FINAL REPORT

Project Title: Characterization of Starch Properties in Traditional Rice Products of Assam and Development of a Small Scale Processing Unit for the Products

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Annexure-IX

PROJECT COMPLETION REPORT

1. **Title of the project**: "Characterization of starch properties in traditional rice products of Assam and development of a small scale processing unit for the products"

2. **Principal Investigator(s) and Co-Investigator(s)**:
   Prof. Charu Lata Mahanta (PI)
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3. **Implementing Institution(s) and other collaborating Institution(s)**: Tezpur University

4. **Date of commencement**: 22/08/2011

5. **Planned date of completion**: 22/03/2014

6. **Actual date of completion**: 25/02/2014

7. **Objectives as stated in the project proposal**:
   A. To study the physicochemical properties of the variously parboiled rices for processing into rice products.
   B. To study the crystalline properties of the starch in variously parboiled rices required for making different rice products.
   C. To understand the thermal properties of the starch in variously parboiled rices.
   D. To elucidate the effect of parboiling for making different rice products on the fine structure of amylopectin and breakdown of starch fractions.
   E. To ascertain the effect of parboiling on the starch granular structure.
   F. To determine the viscosity profiles of the parboiled rice and rice products.
   G. To analyse the digestibility of the starch and protein in the rice products.
   H. To develop processing units relevant for making the rice products from 50-100 kg paddy/day.

8. **Deviation made from original objectives if any, while implementing the project and reasons thereof:**

A demonstration program on the small-scale processing unit developed for making Komal chaul product was additionally carried out amongst the members of the local Self Help Groups (SHGs) as per the recommendations of the project evaluation group of DST.

The thermal properties of the starch (point 7D of objectives) in the processed rice and products could not be studied extensively due to the unavailability of the DSC equipment. The equipment was not sanctioned under the project (which was in the proposed list of equipment for approval). Limited DSC analyses were however carried out in other organizations of the region as was considered necessary.

The rest of the objectives were accomplished during the tenure of the project.

9. Experimental work giving full details of experimental set up, methods adopted, data collected supported by necessary table, charts, diagrams & photographs:

Collection of paddy

Rice samples (*Ranjit, Kola Chokua, Aghoni Bora and Bhogali Bora*) were collected from the Regional Rice Research Centre of Assam Agricultural University, Titabor, Assam. Samples were stored at 4 °C until required.

Sample preparation by different parboiling techniques

A. STEAM PARBOILING METHOD 1

For parboiling, 400 g paddy of each sample was added to water raised to 70°C and kept for 18 h for hydration. The container was covered with a thick gunny bag to prevent rapid cooling of the water. The water was then decanted and the samples were immediately steamed in an autoclave (Equitron 7407ST, India) fitted with a pressure gauge for 10 min (mild), 15 min (moderate) and 20 min (severe treatment) at conditions of 0 psig (100°C/ open steaming) and 15 psig (121°C/ pressure steaming), respectively. The steamed paddy samples were then layered on a flat surface and air-dried at room temperature for 2-3 days to moisture levels between 11 and 13 % (wb). This was followed by milling (8 %, weight basis) in a dehusker and a polisher (Satake, Japan). A portion of each sample was ground into flour in a laboratory grain mill (Pulverisette 14, Fritsch, Germany) to pass through 100 µm sieve. Whole kernels 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 1).

Experimental methods

i. Estimation of total starch, amylose, moisture, fat and protein in raw rice

For estimation of total starch, 0.5 g of sample was repeatedly washed with hot 80% ethanol to remove sugars until the washing did not give colour with anthrone reagent. The residue was then dried over a water bath. Distilled water (5 mL) and 6.5 mL of 52% perchloric acid were then added to it and the solution was kept at 4°C for 30 min for starch extraction. Supernatant was collected after centrifugation (3000 rpm). This step was repeated with the residue several times using fresh perchloric acid for maximum extraction. The volume of supernatant was made up to 100 mL. An aliquot of 0.2 mL was pipetted out and volume was made up to 1 mL. A standard curve was prepared using glucose (Sigma) at different concentrations and making up the volumes to 1 mL with distilled water. Anthrone reagent (4 mL) was added to each and heated for 8 min and intensity of colour was measured at 630 nm in a spectrophotometer (Cecil Aquarius 7400, England). The amount of glucose was calculated from the standard curve and converted to starch by multiplying by a factor of 0.9.

$$\text{Total starch (\%, db)} = \frac{(\text{Amount of glucose} \times 0.9)}{\text{Dry weigh of sample}} \times 100$$

For estimation of apparent amylose content, rice flour samples (<100 µm) and amylose standards were exposed to 50% relative humidity for 24 h. Hundred milligrams of the flour was taken in a stoppered conical flask, wetted with 1 mL ethanol and 10 mL of 1N NaOH was gently added. After keeping for 18h, the solution was heated in a boiling water bath (Voltam, India) for 2 min. The volume was made up to 100 mL and 20 mL of the alkaline dispersion was taken in a graduated glass cylinder. Petroleum ether (7 mL) was added to it and manually shaken for 10

min. The ether layer was sucked off with water suction. This was repeated with 7 mL carbon tetrachloride and allowed to stand for 15 min. Carbon tetrachloride being heavier than water,

Table 1. Sample codes based on rice type, name, steaming pressure and temperature.

Variety	Variety codes	Steaming pressure (psig)	Steaming time (min)	Sample codes
Ranjit	HR	-	-	HR(N)*
		0	10	HR-0-10
		0	15	HR-0-15
		0	20	HR-0-20
		15	10	HR-15-10
		15	15	HR-15-15
		15	20	HR-15-20
Kola chokua	LK	-	-	LK(N)
		0	10	LK-0-10
		0	15	LK-0-15
		0	20	LK-0-20
		15	10	LK-15-10
		15	15	LK-15-15
		15	20	LK-15-20
Aghoni bora	WA	-	-	WA(N)
		0	10	WA-0-10
		0	15	WA-0-15
		0	20	WA-0-20
		15	10	WA-15-10
		15	15	WA-15-15
		15	20	WA-15-20
Bhogali bora	WB	-	-	WB(N)
		0	10	WB-0-10
		0	15	WB-0-15
		0	20	WB-0-20
		15	10	WB-15-10
		15	15	WB-15-15
		15	20	WB-15-20

*Sample code followed by (N) represents raw samples

settled as a layer below it. Five millilitres of the aqueous layer from the top was pipetted out and neutralized with hydrochloric acid. Two millilitres iodine reagent (0.2%) was added and volume made up to 100 mL with distilled water. The process was also carried out using the standard potato amylose. Two millilitres of the iodine solution made up to 100 mL served as blank for reading the colour of the solutions in a spectrophotometer (Cecil Aquarius 7400, England) at 630 nm after 20 min of dark incubation. The apparent amylose content was then estimated.

Apparent amylose content (%,db) = $(R \times a)/(A \times r) \times 20$

Where,

R = reading of rice flour dispersion

A = reading of standard amylose solution

a = amount of standard amylose weighed (mg)

r = amount of rice flour weighed

Other analyses viz., moisture, fat and protein contents (all in %, db) were done as per AOAC standard protocols. Moisture content was determined by the vacuum oven drying method. Briefly, milled rice sample was taken in previously dried and weighed covered dishes. The sample was allowed to dry in a vacuum oven at 100°C and vacuum pressure equivalent to 3 kPa till constant weight was attained. Weight of the dish containing sample was measured both before and after drying and moisture content was calculated.

Moisture content (%,db)=(Initial weight – Final weight)/(Final weight-Weight of empty dish) × 100

For estimating crude fat in the rice flour samples, a soxhlet method was used. Briefly, 5 g flour sample was taken in a cellulose thimble, dried to constant weight at 102°C and extracted with petroleum ether (boiling point = 60°-80°C) at 100°C for 2 h (Socs Plus, Pelican Equipment, India). After the extraction, solvent was allowed to evaporate at 200°C and was collected by distillation. The fat that collected in the extraction cup was then dried at 70°C to remove any trace of moisture, cooled in desiccator and weighed. Crude fat was quantified using the following formula.

$$\text{Crude fat (\%, db)} = \frac{\text{Weight of cup containing fat} - \text{Weight of empty cup}}{\text{Dry weight of sample}} \times 100$$

Protein content was measured by the standard AOAC method (920.87) using a Micro-Kjeldahl apparatus (KelPlus, Pelican Equipment, Chennai, India). Two grams flour sample was digested in a digestion flask by adding 0.7 g mercury (II) oxide, 15 g potassium sulfate and 25 mL of concentrated sulphuric acid followed by heating at 80°C for 2 h. The solution was then added with 1 M sodium hydroxide solution and the ammonia gas liberated was collected in a boric acid solution. The nitrogen content (N, %) was estimated by titrating the solution with 0.1 N hydrochloric acid using methyl red (1%, w/v) as indicator.

$$\text{N (\%, db)} = \frac{[0.1 \times (\text{Titrated volume of acid}) \times 0.014]}{\text{Dry weight of sample}} \times 100$$

Amount of protein was calculated by multiplying it by a factor of 6.25.

$$\text{Protein (\%, db)} = \text{N} \times 6.25$$

ii. Degree of gelatinization (DG)

Two hundred milligram sample was dispersed in 100 mL distilled water with stirring for 5 min and centrifuged at 1500 rpm for 25 min. One milliliter supernatant was then diluted to 10 mL with distilled water and 0.1mL iodine solution was added. The method was repeated using 100 mL of 10 M potassium hydroxide instead of water and absorbance of both solutions were read at 600 nm in a Spectrophotometer (Cecil Aquarius 7400, England).

DG (%) = (Absorbance of fresh solution/ Absorbance of alkali solubilized solution) x 100

iii. Colour measurement

The colour of all samples was determined in a Colour Measurement Spectrophotometer (Ultrascan Vis, Hunter Color-Lab, Virginia). The result was expressed as L, a, b using

corresponding native rice samples as reference. The chroma value (C) of parboiled rice was calculated.

$C = (a^2+b^2)^{1/2}$

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

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 was calculated.

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

v. Sediment volume (SV)

Briefly, 1 g of desiccated flour sample was taken in a measuring cylinder and 15 mL of 0.05 N hydrochloric acid 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.

vi. Pasting properties

The pasting profiles of flour suspensions (10 % w/w; 28 g total weight) were recorded using a Rapid Visco Analyser (RVA Starchmaster2, Newport Scientific Instruments, Australia). 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, held at 95°C for 2.40 min followed by cooling to 50°C and finally holding at 50°C for 1 min. The pasting temperature (PT), peak viscosity (PV), hot paste viscosity (HPV), cold paste viscosity (CPV), breakdown (BD) and setback (SB) were recorded. 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 was obtained after subtracting PV from CPV.

vii. FTIR spectroscopy

Two milligrams of properly vacuum dried rice flour samples and 50 mg dessicated potassium bromide powder were thoroughly mixed in a mortar and pestle before pressing into a thin pellet. The infra-red absorption spectra of the sample pellets were obtained using a FTIR spectrometer (Nicolet Impact 410, Thermoscientific, United Kingdom) equipped with KBr optics and a DTGS detector. The equipment was operated with a resolution of 2.0 cm^{-1} and scanning range of 4000–450 cm^{-1}.

viii. Wide angle X-ray scattering (WAXS)

The rice flour samples were conditioned at 50% relative humidity for 5 days in order to attain uniform moisture content in the samples. WAXS diffractographs were obtained with an X-ray diffractometer (Rigaku Miniflex, Japan) with a K value of 1.54040 operating at 30 kV acceleration potential and 15 mA current with a copper target. The scanning range was 10–40° of 2θ values with a scan speed of 5° 2θ /min. The total area under the curve and the area under each prominent peak was determined using OriginPro 8.0 software (OriginLab Corp., UK) and the percentage crystallinity was determined.

$$\% \text{ Crystallinity} = \frac{\text{Area under peaks}}{\text{Total area under the XRD curve}} \times 100$$

ix. **Starch digestibility**

One hundred milligram flour was first incubated with 7 mL acetate buffer (5.2 pH) at 37°C for 20 min in a shaking water bath. The stoppered incubation tubes contained glass balls for proper disruption of the flour particles and guar gum for standardizing the viscosity of the solution. To this, 3 mL of an enzyme mixture comprising of invertase (220 U/mL), pancreatic α-amylase (3000 U/mL) and amyloglucosidase (15 U/mL) was added. After 20 min of incubation, an aliquot was taken out and estimated for rapidly available glucose (G_{20}) using a D-glucose oxidase-peroxidase assay kit (Robonik, India) and a standard curve prepared by similar manner with different concentrations of D-glucose. A second aliquot was similarly estimated for glucose after further 100 min incubation (G_{120}). Both these values were multiplied by a factor of 0.9 to measure the rapidly digestible starch (RDS) and slowly digestible starch (SDS) respectively and expressed as a percentage of dry matter.

$RDS = G_{20} \times 0.9$

$SDS = (G_{120} - G_{20}) \times 0.9$

RS is considered to be the undigested starch after the 120 min incubation and hence was calculated as the difference between total starch (TS) and the starch digested during the incubation period.

$RS = TS - (RDS + SDS)$

x. **Statistical analysis**

All the experiments were carried out in triplicates and means are reported. Pearson's correlation and significant differences between means by Duncan's multiple range test at a significance level of 0.05 was performed using SPSS 11.5 (SPSS Inc., USA).

B. STEAM PARBOILING 2

Initially, 400g *Kola chokua* paddy was added to 5 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 after the required boiling time was removed from flame and 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 2). 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 min) of hot soaking followed by the steaming time (in min). For examples, pressure parboiled paddy hot soaked for 1 min and steamed for 15 min was coded as P-1-15.

Experimental methods

i. Colour measurement

As reported in Steam parboiling I

ii. 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.

Table 2. Processing conditions and sample codes.

Broad classification	Soaking time at 100°C (min)	Steaming time (min)	Sample codes
N	-	-	N
N	1	-	N-1-0
O	1	10	O-1-10
O	1	15	O-1-15
O	1	20	O-1-20
P	1	10	P-1-10
P	1	15	P-1-15
P	1	20	P-1-20
N	3	-	N-3-0
O	3	10	O-3-10
O	3	15	O-3-15
O	3	20	O-3-20
P	3	10	P-3-10
P	3	15	P-3-15
P	3	20	P-3-20

iii. Porosity (ε) bulk density (ρb) and true density (ρt)

ρb and ρt were first determined for calculating ε. An established method was slightly modified for determining ρb. 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 ρb was calculated.

$$\rho b = \frac{\text{mass of grain}}{\text{volume occupied}}$$

ρt 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 (ρt) was calculated.

$$\rho t = \frac{\text{mass of grain}}{\text{volume of toluene displaced}}$$

The porosity (ε) was determined from values obtained from Eq 5.3 and Eq 5.4.

$$\varepsilon(\%) = \frac{(\rho t - \rho b)}{\rho t} \times 100$$

iv. Cooking time (T)

Cooking time was determined by an objective method. 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.

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

As described in Steam parboiling 1

vi. Sediment volume (SV)

As described in Steam parboiling 1

vii. **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.

viii. Pasting properties

As described in Steam parboiling 1

ix. Wide angle X-ray scattering (WAXS)

As described in Steam parboiling 1

x. **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°-150°C at a heating rate of 5 C/min under N_2 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.

xi. Starch digestibility
As described in Steam parboiling 1

xii. 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).

C. DRY HEAT PARBOILING 1

Water (~2 L) was taken in an aluminium vessel and heated to 70°C over a burner. The flame was put off and 200 g paddy of each sample was immediately soaked in it. The temperature of water on addition of paddy immediately reduced to 60-62°C. The vessel was then covered with a gunny bag and kept for 18 h for hydration of the paddy. The excess water was then decanted and the soaked paddy was immediately roasted in a manually operated drum type roaster with sand (1:3 paddy to sand, 110-120 rpm). The sand particles (less than 3 mm in diameter) were preheated to temperatures of 220°C and 270°C so that it came down to 140°C and 200°C, respectively after addition of the wet paddy. Temperature was maintained during processing by wrapping the drum of the roaster with a wet piece of gunny bag. The paddy samples were roasted under two conditions - low temperature for longer time (LTLT, 140°C for 11, 13 and 15 min) and high temperature for shorter time (HTST, 200°C for 3, 4 and 5 min). No popping of paddy occurred during processing. The roaster was tilted to take out the roasted paddy and sand. The hot sand was sieved out and the paddy was stored at room temperature (RT, 25±2°C) in a thin layer for 6 h allowing sufficient cooling down to RT. The samples were further stored at 4°C before milling in a dehusker and a polisher (Satake, Japan). The milled kernels (8-10% milling, w/w) were stored in polypropylene bags at 4°C for further analysis. For ease of identification, the rice varieties were coded as HR meaning high amylose Ranjit, LK meaning low amylose Kola chokua and WA meaning waxy Aghoni bora. HR, LK and WA suffixed with (N) indicated native raw rice. Processed sample code indicated variety code suffixed with roasting temperature and time of roasting. Thus, HR-140-11 indicates high amylose Ranjit paddy roasted at 140°C for 11 min.

Experimental methods

i. Moisture content of raw, soaked and dry heat parboiled samples
Moisture content of raw paddy was estimated using a standard AOAC protocol. The moisture content of soaked paddy was determined after surface moisture was carefully removed with a blotting paper. For dry heat parboiled samples, portions were immediately collected after roasting in a pre-weighed moisture cup and weighed for moisture estimation. Briefly, milled rice sample was taken in previously dried and weighed covered dishes. The sample was allowed to dry in a vacuum oven at 100°C and vacuum pressure equivalent to 3 kPa till constant weight was attained. Weight of the dish containing sample was measured both before and after drying and moisture content was calculated.

$$\text{Moisture content (\%, db)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Final weight} - \text{Weight of empty dish}} \times 100$$

ii. **Head rice yield (HRY)**

HRY (%) was determined as the weight average percentage of intact kernels obtained after milling to that of total milled rice containing both intact and broken kernels.

$$\text{HRY (\%)} = \frac{\text{Weight of intact kernels}}{\text{Weight of total milled rice}} \times 100$$

iii. Kernel hardness and L/B ratio

Milled whole rice kernels were tested for hardness (H) using a Texture Analyzer (TA.HD.plus, Stable Micro Systems, UK) with a 25 kg load cell using single compression. A single kernel was compressed with a 2 cm diameter stainless steel probe along the thickness at a speed of 0.5 mm/min and returned to its original position. The test was repeated for 25 kernels from each sample and the mean was calculated. The maximum force indicated by the force-time curve generated by the inbuilt software (Exponent Lite) was taken as the hardness. The length (L) and breadth (B) of ten milled kernels from each sample were determined using a Seed dial calliper (Baker, India) and L/B ratios were determined.

iv. Colour measurement

As described in Steam parboiling 1

v. Degree of gelatinization (DG)

As described in Steam parboiling 1

vi. **Scanning electron microscopy (SEM)**

Transverse sections of the milled raw kernels and samples roasted at 140°C and 200°C for 15 min and 5 min respectively were carefully cut using a sharp blade. The sections were then fixed using liquid nitrogen and sputter coated with gold before observing under a Scanning Electron Microscope (JEOL 6993V) operating at an acceleration voltage of 15 kV and magnifications of 30X and 2000X.

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

As described in Steam parboiling 1

viii. Sediment volume (SV)

As described in Steam parboiling 1

ix. Pasting properties

As described in Steam parboiling 1

x. Wide angle X-ray scattering (WAXS)

As described in Steam parboiling 1

xi. Differential scanning calorimetry (DSC)

Flour slurries of raw rice and samples roasted at 140° and 200°C for 15 and 5 min respectively from each variety were analysed for thermal properties. Slurries were prepared in aluminium pans by weighing 4 mg flour and adding 8 mg deionized water to it. The pans were then saturated for 1 h at 4°C before hermetic sealing

followed by heating in a Differential Scanning Calorimeter (model DSC-60; Shimadzu, Japan) against an empty reference pan from 30°–130°C at a heating rate of 5°C/min under nitrogen atmosphere. The instrument was periodically calibrated with pure indium for heat flow and temperature. The onset (To), peak (Tp), and conclusion (Tc) temperatures and enthalpy of gelatinization (ΔH, in J/g) were obtained from the thermograms using TA-60WS software.

xii. Starch digestibility

As described in Steam parboiling 1

xiii. Statistical Analysis

All the experiments were carried out in multiple replicates and means are reported. Significant differences between means were determined by Duncan's multiple range test at a significance level of 0.05. The tests were performed using SPSS 11.5 (SPSS Inc., USA).

D. DRY HEAT PARBOILING 2

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.

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.

$H = \tan\text{-}1\ (b/a)$

$C = [(a^2 + b^2]^{1/2}$

Experimental methods

i. 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.

ii. 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 ρb was calculated.

ρb (g/cm^3)= mass of grain / volume occupied

ρt 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 ρt was calculated.

