using a HPLC method (Hitachi AS-4000, Hitachi Ltd., Japan; normal range: 4.1–6.1%). Plasma glucose concentrations were determined by the glucose–oxidase method (YSI Model 2300 STAT PLUS, Yellow Springs Instrument Co. Inc., Ohio, USA) and serum insulin concentrations by ELISA kit (DAKO Insulin ELISA Kit, DAKO Diagnostics Ltd., UK) based on mouse monoclonal antibodies (Andersen *et al*, 1993). Urinary glucose concentrations were determined by the glucose–oxidase method.

*Differential scanning calorimetry*
Calorimetric measurements were made with a DSC 10 differential scanning calorimeter (TA Instruments, USA). Sealed aluminum pans (Perkin–Elmer) were used in all experiments. An empty pan was used as reference and gallium (99.9999%, Mp. 29.78°C, melting enthalpy: 80.1 J/g; Aldrich, Milwaukee, USA) was used for temperature and enthalpy calibration. Raw rice samples were ground to a particle size of 0.5 mm with a Laboratory Mill 120 (Perten Instruments, Sweden). The samples were analysed as approximately 50% w/w aqueous dispersions of the ground rice grains. Each sample (5–10 mg) was heated from 20–140°C using a scanning rate of 5°C per minute. The temperature values obtained were the onset temperature of transition ($T_{onset}$), the temperature at completion of transition ($T_{completion}$) and the peak transition temperature ($T_{max}$), the latter being defined as the temperature at peak maximum. The enthalpy of transition was estimated from the integrated heat flow over the temperature range of the transition. Analyses were performed in quadruplicate.

*Statistical methods*
The incremental area under the glucose and insulin response curves (IAUC) was calculated according to the method of Wolever & Jenkins (1986) ignoring values beneath basal level. Basal values were calculated as the mean value of the samples drawn 15 min and immediately before test meal ingestion. Glucose and insulin data were analysed by two-way analysis of variance (ANOVA), followed by paired comparisons (*t*-tests) of means if the ANOVA indicated significant differences. Statistical analyses were carried out using SAS software, 6.08 (SAS Institute, Inc., Cary, NC, USA). The limit of significance was set at $P < 0.05$.

## Results

The nine participants included in the study consumed all test meals within 15 min. Data for the metabolic responses are given in Table 3 and mean postprandial plasma glucose and serum insulin response curves are shown in Figure 1. The fasting concentrations for both glucose and insulin were similar for the four test meals, whereas the incremental response areas were lower for all rice test meals compared to white bread ($P < 0.001$). Within the rice test meals the incremental response area for glucose tended to be lower for PP than NP ($P = 0.07$), whereas the insulin response areas were similar. The glycaemic indices (GI) were 55 ± 5 (means ± s.e.m.), 46 ± 8 and 39 ± 6 for NP, TP and PP, respectively, thus the GI for PP was almost 30% lower than NP ($P < 0.05$). All rice meals had similar peak p-glucose concentrations, which were lower than that after white bread ($P < 0.001$). Urinary glucose excretion after ingestion of white bread, NP, TP and PP was observed in five, two, two and one participants, respectively.

The content of resistant starch in the freshly cooked rice samples is given in Table 2. Differential scanning calorimetry showed different patterns for the rice samples. All three rice samples exhibited two endotherms of which one was below and one above 100°C, however, temperature ranges and enthalpies differed between the samples (Table 4).

## Discussion

Hyperglycaemia in type 2 diabetic subjects is considered a risk factor for developing microvascular and possibly also

**Table 3** Metabolic responses to test meals ($n = 9$ type 2 diabetic subjects; means ± s.e.m.)

| | *White bread* | *Rice NP* | *Rice TP* | *Rice PP* |
|---|---|---|---|---|
| P-glucose IAUC: (mmol/l * 180min) | 626 ± 80[a] | 335 ± 43[b] | 274 ± 53[b] | 231 ± 37[b] |
| GI | 100[a] | 55 ± 5[b] | 46 ± 8[b] | 39 ± 6[c] |
| P-glucose peak (mmol/l) | 14.0 ± 0.6[a] | 10.9 ± 0.5[b] | 11.0 ± 0.5[b] | 10.5 ± 0.5[b] |
| Fasting p-glucose (mmol/1) | 8.2 ± 0.4 | 7.8 ± 0.4 | 8.2 ± 0.5 | 8.1 ± 0.4 |
| S-insulin IAUC (pmol/l * 180min) | 16562 ± 3142[a] | 7595 ± 1474[b] | 7719 ± 1292[b] | 7590 ± 1600[b] |

NP: Non-parboiled; TP: traditionally parboiled; PP: pressure parboiled; IAUC: incremental area under curve; GI: glycaemic index.
Means in the same row followed by different superscript letters are significantly different.

