Chapter 5

CHARACTERIZATION OF READY-TO-EAT KOMAL CHAUL PROCESSED BY A LABORATORY-SCALE STEAM PARBOILING METHOD

5.1. Introduction

Rice (*Oryza sativa* L.) is an important food crop and is a staple food in many countries.\(^1\) Rice flour is an important ingredient of various food products.\(^2\) About 90% of a polished rice kernel is composed of starch granules. Starch is a semicrystalline biopolymer of D-glucose and primarily composed of linear long chains of amylose and shorter branched clusters of amylopectin. While amylose consists of glucose monomers linked by \(\alpha-1,4\) linkages, amylopectin contains additional \(\alpha-1,6\) branch points. There have also been reports of some intermediate material whose structure falls in between these two fractions.\(^3\) The ratio of amylose and amylopectin basically decides the peculiar properties of the starch granule. Based on the amylose content, Juliano (1979) classified rice into high amylose (>25 %), intermediate amylose (20-25 %), low amylose (7-20 %) and waxy or glutinous (1-2 %) types.\(^4\) All the four types have distinctly different properties. Other factors like granule size, molecular chain length and coiling pattern etc. also play important roles in industrial uses of the polymer. Rice starch has been modified by different methods for different uses.\(^5,6\) Hydrothermal modification is the most popular and widely studied due to the extensive changes brought about in the physical as well as physicochemical properties.\(^7\)

Parboiling is a unique hydrothermal technique involving soaking of paddy in water followed by steaming, drying and milling. Temperature of water used for soaking and the soaking time play vital roles in properties parboiled rice.\(^8\) Parboiled rice possesses many improved properties like higher nutrition, higher head rice yield, lower insect infestation, etc., however, with disadvantages of higher energy input for polishing,
lower keeping quality due to lipid oxidation, browning, etc.\textsuperscript{(9,10)} Parboiled rice flour shows different properties from raw rice flour.\textsuperscript{(11)} Gelatinization and retrogradation are the basic phenomena involved behind all these changes. The starch molecule takes up water when its slurry is heated up to its gelatinization temperature. The granules swell and the helical structures of the chains get decoiled, often accompanied with partial breakdown of the chains. When this gelatinized hot suspension is cooled, retrogradation occurs, involving formation of new crystallites with simultaneous release of the water molecules.\textsuperscript{(12)} The extent of retrogradation is the principal factor for the end product quality.\textsuperscript{(1)} Due to formation of newer polymorphic structures during retrogradation, the native structure is never regained. These molecular changes are reflected in the changed properties of the rice kernel as well as the rice flour. Physical properties of kernel like colour, appearance, kernel dimensions, density, cooking time, moisture absorption, etc. are very important for commercialization of the products.\textsuperscript{(13)} The texture of the cooked rice kernels and the viscosity of the pastes made from their flours also are very important for the consumers’ satisfaction and food uses. Bello et al. (2004) observed harder texture of parboiled cooked rice with lesser stickiness as compared to raw rice.\textsuperscript{(14)} Leelayuthsoontorn and Thipayarat (2006) worked on cooked rice texture and reported that higher temperature cooking resulted in softer and stickier texture.\textsuperscript{(15)} The pasting curve of the flour slurry obtained from the Rapid Viscosity Analyzer (RVA) also give an idea of the end product texture.\textsuperscript{(16)} The crystallinity of the starch polymer which is lost after the hydrothermal treatment can be studied by the Wide Angle X-Ray diffractography (XRD) of the rice flour. The diffractograph of raw rice flour shows peaks at $\theta$ values near $15^\circ$, $17^\circ$, $18^\circ$, and $23^\circ$, which is called the typical A-type starch diffraction pattern.\textsuperscript{(17)} However, parboiled rice flour shows altered diffraction patterns with formation of new peaks and loss of some A-type peaks indicating formation of new crystalline polymorphs as well as loss of a few native crystallites. A new peak generally reported at $\theta = 20$ depicts formation of amylose-lipid complexes on parboiling treatments, which on thermal analysis using the Differential Scanning Calorimeter (DSC), gives an endothermic melting peak.\textsuperscript{(18,19)} The B-type polymorphs formed after parboiling are characterized by the XRD peaks at $\theta$ values near $17.1$, $22.0$ and $24.0$, resulting in a C-type (A+B) crystalline structure in the parboiled rice. Thermal analysis gives the amount of crystalline polymorphs present in the sample based on their melting enthalpies.\textsuperscript{(20)} Pregelatinized and retrograded starches have different melting enthalpies.
and DSC is an effective tool for this analysis.\(^{21}\) Another important parameter for all starchy foods is the starch digestibility as the health effects of foods have become a primary concern of the consumers. Hydrothermal processing of starchy foods has been found to be effective in the formation of slowly digestible starch fractions, that lowers the glycemic response.\(^ {22}\) However, conflicting findings have also been reported.\(^ {23}\)

