Effect of soaking medium on the physicochemical properties of parboiled glutinous rice of selected Laotian cultivars

Malik A. Nawaz, Shu Fukai, Sangeeta Prakash, and Bhesh Bhandari

School of Agriculture and Food Sciences, The University of Queensland, Brisbane, Australia

ABSTRACT

The effect of various soaking mediums, viz. water (control), 3% NaCl and 0.2% acetic acid, and without soaking on the physicochemical properties of parboiled selected glutinous (TDK8 and TDK11) and non-glutinous (Doongara) was investigated in the present study. Results showed that the chemistry of soaking had a significant effect on the head rice yield (HRY), grain hardness, crystallinity, color, pasting and thermal properties, textural attributes, and glycemic index of these rice varieties. Soaking with NaCl and acetic acid significantly increased the grain hardness and HRY than control and without soaking treatments. Acetic acid and NaCl soaking significantly affected crystalline regions of starch resulting in reduced crystallinity in X-ray diffraction analysis and thermal endotherms in DSC analysis. NaCl soaking induced swelling of starch granules resulting in high peak and final viscosities. However, acetic acid restricted swelling resulting in reduced peak and final viscosities. NaCl and acetic acid soakings also resulted in increased hardness and adhesiveness of cooked grains than normal water soaked and un-soaked parboiled rice samples. Interestingly, change in textural attributes was prominent in parboiled glutinous rice. The color difference value for fresh parboiled samples was significantly lower for acetic acid soaked samples compared to NaCl soaked and un-soaked samples probably due to bleaching effect of acetic acid. Moreover, parboiling also resulted in significant reduction in glycemic index of glutinous rice. These findings revealed the potential application of parboiling with modified soaking techniques to improve the grain quality.

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Introduction

Parboiling is hydrothermal processing of paddy and/or brown rice to improve the head rice yield, nutritional and organoleptic properties by using a three-stage process, viz. soaking, steaming, and drying.\[^{1-3}\] According to the recent statistics, 130 million tons of paddy is parboiled annually around the globe with about 3–4 million tons high-value parboiled milled rice being moved in world trade.\[^{4}\] Parboiling was initially originated and is largely practiced in India.\[^{5,6}\] It is also processed and consumed in other South Asian countries including Bangladesh\[^{7}\] and Sri Lanka\[^{8}\] as well as some Sub-Saharan African countries including Ghana,\[^{9}\] Benin,\[^{10}\] Senegal,\[^{11}\] and Nigeria.\[^{12}\]

Parboiling results in profound changes in the physicochemical and functional properties of rice.\[^{13}\] Starch granules are swelled due to gelatinization, protein bodies are disrupted due to denaturation and disulfide cross-linking, and lipid–amylose complex formation takes place.\[^{14}\] Moreover, parboiling also results in inward diffusion of water-soluble vitamins and minerals from bran to endosperm improving the nutritional quality.\[^{15,16}\] These changes in physicochemical...
properties of rice due to parboiling increase grain hardness and improve the milling yield.\cite{17} Furthermore, physicochemical changes create more translucency and amber coloration in rice.\cite{18} These changes also influence cooking properties such as the harder texture of cooked grains. Moreover, parboiling may result in increased resistant starch fraction and low glycemic index (GI) which are health-promoting.\cite{19}

Traditionally to make parboiled rice, paddy is soaked in water for 48 h followed by steaming and drying.\cite{3} As the global food index is taking a step forward from food security to food safety, innovations and improvements in the parboiling process are becoming a subject of research interest. Therefore, several types of research have been conducted in the past to improve the parboiling operation by varying the soaking temperature,\cite{20} reduction in soaking process of paddy by using a tumbler,\cite{13} modifications in steaming process,\cite{21} and modifications in drying process.\cite{22} In recent years, dry-heat parboiling operations have also been introduced to improve parboiling efficiency.\cite{23,24}

In the past, scientists have considered on the soaking time and temperature on parboiled rice quality, but to our understanding, the effect of the modified soaking medium by the addition of organic acids and/or salt on the parboiled glutinous rice is still not well defined. Previous studies have established a weak correlation between water uptake by paddy during soaking and chemistry of soaking medium and reported that the rate of soaking could be altered by the addition of organic acids, alkalis, and salts.\cite{25} They reported that the incorporation of acids (hydrochloric acid, acetic acid, and phosphoric acid) into the soaking water reduced the water absorption than control soaking. However, the addition of alkali (sodium hydroxide and sodium bicarbonate) significantly increased the water absorption than control soaking. Thammapat et al.\cite{26} reported that saline soaking of Thai glutinous rice (RD6) before parboiling significantly increased the amounts of total phenolic contents, phenolic acid, γ-oryzanol, saturated fatty acids, and monosaturated fatty acids and decreased α-tocopherol and polyunsaturated fatty acids compared to controlled samples resulting in improvement of bioactive compounds and cooking quality.