ρt (g/cm^3) = mass of grain / volume of kerosene displaced

ε was determined from the above equations

$\varepsilon\ (\%) = [(\rho t - \rho b) / \rho t\ ] \times 100$

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

As described in Steam parboiling 1

iv. Sediment volume (SV)

As described in Steam parboiling 1

v. Cooking time of raw rice

As described in Steam parboiling 1

vi. Pasting properties

As described in Steam parboiling 1

vii. 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.

$$\% \text{ Crystallinity} = \frac{\text{Area under peaks}}{\text{Total area under the XRD curve}} \times 100$$

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.

viii. 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 N_2 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.

ix. Starch digestibility

As described in Steam parboiling 1

x. Texture comparison of cooked rice and the RTE product

As described in Steam parboiling 1

xi. 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).

10. Detailed analysis of results indicating contributions made towards increasing the state of knowledge in the subject:

A. STEAM PARBOILING 1

i. Total starch, amylose, moisture, fat and protein in raw rice

Total starch content was almost similar for all the polished rice samples (Table 3). Apparent amylose content of each sample clearly differentiated HR as high amylose, LK as low amylose and WA and WB as waxy rice varieties. All the samples had almost similar moisture and protein contents. The fat content, however was markedly higher in the two polished waxy samples which was almost double the content in the LK(N) sample. Such varied contents of fat in different paddy samples have also been reported by other researchers and was also found in the traditional waxy rice varieties of North-East India in our laboratory.

ii. Degree of gelatinization

The values of DG (%) are given in Table 4. Gelatinized starch content increased with severity of parboiling in both open and pressure steamed samples and was markedly higher in the pressure parboiled samples. The greater extent of gelatinization with process severity may be

attributed to higher water absorption during parboiling, as water absorption by rice kernel increases with time and pressure of steaming and to the increased temperature due to increase in pressure.

Table 3. Apparent amylose, moisture and fat contents in raw rice samples (mean± SD).

	HR(N)	LK(N)	WA(N)	WB(N)
Total starch (%,db)	84.3±0.12[a]	85.6±0.89[b]	85.8±0.41[b]	84.2±0.72[a]
Apparent amylose (%, db)	27.2±0.12[a]	12.6±0.03[b]	1.1±0.02[c]	1.1±0.08[c]
Moisture (%, db)	13.1±0.09[a]	12.9± 0.04[b]	13.1±0.06[a]	13.1±0.04[a]
Fat (%, db)	1.2±0.04[c]	0.9±0.01[d]	1.8±0.05[b]	1.9±0.04[a]
Protein (%, db)	5.7±0.66[b]	5.8±0.52[a]	5.4±0.72[c]	5.8±0.48[a]

[a] Means with the same superscript in a row do not differ significantly from one another ($p<0.05$)

iii. Colour measurement

Colour change in parboiled rice kernels is an important indication of rice parboiling and is attributed to the migration of husk or bran pigments and non-enzymatic browning taking place during processing. All the three colour parameter values of the rice kernels changed appreciably on parboiling (Table 4). With processing severity, the 'L' value representing whiteness for all varieties fell gradually as was also reported for paddy soaked at elevated temperatures. This fall was significant for the pressure parboiled rice samples. This may be attributed to the increased migration of husk and bran and severe non-enzymatic browning at the elevated temperature achieved during steaming under pressure. The degree of redness represented by positive value of 'a' which is attributed to the husk and bran pigments initially decreased drastically on mild parboiling at both processing conditions but again increased with further severity of processing indicating higher migration of pigments into the rice endosperm. The positive 'b' value indicating yellowness showed a drop for the mildly processed samples but remained almost unchanged with processing severity. The changes in colour values were more prominent in the high pressure processed samples. The drastic decrease in colour value 'C' was due to similar losses of the 'b' value on processing. The changes in redness and yellowness were not found to be interrelated as indicated by the irregular patterns of changes in the B values of the processed samples. The decrease in L, a, b and C values of parboiled rice samples as compared to the raw could also probably be due to the translucent nature of the rice starch on account of gelatinization.

iv. Equilibrium moisture content on soaking at room temperature

Both raw waxy samples, showed highest EMC-S (%, db) followed by the low amylose and high amylose samples, in that order, indicating a direct negative correlation of EMC-S with amylose content. EMC-S increased with process severity in both open steamed and pressure steamed samples (Fig 1) indicating that hydrothermal processing definitely increased the water uptake capacity of the parboiled rice kernel. High pressure treated samples from each variety showed distinctly higher EMC-S % than the raw and open steamed samples of the same variety. The kernel structures of moderate and severely pressure parboiled waxy samples, although showing a longitudinal split after the soaking period, did not lose kernel integrity. The highest EMC-S

value of 256.8 % (db) was exhibited by WA-15-20 followed by WB-15-20 with a value of 248.5 % (db).

Table 4. Degrees of gelatinization and colour values of raw and processed rice samples.

Samples	DG (%)	Colour values			
		L	a	b	C
HR(N)	-	46.67±1.31 [a]	2.22±0.04 [a]	10.54±0.10 [a]	10.77±0.10 [a]
HR-0-10	32.61±1.14 [f]	42.44±1.71 [b]	1.35±0.05 [e]	7.69±0.11 [b]	7.80±0.08 [b]
HR-0-15	42.67±2.11 [e]	41.18±1.32 [c]	1.36±0.09 [d]	7.64±0.07 [c]	7.76±0.13 [c]
HR-0-20	55.27±1.49 [c]	38.76±1.38 [e]	1.38±0.11 [c]	7.60±0.08 [d]	7.74±0.08 [c]
HR-15-10	51.54±2.23 [d]	39.78±1.26 [d]	1.31±0.04 [g]	7.11±0.14 [f]	7.23±0.10 [e]
HR-15-15	62.56±2.11 [b]	37.11±2.12 [f]	1.34±0.15 [f]	7.13±0.07 [e]	7.25±0.13 [d]
HR-15-20	69.42±1.15 [a]	34.74±2.15 [g]	1.39±0.03 [b]	7.11±0.13 [f]	7.23±0.07 [e]
LK(N)	-	57.5±1.38 [a]	2.34±0.14 [a]	10.29±0.13 [a]	10.55±0.14 [a]
LK-0-10	34.23±1.74 [f]	45.51±2.15 [b]	1.46±0.17 [e]	7.75±0.05 [c]	7.88±0.09 [c]
LK-0-15	44.25±2.36 [e]	44.42±2.17 [c]	1.48±0.13 [c]	7.75±0.07 [c]	7.89±0.08 [b]
LK-0-20	54.68±2.12 [c]	43.82±2.13 [d]	1.52±0.02 [b]	7.75±0.11 [c]	7.89±0.09 [b]
LK-15-10	50.34±1.92 [d]	43.30±1.35 [d]	1.42±0.12 [g]	7.62±0.08 [d]	7.75±0.10 [e]
LK-15-15	60.14±1.78 [b]	40.14±2.17 [e]	1.44±0.101 [f]	7.62±0.09 [d]	7.75±0.09 [e]
LK-15-20	68.88±1.56 [a]	37.89±2.11 [f]	1.47±0.09 [d]	7.64±0.14 [b]	7.78±0.07 [d]
WA(N)	-	66.71±1.75 [a]	2.18±0.08 [a]	11.23±0.07 [a]	11.43±0.14 [a]
WA-0-10	32.17±1.78 [f]	47.82±1.37 [b]	1.14±0.19 [e]	7.34±0.15 [b]	7.43±0.09 [b]
WA-0-15	42.56±0.83 [e]	46.54±1.34 [c]	1.17±0.15 [c]	7.32±0.14 [b]	7.41±0.09 [b]
WA-0-20	54.47±1.65 [c]	44.14±1.36 [d]	1.21±0.07 [b]	7.37±0.06 [b]	7.46±0.08 [b]
WA-15-10	53.23±1.38 [d]	44.44±2.17 [d]	1.15±0.08 [d]	7.31±0.09 [b]	7.39±0.07 [b]
WA-15-15	62.34±1.82 [b]	41.05±2.15 [e]	1.12±0.05 [f]	7.34±0.07 [b]	7.42±0.13 [b]
WA-15-20	68.26±1.96 [a]	37.78±2.11 [f]	1.13±0.07 [ef]	7.33±0.15 [b]	7.41±0.10 [b]
WB(N)	-	64.84±2.12 [a]	2.35±0.13 [a]	11.98±0.15 [a]	12.20±0.14 [a]
WB-0-10	34.42±0.57 [e]	43.29±2.17 [b]	1.32±0.06 [e]	8.09±0.17 [b]	8.19±0.02 [b]
WB-0-15	44.12±1.42 [d]	43.12±1.39 [b]	1.37±0.16 [c]	8.03±0.09 [b]	8.14±0.08 [b]
WB-0-20	54.39±0.98 [c]	42.11±2.1 [c]	1.44±0.08 [b]	8.10±0.14 [b]	8.22±0.14 [b]
WB-15-10	53.32±1.89 [c]	39.95±1.33 [d]	1.29±0.09 [f]	7.89±0.07 [b]	7.99±0.10 [c]
WB-15-15	64.37±1.13 [b]	36.29±2.15 [c]	1.32±0.11 [e]	7.91±0.09 [b]	8.01±0.14 [ab]
WB-15-20	71.17±0.66 [a]	32.28±1.72 [e]	1.33±0.07 [d]	7.89±0.14 [b]	8.00±0.08 [ab]

[a] Means with the same superscript in a row do not differ significantly from one another ($p < 0.05$)

v. Sediment volume

SV showed a similar change in pattern as with EMC-S (%, db) for the open steam processed samples of all the varieties (Fig 1). However, the high pressure processed samples indicated a milder increase which may be due to leaching of smaller starch fractions generated due to thermal degradation of the samples. This was also indicated by development of turbidity in the acidic media used for the test (not shown) which increased with process severity. This difference

between EMC-S and SV also indicated that the kernels from the high pressure treated rice samples behaved quite differently from its flour when in aqueous suspension. Thus, particle size may play an important role in incorporating parboiled rice in other food uses.

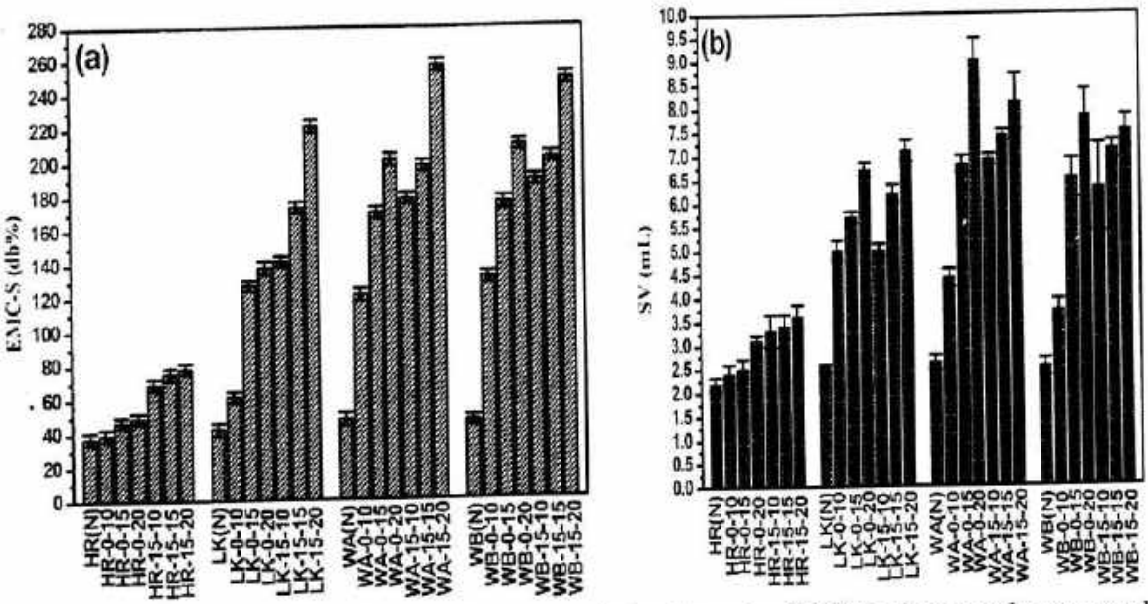


Fig. 1. (a) EMC-S % (db) of raw and processed rice kernels; (b) SV of raw and processed rice flour.

vi. Pasting properties

The pasting behaviour of amylose rice was different from the low amylose and waxy rices (Table 5). Viscosity values of the mildly parboiled rice under both processing conditions were low which increased with processing severity. It is well known that the water absorption ability of parboiled rice is low at temperatures above GT because of the effect of retrogradation. Being high in amylose, the amount of retrograded starch formed with increasing severity of processing is also greater and may have prevented the development of viscosity. However, extensive thermal breakdown of the starch in the pressure parboiled high amylose rice may have caused the very low viscosity values during both the heating and cooling phases. On the other hand, in the low amylose and waxy rices, the viscosity values of the open parboiled rice was higher than the corresponding raw rice due to the high content of amylopectin. The viscosity increased with increasing severity of parboiling. However, the viscosity of pressure parboiled rice was lower than the open parboiled rice. Parboiled rice of the low amylose and waxy rice were more resistant to shear in the cooking process and therefore showed lesser BD than the high amylose rice. The ability of the cooked rice fractions to retrograde on cooling as studied from SB values revealed that low amylose rice had greater ability to retrograde than the high amylose rice. Probably the amylopectin chain length of the low amylose rice was long enough to enable retrograded fractions to develop. Parboiled waxy rices, on the other hand, due to their high amylopectin content did not show any SB.

The extent of changes in the viscosity patterns of processed samples showed clear relationship with the amylose contents. Increase in PT with processing as reported by previous workers was observed for the open steamed high amylose and low amylose varieties. Pressure parboiled samples of all varieties showed variable fall in the PT with the waxy samples exhibiting a more

drastic drop with process severity indicating rapid water absorption. In the case of HR sample, initial drop in viscosity parameters observed for mildly parboiled HR-0-10 sample, may be due to milder gelatinization (as also revealed from lower DG % and % Crystallinity) resulting in molecular patterns that prevents water uptake. This was reversed in HR-0-15 and HR-0-20 due to higher gelatinised fractions of starch resulting in better water absorption and thereby higher viscosity. Severe pressure parboiling caused extensive loss of all pasting parameters indicating complete thermal degradation of these hygroscopic starch fractions with absolutely no tendency of gel formation. This also indicates that although being harder in the native and cooked form the starch granules from high amylose HR are very sensitive to hydrothermal degradation on parboiling.

On the contrary, the low amylose and waxy varieties exhibited distinct increase in viscosity on mild open steam processing followed by a marginal fall for the LK-0-15 and LK-0-20. SB values show that the low amylose rice properties stand in between those of high amylose and waxy varieties indicating that the raw rice amylose content plays the key role in the properties of parboiled rice. Pressure treated LK samples, however, showed a trend just opposite to the open steamed samples. After an initial drop in PV for LK-15-10, the value increased marginally for LK-15-15 and LK-15-20 samples accompanied with a very low BD. However, exceptionally high SB indicated very high tendency towards retrogradation with formation of higher thermostable hygroscopic fractions. Patterns for the two raw waxy samples were similar except for WA(N) showing a markedly lower PV than WB(N). This difference may be due to differences in amylose activities and in amylopectin fine structures. High pressure treated waxy samples had GT values very close to the initialization temperature of the RVA profile used (50°C) indicating that the samples have taken up water to attain viscosity at a temperature below 50°C. As also found from the turbidity generated in the aqueous acidic media used for the SV study at room temperature (section 3.4), it can be said that in the pressure parboiled samples, there occurs destruction of starch to fractions that have greater tendency to bind to water causing low temperature pasting. In addition, there may be formation of some fine structures, that leach out to the water in the suspension after attaining PV at high temperature (95°C in this case) as indicated by increased BD. The loss of SB in these samples reflects the absence of retrogradation during the cooling phase of the RVA profile.

vii. FTIR spectroscopy

The IR absorption spectra of the different rice flour samples are shown in. All the characteristic bands were observed in all the samples (Fig 2 a-d) with very minor and variable changes in intensities indicating definite changes in the molecular bonding parameters on processing. The ratio of the intensities of the two bands (1047 cm^{-1}:1022 cm^{-1}) representing crystallinity showed irregular and dissimilar patterns for the different varieties and between the processed samples of the same variety (Fig 2 e-h). These differences in the values also indicate differences in the helical and crystalline arrangements in the raw and processed samples of the different varieties. An interesting observation was that the pattern of changes in the ratio of band intensities at 2855 cm^{-1} and 2925 cm^{-1} (Fig 2 e-h) responsible for symmetric and asymmetric stretch of H-C-H respectively, showed good correlation with the 1047cm^{-1}:1022$cm^{-1}$$cm^{-1}$ ratio indicating shift of the stretching modes of the CH_2 group with retrogradation. This creates possibility of being

Table 5. Pasting parameter values of raw and processed rice flour samples.

Samples	PV (cP)	HPV (cP)	CPV (cP)	BD (cP)	SB (cP)
HR(N)	4219[a]	3347[a]	5990[a]	872[a]	1771[c]
HR-0-10	659[d]	603[d]	1304[d]	56[d]	645[d]
HR-0-15	2094[c]	1996[c]	4086[b]	98[c]	1992[a]
HR-0-20	2119[b]	2015[b]	4074[c]	104[b]	1955[b]
HR-15-10	149[g]	139[g]	200[g]	10[f]	51[f]
HR-15-15	191[e]	181[e]	261[e]	10[f]	70[e]
HR-15-20	167[f]	156[f]	243[f]	11[e]	76[e]
LK(N)	1687[c]	1287[f]	2916[g]	400[b]	1229[f]
LK-0-10	3720[a]	2844[a]	4357[b]	876[a]	637[g]
LK-0-15	2540[b]	2433[b]	5379[a]	107[e]	2839[a]
LK-0-20	1463[f]	1338[e]	3935[d]	125[d]	2472[b]
LK-15-10	1403[g]	1255[g]	3583[f]	148[c]	2180[e]
LK-15-15	1574[e]	1512[d]	3846[c]	62[f]	2272[d]
LK-15-20	1605[d]	1573[c]	3965[c]	32[g]	2360[c]
WA(N)	1723[f]	1181[f]	1565[f]	542[f]	-158[a]
WA-0-10	3159[c]	2181[c]	2897[c]	978[d]	-262[d]
WA-0-15	3461[b]	2202[b]	3236[b]	1259[b]	-225[b]
WA-0-20	3687[a]	2402[a]	3443[a]	1285[a]	-244[c]
WA-15-10	1563[g]	891[g]	1319[g]	672[e]	-244[c]
WA-15-15	2647[c]	1496[e]	1898[e]	1151[c]	-749[e]
WA-15-20	2768[d]	1511[d]	1969[d]	1257[b]	-799[f]
WB(N)	3109[e]	1809[d]	2294[d]	1300[f]	-815[e]
WB-0-10	3991[c]	2075[c]	2673[b]	1916[c]	-1318[d]
WB-0-15	4285[b]	2398[a]	2622[c]	1887[d]	-1369[e]
WB-0-20	4318[a]	2319[b]	2922[a]	1999[b]	-1396[f]
WB-15-10	2037[g]	1367[g]	1736[f]	670[g]	-301[a]
WB-15-15	2796[f]	1477[f]	2169[e]	1319[e]	-627[b]
WB-15-20	3757[d]	1536[e]	2168[e]	2221[a]	-1591[g]

[a] Values with the same superscript in a row do not differ significantly from one another ($p < 0.05$)

another indicative parameter for the study of starch crystallization by FTIR. Retrogradation directly influences the vibrational mode of C-H bonds in starch and was confirmed by loss of intensity of small peaks at 866 cm^{-1} and 1344 cm^{-1}. Indications of possible damage of the pyranose ring structure due to severe processing were also noticed by the loss of the sharp peak near 590 cm^{-1}.

viii. Wide angle X-ray scattering

All the native rice flour samples exhibited the typical A-type starch crystalline pattern (Fig 3 a-d) with major peaks at Bragg's angle (2θ) positions near 15.2 (Peak 1), 17.4 (Peak 2), 18.1 (Peak 3) and 23.3 (Peak 4). A minor peak at 2θ = 20, was evident in all the raw samples indicating

presence of crystallites, which supports the idea of 'in situ' amorphous amylose complex formation. Development of major peaks (indicating V-type polymorph) in the same domain were seen in all processed HR and LK samples and in the high pressure parboiled samples. In spite of the very low contents of amylose, there were distinct formations of the V-type polymorph in the pressure processed waxy rice samples. In addition to it, the gradual loss in intensity of peak 1 on severe parboiling with formation of a weak peak near 2θ of ~22 indicated superimposition of partial B-type spectra in all the pressure parboiled samples. All the A-type peaks were retained in the open steamed waxy samples. Peaks 2, 3 and 4 were found in the open steamed samples of HR and LK. Peak 2 and 3 were subdued in all the pressure parboiled samples. Hence, there were distinct superimposition of A and V-type patterns in open steamed high and low amylose samples and superimposed A, B and V-type patterns in all the pressure parboiled samples indicating formation of all the three main parboiled rice starch polymorphs. There were obvious losses in crystallinity as indicated by the loss of intensities of the major native peaks. Highest % Crystallinity of 27.1% was exhibited by WB(N). Mild open steaming caused drastic loss of crystallinity in all varieties (Fig 3e). However, after moderate treatment, there was rise in the % Crystallinity values for HR and LK suggesting higher retrogradation with formation of crystalline polymorphs. This may be related to higher degree of gelatinization as previously mentioned (section 3.3.2) and subsequent retrogradation of the same leading to formation of retrograded crystallites. Similarly, for the pressure processed HR and LK samples, crystallinity drop was seen till moderate processing and recrystallization occurred after the severe treatment, thereby nullifying any direct relationship between DG (%) and retrogradation. Adding to it, for waxy samples, continuous loss in crystallinity was observed. Hence, the loss in crystallinity was higher in the processed waxy samples than HR and LK suggesting that the extent of recrystallization was dependent on the amylose content and the higher tendency of water absorption of the pressure parboiled waxy varieties as seen from the EMC-S%, SV and RVA studies is due to amorphous fractions of the rice starch rather than the crystallites present. Again, no significant correlation was observed between the change in the % Crystallinity with the pattern of change of the FTIR band ratios $1047cm^{-1}$:$1022cm^{-1}$ which is obvious as the calculation of % Crystallinity considers only a small range (10-40°of 2θ in this case) of the whole diffractograph with major emphasis on the strong peaks, while the FTIR method considers the bonding vibrational modes at two band positions of the spectra.

ix. Starch digestibility

The digestibility of the rice sample was found to be dependent upon the amylose content (Fig 4). Native and processed HR samples showed lowest levels of RDS, followed by LK, WA and WB samples. An opposite trend was observed for SDS values of the samples. At least 50% (db) RDS and a maximum of 15% (db) SDS were present in all the samples. The differences in the digestible fractions were clearly reflected in their RS contents (%, db). Raw HR(N) showed the highest RS content of 7.42%, followed by LK(N), WB(N) and WA(N) with 6.83%, 4.24% and 4.39% RS, respectively. In general, the RS content is positively correlated with the level of amylose. Distinct drop in RS content with processing severity was observed for all the four varieties. The decrease in RS content was more extensive for the processed HR samples and was minimal for the processed LK, WA and WB samples. Hydrothermal processing resulting in the breakdown of the starch polymeric chains and specially long chains of amylose, as also revealed

by EMC-S, SV, RVA and WAXS results, must have resulted in the formation of simpler and more digestible fractions.