The ease of cooking along with economy in fuel and time consumption have made the instant cooking and quick cooking starchy foods much popular in recent times. A special quick cooking rice product called *komal chaul* is prepared in the Assamese households from ages following traditional parboiling techniques and eaten as a breakfast cereal.\(^ {24}\) *Komal chaul* is principally parboiled rice but the unique characteristic of this parboiled rice is that it does not need any cooking prior to consumption. *Komal chaul* is a whole rice product. Simple soaking of the *komal chaul* makes it soft enough to eat. In the present study, the traditional parboiling technique was improvised at the laboratory scale to obtain *komal chaul* and the important product qualities of the whole kernel and flour of *komal chaul* were characterized.

### 5.2. Materials and methods

Pure line *Kola chokua* (LK) variety paddy from the harvest of 2011 was purchased from the local farmers of Titabor, Assam (L indicates low amylose and K stands for *Kola chokua*). The rice variety falls under low amylose type with 12.6 % (db) apparent amylose content as was mentioned 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.

#### 5.2.1. Processing and coding of samples

Initially, 400g paddy was added to 10 L water at 100°C in a vessel kept over flame and the water was constantly stirred for 1 min and 3 min. The temperature instantly fell down to 92±1°C and thereafter increased to 100°C in 2.5 min. The vessel was covered with a thick gunny bag and kept at room temperature (27±2°C) for 18 h to allow the paddy to hydrate. The excess water was decanted after 18h and the soaked paddy was immediately steamed in an autoclave (Equitron 7407ST, India) fitted with a pressure gauge for 10 (mild treatment), 15 (moderate treatment) and 20 min (severe treatment) at conditions of 0 psig (100°C, open steaming) and 15 psig (121°C, pressure steaming), respectively. Drying was carried out at room temperature for 48 h followed by milling (8 %, weight basis) in a Satake huller and polisher (Satake, Japan). A portion of each sample was
ground into flour in a laboratory grain mill (Fritsch Pulverisette 14) and passed through a 100 μm sieve. All the kernel and flour samples were stored in polypropylene pouches at 4°C for further analysis. The samples were coded as per the steaming conditions applied (Table 5.1). The raw and hot soaked but non-steamed samples were primarily coded as N, open steamed samples as O and pressure steamed samples as P. The primary codes were followed by time (in minutes) of hot soaking followed by the steaming time (in minutes). For examples, pressure parboiled paddy hot soaked for 1 min and steamed for 15 min was coded as P-1-15.

<table>
<thead>
<tr>
<th>Broad classification</th>
<th>Soaking time at 100°C (min)</th>
<th>Steaming time (min)</th>
<th>Sample codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>-</td>
<td>-</td>
<td>N</td>
</tr>
<tr>
<td>N</td>
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</tr>
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<td>15</td>
<td>P-1-15</td>
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<tr>
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</tr>
<tr>
<td>P</td>
<td>3</td>
<td>20</td>
<td>P-3-20</td>
</tr>
</tbody>
</table>

5.2.2. Colour measurement

The Hunter ‘L’, ‘a’ and ‘b’ colour values of all kernel samples were obtained by a colour measurement spectrophotometer (Hunter Color-Lab Ultrascan Vis). From these values, the hue angle (H) and chroma (C) values were calculated as per previous reports.\(^{(25,26)}\)

\[ H = \tan^{-1} \left( \frac{b}{a} \right) \tag{5.1} \]

\[ C = \left( a^2 + b^2 \right)^{1/2} \tag{5.2} \]
5.2.3. L/B Ratio

The length (L) and breadth at the midpoint (B) of the polished kernels were determined using a Vernier calipers and a screw gauge (Mitutoyo, Japan) respectively and the L/B ratio was calculated.

