Chapter 6

CHARACTERIZATION OF READY-TO-EAT BHOJA CHAUL PROCESSED BY A LABORATORY-SCALE DRY HEAT PARBOILING METHOD

6.1. Introduction

Rice (Oryza sativa L.) is parboiled to bring about desirable properties and be consumed as staple food. Parboiling often involves soaking of paddy in water followed by steaming, drying, and milling. Bhattacharya (1985) however has specifically termed this as the conventional parboiling process while a process where steaming is carried out under elevated pressure has been termed as pressure parboiling. A third technique, called dry heat parboiling has been defined to involve conduction heating of moistened paddy at higher temperature for shorter durations. This method with variations in the processing conditions is generally used for making certain speciality rice products. While steam parboiling causes starch gelatinization during steaming followed by retrogradation during prolonged drying, dry heat parboiling results in starch gelatinization with no retrogradation due to the simultaneous rapid loss of water from the paddy during conduction heating. This results in development of certain peculiar properties in parboiled rice.

Assam, a state in India, produces rice varieties with wide range of apparent amylose content. While the high and intermediate amylose varieties are consumed in staple diet throughout Assam, the low amylose and waxy varieties are often processed into speciality products. Ready-to-eat (RTE) rice products have gained much popularity in the last few decades due to the ease of cooking and fuel economy. Bhoja chaul is a popular RTE product of Assam. The traditional product is conventionally processed by soaking low amylose or waxy paddy in water at room temperature for 3-4 days for maximum hydration followed by roasting in iron vessel over wood fire with constant
stirring. The roasting temperature is controlled by the intensity of the wood fire and is stopped when the grains sufficiently dry up. The roasted paddy is then spread over mud floor to cool before milling in dheki (a foot pounding machine) to get the product. The prepared Bhoja chaul is soaked in water at room temperature prior to consumption to let it hydrate sufficiently to a softer and somewhat sticky texture. After draining the water, the chaul is eaten with milk, cream, curd and jaggery. The roasted aroma, colour, and sticky as well as chewy texture of Bhoja chaul are considered to be its desirable characteristics by the rural household processors. There is no cooking involved. As per the traditional food processors, extensive hydration of the soaked paddy followed by extensive roasting without allowing puffing yields high quality Bhoja chaul. This peculiar edible nature of dry heat parboiled low amylose and waxy varieties has never been discussed before.\(^7\)

Modern analytical tools like Rapid Viscosity Analysis (RVA), X-ray diffraction (XRD), Differential Scanning Calorimetry (DSC) and Texture Profile Analysis (TPA), have been extensively used for understanding the molecular and functional properties of starch and starchy flours. RVA is important for analysing the cooking behaviour that primarily decides their targeted use in processed food systems.\(^8\) XRD and DSC give the idea of molecular structures and their arrangements in a complex polymeric food material.\(^9\) TPA is used as a mechanical tool to assess the human sensory attributes of cooked rice.\(^10\)

Digestibility is one of the primary factors for determining the nutritional status of the starchy foods.\(^{11-13}\) Mujoo et al (1998) opined that rice roasting results in gelatinization of starch that is more susceptible to enzymatic digestion.\(^{14}\) Contrary to this, Chitra et al (2010) worked on in vitro starch digestibility of three sand roasted rice products and reported the formation of resistant starch which passed the human digestive tract unhydrolyzed.\(^{15}\) The present study aimed at using an improvised laboratory-scale process for making RTE Bhoja chaul, essentially a dry heat parboiled rice product, from a low amylose and a waxy variety of rice and characterizing the product for its physical, physicochemical and nutritional properties.
6.2. Materials and methods

*Kola chokua* and *Aghoni bora* varieties of paddy from the recent harvest of 2012 were purchased from local farmers of Jorhat district, Assam. The rice varieties fell under low amylose and waxy types with 12.6 % and 1.15% (db) apparent amylose contents, respectively as reported in chapter 3 (section 3.3.1). The samples were kept at room temperature for 24 h and then stored at 4°C until processing. Enzymes and D-glucose standards were procured from Sigma-Aldrich (U.S.A.).