The researches reported on the parboiling of glutinous rice in the past focused only on head rice yield and nutrient diffusion, and less focus was given on the cooking quality and GI of parboiled glutinous rice. Moreover, there is no data available on the parboiling of Laotian glutinous varieties such as TDK8 and TDK11. Therefore, in this study, the focus is given on the effect of soaking medium on the physicochemical properties of parboiled selected glutinous rice mainly focusing on cooking attributes and GI using in vitro digestion method.

**Materials and methods**

Fresh paddies (February 2017) of two *Oryza sativa* indica cultivar of glutinous rice, viz. Thadokhham-8 (TDK8) and Thadokhham-11 (TDK11) having 3.77% and 3.72% (w/w) apparent amylose contents (AAC), respectively, were used in this study. Moreover, fresh paddy of one *O. sativa* japonica cultivar of non-glutinous rice, viz. Doongara (DG) having 19.71% (w/w) AAC was also studied for comparison. The AAC of selected cultivars were determined by iodine colorimetric method.\cite{27} Average AAC with standard deviation are reported in the online supplementary information (SI) (Table T1).

**Parboiling**

**Soaking**

Paddies (250 grams each) were soaked in three different soaking media, namely water, 0.2% acetic acid, and 3% NaCl for 24 h at room temperature (22 ± 1°C) with paddy to solvent ratio of 1:8. The concentrations of acetic acid and NaCl, viz. 0.2 and 3% (w/w), respectively, were selected. Fresh paddy without soaking was also analyzed for comparison.
Steaming
The steaming process was carried out in a programmable fully automatic pressure cooker (Breville, VIC, Australia); labelled diagram of pressure cooker is presented in SI section Fig. S1. The overnight (24 h) soaked paddy (250 grams) was drained and placed in stainless steamer and 2 liters of water was added in the cooking bowl of pressure cooker. Pressure cooker was turned on and program of 50 kPa pressure for 10 min was selected. Pressure cooker took 10 min to ramp up the steam pressure to 50 kPa (pressure calculated by the gauge attached to the pressure cooker) and maintained it for 10 min and then ramped down to 0 kPa in 10 min. The time-pressure profile is mentioned in SI section Fig. S2. Sample without soaking was also parboiled using the same steaming conditions.

Drying
The parboiled paddy samples were spread on blotting paper and kept in a fume hood at room temperature (22 ± 1°C, RH ~50%) to dry for 72 h to the moisture content of 14% (w/w).

Head rice yield (HRY)
The fresh and parboiled paddies (without soaking, water (control) soaking, 3% NaCl soaking, and 0.2% acetic acid soaking) were milled to brown rice using husker (Satake, Japan). The brown rice was then milled to white rice using an abrasive polisher (Satake, Japan). The degree of milling (DOM) was 9% for all treatments, which was calculated by using Eq. (1).

\[
\text{DOM}(\%) = \left[1 - \frac{\text{WMPR}}{\text{WBPR}}\right] \times 100
\]  

WMPR and WBPR are the weight of milled parboiled rice and brown parboiled rice in grams, respectively.

The head rice yield (HRY%) was calculated as a percentage of whole milled grains with respect to the paddy rice as shown in Eq. (2).

\[
\text{Head rice yield (HRY\%)} = \frac{\text{weight of whole milled grains (g)}}{\text{weight of paddy (g)}} \times 100
\]

Mechanical strength
The mechanical strength of individual sound milled grain of fresh and parboiled (without soaking, water (control) soaking, 3% NaCl soaking, and 0.2% acetic acid soaking) samples of three varieties was measured by using three-point bending test according to the method of Truong. A special attachment including a cutting probe and a sample holder plate with grooves of five different sizes was used. The cutting probe was attached to the TA-XTplus Texture Analyzer (Stable Microsystems, UK) and grains were placed in the grooves of the sample holder. The bending test was performed in a compression test mode using pre-test, test, and post-test speeds of 1 mm/s, 2 mm/s, and 10 mm/s, respectively. The hardness (N), the maximum force required to break the grains, was calculated.

Color estimation
The color measurements of samples for all treatments were done by using Konica Minolta Chroma Meter CR-400 (Tokyo, Japan). The color meter was calibrated with a white tile. Samples were packed in a clean petri dish. The color was measured in CIE \(L^*a^*b^*\) color space. The color difference \(\Delta E_{ab}^*\) between fresh and parboiled rice (without soaking, water (control) soaking, 3% NaCl soaking, and 0.2% acetic acid soaking) was also calculated using Eq. (3).

\[
\Delta E_{ab}^* = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2}
\]
where $L^*_2$ is the brightness of parboiled rice, $L^*_1$ is the brightness of fresh rice, $a^*_2$ refers to red-green color of parboiled rice, $a^*_1$ refers to red-green color of fresh rice, $b^*_2$ refers to yellow-blue color of parboiled rice, and $b^*_1$ refers to yellow-blue color of fresh rice.