5.2.4. Porosity ($\varepsilon$) bulk density ($\rho_b$) and true density ($\rho_t$)

$\rho_b$ and $\rho_t$ were first determined for calculating $\varepsilon$. An established method was slightly modified for determining $\rho_b$.$^{(13)}$ Briefly, 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.

$$\rho_b = \frac{\text{mass of grain}}{\text{volume occupied}} \quad \text{Eq. 5.3}$$

True volume was determined by the toluene displacement method. Briefly, to a known volume of toluene (Merck, India) in a measuring cylinder, polished kernels of known weight were immersed and the volume displaced by the kernels was recorded and the density ($\rho_t$) was calculated.

$$\rho_t = \frac{\text{mass of grain}}{\text{volume of toluene displaced}} \quad \text{Eq. 5.4}$$

The porosity ($\varepsilon$) was determined from values obtained from Eq 5.3 and Eq 5.4.

$$\varepsilon \, (\%) = \frac{(\rho_t - \rho_b)}{\rho_t} \times 100 \quad \text{Eq. 5.5}$$

5.2.5. Cooking time (T)

Cooking time was determined by an objective method.$^{(27)}$ Kernels weighing 20 g were cooked in 200 ml water at 98°C on 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 sample.

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

Equilibrium moisture content (EMC-S, %, db) of polished rice kernels soaked at room temperature for 4 'h were determined by the method of Indudhara Swamy et al.
Whole-grain milled rice (about 3-5 g) with 11 to 13% moisture content (db) was put in 50 mL water in a covered 100 mL beaker and left aside. The rice was strained through a wire strainer after 20-24 h and dried between Whatman No.1 filter paper sheets. The moisture content of the rice was determined by a drying method (AOAC, 2000) and EMC-S calculated.

\[ EMC(\%, \text{db}) = \frac{\text{Moisture evaporated}}{\text{Dried weight of kernels (g)}} \times 100 \]  

5.2.7. Sediment volume (SV)

The test for SV gives an indirect indication of degree of gelatinization of pregelatinized rice flour. Briefly, 1 g each of desiccated 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 (ml) of the sample.

5.2.8. Cooked rice texture

Briefly, 20 g samples from both raw and processed rice kernels were cooked for their cooking times and texture profile analysis (TPA) of the cooked grains was performed using a Texture Analyzer (TA.HD.plus, Stable Micro Systems, UK). A 5 kg load cell fitted with a cylindrical probe of 2 cm diameter was used for performing the two-cycle compression test. A single kernel was collected from the middle of the cooked rice mass and compressed to 70 % at 0.5 mm/s. The time between two chews was 3 s. All the TPA parameters, viz., hardness, fracturability, adhesiveness, springiness and chewiness were determined by the inbuilt software (Exponent Lite). Ten replicates for each sample were run and the mean values for each parameter taken. In addition to this, looking at the quick cooking nature of the product, the samples were soaked in excess water at 20°C and 50°C for 60 and 20 min respectively in a hot water bath (Labtech, India) and the TPA parameter values were compared.

5.2.9. Pasting properties

The pasting profiles of flour suspensions (12 % w/w; 28 g total weight) were recorded using a Rapid Visco Analyser (RVA Starchmaster2, Newport Scientific Instruments). The Rice1 profile of Newport Scientific was used, where the samples were
held at 50°C for 1 min, heated from 50°C to 95°C at 12°C/min, held at 95°C for 2.40 min followed by cooling to 50°C at 11.25°C/min and finally holding at 50°C for 1 min. The pasting curves obtained were compared and the pasting parameters, viz., peak viscosity (PV), hot paste viscosity (HPV), cold paste viscosity (CPV), breakdown (BD) and total setback (SBt) were recorded. PV is the maximum viscosity during heating, HPV is the minimum viscosity at 95°C, CPV is the final viscosity at 50°C, BD is obtained after subtracting HPV from PV. SBt is obtained after subtracting PV from CPV.