6.2.1. Processing and coding of samples

As the normal process of dry heat parboiling mentioned by Bhattacharya (1985) gave *Bhoja chaul* that had raw rice texture while eating (revealed during preliminary studies) due to low moisture absorption on soaking, an improvised method was developed in the laboratory. Briefly, 200g paddy was brought to room temperature and kept for 5 h. The paddy was then added to 3 L of water at 100°C in a vessel kept over flame with continuous stirring for 1 and 3 min. Such hot soaking results in higher absorption of water by the paddy within shorter soaking duration and thereby allows for extensive starch gelatinisation in the kernel. The vessel was then removed from the flame, immediately covered with a thick gunny bag to prevent rapid cooling and kept at room temperature (25±2 C) for 18 h. *Kola chokua* and *Aghoni bora* attained moisture content above 36% (wb) against ~30% moisture that would have been attained without the 1min or 3 min boiling steps as revealed by trials in our laboratory. The excess water was then decanted and the hydrated paddy was roasted with hot sand in a drum type roaster (1:3 paddy to sand). The sand particles (less than 3 mm in diameter) were preheated to temperatures of 220°C which came down to 140°C after addition of the paddy (determined from repeated trials) and was controlled as such throughout the roasting time by wrapping the drum of the roaster with a moistened piece of gunny bag. The roaster had an internal rotatable shaft which was operated at 110-120 rpm for maximum heat distribution throughout the paddy mass. The paddy samples were roasted for 11, 13 and 15 min. The roasted paddy had moisture content between 11-12 % (wb) as was determined immediately after roasting. The roasted samples were then cooled at room temperature for 6 h and milled (8-10% milling, w/w) in a Satake dehusker and a polisher (Satake, Japan). A portion of each sample was ground into flour in a laboratory grain mill (Fritsch Pulverisette 14,
Germany) and passed through a 100 μm sieve. All the samples were stored in polypropylene bags at 4°C until further analyses were carried out. For ease of identification, the rice varieties were coded as LK meaning low amylose Kola chokua and WA meaning waxy Aghoni bora. LK and WA suffixed with (N) indicated raw rice. Processed sample code indicated variety code suffixed with time of boiling prior to overnight soaking and time of roasting. Thus, LK-1-11 indicated low amylose Kola chokua boiled for 1 min prior to overnight soaking followed by roasting at 140°C for 11 min.

6.2.2. Colour measurement

The colour values of all flour samples were obtained by a colour measurement spectrophotometer (Hunter Colour-Lab Ultrascan Vis, US). The results for L (lightness), a (red-green), and b (yellow-blue) values were used to calculate the corresponding hue angle (H) and chroma (C) values.(16)

\[ H = \tan^{-1}\left(\frac{b}{a}\right) \quad \text{Eq. 6.1} \]

\[ C = \left[\left(a^2 + b^2\right)\right]^{1/2} \quad \text{Eq. 6.2} \]

6.2.3. L/B ratio, kernel hardness (H) and head rice yield (HRY)

The length (L) and breadth at the midpoint (B) of the polished kernels were determined using a Seed dial calliper (Baker, India) and the L/B ratio was calculated. H was tested in a Texture Analyzer (TA.HD.plus, Stable Micro Systems, UK) with a 25 kg load cell by using a single compression test with a 2 cm diameter stainless steel probe along the kernel thickness at a speed of 0.5 mm/min followed by return to its original position. The test was repeated for 20 kernels from each sample and the mean was calculated. The maximum force (in Newton) indicated by the force-time curve generated by the inbuilt software (Exponent Lite) was taken as H. HRY was determined as the percentage weight of intact kernels obtained after milling to that of total milled rice.

6.2.4. Porosity (ε)

For ε (%) determination, bulk density (ρb), and true density (ρt) were first determined. For ρb determination, polished grains were allowed to fall into a measuring cylinder from
a constant height up to a known volume. The top level was adjusted by gentle tapping. The weight of the filled grains was determined and \( \rho_b \) was calculated.

\[
\rho_b \quad (g/cm^3) = \text{mass of grain} / \text{volume occupied} \quad \text{Eq. 6.3}
\]

\( \rho_t \) was determined by the solvent displacement method. Polished kernels of known weight were immersed in a known volume of kerosene taken in a measuring cylinder. The cylinder was gently agitated to release any possible air gap. The volume of kerosene displaced by the kernels was then recorded and the \( \rho_t \) was calculated.

\[
\rho_t \quad (g/cm^3) = \text{mass of grain} / \text{volume of kerosene displaced} \quad \text{Eq. 6.4}
\]

The porosity (\( \varepsilon \)) was determined from Eqs 6.3 and 6.4

\[
\varepsilon \quad (\%) = [(\rho_t - \rho_b) / \rho_t] \times 100 \quad \text{Eq. 6.5}
\]

6.2.5. Equilibrium moisture content on soaking at room temperature (EMC-S)

Polished rice kernels were soaked at room temperature for 4 h. The excess water was decanted and the surface moisture from the kernels was removed with a piece of blotting paper. The moisture content was then estimated (AOAC, 2000). EMC-S was calculated from the following equation

\[
\text{EMC-S (\%, db)} = \left[ \frac{\text{Moisture content (g)}}{\text{Dried weight of kernels (g)}} \right] \times 100 \quad \text{Eq. 6.6}
\]

6.2.6. Sediment volume (SV)

The test for sediment volume (SV, mL) gives an indirect indication of the degree of gelatinization of pregelatinized rice flour. Briefly, 1 g each of the flour samples was taken in a measuring cylinder and 15 ml of 0.05 N hydrochloric acid was added to it with agitation after each 5 min for 1 h. The level of the flour sediment was observed after 4 h and was reported as the SV of the sample.