**X-ray diffraction**

Samples were ground to a flour (particle size ≤125 µm) using disc mill (Good Friends of the Guangzhou Machinery Co. Ltd., Guangzhou, China) equipped with a plate of 125 µm size. Fine flour (particle size ≤125 µm) was used to get smooth diffractograms. X-ray diffraction pattern of rice flour was analyzed by using Bruker Advance D8 X-Ray diffractometer equipped with a LynxEye detector and Cu-ka (1.54 Å) radiation. The accelerating voltage and current of 30 kV and 30 mA, respectively, in combination with scan rate 2°/min, were used. The diffractograms were recorded in a 2θ ranged from 4° to 35° with sampling width of 0.02°. Traces were analyzed using the Diffract$^+$ Evaluation Package (Release V3.1, PDF-2 Release 2014).

The crystallinity percentage was calculated with normalized values of the intensities at each diffraction angle, using the method of Htoon et al.$^{[29]}$ The ratio of the upper diffraction peak area taken as the crystalline portion, to total diffraction area (two-phase model), represented the percentage of crystallinity. The diffractograms were smoothed by 13 points using Traces version 3.01 software (Diffraction Technology Pty LTD, Mitchell, ACT, Australia) before calculating the percentage of crystallinity.

**Pasting properties**

Samples were ground to a flour (particle size ≤500 µm) using disc mill (Good Friends of the Guangzhou Machinery Co. Ltd., Guangzhou, China). Pasting properties of rice flour samples were determined according to the AACC International Method 61–02.01 using a Rapid Visco Analyser (RVA-4 model Thermocline Windows Control and analysis software, Version 1.2 (New Port Scientific, Sydney, Australia)).$^{[30]}$ Rice flour (3.01 g, 12.4% moisture basis) was mixed with 25.0 g MilliQ water in the RVA canister. A programmed heating and cooling cycle was used; the samples were held at 50°C for 1 min, heated to 95°C in 3.45 min, held at 95°C for 2.7 min before cooling to 50°C in 3.91 min, and holding at 50°C for 1.24 min. Pasting temperature ($P_{temp}$), Peak viscosity ($V_p$), Trough viscosity ($V_t$), Breakdown (BD), Final viscosity ($V_f$), and Setback (SB) were recorded.

**Thermal properties**

Differential Scanning Calorimeter (DSC) (Mettler Toledo, Schwerzenbach, Switzerland) with internal coolant and nitrogen/air purge gas was used to determine the gelatinization characteristics of rice flours. The DSC was calibrated for the heat flow using indium as standard. Rice flour (approximately 4 mg, dry weight basis) was accurately weighed into an aluminum pan and 6 µL MilliQ water was added. The pan was hermetically sealed and equilibrated at room temperature for 30 min, then scanned at the heating rate of 15°C/min from 0°C to 100°C with the empty sealed pan as a reference. The onset ($T_o$), peak ($T_p$), and conclusion ($T_c$) temperatures, and enthalpy ($\Delta H$) of gelatinization were determined by Star® Software Version 9.1 (Mettler Toledo).

After cooling, the scanned samples pans were placed in a refrigerator at 4 ± 1°C for 7 days. Retrogradation properties were measured by rescanning these samples at the rate of 15°C/min from 0°C to 100°C. The onset ($T_{o(r)}$), peak ($T_{p(r)}$), and conclusion ($T_{c(r)}$) temperatures, and enthalpy of retrograded starch ($\Delta H_{(r)}$) were determined. The percentage of retrogradation (R%) was calculated as $\Delta H_{(r)}/\Delta H \times 100$. 
Texture profile analysis

Rice grains (5 g) were added in 15 mL of MilliQ water (rice:water ratio = 1:3) in a 50 mL glass beaker and cooked at 95 ± 1°C in a water bath. Analysis of textural attributes was performed on a TA-XTplus Texture Analyzer (Stable Microsystems, UK) using 35-mm circular probe. Three cooked grains (The instrumental estimation of textural profile of food products, especially rice, can vary due to the side of grain exposed to the TA-XTplus probe. Therefore, use of single grain can give huge variation and affect the statistical analysis of data. To account for this variation, three grains were used. The grains were placed in trigonal pattern as shown in SI section Fig. S3) were on the flat stage, and the texture determined. The texture analyzer settings were as follows: pre-test speed, 2.00 mm/s; post-test speed, 2.00 mm/s; distance, 2.00 mm; time, 10.00 s; (auto) trigger force, 0.05 N. From the force-time curve obtained, textural attributes of hardness (height of the force peak on cycle 1, N) and adhesiveness (negative force area of the first cycle, N.s) were computed using the EXPONENT Stable Micro Systems software supplied with instrument.