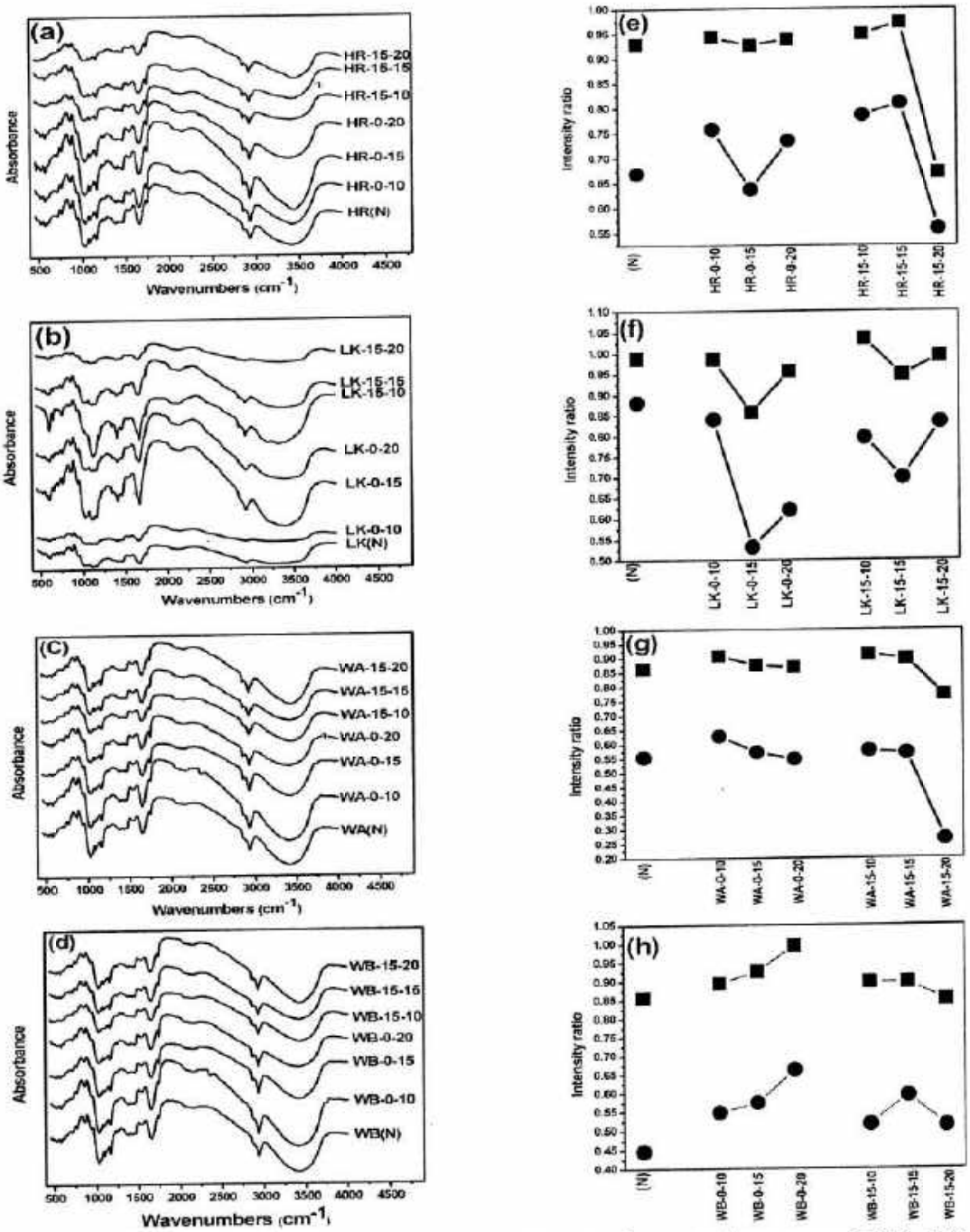


Fig. 2. (a,b,c and d) FTIR spectroscopic patterns of raw and processed HR, LK, WA and WB flour samples respectively; (e, f, g, h) changes in the ratio of IR absorption intensities 1047 cm^{-1}:1022 cm^{-1} and 2855 cm^{-1}:2925 cm^{-1} of the raw and processed samples.

B. STEAM PARBOILING 2

i. 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 6). 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 LK 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.

ii. L/B ratio

Hot soaking caused increase in the grain L/B values (Table 6). While the L values of the kernels remained almost unchanged on open steaming, pressure steaming caused marked increase in the L values. 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. Increase in L/B ratio in the present study was more prominent in the pressure steamed samples than the open steamed samples.

iii. 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. The changes in bulk and true density were marginal; both properties increased with parboiling. The decrease in porosity was higher for the pressure parboiled samples indicating better packing properties.

iv. Cooking time

Table 6 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. 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.

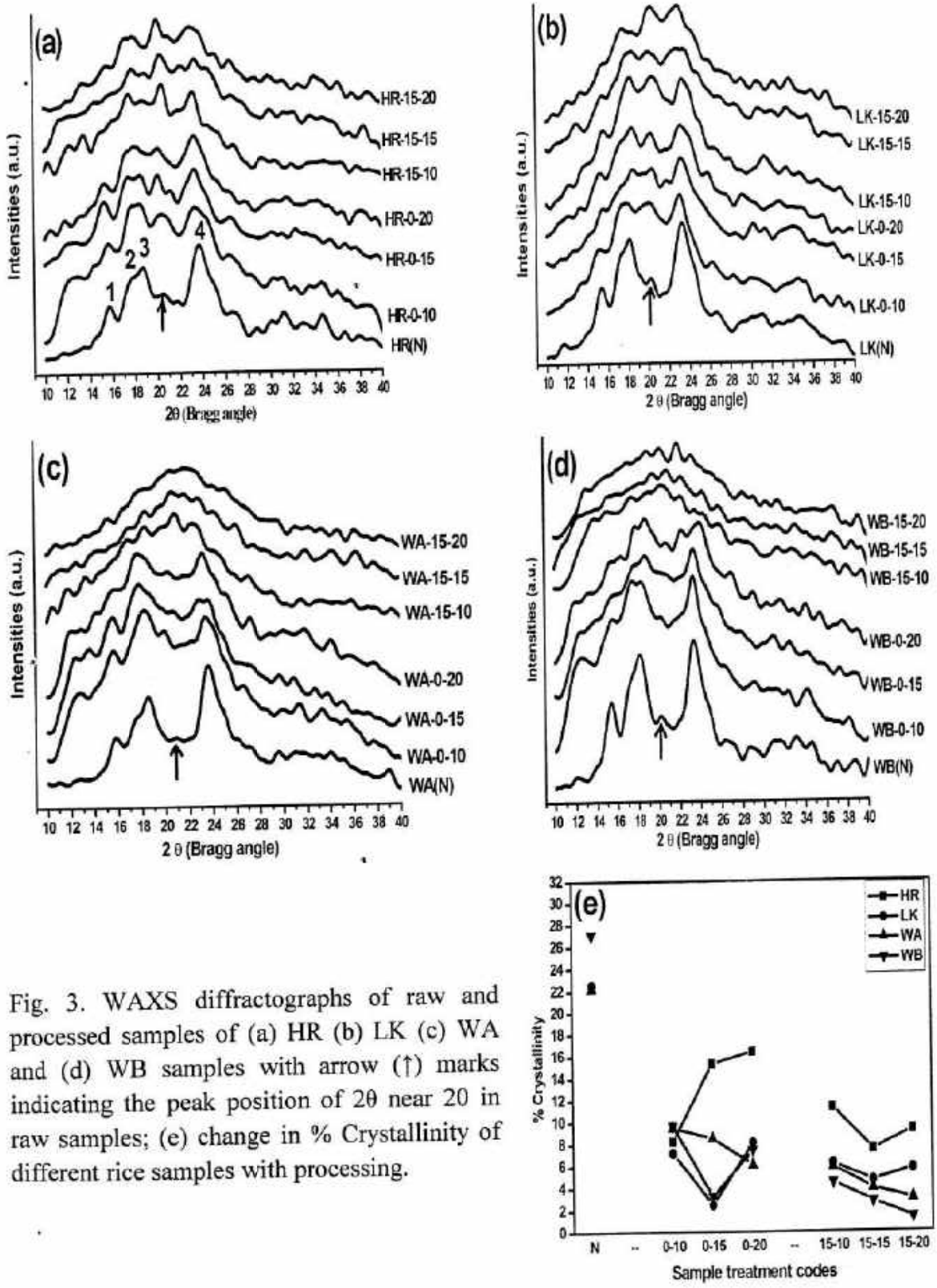


Fig. 3. WAXS diffractographs of raw and processed samples of (a) HR (b) LK (c) WA and (d) WB samples with arrow (↑) marks indicating the peak position of 2θ near 20 in raw samples; (e) change in % Crystallinity of different rice samples with processing.

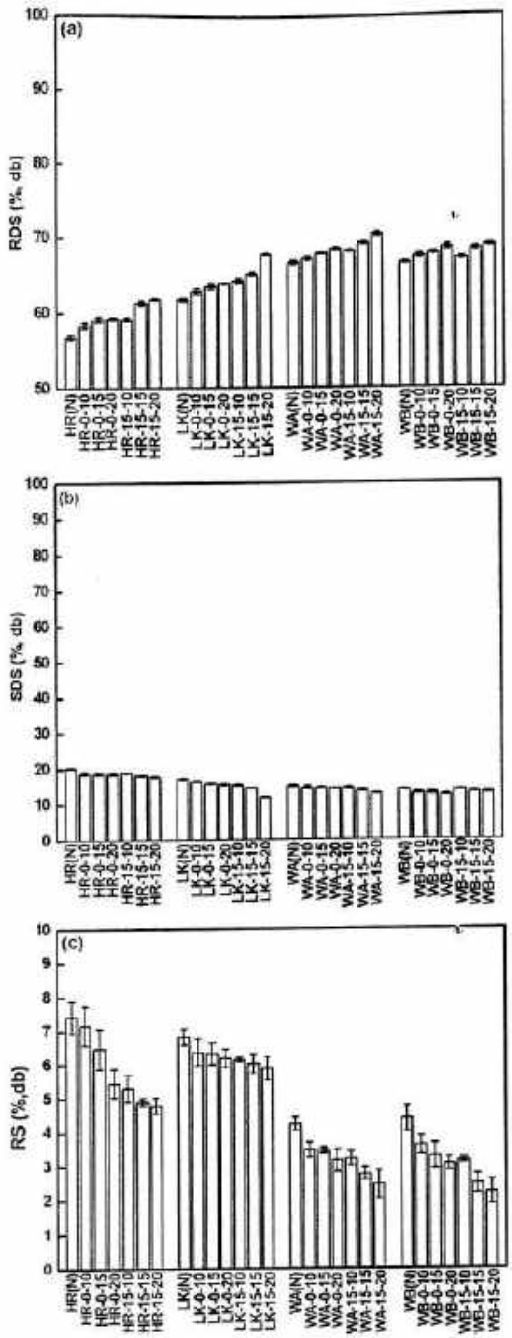


Fig. 4. (a) Rapidly digestible starch (RDS, % db), (b) slowly digestible starch (SDS, % db) and (c) resistant starch (%, db) in the native and processed rice flour samples.

v. Equilibrium moisture content on soaking at room temperature

Marked increases in EMC-S (%, db) were observed on processing (Fig 5a). 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 LK3-15-20 followed by LK1-15-20 with values of 259.9% and 236.6% respectively. The increased EMC-S was probably due to the thermally degraded starch in the samples.

vi. 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 5b). It was indicative of increased degree of starch gelatinization and subsequent thermal degradation with severity of processing.

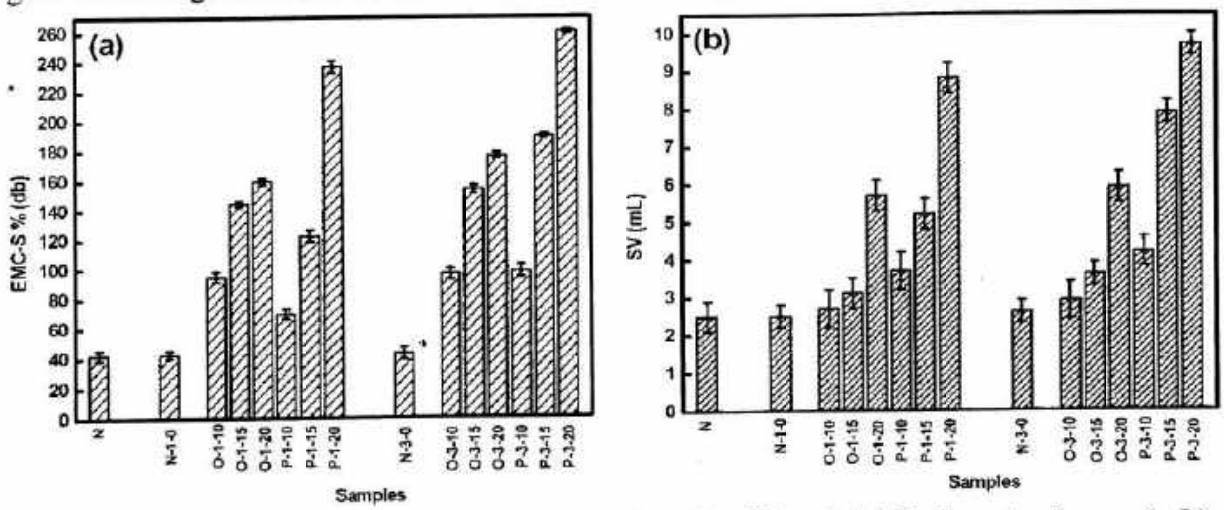


Fig. 5 (a) Equilibrium moisture contents on soaking (%, db) and (b) Sediment volumes (mL) of the raw and processed samples.

vii. 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 6). Hardness decreased 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[48] 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.

viii. 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 reassociate forming retrograded starch. Pressure steaming resulted in gradual yet extensive drop in the PV as was also evident in some earlier works. This drop is similar to that of acid thinned starch used in paper and textile industries. This was accompanied by very low BD with higher CPV. Severe processing causes thermal degradation of starch polymer structure. Increase in the final slurry viscosity, hence may be attributed to leaching of the degraded simpler chains causing rise in slurry 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.

ix. 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 8a). While both open and pressure steamed samples from LK1 and only open steamed samples from LK3 conditions gave a mixed patternCrystallinity 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. Probably, the new polymorphic forms (B and V type) had increased the % Crystallinity (Fig 8b).

x. Thermal properties

The DSC thermographs of the samples are shown in Fig 9 and the thermal parameter values presented in Table 7. Hot soaked sample with no steaming showed marked decrease in melting enthalpy of the rice flour. However, mildly parboiled samples showed higher transition enthalpies with a shift of the melting peak towards higher temperatures. 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. 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. 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).

xi. Starch digestibility

Starch digestibility rapidly increased till 90 min of incubation for all flour samples (Fig 10), 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 .

Table 6. Color values, L/B ratio, density, porosity and cooking time of the raw and processed rice kernels.

Samples	Color					L/B ratio			Bulk density	True density	Porosity	Cooking time
	L	a	b	H	C	L	B	L/B	ρ_b	ρ_t	ε (%)	T (min)
N	79.3±0.3^{o}	0.6±0.1^{a}	14.2±0.1^{a}	87.4±0.4^{o}	14.2±0.6^{n}	6.0±0.3^{a}	2.7±0.2^{a}	2.1±0.2^{a}	0.7±0.3^{a}	1.4±0.2^{a}	48.6±0.3^{j}	18.1±0.4^{o}
N-1-0	78.1±0.4^{n}	2.0±0.1^{b}	15.2±0.3^{b}	82.3±0.3^{n}	15.3±0.4^{b}	6.0±0.3^{a}	2.7±0.4^{a}	2.2±0.1^{b}	0.7±0.5^{b}	1.4±0.1^{a}	46.5±0.4^{e}	17.1±0.3^{n}
O-1-10	75.1±0.3^{m}	3.2±0.2^{d}	19.1±0.4^{d}	80.3±0.4^{l}	19.4±0.2^{d}	6.0±0.2^{a}	2.7±0.7^{a}	2.2±0.1^{b}	0.7±0.4^{bc}	1.4±0.2^{ab}	46.2±0.4^{d}	16.1±0.4^{l}
O-1-15	69.1±0.3^{i}	5.4±0.1^{h}	22.1±0.8^{h}	76.2±0.3^{h}	22.7±0.3^{h}	6.0±0.4^{a}	2.7±0.4^{b}	2.2±0.1^{b}	0.7±0.5^{bc}	1.4±0.1^{bc}	46.6±0.7^{f}	14.2±0.1^{j}
O-1-20	63.3±0.2^{e}	8.0±0.4^{l}	24.3±0.7^{k}	71.8±0.6^{d}	25.6±0.3^{k}	6.1±0.1^{b}	2.7±0.4^{b}	2.2±0.1^{b}	0.8±0.7^{cd}	1.4±0.1^{bc}	45.9±0.6^{b}	13.6±0.2^{f}
P-1-10	71.2±0.4^{k}	4.3±0.4^{g}	21.1±0.4^{g}	78.4±0.6^{i}	21.5±0.4^{g}	6.0±0.3^{a}	2.7±0.3^{b}	2.2±0.3^{bc}	0.7±0.3^{bc}	1.4±0.2^{bc}	46.6±0.4^{f}	14.2±0.4^{k}
P-1-15	66.9±0.4^{g}	6.4±0.5^{j}	22.4±0.5i	73.9±0.6^{f}	23.3±0.1^{i}	6.1±0.2^{b}	2.7±0.1^{b}	2.2±0.3^{bc}	0.8±0.4^{cd}	1.4±0.3^{bc}	45.9±0.3^{b}	12.8±0.4^{d}
P-1-20	57.8±0.4^{b}	9.6±0.6^{n}	25.1±0.6^{n}	68.9±0.5^{b}	26.9±0.2^{n}	6.1±0.2^{b}	2.6±0.4^{bc}	2.2±0.3^{bc}	0.8±0.3^{e}	1.4±0.1^{cd}	45.6±0.3^{a}	11.6±0.3^{a}
N-3-0	73.0±0.3^{l}	2.4±0.4^{c}	15.7±0.6^{c}	81.1±0.6^{m}	15.9±0.4^{c}	6.0±0.5^{ab}	2.6±0.2^{a}	2.2±0.1^{b}	0.7±0.1^{bc}	1.4±0.1^{a}	46.8±0.2^{h}	16.9±0.5^{m}
O-3-10	71.0±0.3^{j}	3.8±0.3^{e}	20.2±0.3^{e}	79.1±0.3^{k}	20.5±0.8^{e}	6.0±0.5^{ab}	2.6±0.2^{b}	2.2±0.1^{b}	0.7±0.1^{bc}	1.4±0.1^{bc}	46.6±0.2^{f}	14.1±0.4^{h}
O-3-15	64.4±0.6^{f}	5.8±0.2^{i}	23.6±0.3^{j}	76.1±0.4^{g}	24.3±0.3^{j}	6.0±0.3^{a}	2.6±0.3^{bc}	2.2±0.1^{b}	0.7±0.1^{bc}	1.4±0.2^{cd}	46.9±0.3^{i}	13.3±0.4^{e}
O-3-20	60.0±0.5^{c}	9.2±0.7^{m}	24.9±0.4^{m}	69.7±0.5^{c}	26.6±0.7^{m}	6.1±0.3^{b}	2.6±0.3^{c}	2.3±0.2^{d}	0.8±0.2^{cd}	1.5±0.1^{e}	46.6±0.1^{g}	14.1±0.2^{i}
P-3-10	67.7±0.3^{h}	4.0±0.3^{f}	20.8±0.3^{f}	78.8±0.3^{j}	21.2±0.4^{f}	6.0±0.3^{a}	2.6±0.7^{bc}	2.3±0.3^{d}	0.7±0.1^{bc}	1.4±0.2^{cd}	46.9±0.3^{i}	13.9±0.3^{g}
P-3-15	61.2±0.2^{d}	7.6±0.1^{k}	24.7±0.3^{l}	72.7±0.2^{e}	25.9±0.3^{l}	6.1±0.3^{b}	2.6±0.2^{c}	2.3±0.2^{d}	0.8±0.2^{cd}	1.5±0.1^{e}	46.6±0.3^{g}	11.8±0.4^{b}
P-3-20	54.1±0.7^{a}	12.7±0.3^{o}	29.8±0.4^{o}	66.9±0.3^{a}	32.4±0.5^{o}	6.1±0.1^{b}	2.5±0.2^{c}	2.3±0.1^{d}	0.8±0.1^{c}	1.5±0.1^{e}	46.0±0.1^{c}	9.3±0.5^{c}