6.2.7. Cooking time of raw rice

The objective method of Juliano (1982) was used to determine the cooking time (in min) of the raw rice samples. Sample weighing 20 g was cooked in 200 ml water at 98°C on
595.2x842.2

a hot plate. After 10 min of cooking, ten kernels were brought out from the middle of the cooked mass and pressed between two clean glass slides. The number of translucent kernels were counted and recorded. The pressing test was repeated after each minute and the time at which 90% of the kernels were translucent was considered as the cooking time of that rice.

**6.2.8. Pasting properties**

Flour sample (12 % moisture content w/w; 28 g total weight) was added to 25 mL water and allowed for saturation for 5 min. The slurry was then held at 50°C for 1 min, heated from 50°C to 95°C in 3.45 min, held at 95°C for 2.40 min followed by cooling to 50°C in 3.45 min and finally holding at 50°C for 1 min in a Rapid Viscosity Analyser (RVA Starchmaster2, Newport Scientific Instruments, US). The pasting curves obtained were compared and the pasting parameters, namely PV (maximum viscosity during heating phase); HPV (minimum viscosity at 95°C); CPV (final viscosity at 50°C); BD (PV-HPV) and SB (CPV-HPV) were recorded.

**6.2.9. Wide angle X-ray scattering (WAXS)**

An X-ray diffractometer (Rigaku Miniflex, Japan) with a λ value of 1.54 A°, operating at an acceleration potential of 30 kV with 15 mA current and a copper target was used to obtain wide angle X-ray diffractograms (XRD) of the flour samples. The scanning range was 10–40° of 2θ values in steps of 0.05°. The total area under the curve and the area under each prominent peak were determined and the percentage crystallinity was calculated.\(^{(18)}\)

\[
\text{% crystallinity} = \left( \frac{\text{area under peaks}}{\text{total area under the curve}} \right) \times 100 \quad \text{Eq. 6.7}
\]

Gaussian fit curves of the diffractograms were obtained using Origin 8 software (OriginLab Corporation, UK) to study any notable change in the overall diffraction patterns of the flour samples.

**6.2.10. Thermal properties**

Flours of raw rice and 1 min and 3 min hot soaked samples roasted for 15 min were analysed for their thermal profiles. Saturated flour slurries were prepared by mixing 4 mg
each of sample and deionized water (1:2 flour to moisture ratio, db) in aluminium pans and keeping for 1 h at 4°C. The pans were then hermetically sealed and heated in a Differential Scanning Calorimeter (DSC, model DSC-60; Shimadzu, Tokyo, Japan) against an empty reference pan from 30°C to 130°C at a heating rate of 5°C/min under N₂ atmosphere. The onset (To), peak (Tp), and conclusion (Tc) temperatures and enthalpy of gelatinization and/or crystallite melting (ΔH, J/g) were obtained from the thermograms using the inbuilt TA-60WS software.

6.2.11. Starch digestibility

The in vitro starch hydrolysis rate of each sample was estimated by the method of Goni et al (1996). A solution containing 1 g of pepsin in 10 mL of HCl-KCl buffer (pH 1.5) was prepared and 0.2 mL of this solution was mixed with 50 mg of flour sample and kept for deproteinisation in a shaking water bath at 40°C for 60 min. The volume was then made up to 25 mL with Tris-maleate buffer (pH 6.9) and 5 mL of a Tris-maleate buffer solution containing 2.6 IU pancreatic α-amylase was added before incubating at 37°C for 180 min. One milliliter aliquot was taken out after each 30 min, boiled to inactivate the enzymes and stored under refrigeration. Three millilitres of 0.4 M sodium acetate buffer (pH 4.75) containing 60 µL of amylglucosidase (Sigma Aldrich) was then added and further incubated at 60°C for 45 min. The glucose liberated was estimated using a D-glucose oxidase-peroxidase assay kit (Robonik, India) and a previously prepared glucose standard curve. The value was converted to starch by multiplying by a factor of 0.9. The total starch content of each sample was calculated by the standard protocol of AOAC (2000) and the degree of hydrolysis (% db) was calculated as the percentage of starch degraded from each sample after each time interval.