Starch hydrolysis kinetics and GI prediction

Starch hydrolysis

The starch hydrolysis was conducted by adapting the method of Goñi et al.\textsuperscript{31} Rice grains (200 mg) were cooked in 4 mL of MilliQ water at 80°C for 30 min (The pasting profiles and DSC results showed that the gelatinization temperature for all treatments was less than 80°C; therefore, cooking of rice grains for in vitro digestion was conducted at 80°C instead of 95°C). Then, 10 mL of HCl-KCl buffer (pH 1.5) was added to the cooked samples for protein digestion, and the mixture was smashed to make a paste. Solution (0.2 mL) containing 1.0 mg of pepsin in 10 mL of HCl-KCl buffer (pH 1.5) was added to samples. Samples were transferred to 50 mL beaker and incubated at 40°C for 60 min in a shaking water bath (100 RPM). Then, 15 mL of Tris-maleate buffer (pH 6.9) was added to adjust the volume to 25 mL. For starch hydrolysis, 5 mL of Tris-maleate buffer containing 2.6 IU of porcine pancreatic α-amylase (A-3176, Sigma, Missouri, USA) was added and samples were incubated at 37°C in a shaking water bath. Aliquots of 0.1 mL were taken in a test tube at 30, 90, and 180 min and boiled in a water bath (100°C) for 5 min to inactivate the α-amylase. Then, 1 mL of 0.4 M sodium acetate (pH 4.75) and 30 µL of amyloglucosidase from Aspergillus niger (A-1602, Sigma, Missouri, USA) were added to each tube followed by incubation at 60°C for 40 min in a water bath to allow amyloglucosidase to decompose starch into glucose. The glucose released by in vitro digestion of rice was estimated by using glucose oxidase-peroxidase kit (GAGO-20, Sigma, Missouri, USA).

GI prediction

The kinetics of starch hydrolysis and GI were calculated by using the non-linear first-order kinetic model as described by Rattanamechaikul et al.\textsuperscript{32} Following equations were used:

\[ C = C_\infty (1 - e^{-kt}) \]  
\[ \text{AUC} = C_\infty (t_f - t_0) - \left( \frac{C_\infty}{k} \right) (1 - \exp(-k(t_f - t_0))) \]  
\[ \text{HI} = \left( \frac{\text{AUC}_{\text{sample}}}{\text{AUC}_{\text{whitebread}}} \right) \times 100 \]  
\[ \text{GI} = 39.71 + 0.549(\text{HI}) \]

where \( C \) is the percentage of starch hydrolyzed at time \( t \), \( C_\infty \) is the equilibrium concentration of hydrolyzed starch, \( k \) is the kinetic constant (min\(^{-1}\)), \( t \) is the time (min), AUC is the area under hydrolysis curve, \( t_f \) is the final time (180 min), \( t_0 \) is the initial time (0 min), and HI is the hydrolysis index, which is the percentage of area under hydrolysis curve of sample divided by the area under hydrolysis curve white bread as a reference.
**Statistical analysis**

All treatments were replicated three times to obtain mean values. The reported data of head rice yield, CIEL*a*b* color space, pasting properties, thermal properties, texture profile analysis, and GI prediction for each variety was analyzed separately by analysis of variance using Minitab R17 (Minitab® for Windows Release 17, Minitab Inc., Chicago) to determine significant differences. The data was then analyzed using Tukey’s pair-wise comparison, at 5% level of significance, to compare the means between different treatments.

**Results and discussions**

**Hardness of parboiled and milled kernels**

The mechanical strength of milled grains of fresh and parboiled grain samples was expressed as grain hardness, which is the force (N) required to break the grains. Results showed that the parboiling and subsequent drying of paddy resulted in significant \((p < 0.05)\) increase in grain hardness as compared to the fresh non-parboiled grains (Fig. 1). These results are in agreement with the findings of previous researches, which reported that the increased grain hardness is due to less internal fissures in parboiled rice grain because of the gelatinization and fusion of starch granules during parboiling process.\(^{[14,17,33]}\) Among various parboiling treatments, acetic acid treated grains were significantly \((p < 0.05)\) harder than NaCl treated followed by water (control), without soaking treatment and non-parboiled rice for all varieties. Acetic acid and saline soakings might reduce more internal fissures than control soaking resulting harder grains. This increase hardness of saline and acidic soaked parboiled glutinous and non-glutinous was an interesting result and needs to be further researched.

**Head rice yield (HRY)**

The primary parameter used in the industry to quantify rice milling efficiency is the head rice yield (HRY).\(^{[34]}\) The head rice yield (HRY) of fresh and parboiled samples of selected varieties using different soaking conditions are presented in Fig. 1. HRY was expressed as a percentage of whole milled grains (70% of the full length) produced in the milling of paddy at 9% DOM. Results showed that parboiling significantly \((p < 0.05)\) increased the HRY in all varieties: glutinous TDK8 (Fig. 1a), TDK11 (Fig. 1c), and non-glutinous DG (Fig. 1d). Moreover, it was observed that the chemistry of soaking medium also significantly \((p < 0.05)\) affected the HRY. Maximum yield was gained in the acetic acid soaked samples followed by NaCl soaked, water (control), and without soaking treatments in all selected varieties. As expected, there was a positive correlation between grain hardness and HRY (Fig. 1b, 1d, and 1f).