5.2.10. Wide angle X-ray scattering (WAXS)

WAXS diffractograms were obtained using a Rigaku Miniflex X-ray diffractometer with a Cu target and 'K' value of 1.5404 Å operating at 30 kV acceleration potential and 15 mA current with a copper target. 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 (Singh et al., 2006).

\[
\text{% Crystallinity} = \left( \frac{\text{Area under the peaks}}{\text{Total area under the XRD curve}} \right) \times 100 \quad \text{Eq.5.1}
\]

5.2.11. Thermal analysis

A Differential Scanning Calorimeter (model DSC-60; Shimadzu, Tokyo, Japan), periodically calibrated with pure indium for heat flow and temperature was used for thermal profile analysis of the flour samples. Flour to moisture ratio (1:2) was taken in an aluminium pan and saturated for 12 h at 4°C. The pan was then hermetically sealed and heated against an empty reference pan from 25°C-150°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 (ΔH, J/g) were obtained from the thermograms using TA-60WS software.

5.2.12. Starch digestibility

The extent of enzymatic hydrolysis leading to release of glucose from starch gives an indication of digestibility of starchy foods. The amount of glucose liberated on hydrolysis gives a measure of digestible starch fractions present in it. The in vitro starch hydrolysis rates (Goni et al., 1996) of the rice flour samples were estimated. A solution containing 1g 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 made up to 25 mL with Tris-Maleate buffer (pH 6.9). To this, 5 mL of a solution of pancreatic α-amylase (Sigma-Aldrich) was then added to each sample and incubated at 37°C. One millilitre aliquot was taken out from each tube after each 30 min from 0 min up to 180 min to determine the hydrolysis rate at different times. The aliquots were boiled to inactivate the enzymes and stored under refrigeration for further analysis. Then 3 mL of 0.4M Sodium acetate buffer (pH 4.75) containing 60 μL of amylloglucosidase (Sigma-Aldrich) was added to each aliquot and incubated at 60°C for 45 min to hydrolyse the digested starch into glucose. The glucose liberated was estimated by the DNS (3,5-dinitrosalicylic acid) method and was converted to starch by multiplying by a factor of 0.9. The degree of hydrolysis was calculated as the percentage of starch degraded from the total starch content.

5.2.13. Statistical analysis

All the experiments were carried out in three or more replicates and the means are reported. Significant differences between the means by Duncan’s multiple range test at a significance level of 95% were determined using SPSS 11.5 (SPSS Inc., USA).

5.3. Results and discussion

5.3.1. Colour measurement

It was observed that the lightness values (L) decreased on hot soaking alone compared to raw and further with extent of steaming (Table 5.2). The hue angle (H) value also exhibited a similar fall indicating increased redness in the samples. These values indicating loss of whiteness and significant rise in the redness may be attributed to the migration of husk and bran pigments into the endosperm as the husk of the paddy L.K was highly pigmented. Additionally, there might have also occurred Maillard browning due to the high heat applied during soaking and steaming. The C value indicative of colour purity and clarity increased markedly with extent of processing indicating more uniform product appearance. More drastic changes in the colour values were observed in a different study (Chapter 3, section 3.3.3) where similar steaming conditions were employed with the same paddy variety after the same soaking duration but without the short-term boiling step. An explanation for this may be that the hot soaking causes surface gelatinization of the rice starch accompanied by pigment migration. On cooling, the gelatinized surface starch retrogrades. The retrograded layer has a harder texture and
hence might have served as a partial barrier that lowered the migration of pigments during the steaming step.\(^\text{1,37}\)

### 5.3.2. L/B ratio

Hot soaking caused increase in the grain L/B values (Table 5.2). While the L values of the kernels remained almost unchanged on open steaming, pressure steaming caused marked increase in the L values.\(^\text{38}\) This was however accompanied by simultaneous decrease in the B values which was indicative of elastic stress development in the kernels during steaming and subsequent drying.\(^\text{39,40}\) The pattern of increase in L/B ratio on parboiling was found to be variety dependent by Siddiquee et al. (2002).\(^\text{41}\) Saeed et al. (2011) have however reported general increase in the dimensional ratio during parboiling of five different rice varieties.\(^\text{42}\) Increase in L/B ratio in the present study was more prominent in the pressure steamed samples than the open steamed samples.