The means followed by a common letter are not significantly different by Duncan's Multiple Range Test at $p<0.05$

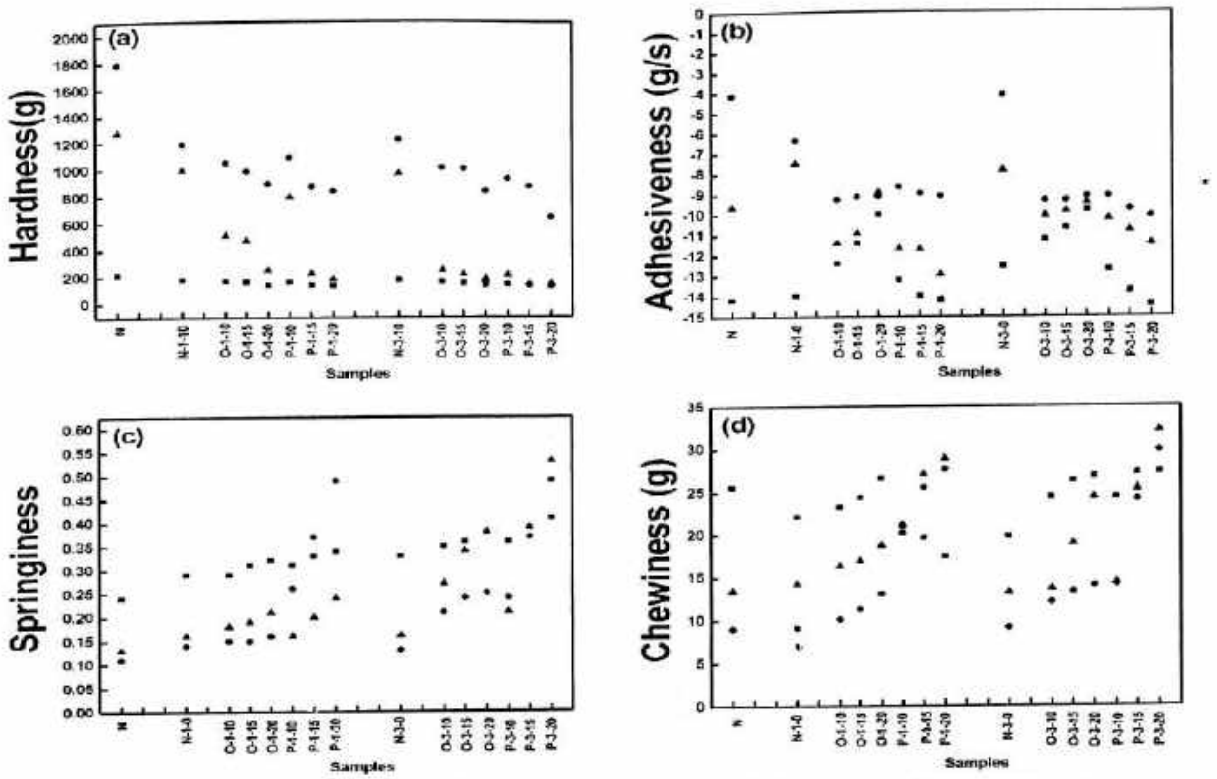


Fig. 6. The TPA parameter values viz (a) Harness (g) (b) Adhesiveness (g/s) (c) Springiness and (d) Chewiness (g) of the parboiled samples cooked at 100°C till done (■), 50°C for 20 min (▲) and 20°C for 60 min (•).

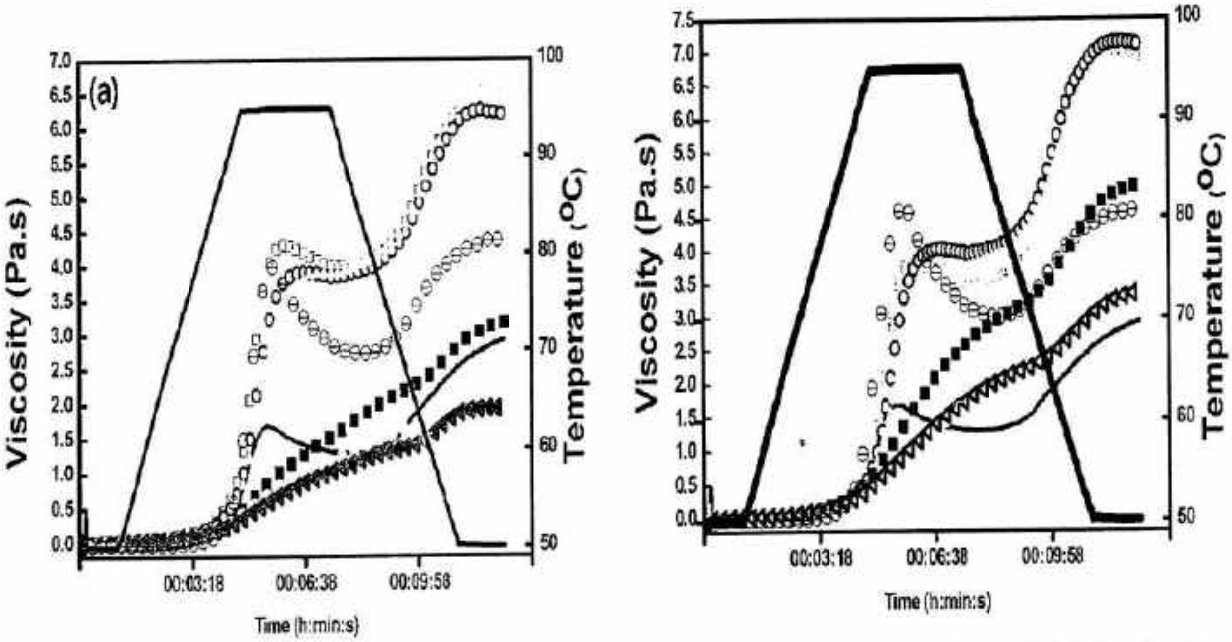


Fig. 7. RVA pasting curves of parboiled samples hot soaked for (a) 1 min and (b) 3 min. The representations of the symbolic curves are as follows: Native (-), hot soaked and non-steamed (θ), -0-10 (□), -0-15 (o), -0-20 (Δ), -15-10 (■), -15-15 (•) and -15-20 (◂).

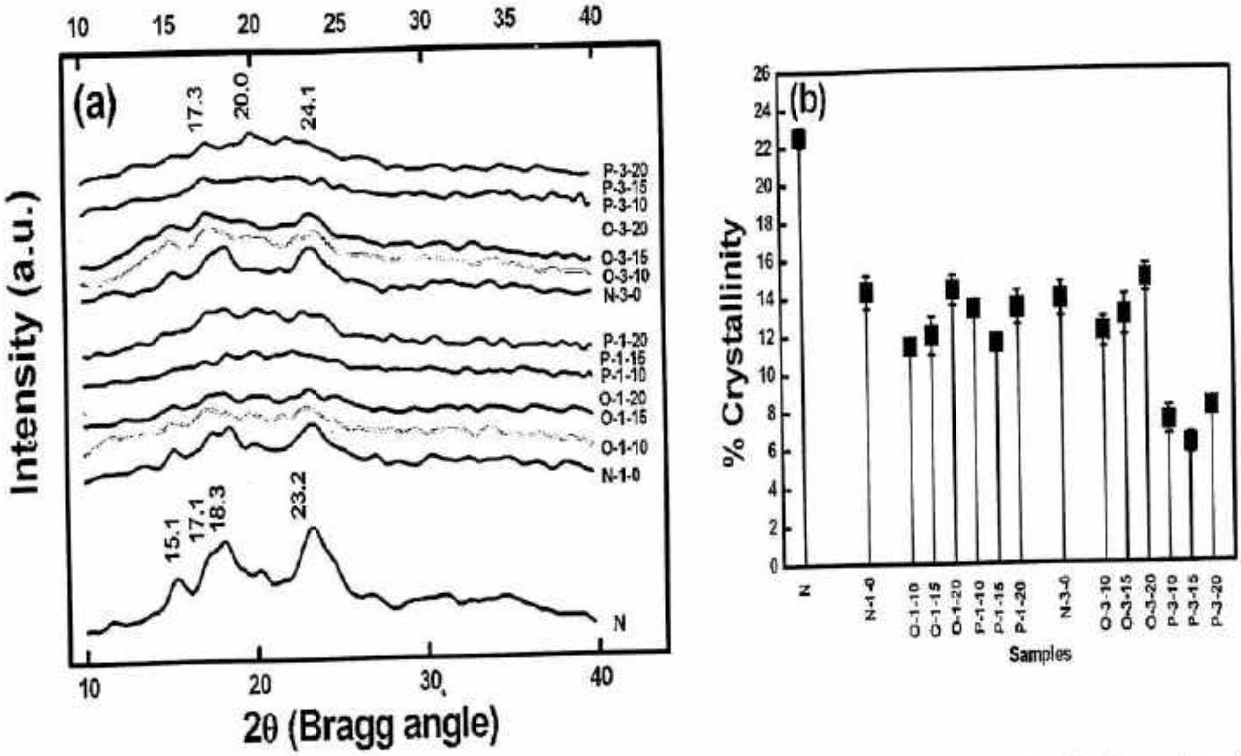


Fig. 8. (a) The XRD patterns of raw and processed flour samples with peaks indicated and (b) % Crystallinity of the samples with processing.

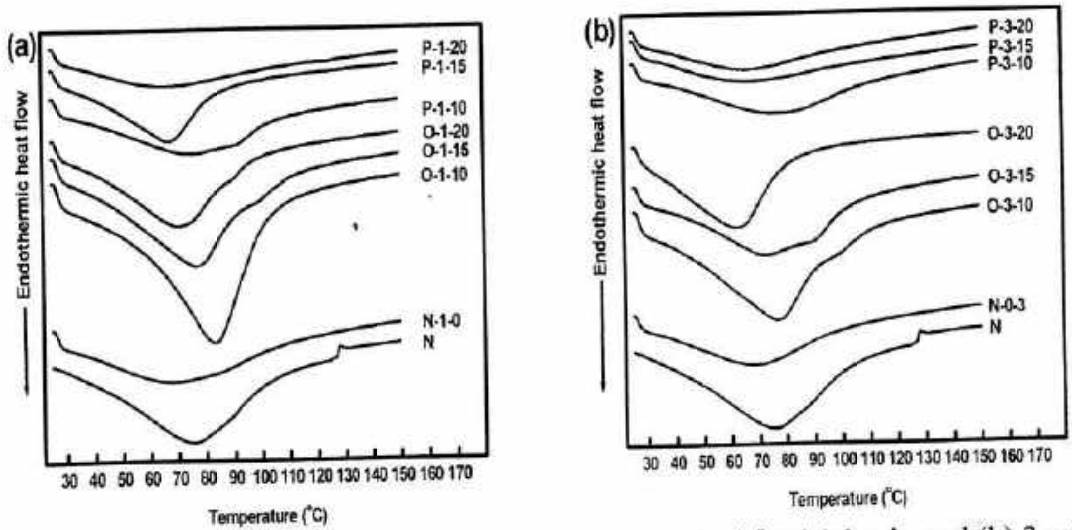


Fig. 9. DSC thermographs of parboiled samples hot soaked for (a) 1 min and (b) 3 min.

Table 7. DSC thermal parameter values of the raw and processed rice flour samples.*

Sample	To (°C)	Tp (°C)	Tc (°C)	ΔH (J/g)
N	63.4 ± 1.2^{m}	75.1 ± 0.8^{k}	82.3 ± 1.2^{l}	10.6 ± 0.8^{i}
N-1-0	50.0 ± 2.1^{c}	68.6 ± 1.9^{e}	75.2 ± 2.1^{d}	8.6 ± 1.4^{f}
O-1-10	68.1 ± 1.4^{n}	83.1 ± 1.4^{o}	90.1 ± 1.4^{m}	45.4 ± 1.3^{o}
O-1-15	69.2 ± 1.3^{o}	78.9 ± 2.2^{m}	83.3 ± 1.4^{j}	20.4 ± 1.3^{m}
O-1-20	59.8 ± 1.2^{j}	70.6 ± 1.2^{h}	80.0 ± 1.3^{f}	12.8 ± 1.6^{j}
P-1-10	61.1 ± 2.3^{l}	72.0 ± 2.1^{j}	80.0 ± 2.2^{f}	9.4 ± 1.4^{h}
P-1-15	57.8 ± 1.4^{g}	69.4 ± 1.2^{f}	74.9 ± 1.2^{b}	8.2 ± 1.1^{e}
P-1-20	53.3 ± 2.1^{f}	67.8 ± 1.3^{d}	76.2 ± 2.3^{e}	7.2 ± 0.8^{d}
N-3-0	50.1 ± 1.2^{d}	69.8 ± 1.2^{g}	84.2 ± 1.0^{k}	9.2 ± 1.1^{g}
O-3-10	60.0 ± 2.1^{k}	78.2 ± 0.4^{l}	89.2 ± 2.1^{l}	26.8 ± 0.7^{n}
O-3-15	59.3 ± 1.2^{i}	71.9 ± 1.1^{i}	80.2 ± 1.2^{g}	17.2 ± 0.9^{l}
O-3-20	51.8 ± 2.3^{e}	62.0 ± 2.1^{a}	70.1 ± 1.3^{a}	17.2 ± 1.3^{k}
P-3-10	58.3 ± 1.4^{h}	79.9 ± 2.0^{n}	95.2 ± 2.2^{n}	7.1 ± 1.2^{c}
P-3-15	47.7 ± 2.2^{a}	66.3 ± 1.6^{c}	75.0 ± 1.1^{c}	6.3 ± 1.6^{a}
P-3-20	49.1 ± 1.2^{b}	66.2 ± 1.3^{b}	82.2 ± 1.2^{h}	6.3 ± 0.6^{b}

*To is onset temperature, Tp is peak temperature, Tc 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 $p<0.05$

increased the digestibility markedly and was highest (93.8 % after 180 min) for LK3-15-20. Hence, the results were indicative of clear differences in starch digestibility between the products of the two processes.

xii. 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.

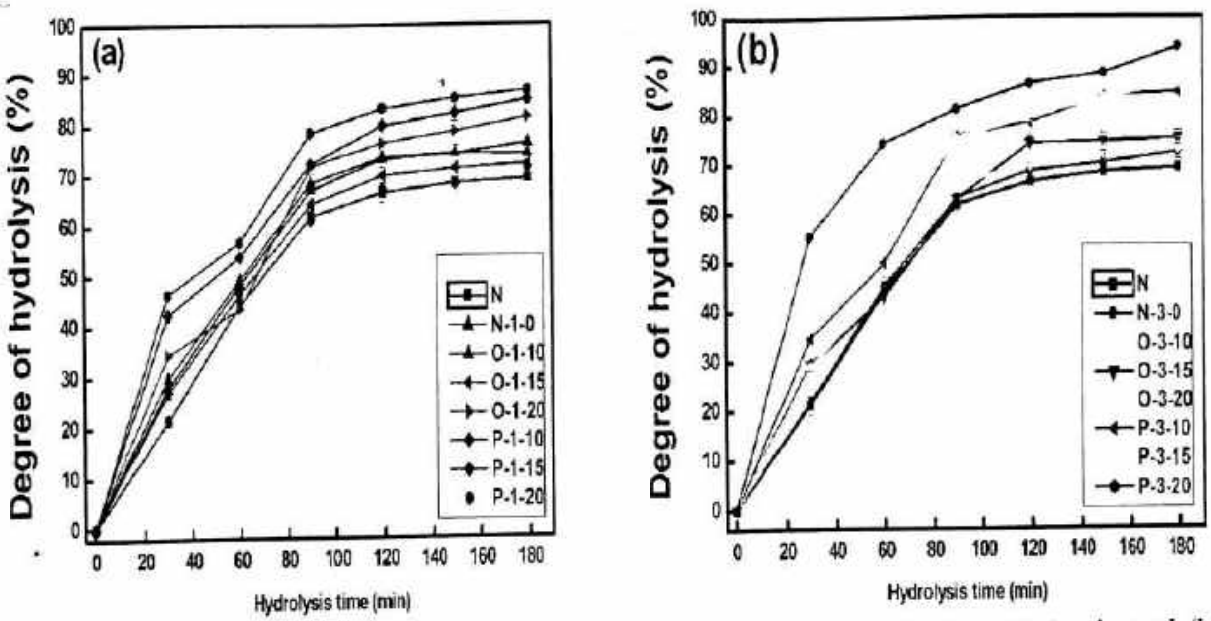


Fig. 10. Starch hydrolysis rate of flours of parboiled samples hot soaked for (a) 1 min and (b) 3 min.

C. DRY HEAT PARBOILING

i. Moisture content of raw, soaked and dry heat parboiled samples

The moisture content of raw *Ranjit*, *Kola chokua* and *Aghoni bora* was between 12.5 to 13.0 % (wb) that increased to 34.6%, 35.2% and 35.1% respectively on soaking, indicating sufficient hydration of the rice endosperms. Dry heat parboiling significantly reduced the moisture content of the paddy samples (Table 8). It was observed that temperature severity played the crucial role in moisture reduction than processing time.

ii. Head rice yield

LTLT dry heat parboiling significantly improved the head rice yield of all the three varieties (Table 8) with values nearing 100%. HTST processed samples however exhibited HRY values in between raw and LTLT samples. This might be attributed to the development of higher temperature and moisture gradient within the kernels during initiation of roasting and during sudden release of the roasted mass to room temperature that created internal fissures and cracks resulting in kernel breakage during milling. The pre and post-roasting temperature change hence needs to be controlled for getting a higher head rice yield out of the HTST samples.

iii. Kernel hardness and physical L/B ratio

Dry heat parboiling increased kernel hardness of the three rice varieties (Table 8) and HTST processed samples were less hard than LTLT processed samples due to the development of internal fractures. All the three rice varieties were medium in size with L/B between 2.5 to 2.9. Reduction in kernel lengths with simultaneous increase in breadths of LK and WA samples resulted in marked reduction of L/B ratio making the dry heat parboiled rice bolder in shape. Possibly higher tension developed along the horizontal axis of the cylindrical kernels during starch gelatinization and drying. HR kernels however did not exhibit such

notable changes indicating the effect of varietal differences.

iv. Colour measurement

The reduction in L of the processed kernels was due to gelatinization of starch and inward migration of husk and bran pigments as was earlier observed in steam parboiled rice (Chapter 3, section 3.3.3). Similarly, the increased positive values of a and b were indicative of pigment migration and Maillard browning reactions (Table 8), as has been reported in steam parboiled rice. The high temperature used in dry heat parboiling probably increased the C value of the samples which were higher than those reported for steam parboiled rice.

v. Degree of gelatinization

LTLT processing resulted in rice kernels with some ungelatinized starch fractions in the kernels (Table 8). However, HTST processing resulted in complete gelatinisation of starch suggesting higher efficiency of the method in attaining gelatinization. High heat applied in HTST must have reached the centre of the rice kernels extensively to result in sufficient gelatinization throughout the kernel, which the lower heat in LTLT samples could not. Precisely, HTST processing could overcome the temperature gradient occurring between the external layers and the centre of the paddy than LTLT. Effect of this was indicated by the observations made from the following electron microscopic study (section 4.3.6).

vi. Scanning electron microscopy

Distinct morphological differences in the surface integrity of the sections of rice kernels were observed (Fig 11). The loss in starch granular structure and sealing of naturally occurring fissures in the raw endosperms after starch gelatinization on dry heat parboiling was seen from the SEM at 2000x (dii, eii, fii, gii, hii, iii). The effect of severity of gelatinisation was visible when HTST and LTLT samples were compared. Magnification at 30X however demonstrated development of a distinct cavity in radial direction of HTST kernels namely HR-200-5, LK-200-5 and WA-200-5 (gii, hii, iii). Probably, when suddenly subjected to very high temperature, the water in the soaked paddy simultaneously participated in starch gelatinization process as well as tried to migrate out of the gelatinized core of the endosperm. This releasing force pushed the softened kernel material in all directions creating a cavity in the middle of the kernel which because of instantaneous drying did not get sufficient scope to refill. The lower kernel hardness and head rice yield of the HTST samples may be attributed to this cavity formation. The characteristic splitting of dry heat parboiled rice kernel when subjected to alkali solution as reported elsewhere may also be related with this phenomenon.

vii. Equilibrium moisture content on soaking at room temperature

EMC-S (% db) was higher for both raw and dry heat parboiled WA and LK samples than the HR samples clearly indicating the role of amylose content (Fig 12a). Dry heat parboiling increased the water absorption capacities of the three rice varieties due to extensive starch gelatinization. HTST treatment resulted in notably sharp increase in EMC-S than LTLT treated samples probably due to the accumulation of water in the cavity formed in the kernel.