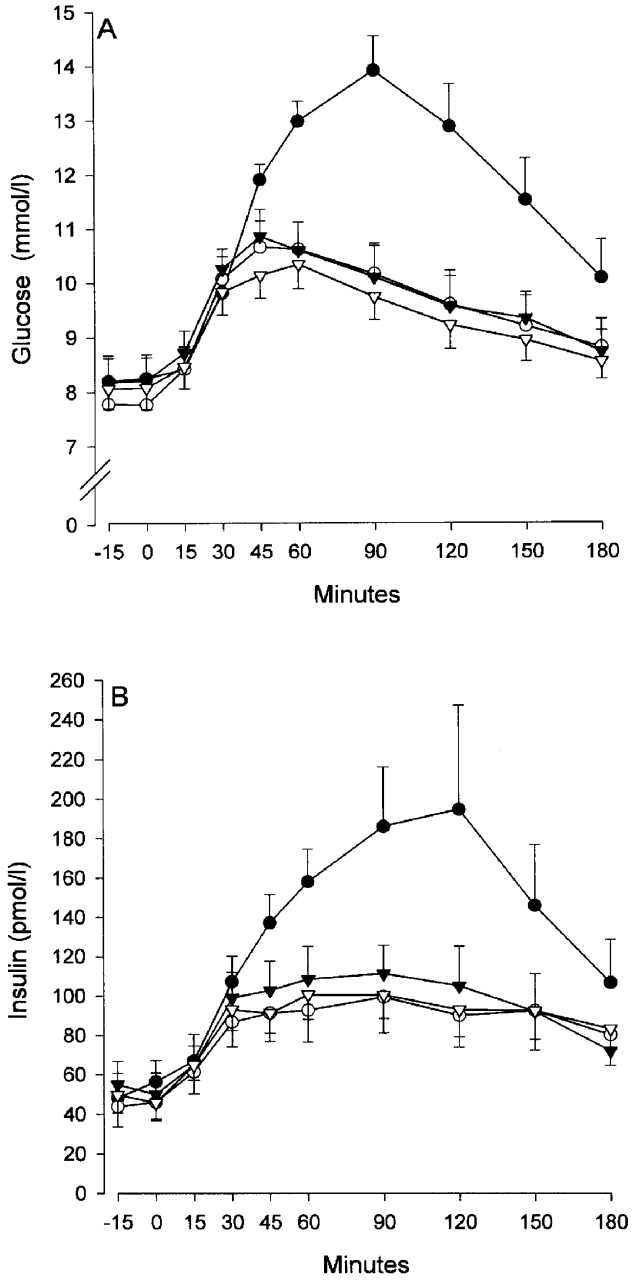


**Figure 1** (A) plasma glucose and (B) serum insulin responses (means ± s.e.m.) in nine type 2 diabetic subjects to four different test meals (50 g available carbohydrates): WB: white bread (●) and cooked rice of the same variety being NP: non-parboiled (○); TP: traditionally parboiled (▼) and PP: pressure parboiled (▽).

macrovascular complications (Turner *et al*, 1998; Wei *et al*, 1998), the latter, a major cause of death in type 2 diabetic subjects. Moreover, two large prospective studies have recently shown that the dietary glycaemic index is positively associated with the risk of developing type 2 diabetes (Salmerón *et al*, 1997a; Salmerón *et al*, 1997b). These findings heighten the attention given to the GI of staple carbohydrate foods in the diet. The use of GI in the dietary management of diabetes has been much debated (Wolever, 1997). However, a number of longer term studies, comparing high *vs* low glycaemic index diets have shown that the latter improves the metabolic control of diabetic subjects (Brand Miller, 1994), thereby supporting the relevance of GI as a tool for professional health personnel giving dietetic advice. Parboiled rice is widely consumed, but there is only little knowledge about the effect of parboiling on the glycaemic response. In the present study, we compared two rice samples of the same variety, parboiled to different degrees of severity, and found that the GI-values decreased with increasing severity of parboiling and, thus, underlined the importance of the process used. Moreover, these findings confirmed our hypothesis that the influence of parboiling on GI to rice depends on the severity of processing, and this may be an explanatory factor for the previously conflicting results reported on this topic (Brand Miller *et al*, 1992; Casiraghi *et al*, 1993; Larsen *et al*, 1996).