### 5.3.4. Porosity

The pattern of change in porosity on parboiling is dependent on the rice variety and also on the final moisture content of the paddy.\(^\text{43,44}\) The changes in bulk and true density were marginal; both properties increased with parboiling. The marginal decrease in porosity with increasing L/B ratio, however was not in accordance with Bhattacharya et al. (1972) who observed positive relationship of porosity \((\varepsilon)\) with kernel length \((L)\).\(^\text{45}\) The decrease in porosity was higher for the pressure parboiled samples indicating better packing properties.

### 5.3.5. Cooking time

Table 5.2 shows the values of the cooking times of the different samples. \(T\) was highest for the raw LK(N) kernels. LK(N) required around 18 min to cook. Hot soaking only marginally lowered the \(T\) values, which was further reduced on both open and pressure steaming which reflected the effect of gelatinization of starch. LK3-15-10 exhibited the fastest cooking, with almost half the \(T\) value of LK(N). The very low cooking time of severely parboiled rice reflected the effect of both gelatinization and thermal degradation. Although, parboiling is said to increase the cooking time of rice kernels, reduction in cooking time in heat moisture treated starches have also been reported.\(^\text{46,47}\) Further, the low cooking time of chokua parboiled rice may be attributed to the low amylose content of the rice. As amylose content is low in chokua rice, the extent of retrogradation of the gelatinised starch during drying was restricted, which was reflected in the cooking time.
5.3.6. Equilibrium moisture content on soaking at room temperature

Marked increases in EMC-S (%, db) were observed on processing (Fig 5.1a). Although LK1(N) and LK3(N) did not vary much in the EMC-S, both open and pressure steaming resulted in higher water uptake by the kernels. This increase was higher in the pressure steaming of 3 min hot soaked samples than 1 min hot soaked samples. EMC-S was highest for LIG-15-20 followed by LKI-15-20 with values of 259.9% and 236.6% respectively. The increased EMC-S was probably due to the thermally degraded starch in the samples.

5.3.7. Sediment volume

SV also showed a similar pattern as EMC-S, with higher volume increase by the rice flour in acidic solution with increasing severity of processing (Fig 5.1b). It was indicative of increased degree of starch gelatinization and subsequent thermal degradation with severity of processing. (30)

![Fig. 5.1. (a) Equilibrium moisture contents on soaking (% db) and (b) Sediment volumes (mL) of the raw and processed samples.](image)

5.3.8. Cooked rice texture

The textural properties of open pan cooked (100°C) samples and samples soaked at 20°C and 50°C for 60 and 20 min respectively were studied (Fig 5.2). Hardness decreased
Table 5.2. Color values, L/B ratio, density, porosity and cooking time of the raw and processed rice kernels.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Color</th>
<th>L/B ratio</th>
<th>Bulk density</th>
<th>True density</th>
<th>Porosity (%)</th>
<th>Cooking time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>L a b H C L B L/B</td>
<td>( \rho_b )</td>
<td>( \rho_t )</td>
<td>( \varepsilon )</td>
<td>T (min)</td>
</tr>
<tr>
<td>N 79.3±0.3°</td>
<td>0.6±0.1a</td>
<td>14.2±0.1a</td>
<td>87.4±0.4a</td>
<td>14.2±0.6a</td>
<td>6.0±0.3a</td>
<td>2.7±0.2a</td>
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<tr>
<td>N-1-0 78.1±0.4a</td>
<td>2.0±0.1b</td>
<td>15.2±0.3b</td>
<td>82.3±0.3a</td>
<td>15.3±0.4b</td>
<td>6.0±0.3a</td>
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<tr>
<td>O-1-0 75.1±0.3m</td>
<td>3.2±0.2d</td>
<td>19.1±0.4d</td>
<td>80.3±0.4a</td>
<td>19.4±0.2d</td>
<td>6.0±0.2a</td>
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<td>O-1-15 69.1±0.3l</td>
<td>5.4±0.1h</td>
<td>22.1±0.8b</td>
<td>76.2±0.3h</td>
<td>22.7±0.3a</td>
<td>6.0±0.4a</td>
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<td>O-1-20 63.3±0.2e</td>
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<td>24.3±0.7b</td>
<td>71.8±0.6g</td>
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<tr>
<td>P-1-10 71.2±0.4k</td>
<td>4.0±0.4g</td>
<td>21.1±0.4g</td>
<td>78.4±0.6l</td>
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<td>P-1-20 57.8±0.4b</td>
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<td>25.1±0.6t</td>
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<td>6.1±0.2b</td>
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<td>20.2±0.3s</td>
<td>79.1±0.3t</td>
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<td>23.6±0.3c</td>
<td>76.1±0.4f</td>
<td>24.3±0.3j</td>
<td>6.0±0.3a</td>
<td>2.6±0.3bc</td>
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<tr>
<td>O-3-20 60.0±0.5c</td>
<td>9.2±0.7m</td>
<td>24.9±0.4m</td>
<td>69.7±0.5c</td>
<td>26.6±0.7m</td>
<td>6.1±0.3b</td>
<td>2.6±0.3c</td>
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<td>20.8±0.3f</td>
<td>78.8±0.3s</td>
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<td>6.0±0.3a</td>
<td>2.6±0.7bc</td>
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<td>24.7±0.3l</td>
<td>72.7±0.2e</td>
<td>25.9±0.3l</td>
<td>6.1±0.3b</td>
<td>2.6±0.2c</td>
</tr>
<tr>
<td>P-3-20 54.1±0.7a</td>
<td>12.7±0.3o</td>
<td>29.8±0.4g</td>
<td>66.9±0.3r</td>
<td>32.4±0.5p</td>
<td>6.1±0.1b</td>
<td>2.5±0.2a</td>
</tr>
</tbody>
</table>