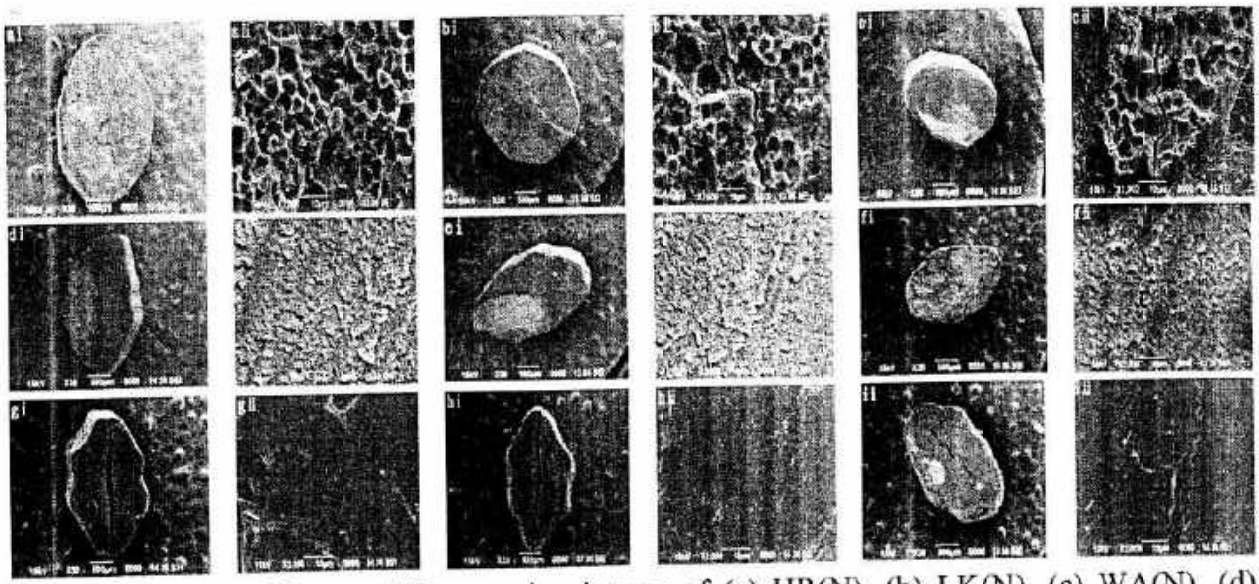


Fig. 11. Scanning Electron Microscopic pictures of (a) HR(N), (b) LK(N), (c) WA(N), (d) HR15, (e) LK15, (f) WA15, (g) HR5, (h) LK5 and (i) WA5 taken at 30x (ai, bi, ci, di, ei, fi, gi, hi, ii) and 2000x (aii, bii, cii, dii, eii, fii, gii, hii, iii) magnification.

viii. Sediment volume

While EMC-S (%, db) was evaluated for whole kernels, sediment volume was determined for rice flour (Fig 12b). Although the pattern of increasing values was similar, the sharp rise in values observed for HTST treated samples in EMC-S test was not found in sediment volume test. This confirmed the role of the cavity in HTST treated rice kernel samples in accumulating water.

ix. Pasting properties

RVA pasting curves of the raw and processed samples of the three varieties are given in Fig 13 (a, b and c). The effect of amylose content in pasting pattern of raw rice was evident. HR(N) required longer time to attain viscosity than LK(N) and WA(N). High amylose wheat starch was reported to be slower in swelling on pasting. These complexes were found in native rice in very low proportion with no significant quantitative difference amongst the varieties. Newer complexes are formed over process temperature above 50°C. Its formation and differential influence on the raw rice samples can hence be nullified. The higher PV in HR(N) also does not imply any such inhibitory effect of amylose on the extent of starch swelling. Amylopectin may however be attributed to the rapid absorption of water. This branched structure being more susceptible to damage by increased temperature during the heating phase of RVA resulted in lower PV. Probably, irreversible damage of the heat labile amylopectin structures and subsequent leaching out in processed LK and WA samples caused continuous rise of the pasting curves. The PV, HPV and CPV of the LTLT samples were even higher than the raw samples of LK and WA, indicating larger degraded fractions resulting in higher density of the heated slurry. The branched chains in waxy WA were probably longer than those of low amylose LK to explain for the highest value of CPV attained. HTST caused further breakdown, bringing the overall slurry viscosity to lower

Table 8. Moisture content, head rice yield, kernel hardness, L/B ratio, colour value and degree of gelatinization of raw and processed rice samples.

Samples	Moisture (% wb)	HRY (%)	H (N)	L (mm)	B (mm)	L/B	L	a	b	C	DG (%)
HR(N)	-	78.4±1.34^{c}	66.4±0.11^{b}	6.2±0.22^{b}	2.4±0.04^{b}	2.5±0.53^{e}	46.6±0.88^{k}	2.1±0.07^{a}	10.5±0.89^{a}	10.7±0.34^{a}	-
HR-140-11	11.9±0.87^{f}	99.3±0.91^{q}	87.4±0.68^{l}	6.2±0.13^{b}	2.4±0.07^{b}	2.6±0.24^{e}	37.3±0.27^{i}	2.6±0.03^{b}	10.7±0.13^{b}	11.0±0.41^{b}	92.4±0.02^{a}
HR-140-13	11.6±0.56^{e}	98.7±0.79^{no}	87.8±0.29^{m}	6.3±0.12^{c}	2.4±0.03^{b}	2.6±0.40^{e}	32.1±0.49^{h}	2.6±0.05^{c}	10.9±0.45^{d}	11.2±0.12^{d}	94.2±0.04^{c}
HR-140-15	11.5±0.29^{e}	98.8±0.47^{o}	89.1±0.48^{n}	6.3±0.17^{c}	2.4±0.07^{b}	2.6±0.26^{e} -	26.6±0.59^{e}	2.7±0.03^{c}	10.9±0.39^{d}	11.2±0.27^{d}	95.1±0.07^{d}
HR-200-3	9.2±0.79^{c}	82.4±1.21^{g}	71.3±0.21e	6.2±0.14^{b}	2.4±0.08^{b}	2.6±0.17^{e}	29.7±0.46^{g}	2.5±0.01^{b}	10.8±0.19^{d}	11.1±0.22^{c}	98.6±0.09^{e}
HR-200-4	8.8±0.66^{b}	84.3±0.72^{j}	72.5±0.76^{f}	6.3±0.09^{c}	2.5±0.04^{c}	2.5±0.19^{b}	24.4±0.38^{d}	2.9±0.02^{d}	11.1±0.39^{e}	11.2±0.19^{d}	99.0±0.03^{f}
HR-200-5	8.6±0.44^{ab}	83.8±0.19^{h}	70.3±0.29^{d}	6.3±0.16^{c}	2.5±0.08^{c}	2.5±0.22^{e}	21.5±0.18^{a}	3.2±0.02^{e}	11.4±0.26^{g}	11.4±0.42^{e}	100.0±0.00^{g}
LK(N)	-	72.1±1.89^{a}	68.8±0.82^{e}	6.7±0.16^{f}	2.4±0.06^{b}	2.8±0.28^{d}	57.5±0.34^{l}	2.3±0.04^{c}	10.5±0.38^{a}	10.7±0.17^{a}	-
LK-140-11	11.4±0.18^{de}	99.5±0.12^{r}	84.3±0.04^{j}	6.5±0.14^{e}	2.6±0.04^{d}	2.5±0.32^{e}	32.1±0.38^{h}	2.6±0.02^{b}	10.8±0.34^{c}	11.1±0.09^{c}	93.0±0.06^{ab}
LK-140-13	11.2±0.55^{d}	98.2±0.27^{m}	86.5±0.29^{k}	6.5±0.18^{e}	2.6±0.07^{de}	2.5±0.24^{e}	28.6±0.18^{f}	2.9±0.05^{d}	10.9±0.42^{d}	11.3±0.18^{e}	94.2±0.12^{c}
LK-140-15	11.2±0.18^{d}	99.1±0.01^{p}	86.9±0.19^{j}	6.4±0.11^{d}	2.7±0.09^{e}	2.4±0.13^{a}	23.1±0.46^{fg}	3.2±0.04^{e}	10.9±0.29^{d}	11.4±0.25^{e}	94.4±0.06^{c}
LK-200-3	8.9±0.48^{ab}	80.6±1.81^{c}	74.2±0.61^{g}	6.3±0.14^{c}	2.6±0.03^{d}	2.4±0.44^{b}	27.7±0.33^{e}	2.8±0.03^{c}	10.8±0.28^{c}	11.2±0.16^{d}	98.7±0.05^{e}
LK-200-4	8.6±0.91^{ab}	82.4±0.38^{g}	77.5±0.44^{i}	6.3±0.19^{c}	2.7±0.03^{e}	2.3±0.62^{a}	24.1±0.28^{cd}	3.4±0.04^{g}	10.8±0.19^{d}	11.3±0.07^{e}	100.0±0.00^{g}
LK-200-5	8.5±0.71^{a}	79.8±1.31d	71.1±0.37^{e}	6.2±0.18^{b}	2.7±0.05^{e}	2.3±0.37^{a}	21.9±0.19^{a}	3.6±0.04^{h}	11.7±0.15^{h}	11.6±0.14^{f}	100.0±0.00^{g}
WA(N)	-	73.8±1.29^{b}	59.8±0.17^{a}	6.4±0.17^{d}	2.2±0.03^{a}	2.9±0.58^{e}	66.7±0.21^{m}	2.2±0.04^{b}	11.2±0.31^{e}	11.4±0.19^{e}	-
WA-140-11	12.1±0.39f	97.8±0.31^{l}	90.9±0.11^{o}	6.3±0.11^{c}	2.4±0.06^{b}	2.6±0.18^{d}	35.1±0.48^{i}	2.7±0.01^{c}	11.3±0.27^{f}	11.6±0.31^{f}	92.2±0.08^{a}
WA-140-13	11.6±0.19^{e}	99.7±0.11^{s}	86.9±0.28^{k}	6.2±0.15^{b}	2.5±0.07^{c}	2.5±0.28^{e}	28.8±0.22^{g}	2.8±0.03^{c}	11.7±0.16^{h}	12.0±0.28^{h}	93.2±0.03^{ab}
WA-140-15	11.4±0.20^{de}	98.6±0.19^{n}	87.6±0.33^{lm}	6.2±0.12^{b}	2.5±0.03^{c}	2.5±0.41^{b}	26.3±0.19^{e}	3.1±0.06^{e}	11.8±0.22^{i}	11.8±0.12^{g}	95.3±0.08^{d}
WA-200-3	9.1±0.17^{c}	84.5±1.82^{j}	72.3±0.21^{h}	6.2±0.18^{b}	2.5±0.04^{c}	2.5±0.47^{e}	28.1±0.29^{ef}	2.8±0.03^{d}	11.4±0.25^{g}	11.7±0.26^{f}	99.1±0.00^{f}
WA-200-4	8.7±0.24^{ab}	81.5±1.43^{f}	70.4±0.19^{f}	6.2±0.11^{b}	2.6±0.05^{d}	2.4±0.20^{b}	23.8±0.17^{c}	2.9±0.04^{d}	11.7±0.19^{h}	12.1±0.26^{i}	100.0±0.00^{g}
WA-200-5	8.7±0.71^{c}	88.6±1.76^{k}	74.8±0.13^{h}	6.1±0.11^{a}	2.6±0.05^{d}	2.3±0.23^{a}	21.7±0.41^{a}	3.3±0.03^{f}	11.7±0.24^{h}	12.1±0.09^{i}	100.0±0.00^{g}

[a] Means with the same superscript in a column do not differ significantly from one another ($p < 0.05$)

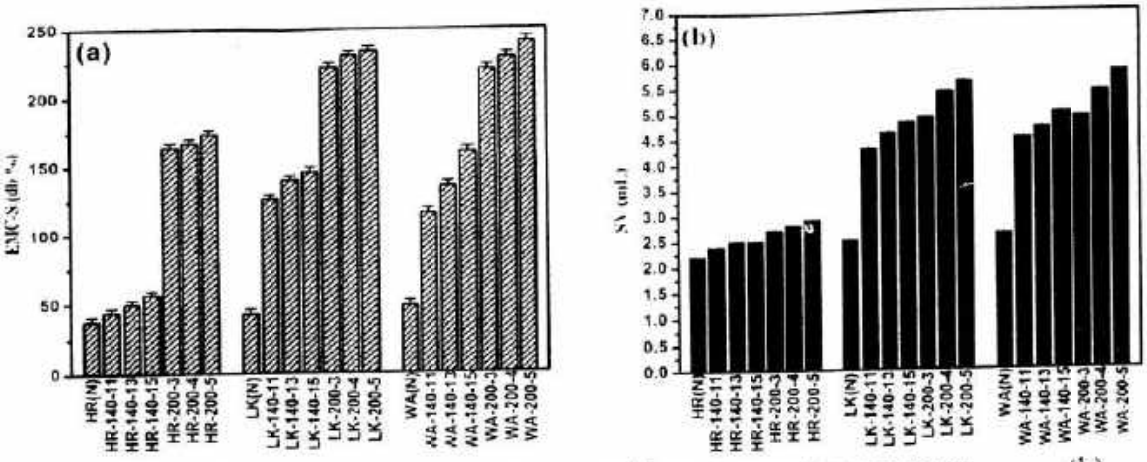


Fig. 12. (a) Equilibrium moisture contents on soaking at room temperature: (b) sediment volumes of the raw and dry heat parboiled HR, LK and WA samples.

values. In addition, amylose-lipid complexes and a protein network formed during the hydrothermal treatment also may have restricted the swelling of the flour pastes to a minor extent. The low SB of all the processed samples indicated their scope for utilization in development of foods that particularly requires low cooked viscosity.

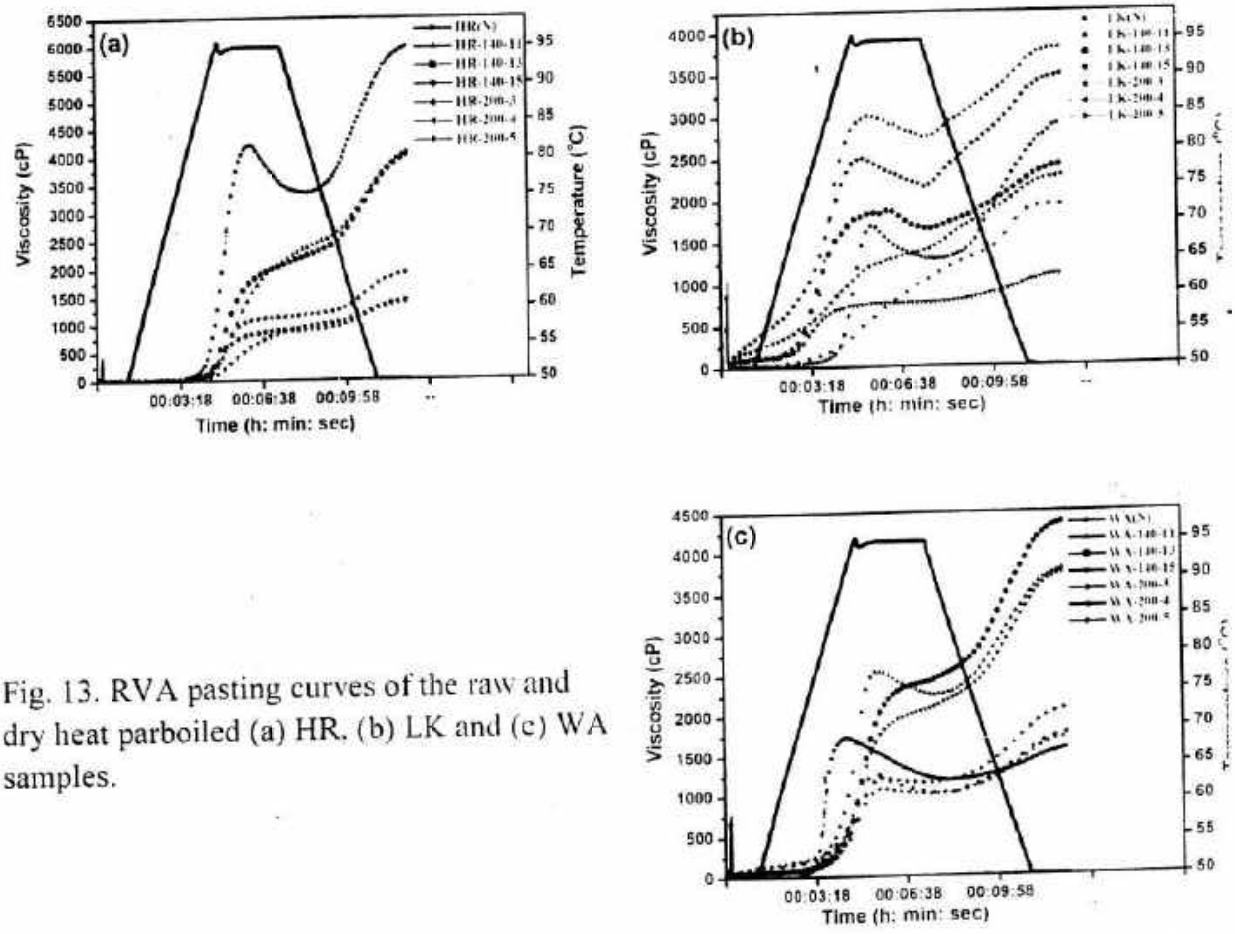


Fig. 13. RVA pasting curves of the raw and dry heat parboiled (a) HR, (b) LK and (c) WA samples.

x. Wide angle X-ray scattering

The native A-type starch diffraction spectra of raw rice flours with major peaks at Bragg's angle (2θ) positions near 15.2 (Peak 1), 17.4 (Peak 2), 18.1 (Peak 3) and 23.3 (Peak 4) were distinctly yet variably altered on dry heat parboiling (Fig 14. a, b, c). The crystallinity was highest in WA(N) followed by LK(N) and HR(N) that was related to the amylopectin content. Significant loss in crystallinity occurred on parboiling (Fig 14 d) owing to rapid amylopectin melting as was also observed in our work on steam parboiling of the same rice varieties (Chapter 3, section 3.3.8). This was also indicated by the DG values which were marginally higher for the HTST and LTLT treated WA and LK samples. Temperature severity results in breakdown of starch fractions. As the process temperature was lower in the LTLT process, starch breakdown occurred to a lesser extent allowing rapid recrystallization of the broken chain. HTST process formed even shorter chains due to thermal degradation which failed to recrystallize to the same extent as LTLT samples, thereby giving lower values of % Crystallinity. The characteristic spectra obtained for LTLT and HTST treatments were also specifically different from each other for all the three varieties owing to the moisture content of the end product. Formation and development of newer crystalline polymorphic structures in parboiled rice starch leading to B-type WAXS for retrograded amylose and V-type for amylose-lipid complexes have been reported. LTLT roasting of the three varieties resulted in distinct superimposition of B- and V-type spectra with minor A-type as suggested by major peaks at 2θ positions of 17.5, 20.0 and minor peaks at 15.2, and 23.3. HTST roasting of HR also resulted in distinct superimposition of the three major types of spectra with peaks at 2θ values of 18.1 (A-type), 20.02 (V-type) and 22.1 (B-type). However, roasted LK and WA samples of HTST gave strictly V-type spectra with a single peak at 2θ positions near 20.02. Earlier it was opined that as dry heat parboiling involved rapid bringing down of the moisture content of paddy to below 18%, storing the rice below room temperature thereafter does not produce retrograded starch because there is no free moisture to be released. But in the present work, formation of partial B- and V-type spectra with traces of the native A-type was suggestive of occurrence of at least minor retrogradation or recrystallization and formation of amylose-lipid complexes. However, WA(N) with very low amylose content (1.1%, db) exhibiting V-type WAXS spectra upon HTST treatment was suggestive of the binding of lipid with either amylopectin or long chains that are formed due to thermal degradation of amylopectin during dry heat parboiling.

xi. Differential scanning calorimetry

Raw rice starch shows a wide range of gelatinization temperature. Our study also supported the same (Table 9). The impact of amylose content on the gelatinization temperature has been strongly debated and impact of other factors like starch structures and nutritional composition of rice have been related to it. Two distinct peaks could be observed in most of the thermograms (Fig 15 a, b and c). While peak 1 was representative of gelatinization of raw rice starch and/or retrograded starch, peak 2 emerging after 90°C represented melting of amylose-lipid complexes. No peak for ungelatinized starch that as was earlier reported to be present from the test for DG was however observed in the DSC curves of the processed samples. This may be due the very low and undetectable amounts of these.