Degree of hydrolysis (%) = (Starch hydrolyzed / Total starch content) x 100  Eq. 6.8

Resistant starch (RS) present in the flour samples was measured by a method modified from Englyst et al (1992). Briefly, 100 mg flour was first added to 7 ml acetate buffer (pH 5.2) and incubated at 37°C for 20 min in a shaking water bath (Voltam, India). Then, 3 ml of an enzyme mixture composed of invertase (220 U/ml), pancreatic α-amylase (3000 U/ml) and amyloglucosidase (15 U/ml) were added and incubated further. Aliquots were taken out after 20 min and 120 min and measured for rapidly released and slowly released glucose (G20 and G120) respectively using the glucose assay kit and
standard curve. Rapidly digestible starch (RDS) and slowly digestible starch (SDS) expressed as a percentage of dry matter were evaluated by the following formulae

\[
\text{RDS} \,(\%) = \left(\frac{G_{20} \times 0.9}{\text{TS}}\right) \times 100 \tag{Eq. 6.9}
\]

\[
\text{SDS} \,(\%) = \left(\frac{(G_{120} - G_{20}) \times 0.9}{\text{TS}}\right) \times 100 \tag{Eq. 6.10}
\]

As mentioned by Patindol et al (2010), the difference between total starch (TS) and the starch digested during the incubation period was calculated as resistant starch (RS) and expressed as percentage of dry matter.\(^{19}\)

\[
\text{RS} \,(\%) = \left(\frac{\text{TS} - (\text{RDS} + \text{SDS})}{\text{TS}}\right) \times 100 \tag{Eq. 6.11}
\]

### 6.2.12. Texture comparison of cooked rice and the RTE product

The raw LK and WA rice samples were cooked at 100°C for 18 and 16 min respectively, their cooking time determined previously and reported in section 6.2.7. Processed samples were soaked in water at room temperature for 20 min as generally practiced in households for Bhoja chaul. Excess water from both was decanted and surface water was removed with a blotting paper. The samples were then subjected to texture profile analysis (TPA). For this, a Texture Analyzer (TA.HD.plus, Stable Micro Systems, UK) with a 5-kg load cell fitted with a cylindrical probe of 2 cm diameter was used. The two-cycle compression test involved compressing single kernels collected from the middle of each sample mass to 70% at 0.5 mm/s (Suzuki, 1979).\(^{20}\) The time between two chews was 3 s. All the TPA parameters, namely hardness, adhesiveness, springiness, and chewiness were determined by the inbuilt software (Exponent Lite). Twenty kernels from each sample were tested separately and average values were taken.

### 6.2.13. Statistical analysis

All the experiments were carried out in multiple replicates and the means are reported. Significant differences between the means were analysed by Duncan’s multiple range test at a significance level of 0.05 using SPSS 11.5 (SPSS Inc., USA).
6.3. Results and discussion

6.3.1. Colour measurement

None of the processed samples exhibited while belly indicating complete gelatinization of starch. Colour values of rice flour samples are presented in Table 6.1. The decreased L value with simultaneous increase in H and C values was indicative of extensive gelatinization of starch, Maillard browning and uniform distribution of the colour compound.\(^{(21)}\) Although inward migration of pigments from husk and bran layers into the kernel was proposed by Bhattacharya (1985)\(^{(1)}\) and Lamberts et al (2006)\(^{(21)}\), it was nullified by the work of Lamberts and Delcour (2008)\(^{(22)}\) who found that the carotenoids present in the epidermal layers got reduced to trace levels after steam parboiling and hence do not contribute to the final colour of parboiled rice. The extent of colour change after dry heat parboiling that involved higher temperature of conduction heating was greater than the colour development in steam parboiled rice as was reported in chapter 3 (section 3.3.3). Hence, the colour development in the dry heat parboiled samples may be principally attributed to Maillard browning which accelerated due to formation of reducing sugars by thermal breakdown of starch.

6.3.2. L/B ratio, kernel hardness and head rice yield

Values for L/B, H and HRY (%) are given in Table 6.1. Notable reduction in length with minor yet simultaneous increase in breadth resulted in reduction of L/B ratio. The Bhoja chaul samples were hence bolder in shape than the raw rice kernels. This was however contradictory to the findings of Sowbhagya et al (1993) who observed increase in length of kernels after dry heat parboiling.\(^{(23)}\) Varietal difference plays an important role in determining raw and parboiled rice properties. Difference in the gap between the raw kernel and the husk and the shape and size of the kernel and swelling tendency of starch can definitely be considered as major determining factors for the shape of the kernel after processing as no splitting of husk layers was observed. Adding to it, conduction heat from the sand probably caused higher tension to develop along the horizontal axis of the kernel which was more exposed to the heating sand. The L/B ratio and H values were indicative of the fact that no puffing occurred during the dry heat parboiling process. Processed kernels were markedly harder than the raw rice. With increased H, the HRY also
increased indicating development of kernel integrity upon processing. Almost all the kernels were intact in the severely dry heat parboiled samples. This indicates suitability of the laboratory-scale process for developing into a commercial parboiling method.

6.3.3. Porosity

Porosity is directly related to the L/B ratio of the kernels. Increase in bulk density upon processing resulted in decreased porosity (Table 6.1) suggesting better packing property of the product than the raw rice, an attribute important for product handling and transportation. This change was comparatively more prominent in the processed WA samples which again may be attributed to difference in paddy structure and higher swelling on gelatinization as amylopectin is the chief factor for deciding starch swelling.