The means followed by a common letter are not significantly different by Duncan’s Multiple Range Test at \( p<0.05 \)
progressively with extent of processing. Adhesiveness of the cooked kernels increased on open steaming which might be attributed to formation of hot water soluble fractions while pressure steaming exhibited decrease with severity of pressure steaming possibly due to thermally degraded starch. Springiness values, however, showed marked increase for both the processing types. The presence and type of amylose and amylopectin fine structures in the starch plays important role in the rice TPA parameters creating scope for further research in this area. Soaking at 50°C for 20 min gave texture parameter values nearer to that of the open cooked samples as compared with soaking in water at 20°C for 60 min. This similarity was more prominent for the pressure processed samples. From the TPA results, it is evident that just soaking at 50°C for 20 min of the hot water soaked and pressure steamed low amylose chokua rice gave similar textural as open pan cooking of such treated rice. Such processing conditions hence obviates the need of cooking and converts the processed chokua rice into ready to eat cereal.

Fig. 5.2. The TPA parameter values viz (a) Harness (g) (b) Adhesiveness (g/s) (c) Springiness and (d) Chewiness (g) of the parboiled samples cooked at 100°C till done (●), 50°C for 20 min (▲) and 20°C for 60 min (★).
5.3.9. Pasting properties

Both 1 and 3 min hot soaked samples (not steamed) had pasting profile similar to the corresponding raw, however, the viscosity at PV, HPV, and CPV were considerably higher (Fig 4). PV for N-1-0 was 4.558 Pas and for N-3-0 was 3.932 Pas. On open steaming, while PV remained almost constant for the LK1 samples (3.577–4.646 Pas), minor drop was

observed for the processed LK3 samples (4.109–3.375 Pas), which was suggestive of lower thermal stability of the polymeric pattern developed on hot soaking. The CPV for the open steamed samples, O-3-10 (6.924 Pas), O-3-15 (7.092 Pas), and O-3-20 (6.682 Pas) were however higher than O-1-10 (6.246 Pas), O-1-15 (6.191 Pas), and O-1-20 (6.446 Pas). SBt values were similarly higher. This may be explained as to the formation of short linear molecular chains on thermal degradation which probably were able to reassoclate forming retrograded starch. Pressure steaming resulted in gradual yet extensive drop in the PV as was also evident in some earlier works.\(^{(50,51)}\) This drop is similar to that of acid thinned starch used in paper and textile industries.\(^{(52)}\) This was accompanied by very low BD with higher CPV. Severe processing causes thermal degradation of starch polymer structure.\(^{(53)}\) Increase in the final slurry viscosity, hence may be attributed to leaching of the degraded simpler chains causing rise in slurry

![Graphs showing RVA pasting curves of parboiled samples hot soaked for (a) 1 min and (b) 3 min. The representations of the symbolic curves are as follows: Native (-), hot soaked and non-steamed (θ), -0-10 (□), -0-15 (○), -0-20 (Δ), -15-10 (■), -15-15 (●) and -15-20 (▲).]
densities. The almost continuous rise in the slurry viscosity with minor BD throughout the RVA cycle indicated the thickening property of the pressure steamed samples, suggesting its suitability for specific uses.

