Chapter 6

Conclusions and future work

6.1. Conclusions

The present research work was carried out on the broken rice of *Ranjit* variety of Assam. Size fractionation of broken rice yielded two fractions i.e., medium and small brokens, where the former is present in higher quantity. Therefore, medium broken rice was used for further study. Effect of different particle size on the physicochemical and pasting properties were studied and eventually investigated their effects on the eating quality of rice noodle. Rice flour with 150 µm showed better pasting properties, gel texture and functional properties than the other two particle size flours. Noodle prepared with 150 µm flour size showed comparatively better and acceptable noodle quality than the other two noodles, however with higher cooking loss and broken rates, which needs to be addressed. Rice starch isolated from medium broken rice flour was modified by HMT and OPT and their dual combinations as HMT-OPT and OPT-HMT. Modified starches were characterized by functional, pasting, crystalline, thermal, and rheological properties and *in vitro* starch digestibility which revealed the enhanced functionalities in comparison to the native counterpart. In the next phase, the modified starches were utilized in rice noodle production by substituting the medium broken rice flour at 10, 20, and 30% level, which resulted in overall improvement in the rice noodle quality that was comparable with the market rice noodle.

The major findings of the thesis are summarized in this Chapter.

6.1.1. Comparative analysis of chemical composition, functional, morphological and pasting characteristics of head rice and broken rice (Chapter 3A)

- Ranjit rice variety was identified as a grain of medium length and medium shape.
- Broken rice fractions were classified as medium brokens (passed through 2 mm sieve but retained on 1.7 mm sieve) and small brokens (passed through 1.7 mm sieve but retained on 0.85 mm sieve) by sieve analysis.
- Medium brokens (57.55 ± 4.91 %) was present in higher amount than small brokens (40.49 ± 4.65 %).
- Compared to medium brokens and head rice of the same variety, small

brokens had higher protein and fat contents and lower starch and amylose contents ($p < 0.05$).

- No significant difference was observed in the swelling power, solubility and oil absorption capacity of medium brokens and head rice.
- Medium brokens showed better pasting profile and higher gel hardness than small brokens.
- Presence of higher amount of damaged starch in small brokens was visible in SEM micrographs than medium brokens and head rice.
- Therefore, medium brokens exhibited properties that can be exploited for rice noodle making.

6.1.2. Chapter 3B: The effect of varied particle size of medium broken rice flour on the cooking, textural and sensory qualities of gluten free rice noodles (Chapter 3B)

- Significant differences in water absorption capacity, oil absorption capacity, swelling power, solubility, pasting properties, and gel hardness were noticed between the flours of varied particle sizes viz. 150, 180 and 212 μm.
- Flour with the smallest particle size (150 μm) showed better pasting properties and harder gel texture than 180 and 212 μm.
- Rice noodle prepared with 150 μm size flour showed considerably improved textural, sensory, and cooking qualities than the noodles made from larger particle size flours.
- However, the cooking loss and broken rate of the noodles made from 150 μm size flour were marginally lower than the maximum limit of a good quality rice noodle.

6.1.3. Process optimization of osmotic pressure treatment and heat moisture treatment of rice starch isolated from medium broken rice (Chapter 3C)

- In the current study, optimal heat moisture treatment and osmotic pressure treatment conditions for rice starch were determined by RSM with FCCD.
- The optimum treatment processes of OPT and HMT raised the final and setback viscosities, gel hardness, swelling power, and solubility of the modified starches.
- For maximum final viscosity, setback viscosity, gel hardness, and minimum

swelling power and solubility, the optimal process conditions for OPT were obtained at a temperature of 117 ^{o}C and heating time of 35 min, while for HMT the optimal results were obtained at a temperature of 111^{o}C, moisture content of 29 %, and heating time of 45 min.

- The optimal treatment processes raised the final and setback viscosities, gel hardness for both modifications, while decreasing the swelling power and solubility with increasing time and temperature (in OPT), and additionally moisture content in HMT.
- Thus, the current study provided significant scope and information for the utilization of OPTS and HMTS in new product development.