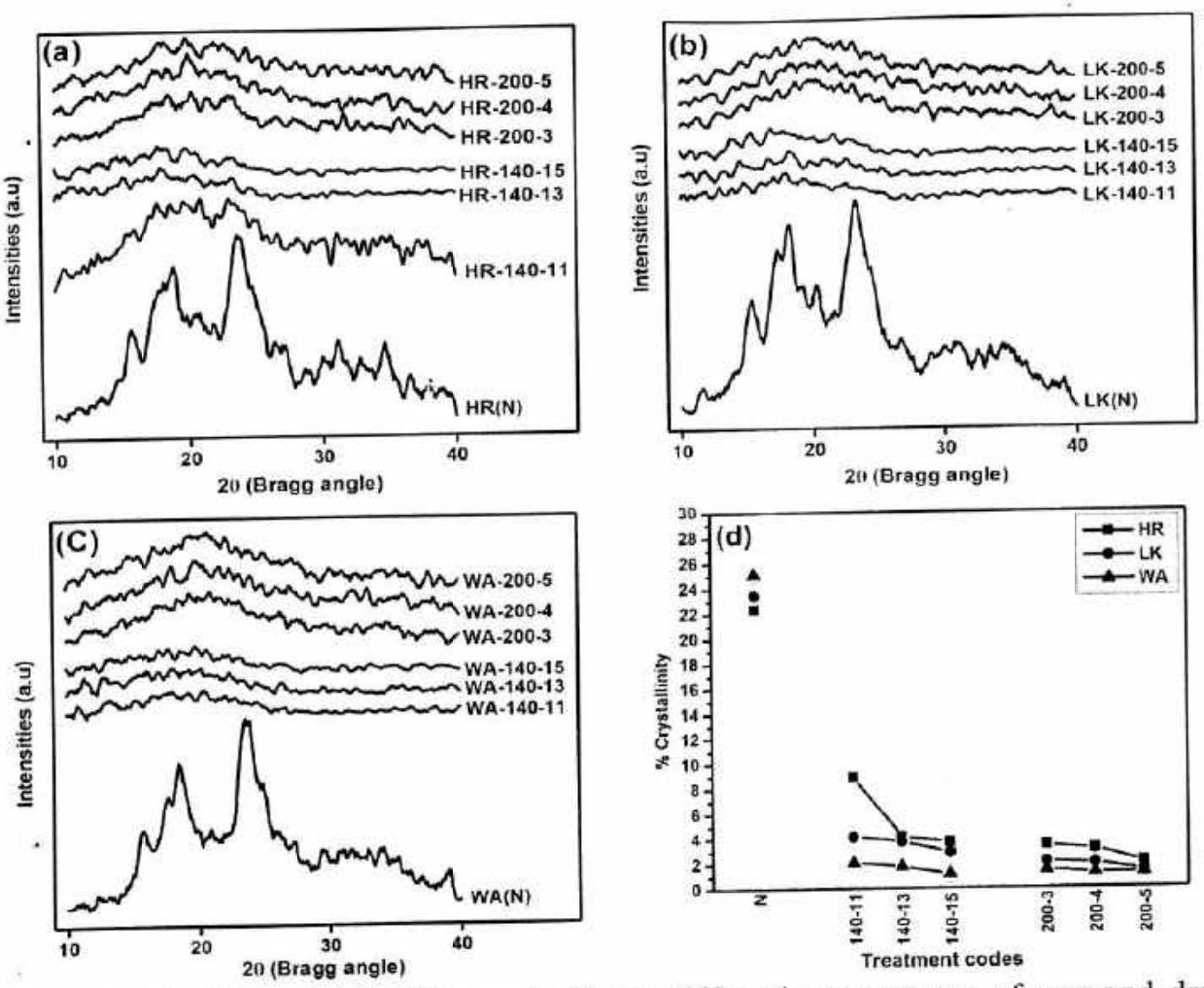


Fig. 14. (a), (b) and (c) Wide angle X-ray diffractinon patterns of raw and dry heat parboiled HR, LK and WA samples, respectively; (d) Changes in % crystallinity of different rice samples with processing.

Retrogradation results in reordering of the amylopectin branches but in less ordered manner, which explains the lower temperature of melting and lower melting enthalpy than gelatinization of the native starch. Peak 1 for HR-140-15 and HR-200-5 and LK-140-15 was hence for retrograded starch which melted at temperatures of 55.1 °C, 54.1° C and 66.0°C respectively with melting enthalpies of 70.1, 68.8 and 33.3 J/g respectively. This is especially notable as it occurred even though there was excessive moisture reduction during dry heat parboiling. It also supports the observation from XRD patterns of LTLT treated HR samples that the gelatinized amylose in particular had a tendency toward recrystallization. Those fractions may have retrograded during the 1 h saturation time prior to DSC analysis. Some portion of the added water must have been used by the starch chains to recoil into B-type polymorphic structures representative of retrograded starch that encompasses higher number of water molecules than native A-type, has a weaker coil structure and hence can be easily formed. Samples processed under HTST conditions however did not generate peak 1 in accordance with the WAXS results indicating formation of irreversibly gelatinized starch with no indication of retrogradation. Emergence of peak 2 with minor enthalpy (9.3 J/g) in thermogram of HR(N) may be considered to have emerged or developed under

hydrothermal condition similar to cooking during the experiment in the DSC system. Peak 2 was not shown by the raw samples of the other two varieties which might be related to comparatively lower availability of free amylose in them. The peak however emerged with much higher intensity for all the three HTST treated samples with LK-200-5 and WA-200-5 giving even higher values of melting enthalpy (39.1 J/g and 38.5 J/g, respectively) than HR-200-5 (37.8 J/g). Extensive thermal breakdown of amylopectin during the high temperature roasting as observed in RVA profiles might have resulted in fractions that readily bind with the lipid bodies during cooling and storage after processing, which was also suggested by WAXS. Different polymorphic forms of amylose-lipid complex exist and indirect evidence on existence of amylopectin-lipid complex has also been reported. In dry heat parboiled samples, however, another hypothesis can be made drown. Gelatinization was accompanied with extensive cleavage in the amylopectin branched structures and formation of smaller branched fractions as suggested by RVA. Such short chains probably gets decoiled and possibly behaves like amylose chains which readily formed complexes with the available lipid molecules. Although present, the intensity of the representative peak for this complex in WAXS was not very sharp as is shown by the complex melting endotherm in DSC. Probably, additional formation of these complexes occurred in the aqueous environment used during DSC sample preparation. The free dehydrated starch fractions formed as a result of gelatinization and subsequent rapid drying were resoponsible for forming the newer structures. Dry heat parboiling followed by hydration can hence be further investigated as a tool for targeted formation of these complexes.

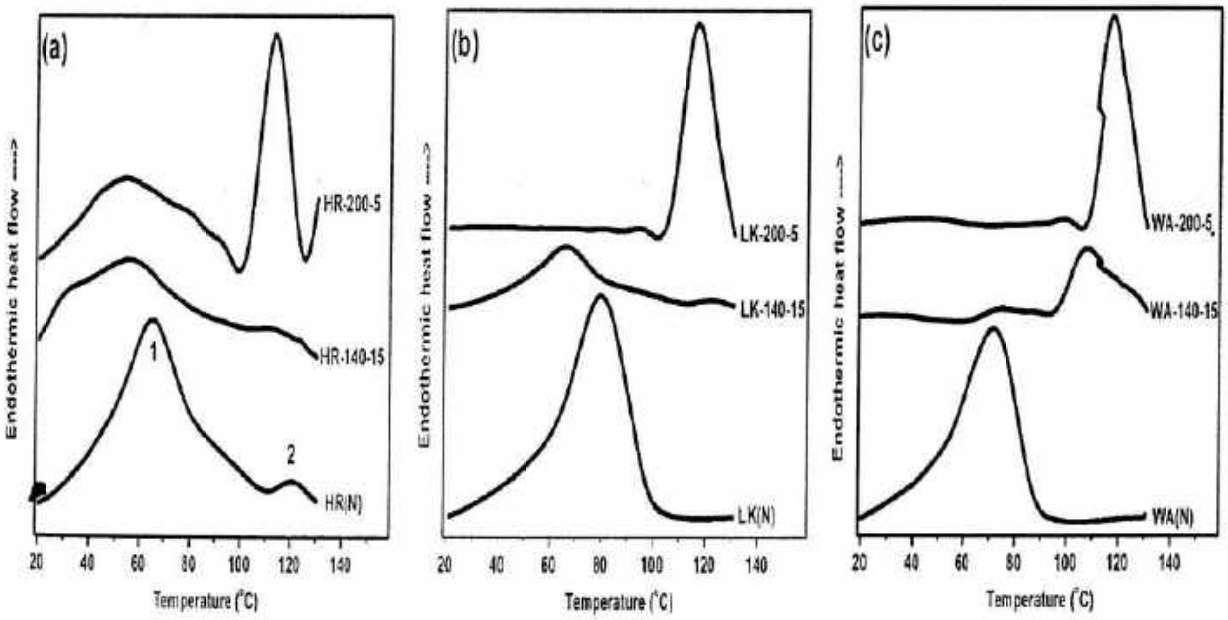


Fig 15. DSC thermographs of the flours of raw rice and samples dry heat parboiled at 140°C and 200°C for 5 and 15 min of (a) HR, (b) LK and (c) WA samples. 1 and 2 indicates DSC peaks emerging before and after 90°C that are representative of melting of the native and/or retrograded starch crystallites and of amylose-lipid complexes respectively.

Table 9. DSC thermal parameter values of the flours of raw rice and rice samples processed for 5 and 15 min.

Samples	Peak 1[1]				Peak 2[1]			
	To (°C)	Tp (°C)	Tc (°C)	ΔH (J/g)	To (°C)	Tp (°C)	Tc (°C)	ΔH (J/g)
HR(N)	44.8 ±1.31^{c}	65.0 ±0.98^{cd}	78.2 ±1.09^{d}	43.4 ±1.21^{e}	112.0 ±1.16^{e}	121.6 ±0.73^{f}	129.3 ±1.19^{bc}	9.3 ±0.26^{b}
HR-140-15	40.7 ±1.23^{b}	55.1 ±0.23^{b}	70.1 ±1.08^{b}	26.2 ±0.88^{c}	100.8 ±1.17^{bc}	114.5 ±1.38^{c}	124.7 ±1.31^{a}	11.7 ±0.45^{c}
HR-200-5	38.7 ±0.91^{a}	54.1 ±0.33^{a}	67.8 ±0.38^{a}	23.4 ±0.29^{b}	100.4 ±1.14^{bc}	113.3 ±1.16^{b}	125.5 ±0.84^{c}	37.8 ±0.56^{e}
LK(N)	56.4 ±0.88^{f}	79.2 ±0.18^{g}	99.1 ±0.72^{f}	48.9 ±0.44^{f}	-	-	-	-
LK-140-15	50.6 ±0.68^{d}	66.0 ±0.43^{d}	77.2 ±0.19^{c}	33.3 ±0.61^{d}	112.0 ±0.89^{e}	120.6 ±1.01^{e}	129.3 ±1.09^{bc}	6.8 ±0.06^{a}
LK-200-5	-	-	-	-	101.6 ±0.41^{c}	116.3 ±0.83^{cd}	129.0 ±1.18^{bc}	39.1 ±0.39^{g}
WA(N)	51.4 ±1.11^{de}	71.4 ±0.76^{e}	87.9 ±1.01^{e}	49.1 ±0.34^{g}	-	-	-	
WA-140-15	62.2 ±0.49^{g}	73.9 ±0.48^{f}	87.6 ±0.92^{e}	13.6 ±0.41^{a}	95.8 ±0.94^{a}	107.2 ±0.92^{a}	125.2 ±1.33^{c}	28.7 ±0.45^{d}
WA-200-5	-	-	-	-	105.4 ±0.89^{d}	116.8 ±0.71^{cd}	129.8 ±1.44^{d}	38.5 ±0.28^{f}

[a] Means with the same superscript in a column do not differ significantly from one another ($p < 0.05$)

[1] Peak 1 and peak 2 are the peaks emerging before and after 90°C in the thermograms respectively

xii. Starch digestibility

Quantified values of the different fractions of enzyme-hydrolysed starch are plotted in Fig 16. HR(N) samples exhibited lower *in vitro* digestibility indicated by lower RDS and higher RS than LK(N) and WA(N) implicating the effect of amylose. The RDS level significantly improved after parboiling for all varieties and was highest for WA samples (66.6 to 94.8%). Extensive starch gelatinization along with molecular breakdown resulted in higher exposure of the starch fractions to the digestive enzymes as was also suggested by the DSC analysis. The dry heat parboiled rice samples were hence quickly digestible. HTST treated WA samples showed highest RDS along with higher levels of SDS. Severity of dry heat parboiling markedly reduced the RS content. RS reduced from 24.5% to 0.4% for HR, 21.2% to 1.9% for LK and 18.4% to 0.1% for WA making the samples almost devoid of RS. The findings indicate that the dry heat parboiled rice samples can have possible application in infant food formulae or may prove useful for post-operation recovery.

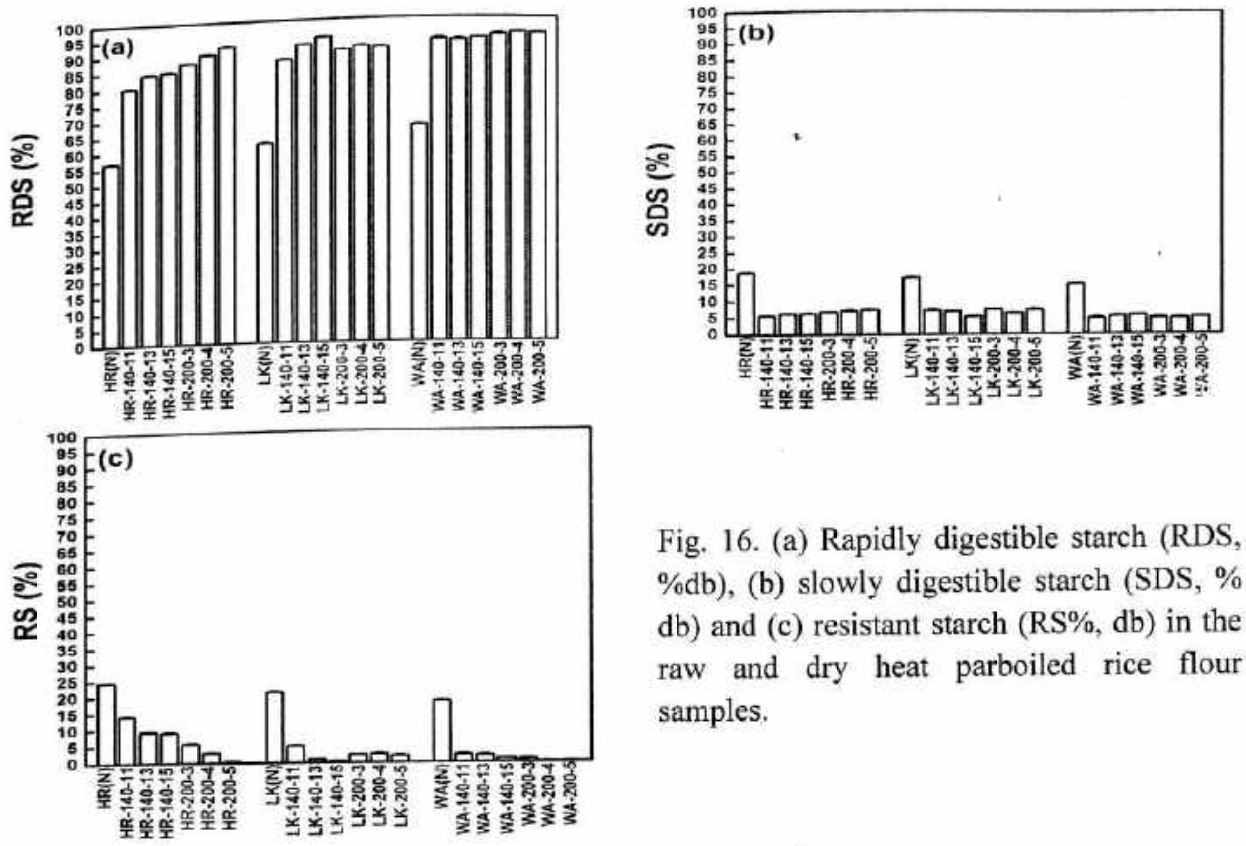


Fig. 16. (a) Rapidly digestible starch (RDS, %db), (b) slowly digestible starch (SDS, % db) and (c) resistant starch (RS%, db) in the raw and dry heat parboiled rice flour samples.

D. DRY HEAT PARBOILING 2

i. Colour measurement

None of the processed samples exhibited while belly indicating that starch was completely gelatinized. Colour values of rice flour samples are presented in Table 10. 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. 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.

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

Values for L/B, H and HRY (%) are given in Table 10. 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. 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

Table 10. Colour values and physical properties of raw and processed samples.

Samples	Colour readings					Physical properties						
	L	a	b	H	C	L (mm)	L/B	H (N)	HRY %	ρb (g/cm^3)	ρt (g/cm^3)	ε (%)
LK(N)	57.5±0.34^{k}	2.3±0.04^{a}	10.5±0.38^{a}	12.8±0.98^{b}	10.7±0.12^{a}	6.7±0.16^{i}	2.8±0.28^{c}	68.8±0.82^{b}	72.1±1.89^{a}	0.7±0.31^{b}	1.4±0.26^{a}	50.0±0.32
LK-1-11	31.0±1.21^{h}	2.7±0.07^{d}	10.7±0.19^{bc}	14.7±1.12^{d}	11.0±0.17^{b}	6.5±0.22^{h}	2.5±0.04^{b}	83.9±1.11^{d}	92.0±1.19^{c}	0.8±0.04^{c}	1.4±0.17^{a}	42.8±5714
LK-1-13	25.3±0.83^{c}	3.0±0.17^{gh}	10.7±0.74^{bc}	15.9±0.83^{gh}	11.1±0.15^{bc}	6.4±0.07^{fg}	2.4±0.31^{a}	85.4±0.98^{g}	98.0±0.21^{f}	0.8±0.04^{c}	1.4±0.22^{a}	42.8±0.14
LK-1-15	21.1±0.29^{b}	3.2±0.35ij	10.8±0.13^{ab}	16.9±1.25^{k}	11.3±0.19^{d}	6.4±0.15^{f}	2.4±0.14^{a}	89.3±0.56^{ijk}	100.0±0.00^{h}	0.9±0.18^{d}	1.5±0.29^{bc}	40.1±0.15
LK-3-11	29.8±1.44^{f}	2.5±0.29c	10.8±0.05^{bc}	13.7±2.11^{c}	11.0±0.11^{b}	6.5±0.28^{h}	2.4±0.17^{a}	84.1±0.39^{d}	91.2±0.12^{c}	0.8±0.13^{c}	1.4±0.37^{a}	42.8±0.57
LK-3-13	24.8±0.99^{c}	2.8±0.41^{ef}	10.8±0.49^{c}	15.1±1.36^{ef}	11.1±0.16^{bc}	6.4±0.19^{f}	2.4±0.16^{a}	84.9±0.18^{f}	96.6±0.67^{e}	0.9±0.14^{d}	1.5±0.19^{b}	40.4±0.17
LK-3-15	20.3±0.39^{a}	2.9±0.03^{fg}	10.9±0.35^{c}	15.6±0.69^{fg}	11.3±0.14^{d}	6.4±0.11^{f}	2.4±0.13^{a}	89.5±1.12^{l}	100.0±0.00^{h}	0.9±0.13^{d}	1.5±0.17^{b}	39.9±0.21
WA(N)	66.7±0.22^{l}	2.2±0.04^{b}	11.2±0.31^{d}	11.2±1.21^{a}	11.4±0.14^{cd}	6.4±0.23^{g}	2.9±0.18^{d}	59.8±0.17^{a}	73.8±1.29^{b}	0.6±0.07^{a}	1.4±0.26^{a}	57.1±0.33
WA-1-11	33.3±1.02^{j}	2.8±0.11^{fg}	11.4±0.77^{e}	14.1±1.48^{e}	11.7±0.17^{e}	6.3±0.26^{e}	2.5±0.33^{b}	83.3±0.19^{e}	94.6±0.39^{d}	0.7±0.06^{b}	1.4±0.31^{a}	50.0±0.28
WA-1-13	30.91±0.69^{h}	3.0±0.18^{gh}	11.5±0.37^{e}	15.1±1.55^{ef}	11.8±0.09^{fg}	6.2±0.17^{cd}	2.4±0.27^{a}	84.1±1.42^{e}	99.0±0.32^{g}	0.8±0.22^{c}	1.5±0.15^{b}	46.6±0.39
WA-1-15	28.1±1.12^{e}	3.3±0.38^{jk}	11.5±0.76^{e}	16.4±1.29^{hi}	11.9±0.22^{gh}	6.2±0.16^{bc}	2.4±0.19^{a}	87.8±0.87^{h}	100.0±0.00^{h}	0.8±0.18^{c}	1.5±0.07^{b}	46.6±0.43
WA-3-11	32.2±0.92^{i}	2.8±0.71^{ef}	11.4±0.99^{e}	14.1±1.37^{e}	11.7±0.16^{e}	6.3±0.26^{e}	2.4±0.26^{a}	83.5±0.97^{e}	94.1±0.45^{d}	0.8±0.17^{c}	1.5±0.24^{bc}	46.6±0.28
WA-3-13	30.1±0.12^{gh}	3.1±0.24^{hi}	11.5±0.51^{e}	15.6±1.92^{fg}	11.9±0.14^{gh}	6.3±0.12^{de}	2.4±0.22^{a}	88.7±0.29^{i}	100.0±0.00^{h}	0.8±0.15^{c}	1.6±0.29^{c}	50.1±0.31
WA-3-15	27.5±0.34^{d}	3.4±0.22^{k}	11.6±0.37^{e}	16.9±1.67^{j}	12.0±0.16^{i}	6.2±0.05^{a}	2.4±0.28^{a}	89.1±0.15^{j}	100±0.00^{h}	0.9±0.14^{d}	1.6±0.18^{c}	43.7±0.14

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

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.

iii. Porosity

Porosity is directly related to the L/B ratio of the kernels. Increase in bulk density upon processing resulted in decreased porosity (Table 10) 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.

iv. 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. EMC-S increased with process severity indicating progressively developed water uptake capacity (Fig 17a). 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.

v. 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 17b). 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.