5.3.10. Wide angle x-ray scattering

The native A-type diffraction pattern of LK(N) with characteristic peaks near 15.1, 17.1, 18.3 and 23.2 remained unaltered on hot soaking (Fig 5.4a). While both open and pressure steamed samples from LK1 and only open steamed samples from LK3 conditions gave a mixed pattern with peaks corresponding to all A(2θ = 15.1°, 23.2°), B(2θ = 17.3°) and V-types (2θ = 20°), the high pressure processed LK(3) samples exhibited almost amorphous diffractographs with feeble peaks indicating mixed pattern of B (2θ = 17.3° and 24.1°) and V-types (2θ = 20°). Crystallinity was maximum in raw rice. Hot soaking reduced crystallinity. In both 1 min and 3 min series of processed samples, open steaming showed gradual increase in % Crystallinity, while for pressure steamed samples, the % Crystallinity was less in 15 min steaming time than 10 min and 20 min steaming. Such changes in crystallinity were also reported by Yu et al. (2010) and Manful et al. (2008). Probably, the new polymorphic forms (B and V type) had increased the % crystallinity (Fig 5.4b).

![Fig. 5.4. (a) The XRD patterns of raw and processed flour samples with peaks indicated and (b) % Crystallinity of the samples with processing.](image)
5.3.11. Thermal Properties

The DSC thermographs of the samples are shown in Fig 5.5 and the thermal parameter values presented in Table 5.3. Hot soaked sample with no steaming showed marked decrease in melting enthalpy of the rice flour.\(^{(55)}\) However, mildly parboiled samples showed higher transition enthalpies with a shift of the melting peak towards higher temperatures.\(^{(56)}\) Further higher treatment lowered the enthalpy values with a shift of the peak towards lower temperature again as was also evident in the RVA patterns of the samples.\(^{(50)}\) This indicates differences in the thermal properties of the different polymorphs formed depending upon the type and extent of processing. Thermal stability was found to lower with processing severity.\(^{(49)}\) Further, hot soaked LK1(N) and LK3(N) with mildly processed LK1-0-10 and the pressure steamed LK1-15-15, LK1-15-20, LK3-15-10, LK3-15-15 and LK3-15-20 did not exhibit any endotherm for amylose-lipid complex melting. The endotherms were observed primarily in the moderately processed samples and all were of type I (melting temperature < 100°C) as reported by Biliaderis and Galloway (1989).\(^{(57)}\)

![Fig. 5.5. DSC thermographs of parboiled samples hot soaked for (a) 1 min and (b) 3 min.](image-url)
Table 5.3. DSC thermal parameter values of the raw and processed rice flour samples.*