**Color change in fresh and parboiled rice**

CIEL*a*b* color space of fresh and parboiled milled rice and color difference \((\Delta E_{ab}^*)\) of parboiled grains (without, water (control), 3% NaCl, and 0.2% acetic acid soaking) with fresh samples of all selected varieties are presented in Table 1. Color represented in terms of \(L^*, a^*,\) and \(b^*\) values of parboiled samples are significantly \((p < 0.05)\) different from the fresh samples in all varieties. There was a significant \((p < 0.05)\) decrease in \(L^*\) value and significant \((p < 0.05)\) increase in \(b^*\) value due to parboiling in all varieties. However, \(a^*\) value significantly \((p < 0.05)\) increased in glutinous (TDK8 and TDK11) varieties and significantly \((p < 0.05)\) decreased in non-glutinous (DG) variety due to parboiling. More redness (+ \(a^*\)) in the parboiled glutinous rice than non-glutinous is due to the color difference in the husk. The husk of TDK8 and TDK11 was more reddish (+ \(a^*\)) and DG husk was more greenish (- \(a^*\)). This shade conversion from milky white (fresh) to amber color (parboiled) in glutinous rice is possibly due to the diffusion of husk color into the endosperm.\(^{[18]}\) Moreover, the Maillard reaction also contributes to color alterations during steaming.\(^{[35,36]}\) The chemistry of
soaking medium had a significant effect on the color of parboiled rice. Interestingly, $b^*$ value was significantly decreased in acetic acid soaked glutinous rice; however, it was significantly increased in non-glutinous rice, possibly due to variety difference and nature of coloring pigments in aleurone.

Figure 1. Head rice yield (%) and grain hardness (N) of fresh and parboiled rice grains; (a) Thadokkham-8 (TDK8), (c) Thadokkham-11 (TDK11), and (d) Doongara (DG). * Correlation (r) between head rice yield (%) and grain hardness (N) in; (b) TDK8, (d), TDK11, and (f) DG. *Means ± SD (n = 3). Within figure, significant differences are denoted by lowercase letters for head rice yield and uppercase letters for grain hardness at 5% probability level.
and sub-aleurone layers. Further research recommended on this contrasting behavior. Without soaking, control soaking and NaCl soaking had significantly ($p<0.05$) higher $\Delta E^*/C_{3ab}$ values than acetic acid soaking in glutinous (TDK8 and TDK11) varieties possibly due to bleaching effect of acetic acid. Acetic acid acts as weak inhibitor of browning due to its metal-chelating characteristics by lowering the pH and can also interact with phenols in rice.\[37\]

### Pasting properties

The pasting profiles of fresh and parboiled rice flour of selected varieties are presented in Fig. 2. Results showed the diverse behavior of glutinous (TDK8 and TDK11) and non-glutinous (DG) samples due to parboiling. Parboiling significantly ($p<0.05$) reduced the pasting temperature in both glutinous flours except without soaking parboiling, where pasting temperature significantly ($p<0.05$) increased as compared to the fresh flour. However, pasting temperature of parboiled non-glutinous (DG) increased as compared to fresh flour. Moreover, significant ($p<0.05$) increase in peak and final viscosities was recorded in parboiled glutinous flours which were significantly ($p<0.05$) decreased in non-glutinous flour compared to fresh flours. This variation in the pasting profiles of glutinous and non-glutinous rice after parboiling may be due to increased starch damage owing to parboiling in DG than TDK8 and TDK11, resulting in resistance of starch granules to absorb water and swell during RVA analysis. Dutta and Mahanta\[38\] reported that the parboiled rice varieties (Ranjit and Kola Chowkua) with higher amylose content showed reduced pasting profiles than glutinous rice varieties (Aghoni bora and Bhogali bora) possibly due to an extensive breakdown of straight chain amylose during parboiling.\[39\] Among various parboiling treatments, saline soaking induced significant swelling of starch resulting in high peak and final viscosities than water (control) in all samples. This might be due to the inter- or intra-molecular cross-linking of Na$^+$ ions with the amylopectin during parboiling,\[40\] resulting in increased water absorption and viscous gels during RVA analysis. However, acetic acid soaking restricted the swelling leading to reduced peak and final viscosities. Acetic acid soaking prior to parboiling might have degraded the amorphous regions,\[41\] resulting in reduced water absorption and starch swelling.