In order to elucidate the possible changes in starch crystallinity due to parboiling, which might explain the observed differences in GI, we examined the three rice samples by DSC, and found that the temperature endotherms below 100°C differed notably. The non-parboiled (NP) sample showed a large endotherm with peak temperature ($T_{max}$) of 75°C, characteristic of the energy used for melting the original crystalline structure and gelatinizing the raw rice starch. The traditionally parboiled (TP) sample exhibited a smaller endotherm at 87°C, presumably reflecting the melting of remaining original crystallites (Biliaderis *et al*, 1993; Ong & Blanshard, 1995) and, thus, demonstrating that this sample was incompletely gelatinized during the parboiling. In contrast, there were no remains of the original crystallites in the pressure parboiled rice (PP), but rather there was an endotherm with a notably lower $T_{max}$ of 54°C, characteristic of the melting of retrograded amylopectin (Biliaderis, 1991). The endotherms observed above 100°C in the three rice samples were more alike with peak temperatures ranging from 108 to 119°C, which are known to reflect the melting of amylose–lipid complexes (Biliaderis, 1991). Investigations on the effect of amylose-lipid complexes on the digestion rate and digestibility are scarce. Holm *et al* (1983) reported

**Table 4** Differential scanning calorimetry characteristics of rice samples (means ± s.d.)[a]

| | | | $T_{range}$ | |
|---|---|---|---|---|
| *Rice sample* | *Enthalpy ΔH (J/g sample)* | $T_{max}$ (°C) | $T_{onset}$ (°C) | $T_{completion}$ (°C) |
| Rice NP | 4.7 ± 0.4 | 75 ± 0.2 | 62 ± 0.5 | 91 ± 2.4 |
| | 0.6 ± 0.3 | 114 ± 0.8 | 111 ± 0.8 | 118 ± 0.8 |
| Rice TP | 1.2 ± 0.2 | 87 ± 3.0 | 75 ± 1.0 | 94 ± 2.6 |
| | 0.8 ± 0.2 | 108 ± 3.2 | 101 ± 2.7 | 116 ± 0.6 |
| Rice PP | 0.9 ± 0.2 | 54 ± 1.9 | 38 ± 3.3 | 65 ± 1.1 |
| | 0.5 ± 0.1 | 119 ± 3.1 | 107 ± 2.2 | 127 ± 0.8 |

NP: non-parboiled; TP: traditionally parboiled; PP pressure parboiled.
[a]50% w/w aqueous dispersions of raw ground rice, heating rate 5°C/min from 20–140°C.

that amylose–lipid complexes were fully digested and absorbed in the small intestine of rats, whereas Eggum *et al* (1993a), using a different study design, found that the complexes were not digestible in the small intestine of rats, but were fermented in the colon. However, it should be noted that two types of amylose–lipid complexes exist: complex I melts just below 100°C and has only little crystalline structure, whereas complex II has a melting temperature well above 100°C and consists of well defined crystallites (Biliaderis & Galloway, 1989). The more complete crystal structure of complex II possibly renders it less susceptible to enzymatic degradation, and this may be a possible explanation for the different conclusions reached in the two studies. Thus, in the study by Eggum *et al* (1993a), DSC analysis revealed the presence of amylose–lipid complex II, whereas in the study by Holm *et al* (1983) the amylose–lipid complexes were prepared at a low temperature, which has been shown to lead to formation of complex I (Biliaderis & Galloway, 1989). We demonstrated that amylose–lipid complexes of the complex II type were present in similar amounts in all three rice samples. Thus, none of the parboiling methods influenced the type or amount of amylose–lipid complexes to any noticeable extent, and the differences observed in the GI-values to the rice test meals cannot be explained by the presence of these complexes.