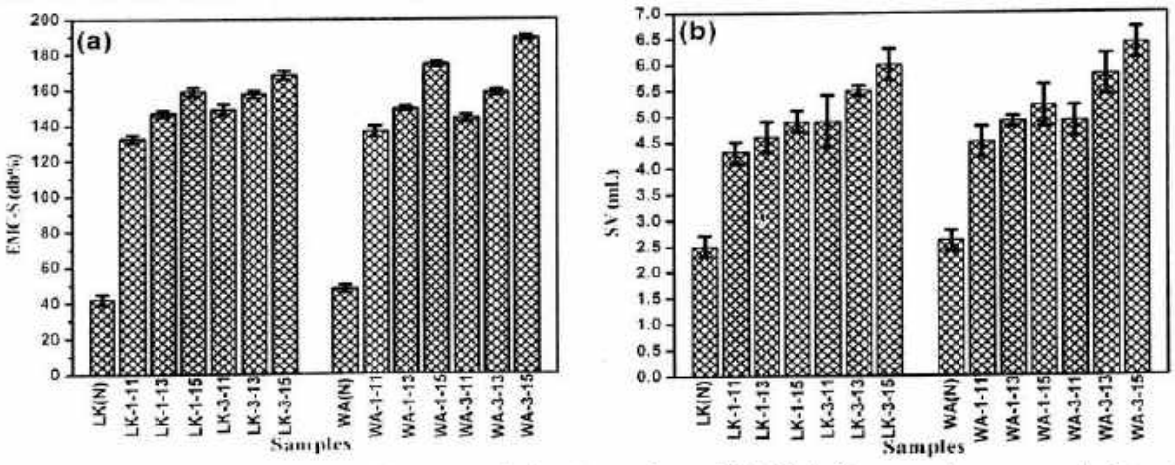


Fig. 17. (a) EMC-S of raw and processed rice kernels and (b) SV of raw and processed rice flour.

This was in accordance with the EMC-S and reflected more extensive gelatinisation of starch in these samples. 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. 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.

vi. Pasting properties

The pasting curves indicative of extensive change in starch structures upon roasting are given in Fig 18 (a and b) and the values of the pasting parameters are given in Table 11. 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. Processed LK samples showed patterns opposite to 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. Other factors like amylose-lipid complexes and protein also may affect the pasting properties which need further investigation. 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. 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. This property of becoming thick on cooling may prove to be useful for the prepared *Bhoja chaul* powder to be used as thickening agent in cooked food systems.

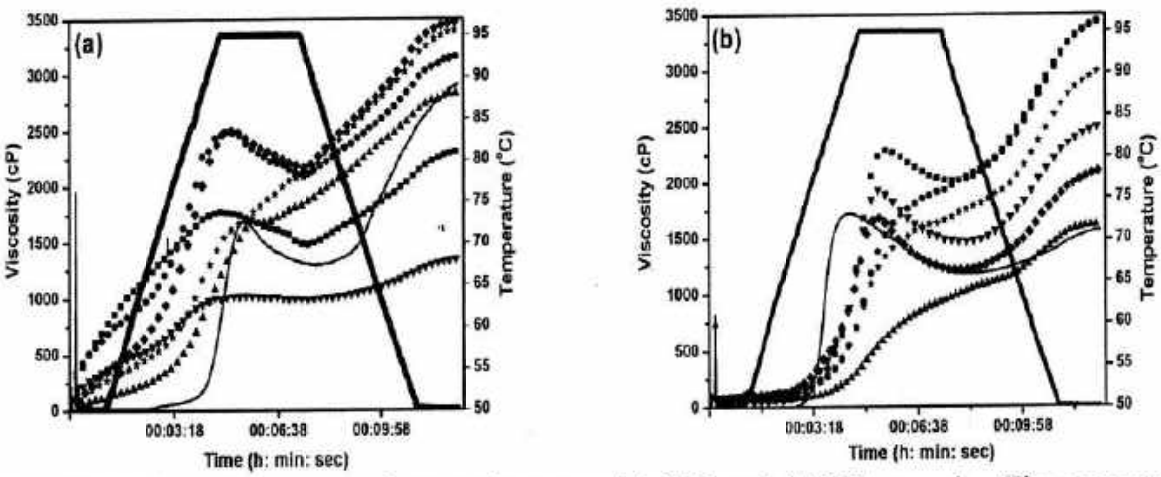


Fig. 18. RVA pasting curves of raw and processed (a) LK and (b) WA samples. The representations of the symbolic curves are as follows: Native (—), 1-11 (■), 1-13 (•), 1-15 (▲), 3-11 (▼), 3-13 (◆), 3-15 (✱).

Table 11. RVA pasting parameters of raw and processed samples.

Samples	PV (cP)	HPV (cP)	CPV (cP)	BD (cP)	SB (cP)
LK (N)	1687±3.44^{f}	1305±1.09^{d}	2880±1.45^{h}	382±2.12^{j}	1575±1.93^{m}
LK- 1-11	1771±2.98^{i}	1487±2.11^{e}	2291±2.15^{e}	284±1.00^{h}	804±2.19^{d}
LK- 1-13	2495±2.13^{m}	2100±1.56^{i}	3141±3.25^{j}	395±2.64^{k}	1041±3.21^{h}
LK- 1-15	1664±2.34^{e}	1835±4.21^{f}	2811±4.12^{g}	-171±2.69^{c}	976±2.54^{f}
LK- 3-11	1002±1.26^{b}	991±2.45^{a}	1337±2.56^{a}	11±3.94^{f}	346±3.12^{a}
LK- 3-13	2490±1.54^{l}	2155±3.22^{j}	3462±2.64^{m}	335±1.69^{i}	1307±1.08^{k}
LK- 3-15	1528±2.43^{d}	2079±3.11^{i}	3385±2.35^{k}	-551±2.64^{a}	1306±2.10^{k}
WA (N)	1720±3.92^{h}	1179±3.24^{c}	1557±1.68^{b}	541±2.18^{n}	378±3.45^{b}
WA-1-11	2273±2.43^{k}	2018±3.21^{h}	3426±2.02^{l}	255±0.34^{g}	1408±4.12^{l}
WA-1-13	1701±3.21^{g}	2192±2.12^{k}	3436±3.00^{m}	-491±1.32^{b}	1244±1.21^{j}
WA-1-15	803±3.69^{a}	1146±2.67^{b}	1610±2.22^{c}	-343±1.38^{d}	464±1.45^{c}
WA-3-11	1909±2.47^{j}	1472±3.42^{e}	2495±3.13^{f}	437±2.32^{l}	1023±2.22^{g}
WA-3-13	1674±1.69^{e}	1198±2.47^{c}	2092±3.21^{d}	476±1.89^{m}	894±3.16^{e}

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

vii. X-Ray diffraction

XRD of raw rice samples exhibited A-type starch crystalline pattern with strong peaks at 2θ = 15.2, 17.4, 18.1 and 23.3 (Fig 18a,b). Feeble peaks at 2θ 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. 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 2θ 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.

Gaussian fitting of the diffractograms of the processed samples (Fig 19 a and b 'insets') indicated that the crystalline peak regions of the curves shifted towards lower values of 2θ. 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

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

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 19c). The loss was marginally greater in processed WA samples as they attained higher degree of starch gelatinization.

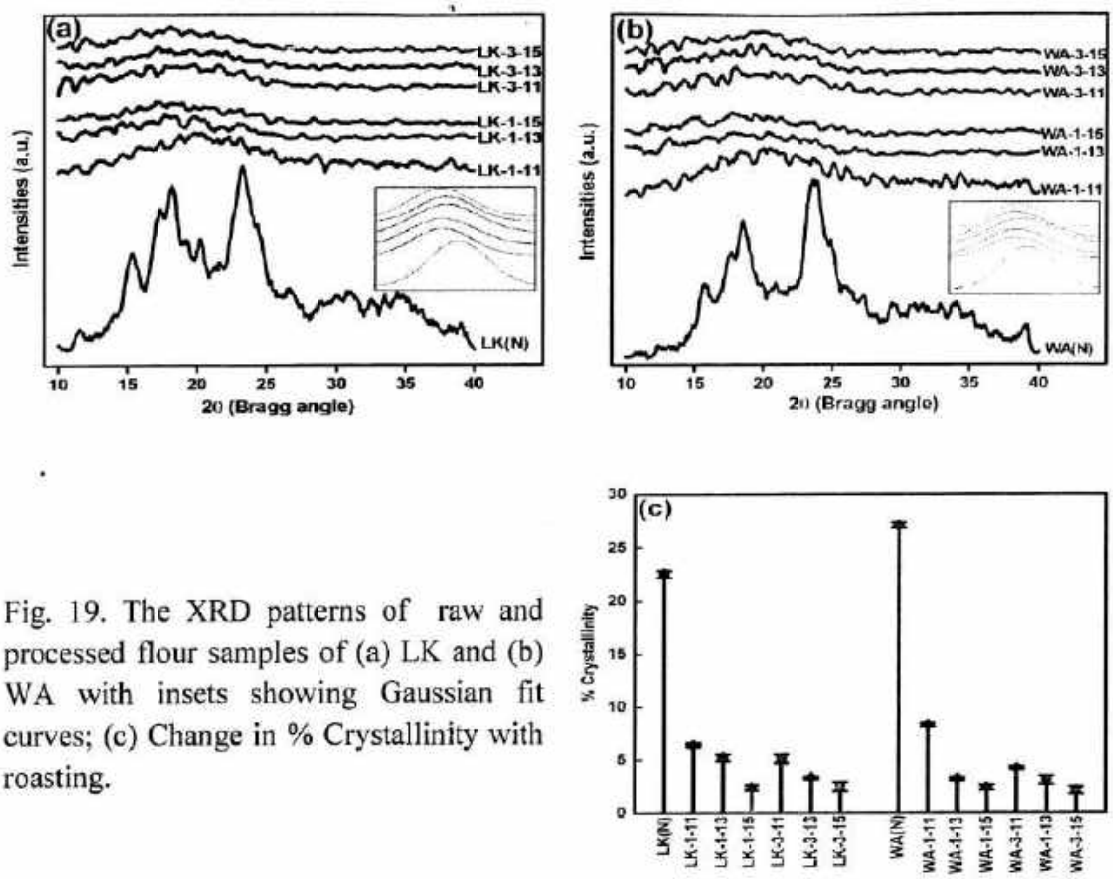


Fig. 19. The XRD patterns of raw and processed flour samples of (a) LK and (b) WA with insets showing Gaussian fit curves; (c) Change in % Crystallinity with roasting.

viii. Thermal properties

DSC thermograms of the raw and processed samples are presented in Fig 20 (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 20(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. 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[42] 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.

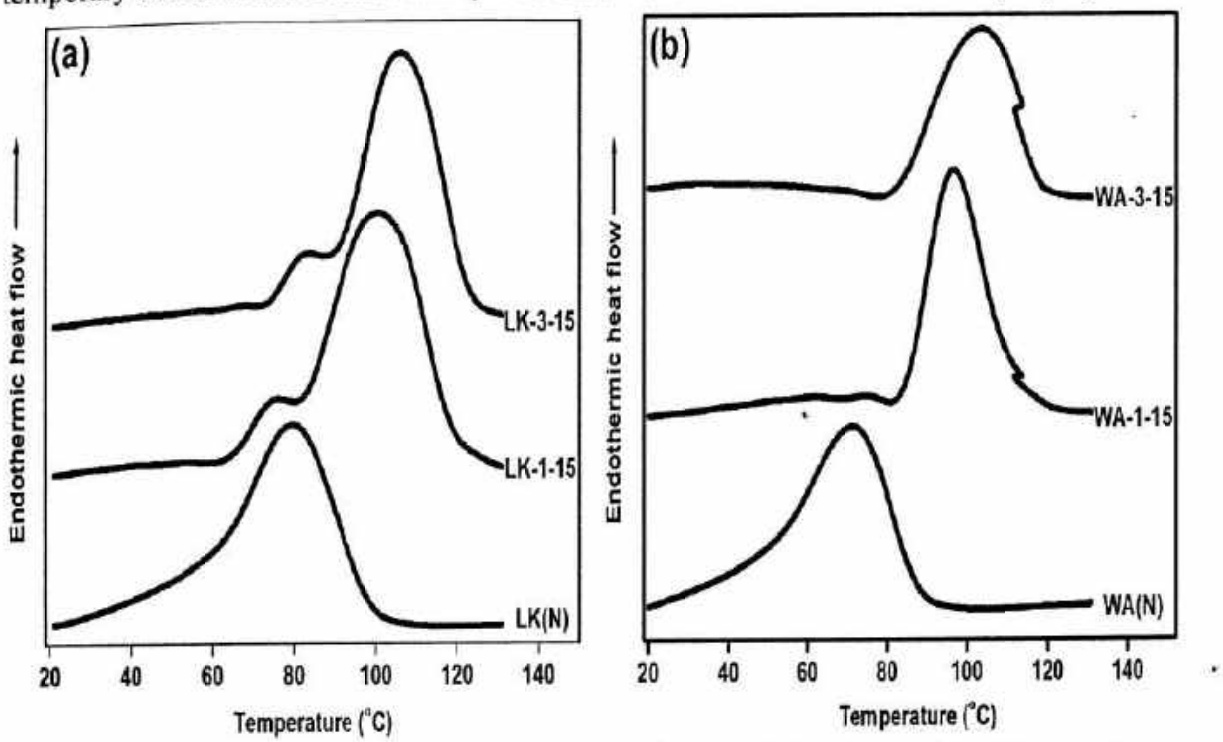


Fig. 20. DSC thermographs of pastes of raw and dry heat parboiled (roasted for 15 min after hot soaking for 1 and 3 min) (a) LK and (b) WA samples.

ix. 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 21a,b). 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.

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 21c,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. *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.

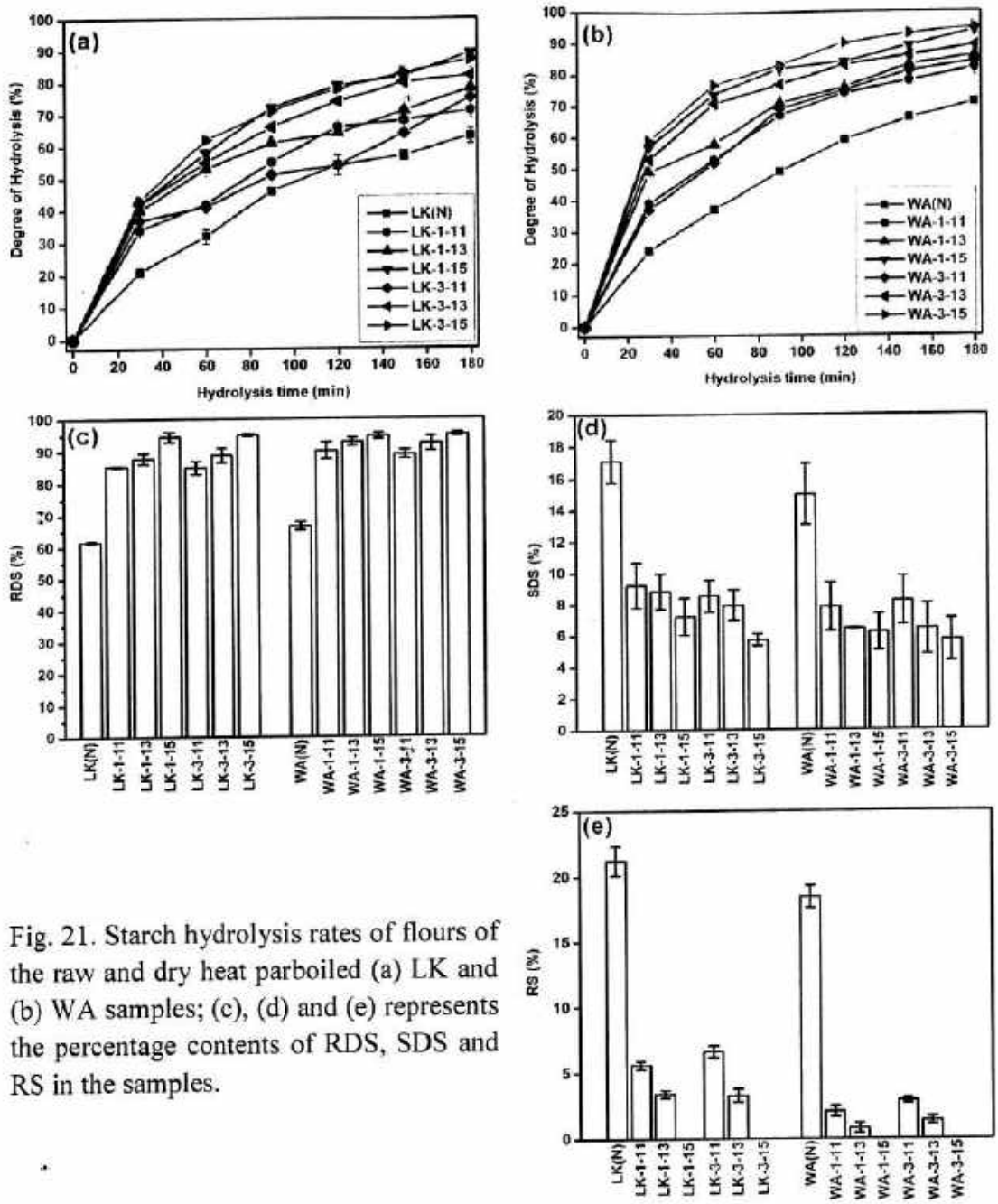


Fig. 21. Starch hydrolysis rates of flours of the raw and dry heat parboiled (a) LK and (b) WA samples; (c), (d) and (e) represents the percentage contents of RDS, SDS and RS in the samples.

x. Texture comparison of cooked rice and the RTE product

Values for the TPA parameters are plotted in Fig 22. Hardness of the soaked *Bhoja chaul* samples were higher than cooked rice. Process severity however resulted in marginal lowering of hardness values (Fig 22a) 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 22b) 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. Significantly lower values of springiness (Fig 22c) in both raw and processed WA samples were due to the higher adhesiveness and lower hardness values than LK samples. LK

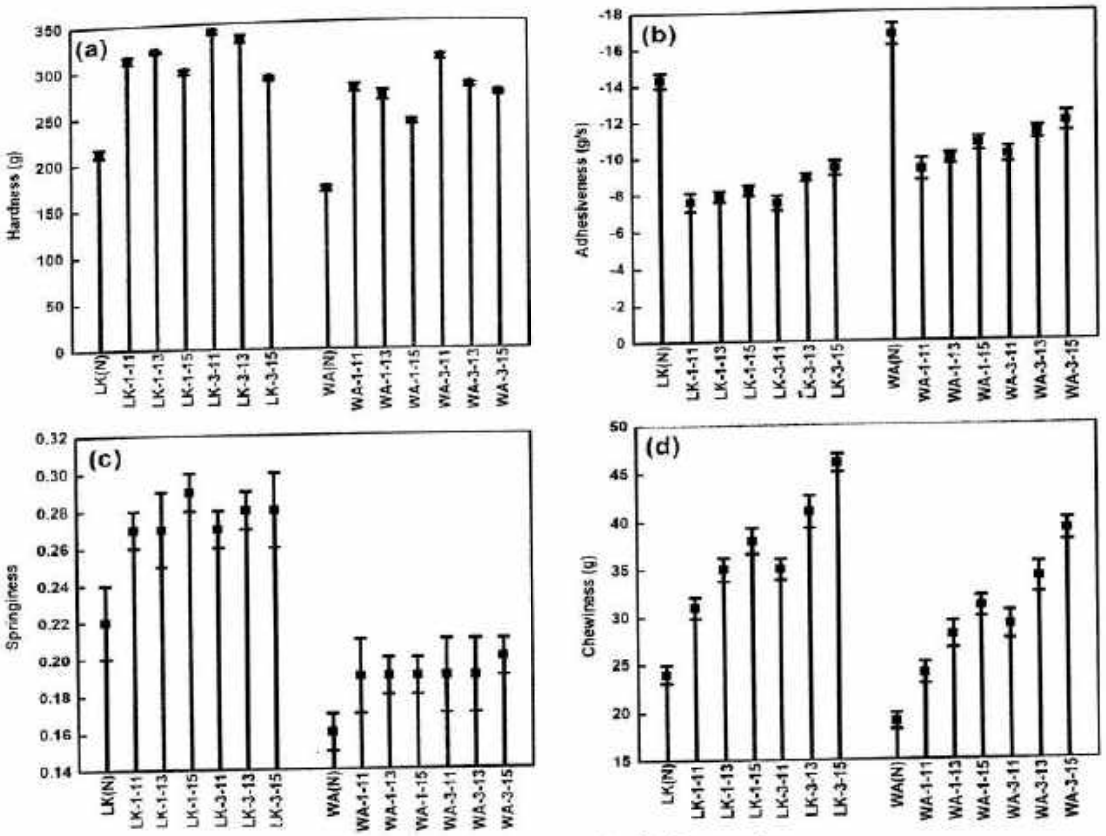


Fig. 22. TPA parameters of raw and dry heat parboiled samples.