### Table 1. CIEL*a*b* color space of fresh and parboiled rice grains of Thadokkham-8 (TDK8), Thadokkham-11 (TDK11), and Doongara (DG)*.

| Rice variety | Treatment            | $L^*$         | $a^*$         | $b^*$         | $\Delta E^*/C_{3ab}$ |
|--------------|----------------------|---------------|---------------|---------------|----------------------|
| TDK8         | Fresh                | 96.7 ± 0.25a  | -0.96 ± 0.02a | 0.55 ± 0.01a  | -                     |
|              | Without soaking      | 89.0 ± 1.00bc | -0.03 ± 0.02b | 11.2 ± 0.33b  | 13.2 ± 1.01bc        |
|              | Water (control) soaking | 86.5 ± 0.50b | 0.47 ± 0.03b  | 11.8 ± 0.45b  | 15.3 ± 0.84a         |
|              | 3% NaCl soaking      | 87.5 ± 0.35ab | 0.82 ± 0.03b  | 11.6 ± 0.59b  | 14.3 ± 0.07ab        |
|              | 0.2% acetic acid soaking | 89.5 ± 0.50b | 1.58 ± 0.13b  | 9.6 ± 0.11b   | 11.8 ± 0.52c         |
| TDK11        | Fresh                | 96.4 ± 0.40a  | -0.97 ± 0.02a | 0.56 ± 0.02a  | -                     |
|              | Without soaking      | 93.6 ± 0.40b  | 0.15 ± 0.03b  | 8.4 ± 0.60b   | 8.4 ± 0.27c          |
|              | Water (control) soaking | 87.8 ± 0.41b | 1.41 ± 0.10b  | 12.8 ± 0.31a  | 15.1 ± 0.74a         |
|              | 3% NaCl soaking      | 90.5 ± 0.32c  | 1.03 ± 0.04c  | 11.57 ± 0.32c | 12.6 ± 0.34b         |
|              | 0.2% acetic acid soaking | 90.7 ± 0.30c | 0.89 ± 0.09c  | 10.65 ± 0.35c | 11.7 ± 0.36b         |
| DG           | Fresh                | 93.19 ± 0.19a | 1.20 ± 0.20a  | 7.25 ± 0.25a  | -                     |
|              | Without soaking      | 89.55 ± 0.55c | 0.94 ± 0.09ab | 7.90 ± 0.30a  | 3.73 ± 0.44b         |
|              | Water (control) soaking | 91.50 ± 0.50b | 0.16 ± 0.02b  | 10.19 ± 0.39b | 3.56 ± 0.62b         |
|              | 3% NaCl soaking      | 88.5 ± 0.27ab | 0.85 ± 0.14b  | 11.94 ± 0.40b | 6.68 ± 0.12a         |
|              | 0.2% acetic acid soaking | 92.33 ± 0.33ab | 0.20 ± 0.02c | 13.12 ± 0.32b | 6.02 ± 0.08a         |

*Means ± SD ($n=3$). For a particular rice variety, means with different letters in the same column denote significant difference at 5% probability level within each rice variety.
Crystallinity change in starch

The X-ray diffraction spectra of fresh and parboiled rice flour of rice samples are shown in Fig. 3. The fresh flour samples of both glutinous (TDK8 and TDK11) and non-glutinous (DG) varieties displayed a typical A-type pattern with main crystalline peaks at 14.9°, 16.9°, 18°, and 22.8° and crystallinity was recorded as 25.95%, 22.62%, and 18.79%, respectively. Parboiled TDK8 in all soaking medium was almost completely amorphous, and no A-type pattern from residual starch was detected. However, a weak A-type pattern was noted in parboiled TDK11 and DG (crystalline peaks at 14.9°, 16.9°, 18°, and 22.8°) with significant \( p < 0.05 \) decrease in crystallinity as compared to untreated samples. Moreover, V-type crystalline peak was also detected in parboiled non-glutinous rice (DG), possibly due to starch–lipid complex formation during parboiling. The variation in the crystallinity of parboiled TDK8 and TDK11 is possibly due to the difference in the amylopectin chain lengths. It has been reported that external and inter-block chain lengths correlated with the retrogradation of amylopectin.\(^{[42]}\) Very short external chains (DP 6–8) prevent retrogradation,\(^{[43]}\) resulting in no crystalline region during XRD analysis. Further studies on the amylopectin chain lengths of TDK8 and TDK11 should be done in future.

The gelatinization temperature of starch of untreated rice flour samples was recorded as ~65°C for glutinous (TDK8 and TDK11) and ~75°C for non-glutinous (DG) (Fig. 2); therefore, almost complete gelatinization has occurred during steaming process of parboiling resulting in complete disappearance of crystalline peaks in TDK8 and weak peaks in TDK11 and DG. The appearance of weak peaks could be attributed to the retrogradation of amylopectin in TDK11 and amylose in DG. Among various soaking medium before parboiling, acetic acid and saline soaking affected the residual starch more than water (control) and without soaking, resulting in significant \( p < 0.05 \) decrease in crystallinity.
Thermal properties

The thermal (gelatinization and retrogradation) properties of fresh and parboiled rice flour of rice samples are presented in Table 2. Parboiling resulted in significant ($p < 0.05$) decrease in thermal transition temperatures ($T_o$, $T_p$, and $T_c$) and enthalpy ($\Delta H$) of gelatinization than fresh flour in glutinous (TDK8 and TDK11) and non-glutinous (DG) flours. Moreover, the retrogradation thermal temperatures ($T_{o(r)}$, $T_{p(r)}$, and $T_{c(r)}$) and enthalpy ($\Delta H_{(r)}$) was also significantly ($p < 0.05$) reduced in parboiled DG and without soaking parboiled TDK8 and TDK11. Interestingly, no retrogradation peaks were detected in water (control), saline, and acetic acid soaking parboiled TDK8 and TDK11. However, significant ($p < 0.05$) reduction in $\Delta H_{(r)}$ was recorded in without soaking parboiled samples led to significant ($p < 0.05$) reduction in the percentage of retrogradation ($R\%$). Results showed that residual of ungelatinized starch might be present in the parboiled glutinous samples made without soaking, resulting in melting enthalpy of gelatinization and retrogradation. The gelatinization endotherms are in agreements with the XRD spectra (Fig. 3), where a significant reduction in the crystallinity was recorded.