The glycaemic response to PP was very low, being reduced by about 30% compared to NP. PP also differed from the other rice samples by containing retrograded amylopectin. The role of this component in relation to glycaemic response and digestibility is not fully explored. Most processed foods, including parboiled rice, are reheated before consumption, and retrograded amylopectin is, generally, thought to melt upon reheating, e.g. cooking, due to the low melting point (46–65°C) of these crystallites (Asp *et al*, 1996). It is possible, though, that the amylopectin crystallites retain some of the associating forces during the reheating, and are partly responsible for the low glucose response observed for PP. This is supported by the findings of starch fractions in human ileal samples, consisting of a mix of potentially digestible amylose and amylopectin (Faisant *et al*, 1993).

Retrograded amylose was not observed by DSC in any of the rice samples in our study and neither in the study on parboiled rice by Ong & Blanshard (1995). Due to the high melting temperature of this component of 120–150°C (Biliaderis, 1991), we repeated the DSC analyses, extending the temperature range to 20–160°C (results not shown), but these analyses did not show the presence of retrograded amylose either. Hence, parboiling did not lead to notable formation of retrograded amylose. It may be present, but in an amount too small to be detected by DSC, as have been reported for other heat treated starches (Sievert & Pomeranz, 1990). The low content of resistant starch in the samples is supportive hereof. It ranged from 0.2% in TP to 1.6% in PP and corroborated other studies on resistant starch in rice (Muir & O'Dea, 1993; Eggum *et al*, 1993b).

All the rice samples investigated in this study were low-glycaemic, independently of parboiling with GI values, ranging from 39 to 55 in type 2 diabetic subjects. Thus, they all appeared useful in low-glycaemic diets. We have previously investigated in type 2 diabetic subjects a non-parboiled and a traditionally parboiled sample of the same rice variety as used in the present study, but produced in another year (Larsen *et al*, 1996), and the GI-values obtained in the first study (NP: $53 \pm 7$ and TP: $50 \pm 7$; means $\pm$ s.e.m.) agree very well with the values obtained in the present study (NP: $55 \pm 5$ and TP: $46 \pm 8$). It is likely that the presence of the amylose–lipid complex II may have contributed to the low postprandial glucose increments, not least since these complexes has a melting temperature above 100°C and, therefore, are not melted during the cooking of neither the non-parboiled nor the parboiled rice samples. Most rice used for parboiling has intermediate (20–25%) or high ( > 25%) amylose content (Luh & Mickus, 1991), and the rice used in the present study was a high amylose variety. It has consistently been shown that a high amylose content lowers the starch digestion rate, measured as the glycaemic or insulinaemic response to rice (Goddard *et al*, 1984; Juliano & Goddard, 1986; Brand Miller *et al*, 1992; Larsen *et al*, 1996). It seems likely, therefore, that the low GI values obtained for all rice samples in the present study are due to the high amylose content of the rice variety as well as to the presence of the stable amylose–lipid complex II. We found that the low GI-values could be further reduced by industrial pressure parboiling. Thus, the results show that it is possible to produce low-glycaemic parboiled rice by using a high amylose rice variety and severe parboiling conditions. Moreover, DSC may be a valuable tool to indicate the severity of parboiling and, along with analysis of the amylose content, the starch digestion rate of parboiled rice.

In conclusion, we found that the rice investigated was low-glycaemic in type 2 diabetic subjects independently of parboiling, presumably due to the high amylose content and the presence of the stable amylose–lipid complex II. Moreover, we observed that the mild traditionally parboiling did not influence the GI in contrast to the pressure parboiling, which reduced the GI by approximately 30% compared to the non-parboiled rice. These results show that the effect of parboiling on the GI to rice in type 2 diabetic subjects depends on the severity of processing and that GI to rice can be lowered through choice of rice variety and parboiling process.

*Acknowledgements*—Thanks are due to the participants in the study and to Mrs Dorthe Rasmussen and Mrs Kirsten Eriksen for expert technical assistance. The Danish Institute of Agricultural Sciences, Tjele, Denmark is thanked for conducting the chemical analyses of the test meals. Special thanks are due to Dr. Thomas Strandt, Bühler GmbH, Braunschweig, Germany for performing the pressure parboiling and for invaluable help in this matter. The 'Konsul Johannes Fogh-Nielsens og Fru Ella Fogh-Nielsens Legat' foundation is thanked for financial support.

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