6.3.4. Equilibrium moisture content on soaking at room temperature

The improved dry heat parboiling process followed to make Bhoja chaul increased the water uptake capacity of the rice kernels. Processed LK samples showed lower values of EMC-S than WA samples processed under similar conditions. Unnikrishnan and Bhattacharya (1987) also observed a negative correlation amongst amylose content and EMC-S of parboiled rice. EMC-S increased with process severity indicating progressively developed water uptake capacity (Fig 6.1a). The values were hence highest for the WA-1-15 and WA-3-15 samples (174.6 % and 189.4 % respectively). Additionally considering our findings from previous chapters, it can be said that waxy varieties attained higher water absorption property following any method of parboiling.

6.3.5. Sediment volume

Water absorption in dry heat parboiled rice is enhanced due to gelatinized starch. LK(N) and WA(N) exhibited SV values of 2.5 mL and 2.6 mL, respectively which increased with process severity (Fig 6.1b). The extent of gelatinization, similar to EMC-S, was hence highest for the severely processed WA-3-15 samples with SV of 6.4 mL. Samples with boiling time of 3 min gave higher SV than the 1 min boiled samples for both the varieties. This was in accordance with the EMC-S and reflected more
extensive gelatinisation of starch in these samples.\(^{(15)}\) Comparison of the values with steam parboiled samples (reported in chapter 3 and 5) showed that the dry heat parboiled rice flour did not swell as much as steam parboiled samples from the same varieties. This was however contradictory to the findings of Bhattacharya and Ali (1976) who opined that the high SV value in dry heat parboiled products is due to lower amounts of retrograded starch in them.\(^{(5)}\) Our results indicate that the starch might have got dextrinised due to the high conduction heating which might not have added to the SV of the processed samples and thereby gave lower values.

![Graphs showing EMC-S and SV values](image)

**Fig. 6.1.** (a) EMC-S of raw and processed rice kernels and (b) SV of raw and processed rice flour.

### 6.3.6. Pasting properties

The pasting curves indicative of extensive change in starch structures upon roasting are given in Fig 6.2 (a and b) and the values of the pasting parameters are given in Table 6.2. Varavinit et al (2003) suggested that the starch granules in waxy rice flour disrupt more easily on cooking and show a lower tendency towards retrogradation due to lower amylose reassociation.\(^{(27)}\) Processing for 11 and 13 min resulted in increased PV for LK variety. For WA, the rise was only for the samples roasted for 11 min. Processed WA samples were seen to be more resistant to swelling on cooking as was evident from the shift of PV to higher time periods.\(^{(28)}\) Processed LK samples showed patterns opposite to
### Table 6.1. Colour values and physical properties of raw and processed samples.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Colour readings</th>
<th>Physical properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L</td>
<td>a</td>
</tr>
<tr>
<td>LK(N)</td>
<td>57.5±0.34b</td>
<td>2.3±0.04k</td>
</tr>
<tr>
<td>LK-1-11</td>
<td>31.0±1.21b</td>
<td>2.7±0.07d</td>
</tr>
<tr>
<td>LK-1-13</td>
<td>25.3±0.83c</td>
<td>3.0±0.17bc</td>
</tr>
<tr>
<td>LK-1-15</td>
<td>21.1±0.29b</td>
<td>3.2±0.35i</td>
</tr>
<tr>
<td>LK-3-11</td>
<td>29.8±1.44f</td>
<td>2.5±0.29c</td>
</tr>
<tr>
<td>LK-3-13</td>
<td>24.8±0.99c</td>
<td>2.8±0.41fr</td>
</tr>
<tr>
<td>LK-3-15</td>
<td>20.3±0.39e</td>
<td>2.9±0.03b</td>
</tr>
<tr>
<td>WA(N)</td>
<td>66.7±0.22l</td>
<td>2.2±0.04b</td>
</tr>
<tr>
<td>WA-1-13</td>
<td>33.3±1.02j</td>
<td>2.8±0.11fg</td>
</tr>
<tr>
<td>WA-1-15</td>
<td>30.9±0.69b</td>
<td>3.0±0.18gh</td>
</tr>
<tr>
<td>WA-3-11</td>
<td>28.1±1.12c</td>
<td>3.3±0.38h</td>
</tr>
<tr>
<td>WA-3-13</td>
<td>32.2±0.92r</td>
<td>2.8±0.71fr</td>
</tr>
<tr>
<td>WA-3-15</td>
<td>30.1±0.12sh</td>
<td>3.1±0.24nh</td>
</tr>
<tr>
<td>WA-3-15</td>
<td>27.5±0.34d</td>
<td>3.4±0.22b</td>
</tr>
</tbody>
</table>