Figure 3. X-ray diffraction and calculated crystallinity (%) of fresh and parboiled rice grains of Thadokkham-8 (TDK8), Thadokkham-11 (TDK11), and Doongara (DG) as shown on the right side of the figures. *

*Means ± SD ($n = 3$). Within each variety, means with different letters in the same figure denote significant difference at 5% probability level.
Table 2. Experimental results of estimated GI, and gelatinization and retrogradation properties of fresh and parboiled rice grains of Thadokkham-8 (TDK8), Thadokkham-11 (TDK11), and Doongara (DG)*.

| Rice variety | Treatment                | GI      | Gelatinization | Thermal properties | Retrogradation |
|--------------|--------------------------|---------|----------------|--------------------|----------------|
|              |                          |         | $T_o$          | $T_p$   | $T_c$ | $\Delta H$ | $T_{oc}$ | $T_{pc}$ | $\Delta H_{oc}$ | $R\%$ |
| TDK8         | Fresh                    | 116.2 ± 0.2 | 66.4 ± 0.0 | 73.7 ± 0.4 | 89.9 ± 1.6 | 10.4 ± 0.5 | 51.7 ± 0.0 | 58.5 ± 0.5 | 65.2 ± 1.3 | 0.2 ± 0.0 | 2.1 ± 0.1 |
|              | Without soaking          | 111.8 ± 0.3 | 50.6 ± 0.4 | 58.1 ± 0.2 | 62.6 ± 0.2 | 5.1 ± 0.1  | 46.0 ± 0.4 | 52.4 ± 0.4 | 60.3 ± 0.2 | 0.1 ± 0.0 | 2.0 ± 0.1 |
|              | Water (control) soaking  | 108.0 ± 1.0 | 48.2 ± 0.1 | 56.1 ± 0.4 | 61.1 ± 0.2 | 3.5 ± 0.2  | ND         | ND         | ND         | ND         | ND         |
|              | 3% NaCl soaking          | 119.2 ± 1.0 | 47.3 ± 0.2 | 54.4 ± 0.4 | 58.0 ± 0.0 | 3.5 ± 0.0  | ND         | ND         | ND         | ND         | ND         |
|              | 0.2% acetic acid soaking | 100.4 ± 0.2 | 45.8 ± 0.2 | 54.0 ± 0.0 | 57.4 ± 0.3 | 3.0 ± 0.1  | ND         | ND         | ND         | ND         | ND         |
| TDK11        | Fresh                    | 105.9 ± 0.2 | 64.8 ± 0.1 | 71.0 ± 0.2 | 81.1 ± 0.2 | 9.1 ± 0.2  | 50.6 ± 0.4 | 57.5 ± 0.4 | 63.8 ± 0.17 | 0.20 ± 0.01 | 2.14 ± 0.02 |
|              | Without soaking          | 101.5 ± 0.3 | 49.5 ± 0.5 | 57.1 ± 0.1 | 61.1 ± 0.2 | 4.4 ± 0.2  | 40.1 ± 0.1 | 50.6 ± 0.4 | 59.06 ± 0.17 | 0.10 ± 0.00 | 2.15 ± 0.00 |
|              | Water (control) soaking  | 97.7 ± 1.0 | 47.3 ± 0.2 | 54.4 ± 0.4 | 58.2 ± 0.2 | 3.6 ± 0.0  | ND         | ND         | ND         | ND         | ND         |
|              | 3% NaCl soaking          | 108.9 ± 1.0 | 45.8 ± 0.2 | 53.7 ± 0.3 | 57.3 ± 0.3 | 3.1 ± 0.1  | ND         | ND         | ND         | ND         | ND         |
|              | 0.2% acetic acid soaking | 90.1 ± 0.2 | 43.4 ± 0.4 | 52.6 ± 0.4 | 56.4 ± 0.3 | 2.0 ± 0.1  | ND         | ND         | ND         | ND         | ND         |
| DG           | Fresh                    | 94.8 ± 1.4 | 72.3 ± 0.7 | 77.1 ± 0.5 | 83.0 ± 1.5 | 3.4 ± 0.0  | 43.7 ± 0.2 | 56.4 ± 0.0 | 62.9 ± 0.2 | 2.0 ± 0.0  | 59.2 ± 0.0 |
|              | Without soaking          | 84.3 ± 0.5 | 70.9 ± 0.2 | 77.6 ± 0.3 | 82.6 ± 0.2 | 3.1 ± 0.1  | 43.1 ± 0.1 | 55.9 ± 0.1 | 61.8 ± 0.1 | 1.6 ± 0.1  | 51.8 ± 1.3 |
|              | Water (control) soaking  | 78.4 ± 0.8 | 70.1 ± 0.1 | 76.8 ± 0.1 | 81.5 ± 0.1 | 3.0 ± 0.0  | 42.9 ± 0.1 | 55.5 ± 0.1 | 60.8 ± 0.0 | 1.4 ± 0.0  | 48.9 ± 1.5 |
|              | 3% NaCl soaking          | 85.6 ± 1.4 | 70.1 ± 0.1 | 76.1 ± 0.1 | 78.7 ± 0.2 | 2.4 ± 0.1  | 41.0 ± 0.1 | 54.9 ± 0.1 | 59.9 ± 0.0 | 1.1 ± 0.0  | 45.7 ± 0.3 |
|              | 0.2% acetic acid soaking | 72.2 ± 0.8 | 69.9 ± 0.1 | 75.5 ± 0.1 | 77.6 ± 0.2 | 1.9 ± 0.1  | 39.9 ± 0.1 | 54.0 ± 0.1 | 59.4 ± 0.2 | 0.9 ± 0.0  | 44.9 ± 1.2 |