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 22d). Chewiness is a positive quality attribute for *Bhoja chaul* acceptability. Cooked rice samples exhibited the lowest chewiness value.

xi. 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.

11. Conclusions summarising the achievements and indication of scope for future work:

The project dealt with studies on the effects of different parboiling procedures and conditions on Assamese rice varieties widely differing in apparent amylose content. Two traditional rice products, namely *komal chaul* and *bhoja chaul* were also characterized after processing by laboratory-scale parboiling techniques. *Kola chokua*, a pigmented low amylose rice variety was processed by the developed technique followed by necessary milling operations to produce *komal chaul*. Further, a

small-scale processing unit was developed for making *komal chaul* product and its working was demonstrated amongst the local SHGs of the region. The major conclusions drawn from the present work are enumerated below.

A. STEAM PARBOILING 1

i. Degree of gelatinization in all the four varieties was higher on pressure parboiling than open steam parboiling.

ii. Marked increase in water uptake properties indicated altered cooking properties attained by the low amylose and waxy rices after parboiling.

iii. Pressure parboiled waxy samples showed extensive drop in gelatinization temperature and increased hydration at lower temperatures as revealed by RVA. Formation of short amylopectin fine structures in these samples was indicated by sediment volume test and viscosity patterns.

iv. Development of crystallinity in the samples was found to be related to stretching vibration patterns of C-H bonds as revealed from FTIR analysis. Crystallinity, measured by XRD, however could not be related to that measured by FTIR. XRD can, therefore, be considered as a more suitable tool than FTIR for crystallinity study.

v. XRD of raw samples showed peaks at 2θ values near 20 which indicated 'in situ' points for amorphous amylose complex formation. A, B and V-type polymorphs were seen in pressure parboiled samples and only A and V-type polymorphs were observed in open steamed samples.

vi. The existence of V-type crystalline pattern was noted even in waxy parboiled rice.

vii. Loss in crystallinity with simultaneous increase in water uptake can be attributed to the amorphous fractions in parboiled rice. Waxy varieties are more susceptible to loss of crystallinity than the high amylose variety. Higher crystallinity observed in the most severely parboiled samples than the moderately parboiled samples may be related to higher retrogradation.

viii. Low amylose parboiled rice samples of both processing conditions showed higher content of resistant starch and can be commercially exploited.

B. STEAM PARBOILING 2

i. The pressure steaming of *chokua* paddy after hot soaking treatment gave *komal chaul* similar in texture to cooked rice. The textural properties of such pressure steamed rice gives soft textured rice kernels on soaking in water for 20 min at 50°C.

ii. Soaking in boiling water results in increased water uptake and altered properties indicating partial gelatinization of the starch. Surface gelatinization of the endosperm prohibits pigment migration on steaming.

iii. While the kernel lengths remained almost unchanged on open steaming, pressure steaming caused marked increase. This was accompanied by simultaneous decrease in the breadths, indicating elastic stress development in the kernels during steaming and subsequent drying.

iv. Increase in water absorption and thereby lowering of cooking time with severity of steaming was prominent.

v. Severe processing caused thermal degradation of starch polymer structure as revealed by the other physicochemical properties. Increase in the final slurry viscosity, hence may be attributed to leaching of the degraded simpler chains causing rise in slurry densities. The almost continuous rise in the slurry viscosity throughout the RVA cycle with minor breakdown indicated the thickening property of the pressure steamed samples, suggesting its suitability for specific uses.

vi. The changes in properties can be attributed to the effect of gelatinisation and thermal degradation of starch which may explain the high rate of starch digestibility of the pressure parboiled samples. On the other hand, *komal chaul* processed by open steaming of hot soaked paddy gave enzyme resistant starch.

vii. The laboratory scale method can be further used for analytical studies on *komal chaul* and can further scaled up.

C. DRY HEAT PARBOILING 1

i. Dry heat parboiling at 140°C resulted in notable improvement in head rice yield. All the samples showed almost 100% head rice yield which could be attributed to the increase in kernel hardness. The laboratory dry heat parboiling can hence be further studied as a replacement of commercially used steam parboiling process.

ii. The lower hardness and head rice yield of the high temperature treated samples was attributed to the development of a cavity in the center of the rice kernels. This cavity was formed as a result of rapid dislocation of the gelatinized starch of the endosperm towards the outer surface of the paddy and simultaneous dehydration as a result of high conduction heating. This also explained the reason for the reported splitting of dry heat parboiled rice on alkali spreading test.

iii. The dry heat parboiled kernels of *Kola chokua* and *Aghoni bora* became bolder in shape than raw rice kernels. Length to breadth ratio of *Ranjit* rice however remained almost unaltered indicating varietal differences in the arrangement of kernel material after parboiling.

iv. The kernels and flours of dry heat parboiled samples were highly hygroscopic.

v. In low amylose and waxy varieties, milder parboiling caused increased peak viscosity on cooking whereas severe parboiling caused drop in viscosity. The high amylose variety exhibited gradual fall in viscosity parameters with process severity.

vi. XRD and DSC curves suggested formation of additional B-type retrograded starch in the high amylose HR variety. Although peaks for amylose-lipid complex formation were feeble in the curves of HR, peaks for melting of starch-lipid complex in processed LK and W A samples were clearly evident from DSC curves.

vii. Dry heat parboiled samples were highly digestible as compared to raw rice. The extensive gelatinization and molecular breakdown led to the development of peculiar physicochemical characteristics.

D. DRY HEAT PARBOILING 2

i. High head rice yield was obtained by the laboratory-scale process. Decreased porosity indicated better packing properties of the product than the raw rice.

ii. No endothermic peak for retrogardation was observed in DSC meaning that the product did not retrograde after gelatinization due to absence of necessary moisture for retrogradation to occur.

iii. However, peak for amylose-lipid complex melting was evident in the severely processed samples. Longer chains of amylopectin may be able to bind lipid molecules.

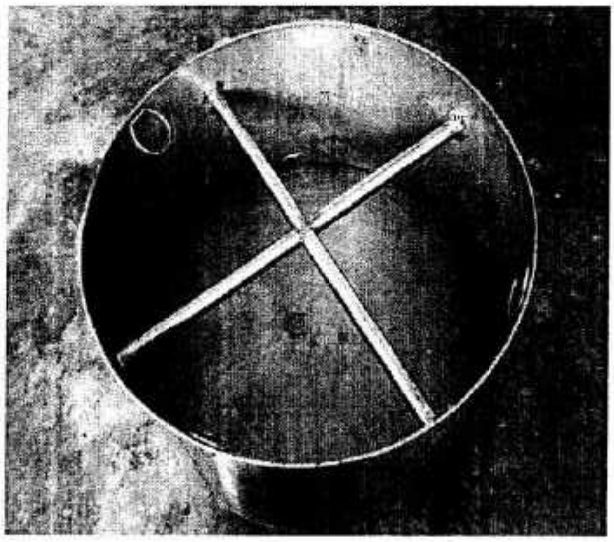
iv. Dry heat parboiling led to significant loss in crystallinity with minor reformation of each type of starch crystalline polymorphs during cooling and storage. Progressive increase in inter-planar spaces of the lamellae could be observed from the shift in the crystalline region of the diffractograms.

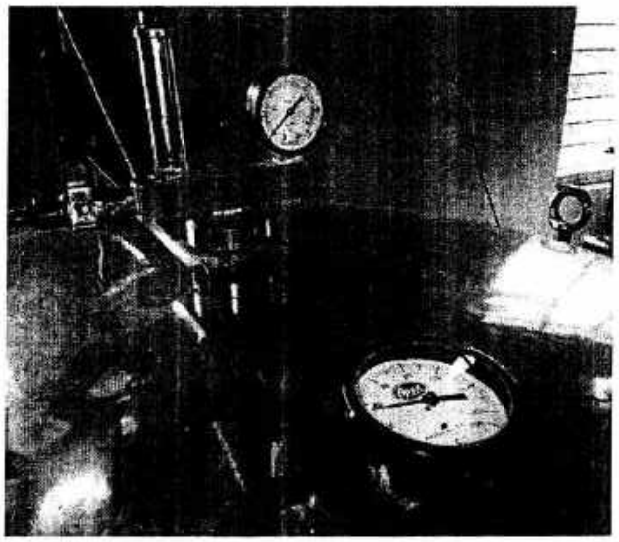
v. The product was highly digestible with very high amount of rapidly digestible starch and almost no resistant starch in the severely processed samples.

vi. 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 on soaking in water at room temperature than cooked rice or processed *Aghoni bora* samples.

E. The small-scale processing unit

The following design was created for constructing the small-scale processing unit for *Komal chaul*:





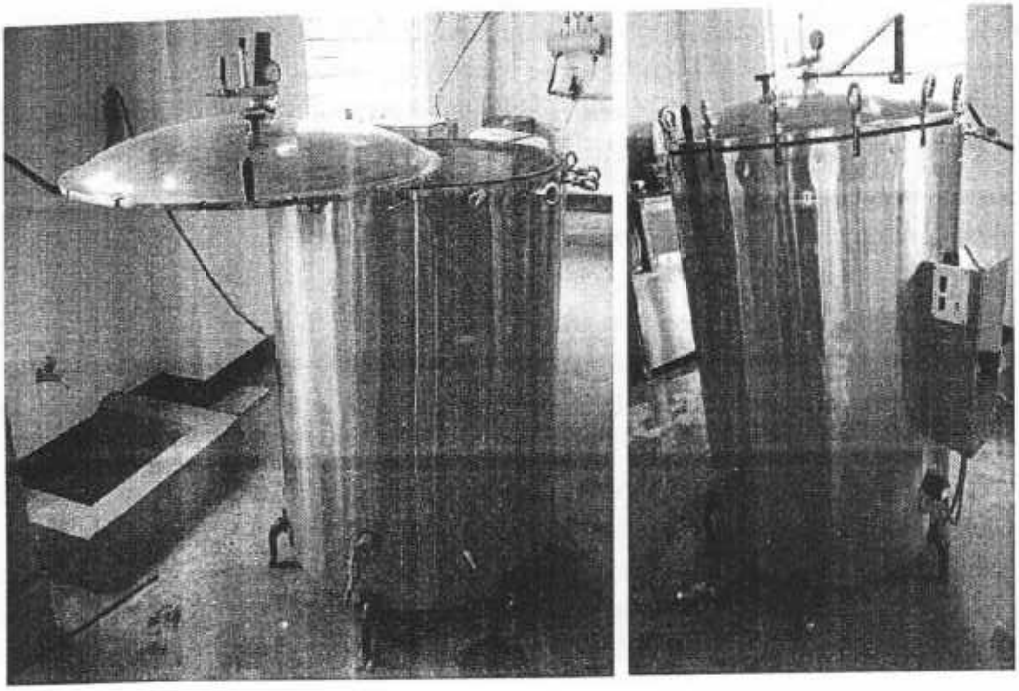


Fig. Processing unit

12. S&T benefits accrued:

i. List of Research publications

S No	Authors	Title of paper	Name of the Journal	Volume	Pages	Year
1	H. Dutta and C. L. Mahanta	Effect of hydrothermal treatment varying in time and pressure on the properties of parboiled rices with different amylose content	Food Research International	49	655-663	2012
2	H. Dutta and C. L. Mahanta	Laboratory process development and physicochemical characterization of a low amylose and hydrothermally treated ready-to-eat rice product requiring no cooking	Food Bioprocess Technology	7	212-223	2014

ii. Manpower trained on the project

a) Research Scientists or Research Associates: None

b) No. of Ph.D. produced: 01 (one), Thesis submitted

c) Other Technical Personnel trained: None

iii. Patents taken, if any: None

13. Financial Position:

No.	Financial Position/ Budget Head	Funds sanctioned		Expenditure	% of Total cost
		1st instalment	2nd instalment		
I	Salaries/ Manpower costs	2,30,400.00	5,00,000.00	3,09,161.00	14.22
II	Equipment	9,46,000.00		8,07,846.00	37.16
III	Supplies & Materials	2,00,000.00		2,83,415.00	13.04
IV	Contingencies	75,000.00		2,66,585.00	12.26
V	Travel	1,00,000.00		1,12,640.00	5.18
VI	Overhead Expenses	1,21,080.00		2,42,160.00	11.14
VII	Others, if any			-	
	Total	**21,72,480.00**		**20,21,807.00**	**93%**

14. Procurement/ Usage of Equipment

a)

S No.	Name of Equipment	Make/Model	Cost (FE/Rs)	Date of Installation	Utilisation Rate (%)	Remarks regarding maintenance/breakdown
1	Electronic balance	Denver, B215DDE	1,44,599.00	22/12/2011	100	Working in good condition
2	HPSEC column	Waters, WAT034207, WAT011520, WAT011520 WAT011530, WAT011540, WAT011565	3,38,554,00	01/11/2012	100	Working in good condition
3	Grain miller	A-Grain, RTE-21AG-07, RTE-07, RTE-08,RTE-15	1,51,355.00	21/06/2013	100	Working in good condition
4	Digital water bath	Voltam Furnace Industries	50,440.00	03/12/2012	100	Working in good condition
5	Sieve shaker	Alfa Instruments, Ai-031	51,008.00	23/08/2012	100	Working in good condition
6	Refrigerator	LG, GL365YVQG5	26,890.00	27/09/2011	100	Working in good condition
7	Computer system	SONY VAIO, VPCEG18FG	45,000.00	10/08/2011	100	Working in good condition

b) Plans for utilising the equipment facilities in future

The equipments purchased in the project are being used by the students of the Department in their M.Tech. and Ph.D. research work. All are properly maintained and will be used in the future.

Name and Signature with Date

Charu Lata Mahanta 27.11.2014

(Charu Lata Mahanta)
Principal Investigator

27.11.2014

(Tapan Kumar Gogoi)
Co-Investigator

Annexure-III

UTILISATION CERTIFICATE (2 COPIES)
FOR THE FINANCIAL YEAR - (ENDING 31ST MARCH)

1. Title of the Project/ Scheme: Characterization of starch properties in traditional rice products of Assam and development of a small scale processing unit for the products

2. Name of the Institution: Tezpur University
3. Principal Investigator: Charu Lata Mahanta
4. Department of Science & Technology sanction order No & date sanctioning the project: DST/SSTP/Assam/09/103

5. Head of account as given in the original sanction order: Demand No. 85
   3425 Other Scientific research (Major head)

6.	Amount brought forward from the previous Financial year quoting DST letter no and date in which the authority to carry forward the said amount was given	i. Amount : 461188/- ii. Letter No: DST/SSTP/Assam/09/103 iii. Date : 23/09/2013
7.	Amount received during the financial year (Please give DST letter/order no and date)	i. Amount: 5,00,000/- ii. Letter/Order No DST/SSTP/Assam/09/103 iii. Date : 23/09/2013
8.	Total amount that was available for expenditure (excluding commitments) during the financial year (Sr. No. 6+7)	Rs. 10,09,212/- (including Rs. 48024/- as interest earned from project fund)
9.	Actual Expenditure Incurred during the financial year (upto 31st March)	Rs. 8,10,515/-

10. Balance amount available at the end of the financial year: Rs. 1,98,697/-

11. Unspent balance refunded, if any (please give details of cheque no etc.): None

12. Amount to be carried forward to the next financial year (if applicable): Project Closed

UTILISATION CERTIFICATE

Certified that out of Rs 5,00,000/- of grants-in-aid sanctioned during the year 2013-2014 in favour of Registrar, Tezpur University under this Ministry/ Department letter/ order No DST/SSTP/Assam/09/103 dated 23/09/2013 and Rs 4,61,188/-on account of unspent balance of the previous year, Rs. 48,024/- being interest earned on project fund, a sum of Rs 8,10,515/- has been utilised for the purpose of research for which it was sanctioned and that the balance of Rs 1,98,697/- remaining utilised at the end of the year has been surrendered to Government (vide Challan no _____ dated _____)

Charu Lata Mahanta

Signature of PI

Date 11/03/14

Principal Investigator
pL of Food Engg. & Tech.
Tezpur University
ezpur -784 028, Assam

Signature of Registrar

Date

Registrar
Tezpur University

Accounts Officer of the Institute

Date

Finance Officer
Tezpur University

P.T.O.

Statement of Expenditure

Sr No	Sanctioned Heads	Funds Allocated (1st installment) On 26/05/2011	Funds Allocated (2nd installment) On 23/09/2013	Interest earned	Expenditure Incurred			Total (V+VI+VII)	Balance, if any	Remarks
					1st year 22/8/2011 to 31st march 2012	2nd year 1st April 2012 to 31st March 2013	3rd year 1st April 2013 To 31/st March 2014			
(I)	(II)	(III)	(IV)		(V)	(VI)	(VII)			
1.	Manpower costs	2,30,400	5,00,000	48,024	1,17,161	1,12,000	80,000	3,09,161		
2.	Consumables	2,00,000			1,25,968	24,200	1,33,247	2,83,415		
3.	Travel	1,00,000			-	44,923	67,717	1,12,640		
4.	Contingencies	75,000			-	9,469	2,57,116	2,66,585		
5.	Others, if any				-	-	-	-		
6.	Equipment	9,46,000			2,16,489	4,40,002	1,51,355	8,07,846		
7.	Overhead expenses	1,21,080			80,280	40,800	1,21,080	2,42,160		
8.	**Total**	**16,72,480**	**5,00,000**		**5,39,898**	**6,71,394**	**8,10,515**	**20,21,807**	**1,50,673/-**	

Unspent balance: 1,50,673/-
Income from the grant: Rs 48,024/-
Amount to be refunded: Rs 1,98,697/-

Name and Signature of Principal Investigator

Date: 4/9/14

Principal Investigator
Dept. of Food Engg. & Tech.
Tezpur University
Tezpur-784 028, Assam

Signature of Competent financial/ audit authority: _____

(with seal)

Date: _____

FINAL STATEMENT OF EXPENDITURE

1. Sanction Letter/ Order No and date of sanctioning the project:
   DST/SSTP/Assam/09/103

2. Total Project Cost:

   Sanctioned =Rs. 23,98,960/-
   Released= Rs 21,72,480/
   (Equipment= 9,46,000/-+ grant-in-aid general=7,26,480/-+ 2nd installment 5,00,000/-)

3. Date of Commencement of Project: 22/08/2011

4. Date of Completion of Project: 25/02/2014

5. Grant received in each year (financial year):

   a. 1st Year : 16,72,480/-
   b. 2nd Year : NIL
   c. 3rd Year : 5,00,000/-
   d. Interest, if any : 48,024/-
   b. Total (a+b+c+d+e): 22,20,504/-