*The means in each row followed by a common letter are not significantly different by Duncan’s Multiple Range Test at p < 0.05.*
it. Similar observations were also earlier reported for open steam parboiling of LK sample (chapter 3, section 3.3.6). This was hence indicative that the starch chains developed property of higher swelling on cooking thereby exhibiting an increased PV. This was followed by distinct BD and SB like those exhibited by raw samples. This peculiar change in pasting property of parboiled low amylose and waxy rice hence requires further research involving molecular weight characterization.\textsuperscript{(29,30)} Other factors like amylose-lipid complexes (Derycke et al. 2005)\textsuperscript{(31)} and protein (Gelders, 2006)\textsuperscript{(32)} also may affect the pasting properties which need further investigation. Resistance to viscosity loss on hydrothermal processing by low amylose and waxy rice varieties was earlier reported by Biswas and Juliano (1988).\textsuperscript{(33)} Severe processing caused drop in the PV and loss of BD like steam parboiled high amylose rice but peculiarly increased SB for both varieties giving an almost continuously rising pasting curve.\textsuperscript{(34)} This may be attributed to excessive breakdown of amylopectin during the high temperature roasting; forming irreversible simpler leachable fractions that continuously got released into the slurry, making it increasingly thicker and viscous.\textsuperscript{(35)} This property of becoming thick on cooling may prove to be useful for the prepared \textit{Bhoja chaul} powder to be used as thickening agent in cooked food systems.

![RVA pasting curves of raw and processed (a) LK and (b) WA samples. The representations of the symbolic curves are as follows: Native (——), 1-11 (■), 1-13 (●), 1-15 (▲), 3-11 (▼), 3-13 (◆), 3-15 (◆).](image)

\textbf{Fig. 6.2.} RVA pasting curves of raw and processed (a) LK and (b) WA samples. The representations of the symbolic curves are as follows: Native (——), 1-11 (■), 1-13 (●), 1-15 (▲), 3-11 (▼), 3-13 (◆), 3-15 (◆).
Table 6.2. RVA pasting parameters of raw and processed samples.

<table>
<thead>
<tr>
<th>Samples</th>
<th>PV (cP)</th>
<th>HPV (cP)</th>
<th>CPV (cP)</th>
<th>BD (cP)</th>
<th>SB (cP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LK (N)</td>
<td>1687±3.44f</td>
<td>1305±1.09d</td>
<td>2880±1.45b</td>
<td>382±2.12l</td>
<td>1575±1.93m</td>
</tr>
<tr>
<td>LK-1-11</td>
<td>1771±2.98e</td>
<td>1487±2.11e</td>
<td>2291±2.15e</td>
<td>284±1.00b</td>
<td>804±2.19d</td>
</tr>
<tr>
<td>LK-1-13</td>
<td>2495±2.13w</td>
<td>2100±1.56d</td>
<td>3141±3.25l</td>
<td>395±2.64k</td>
<td>1041±3.21b</td>
</tr>
<tr>
<td>LK-1-15</td>
<td>1664±2.34j</td>
<td>1835±4.21l</td>
<td>2811±4.12k</td>
<td>-</td>
<td>976±2.54j</td>
</tr>
<tr>
<td>LK-3-11</td>
<td>1002±1.26b</td>
<td>991±2.45a</td>
<td>1337±2.56a</td>
<td>11±3.94f</td>
<td>346±3.12e</td>
</tr>
<tr>
<td>LK-3-13</td>
<td>2490±1.54d</td>
<td>2155±3.22i</td>
<td>3462±2.64m</td>
<td>335±1.69l</td>
<td>1307±1.08k</td>
</tr>
<tr>
<td>LK-3-15</td>
<td>1528±2.43d</td>
<td>2079±3.11j</td>
<td>3385±2.35h</td>
<td>-</td>
<td>1306±2.10k</td>
</tr>
<tr>
<td>WA (N)</td>
<td>1720±3.92b</td>
<td>1179±3.24e</td>
<td>1557±1.68b</td>
<td>541±2.18e</td>
<td>378±3.45b</td>
</tr>
<tr>
<td>WA-1-11</td>
<td>2273±2.43k</td>
<td>2018±3.21b</td>
<td>3426±2.02l</td>
<td>255±0.34g</td>
<td>1408±4.12j</td>
</tr>
<tr>
<td>WA-1-13</td>
<td>1701±3.21k</td>
<td>2192±2.12k</td>
<td>3436±3.00m</td>
<td>491±1.32b</td>
<td>1244±1.21l</td>
</tr>
<tr>
<td>WA-1-15</td>
<td>803±3.69a</td>
<td>1146±2.67b</td>
<td>1610±2.22l</td>
<td>343±1.38d</td>
<td>464±1.45c</td>
</tr>
<tr>
<td>WA-3-11</td>
<td>1909±2.47p</td>
<td>1472±3.42l</td>
<td>2495±3.13f</td>
<td>437±2.32l</td>
<td>1023±2.22e</td>
</tr>
<tr>
<td>WA-3-13</td>
<td>1674±1.69n</td>
<td>1198±2.47j</td>
<td>2092±3.21d</td>
<td>476±1.89m</td>
<td>894±3.16e</td>
</tr>
</tbody>
</table>

*The means in each row followed by a common letter are not significantly different by Duncan’s Multiple Range Test at p < 0.05.