*Means ± SD (n = 3). For a particular rice variety, means with different letters in the same column denote significant difference at 5% probability level within each rice variety.

*Not detected.
Texture profile analysis

Textural profiles of cooked fresh and parboiled grains of glutinous (TDK8 and TDK11) and non-glutinous (DG) are shown in Fig. 4. Parboiling resulted in significant ($p < 0.05$) increase in hardness (N) and adhesiveness (N.s) when compared to the freshly cooked samples for all varieties. Parboiling results in several physicochemical changes such as disruption of surface layers and leaching of components from cells. This cell’s disruption and leaching of cellular components possibly facilitate more damaged starch exposure on the surface, resulting in the increased stickiness of cooked parboiled glutinous rice.\footnote{45} Among various parboiling treatments, saline soaking exhibited the hardest texture followed by acetic acid, water (control), and without soaking. Interestingly, parboiling also resulted in significant ($p < 0.05$) increase in adhesiveness (N.s) especially in glutinous (TDK8 and TDK11) varieties. Chemistry of soaking medium significantly ($p < 0.05$) affected the adhesiveness in TDK8 as shown on Fig. 4, where adhesiveness of acetic acid parboiled rice was significantly ($p < 0.05$) higher than saline, water (control), and without soaking. However, soaking medium had no significant ($p > 0.05$) effect on the adhesiveness of TDK11 and DG. The TPA results are in agreement with XRD analysis (Fig. 3), where no crystalline region was found in parboiled TDK8, and a weak A-type crystalline pattern was found in parboiled TDK11 and DG.

Figure 4. Textural profile analysis of fresh and parboiled rice grains of Thadokkham-8 (TDK8) and Doongara (DG).**Means ± SD (n = 3). Within each variety, significant differences are denoted by lowercase letters for hardness and uppercase letters for adhesiveness at 5% probability level.
**GI prediction**

The results of estimated GI using *in vitro* digestion of 180 min are presented in Table 2. As expected, the predicted GI of glutinous rice varieties, viz. TDK8 and TDK11 was higher than non-glutinous (DG) rice variety. Similar findings were reported by Zambrano et al. Moreover, parboiling resulted in significant (p < 0.05) decrease in GI in both TDK8/TDK11 and DG. Gelatinization and recrystallization are the major physicochemical changes that occur during parboiling. These changes may lead to higher levels of resistant starch resulting in low glucose response and GI. The protein–starch interaction may have restricted the starch digestibility, resulting in reduced GI. However, saline soaked parboiled glutinous rice showed significantly (p < 0.05) higher GI than fresh. NaCl might have increased the postprandial plasma glucose by accelerating the digestion of starch, especially amylopectin, by stimulating α-amylase activity. Further research on the glycemic response of parboiled glutinous rice using animal model is recommended for future studies.

**Conclusion**

This study showed that the soaking medium affected the physicochemical properties of glutinous (TDK8 and TDK11) rice varieties. Milling efficiency of glutinous rice was improved by adding NaCl and acetic acid to the soaking water of paddy before parboiling. Induced coloration from the husk during soaking and steaming and maillard reaction during steaming can be minimized by the bleaching effect of acetic acid used during soaking. Saline soaking can also improve water absorption of parboiled rice. NaCl and acetic acid affected the residual starch resulting in reduced crystalline regions which may be responsible for more adhesiveness during textural profile analysis. The parboiling or rice significantly reduced the GI which may be due to more resistant starch contents. This should be further investigated. Current findings showed the potential of parboiling with modified soaking techniques to improve grain quality of glutinous rice.

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