<table>
<thead>
<tr>
<th>Sample</th>
<th>T_o (°C)</th>
<th>T_p (°C)</th>
<th>T_c (°C)</th>
<th>ΔH (J/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>63.4±1.2</td>
<td>75.1±0.8</td>
<td>82.3±1.2</td>
<td>10.6±1</td>
</tr>
<tr>
<td>N-1-0</td>
<td>50.0±2.1</td>
<td>68.6±1.9</td>
<td>75.2±2.1</td>
<td>8.6±1.4</td>
</tr>
<tr>
<td>O-1-10</td>
<td>68.1±1.4</td>
<td>83.1±1.4</td>
<td>90.1±1.4</td>
<td>45.4±1.3</td>
</tr>
<tr>
<td>O-1-15</td>
<td>69.2±1.3</td>
<td>78.9±2.2</td>
<td>83.3±1.4</td>
<td>20.4±1.3</td>
</tr>
<tr>
<td>O-1-20</td>
<td>59.8±1.2</td>
<td>70.6±1.2</td>
<td>80.0±1.3</td>
<td>12.8±1.6</td>
</tr>
<tr>
<td>P-1-10</td>
<td>61.1±2.3</td>
<td>72.0±2.1</td>
<td>80.0±2.2</td>
<td>9.4±1.4</td>
</tr>
<tr>
<td>P-1-15</td>
<td>57.8±1.4</td>
<td>69.4±1.2</td>
<td>74.9±1.2</td>
<td>8.2±1.1</td>
</tr>
<tr>
<td>P-1-20</td>
<td>53.3±2.1</td>
<td>67.8±1.3</td>
<td>76.2±2.3</td>
<td>7.2±0.8</td>
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<td>N-3-0</td>
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<td>O-3-10</td>
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<td>89.2±2.1</td>
<td>26.8±0.7</td>
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<tr>
<td>O-3-15</td>
<td>59.3±1.2</td>
<td>71.9±1.1</td>
<td>80.2±1.2</td>
<td>17.2±0.9</td>
</tr>
<tr>
<td>O-3-20</td>
<td>51.8±2.3</td>
<td>62.0±2.1</td>
<td>70.1±1.3</td>
<td>17.2±1.3</td>
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<tr>
<td>P-3-10</td>
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<td>79.9±2.0</td>
<td>95.2±2.2</td>
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<tr>
<td>P-3-15</td>
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<td>75.0±1.1</td>
<td>6.3±1.6</td>
</tr>
<tr>
<td>P-3-20</td>
<td>49.1±1.2</td>
<td>66.2±1.3</td>
<td>82.2±1.2</td>
<td>6.3±0.6</td>
</tr>
</tbody>
</table>

*To is onset temperature, T_p is peak temperature, T_c is conclusion temperature and ΔH is enthalpy of the crystallite melting endotherm. The means followed by a common letter are not significantly different by Duncan's Multiple Range Test at p<0.05

5.3.12. Starch digestibility

Starch digestibility rapidly increased till 90 min of incubation for all flour samples (Fig 5.6), thereafter remained almost constant till 180 min. The raw rice flour showed comparatively lower hydrolysis rate than the rest (69.3 % after 180 min). Hot soaked samples did not differ in starch digestibility from raw. Mild open steaming gave higher digestibility than moderate and severe steaming indicating formation of newer indigestible fractions on retrogradation of gelatinized starch as also was observed by previous workers. Increasing severity of open steaming hence might result in the formation of newer enzyme resistant fractions. The trend was however reversed in pressure steamed samples after 1 and 3 min hot soaking times. Steaming severity increased the digestibility markedly and was highest (93.8 % after 180 min) for LK3-15-20, also observed by Takahashi et al (1994) and Niba (2003). Hence, the results were indicative of clear differences in starch digestibility between the products of the two processes.
5.3.13. Ready to eat komal chaul

Komal chaul making process in the traditional way includes simple steps of soaking, steaming, drying and milling. However, traditional process requires longer time of soaking to get the desirable cooking and eating quality. The optimum cooking and eating quality of komal chaul is that the chaul must soften on soaking in water at RT for 30-40 min. The laboratory developed process in this study has shortened the soaking period. In order to hasten the water absorption by the kernels, the paddy was given a hot soaking treatment that involves cooking the chokua paddy in water for 1-3 min and then allowing the paddy to hydrate overnight in that water at RT. The soaked paddy was then steamed. Pressure steaming gives better quality of komal chaul as judged by the texture of the soaked chaul in water. The textural properties of such pressure steamed rice gives soft textured rice kernels on soaking in water for 20 min at 50°C.

5.4. Conclusions

The pressure steaming of chokua paddy after hot soaking treatment gave komal chaul similar in texture to cooked rice. Such parboiled rice had different physicochemical properties than those obtained from open steaming technique. The changes in properties can be attributed to the effect of gelatinisation and thermal degradation of starch which may explain their higher rate of starch digestibility. Thus, pressure steaming of hot soaked chokua paddy gives ready to eat rice product. On the other hand, komal chaul
processed by open steaming of hot soaked paddy gave enzyme resistant starch. Such samples also recorded high pasting and cooling viscosities. These specific properties can be exploited for specific end uses.

**Bibliography**