6.3.7. X-Ray diffraction

XRD of raw rice samples exhibited A-type starch crystalline pattern with strong peaks at $\theta = 15.2, 17.4, 18.1$ and 23.3 (Fig 6.3a,b). Feeble peaks at $\theta$ positions near 20.0 and 22 indicating V-type and B-type starch polymorphs were observed in the diffractograms of processed samples. While the amylose-lipid complex giving V-type diffraction pattern forms during heat processing, the B-type polymorphic structures are retrograded starch.\(^{36,37}\) Formation of retrograded starch despite of insufficient water is however contradictory to the statement of Bhattacharya (1985).\(^{11}\) Minor initiation of formation of these structures during cooling and storage of the roasted rice may however be considered responsible for the feeble peaks. In addition to that, a minor peak retained at $\theta$ value of 18.1 was representative of the native A-type crystalline structure suggesting of either incomplete gelatinization or partial recrystallization into the native structure. These native starch fractions in the processed samples may be related to the distinct PV shown in the RVA pasting curves. Superimposition of the diffractograms of the three basic starch
crystalline structures was earlier reported by Mahanta et al (1989)(39) and was also observed by us in XRD of steam parboiled rice (chapter 3, section 3.3.8). Gaussian fitting of the diffractograms of the processed samples (Fig 6.3 a and b ‘insets’) indicated that the crystalline peak regions of the curves shifted towards lower values of $2\theta$. In LK samples, it shifted from 20.2 (LK-1-11) to 18.4 (LK-1-15) and 18.1 (LK-3-15) and in WA samples the shift was from 20.3 (WA-1-11) to 18.8 (WA-1-15) and 19.0 (WA-3-15). This indicated progressive reduction in the average inter-planar space ($d$) of the crystalline lamellae of starch with process severity$^{(39)}$ as calculated from the Bragg’s equation

$$\lambda = 2d \sin\theta$$

Eq. 6.12

![Fig. 6.3. The XRD patterns of raw and processed flour samples of (a) LK and (b) WA with insets showing Gaussian fit curves; (c) Change in % crystallinity with roasting.](image-url)
Moisture acts as a principal factor for inter-chain interaction of starch. Excessive reduction in moisture from the processed kernels may be considered as the probable reason behind the development of weaker lamellae in dry heat parboiled rice. This may also be related to the significant loss in % crystallinity of both the rice varieties after processing (Fig 6.3c). The loss was marginally greater in processed WA samples as they attained higher degree of starch gelatinization.

6.3.8. Thermal properties

DSC thermograms of the raw and processed samples are presented in Fig 6.4 (a and b). While the gelatinization temperature (Tp) of LK(N) was 79.2°C, WA(N) exhibited a lower Tp of 71.4°C. LK-1-15 and LK-3-15 however showed minor peaks at temperatures of about 79°C indicating melting of native starch fractions in the samples as was also suggested by their pasting curves and XRD spectra. Processed WA samples however did not show this peak indicating higher loss in native crystallinity as shown in Fig 6.3(c). Processed samples of both the varieties exhibited major peaks at 100±10°C for melting of amylose-lipid complexes. Processed LK samples exhibited notably higher values of ΔH for amylose-lipid complex melting (57.3 J/g and 56.3 J/g for LK-1-15 and LK-3-15, respectively) than the processed WA samples (52.2 J/g and 50.0 J/g for WA-1-15 and WA-3-15, respectively). Higher apparent amylose content in LK may be attributed for this significant difference in crystallite formation. Interestingly, formation of such complexes in samples despite of very little amylose indicated that there is scope for further research on this aspect of the product. Murugesan and Bhattacharya (1989) reported significant formation of the complexes when popped rice was hydrated upto 30% moisture content as was also done here during sample preparation prior to the DSC analysis. Iturriaga, Lopez and Anon (2004) also observed formation of such compounds in waxy rice samples. It may be proposed that occurrence of long B-chains in the amylopectin and probable debranching of the same during thermal treatment led to generation of glycosidic chains capable of starch-lipid complex formation. The present study hence suggests that gelatinized starch may form amylose-lipid complex when in excess of water. No distinct peaks for melting of retrograded starch were however observed which indicates that the B-type crystalline polymorph indicated by minor peaks in XRD spectra of the samples were either not detected by the DSC conditions used or
were temporary lamellae that became amorphous once water was added for DSC sample preparation.

Fig. 6.4. DSC thermographs of pastes of raw and dry heat parboiled (roasted for 15 min after hot soaking for 1 and 3 min) (a) LK and (b) WA samples.

6.3.9. Starch digestibility

While starch in waxy WA(N) flour got digested up to 24.3% and 71.2% in 30 min and 180 min respectively, starch in low amylose LK(N) flour was digested up to 21.2% and 63.7% respectively (Fig 6.5a,b). This was in accordance with the findings of Zhu et al (2011)\(^\text{30}\). For both the varieties, hydrolysis rates increased markedly after roasting. While more than 30% of the starch in the processed samples were hydrolysed within 30 min, the moderate and severely processed samples of both the varieties, namely -1-13, -1-15, -3-13 and -3-15 were hydrolysed up to more than 85% (db) after 180 min of incubation. Mujoo et al (1998) suggested that rice roasting resulting in gelatinization causes exposure of starch component to enzymatic digestion\(^\text{14}\). Increased digestibility was related to damage to amyllopectin structures by Jaiboon et al (2011)\(^\text{43}\). Gunaratne and Hoover (2013) reported up to 50% reduction of RS in one rice variety after parboiling\(^\text{28}\). The increase in hydrolytic rate was higher for the processed WA samples. Increased digestibility was also reflected by the amounts of RDS, SDS and RS contents in the samples (Fig 6.5c,d,e). RDS increased from 67.1% to 95% (db) for raw and processed
LK and from 66.6% to 95% for WA samples. SDS was low for all the processed samples (5.7% to 9.2%, db). Severely processed samples did not contain any RS. The results indicated that gelatinization, uncoiling and thermal degradation on dry heat parboiling exposed starch to the enzymes used and thereby significantly enhanced the hydrolysis rate.\(^{(14)}\) *Bhoja chaul* produced by roasting at 140°C for 15 min can hence be well targeted for people with poor state of digestion who require rapid and non-residual digestion.

Fig. 6.5. Starch hydrolysis rates of flours of the raw and dry heat parboiled (a) LK and (b) WA samples; (c), (d) and (e) represents the percentage contents of RDS, SDS and RS in the samples.
6.3.10. Texture comparison of cooked rice and the RTE product

Values for the TPA parameters are plotted in Fig 6.6. Hardness of the soaked *Bhoja chaul* samples were higher than cooked rice. Process severity however resulted in marginal lowering of hardness values (Fig 6.6a) in samples from both the rice varieties probably because of thermally degraded starch. Cooked rice was markedly adhesive as compared to the soaked *Bhoja chaul* samples (Fig 6.6b) because of complete gelatinisation of starch that occurred during cooking. Breakdown of amylopectin to shorter fragments also resulted in progressive increase in adhesiveness of the processed samples.

![Graphs showing TPA parameters](image)

Fig. 6.6. TPA parameters of raw and dry heat parboiled samples.

Significantly lower values of springiness (Fig 6.6c) in both raw and processed WA samples were due to the higher adhesiveness and lower hardness values than LK samples. LK samples exhibited lower adhesiveness and marginally higher springiness. Chewiness
increased progressively with process severity for the RTE samples attributing to the uniformity in kernel texture developed during dry heat parboiling (Fig 6.6d). Chewiness is a positive quality attribute for *Bhoja chaul* acceptability. Cooked rice samples exhibited the lowest chewiness value.

### 6.3.11. The ready to eat product

As no significant difference was observed among the samples boiled for 1 min and 3 min in water before overnight hydration, hot soaking for 1 min can be considered sufficient for the laboratory process used for making *Bhoja chaul*. It was observed that severe sand roasting of *Kola chokua* paddy at 140°C for 13 to 15 min gave superior RTE product. *Aghoni bora* samples showed higher adhesive property and such sticky texture is liked by some sections of the consumers. Roasted aroma, another quality parameter of the product could be sensed in all the processed samples. Industrial processes for making the product may further be developed based on the present findings.

### 6.4. Conclusions

*Bhoja chaul* obtained from the laboratory-scale method was harder in texture than raw rice. The product obtained was uniformly darker in colour due to pigment migration and Maillard browning during processing. The process resulted in marked development in kernel hardness that gave high head rice yield. Better packing property of the product was indicated by the decreased porosity. The peculiar hygroscopicity of the product was due to gelatinized starch as no endothermic peak for retrogradation was observed in DSC. However, peak for amylose-lipid complex melting was evident in the severely processed samples which created scope for further research. Dry heat parboiling led to significant loss in crystallinity with minor reformation of each type of starch crystalline polymorphs during cooling and storage. Progressive increase in inter-planar spaces of the lamellae could be observed from the shift in the crystalline region of the diffractograms. The product was highly digestible with very high amount of rapidly digestible starch and almost no resistant starch in the severely processed samples. This creates scope for the product to be used for children and patients with poor digestive conditions. A general observation was that roasting of the low amylose *Kola chokua* variety for 13 and 15 min at 140°C gave RTE product with better texture than waxy *Aghoni bora*.
Bibliography