6.1.4. Characteristics of rice starches modified by single and dual heat moisture and osmotic pressure treatments (Chapter 4)

- Lower swelling power and solubility, higher amylose content, improved pasting stability, and harder gel texture were the notable changes observed in the rice starches subjected to single and dual HMT and OPT modifications. However, the rise in amylose content of OPTS was lesser than HMTS.
- OPTS showed relatively high PV and BD than HMTS and dual modified starch indicating relatively less paste stability. Dual modification improved paste stability that was substantially better than single modification, as seen by the significantly consistent hot paste viscosity values and low BD.
- All the modified starches showed weaker birefringence. Dual modified starches in particular displayed poorer birefringence with less well-defined quadrants and voids in the middle of the granule.
- HMTS and OPTS showed depression at the centre with eroded surface. Dual modifications caused more eroded and rougher surface, hollow depression, or groove; slightly folded inward structure as observed under SEM.
- The 1047/1022 ratio that reflects the crystallinity (amount of reduced short-range order of double helices) decreased in the order NRS > OPTS > HMT-OPTS = OPT-HMTS > HMTS suggesting the loss of crystallinity on modification.
- All the modified starches exhibited typical A-type pattern and decreased relative crystallinity. However, OPT caused less reduction in relative crystallinity than HMT. Both single and dual modification resulted in the

formation of amylose-lipid complex as evident by higher peak intensity at Bragg's angle (2θ) = 20°.

- Higher gelatinization temperatures were noted in the DSC thermograms of modified starches. All the modified starches had higher onset, peak, and conclusion temperatures than native starch, possibly due to their attenuated swelling behaviour. HMT had higher impact on thermal behaviour of starch than OPT.
- The G' of all modified starches was larger than their G" and had tan δ values smaller than one signifying the solid and elastic characteristics of starch gels.
- The elasticity of HMT-OPTS and OPT-HMTS were improved to higher extent than HMTS and OPTS as evident by their higher G'.
- The modified starch gels showed decreased complex viscosity with angular frequency depicting their shear thinning property.
- Reduction in digestibility with significant increase in RS (RS5 and RS3) and SDS after single and dual modification was observed during *in vitro* digestibility study.
- OPTS had higher RDS and lower SDS and RS than HMTS whereas HMT-OPTS and OPT-HMTS showed further decrease in RDS and increase in SDS and RS as compared to single HMTS and OPTS.
- HMT as a single and in dual form showed the higher effect on the starch digestibility than OPT.
- Thus, the findings of this Chapter are indicative of their possible use in rice noodle made from medium broken rice flour for improved functionality.

6.1.5. Quality evaluation of rice noodles developed from blends of medium broken rice flour and rice starches subjected to single and dual heat moisture and osmotic pressure treatments (Chapter 5)

- Substitution of medium broken rice flour with modified starches had significant effect on cooking, textural, and sensorial properties and digestibility of composite rice noodles, whereas native starch had no significant effect on the noodle quality enhancement.
- Cooking loss was substantially reduced when noodles were prepared by partial substitution of rice flour with modified starches, and the cooking loss was less than the maximum acceptable limit (10%).

- Dual modified starches showed greater impact on the cooking quality as evident by remarkable reduction in cooking loss, low rehydration, and swelling index as compared to single modified starches.
- Usage of 30% HMTS for noodles significantly reduced cooking loss and the value is comparable to MRN. However, substitution of OPTS up to 30% could not bring the cooking loss percentage down to the level of MRN.
- Cooking loss of HOSN20, HOSN30, OSHN10, OSHN20 and OSHN30 were comparable with the MRN. OPTS substitution at 10% level showed higher rehydration than MRN.
- Higher amount (30%) of HMTS and OPTS resulted in significant reduction in swelling index than 10 and 20% substitution. Noodles containing 20-30% dual modified starches showed even lower swelling index than the noodles containing 30% single modified starches.
- Surprisingly, no broken rate was generated by the noodles containing modified starches except in OSN10 and HOSN10, whereas the test control and noodles containing native starch showed high broken rate.
- The noodles prepared from the blends containing 30% HMTS and dual modified starches took significantly more time to cook due to their low swelling power and high gelatinization temperature.
- Higher level of modified starches significantly increased the hardness, springiness, chewiness, gumminess, tensile strength, and breaking distance of the noodles.
- Single modified starches up to 30% and dual modified starches below 20% yielded in noodles with comparable hardness to the market control.
- Results of sensory study indicated improved sensory attributes after incorporation with modified starch.
- Noodles made from blends containing 20-30% single and 10-20% dual modified starches scored higher for overall acceptability ($p > 0.05$). Overall acceptability score of noodles containing 30% dual modified starches had reduced possibly due to much higher firmness or hardness.
- Rice noodles prepared using modified starches showed attenuated digestibility as evident by reduced RDS and higher SDS and RS.
- When noodles were prepared by blending 30% HMT and 30 % OPT the amount of RS formed in both noodles were significantly different.

- The amount of RS formed at 30% level of substitution with single modified starch is comparable to the noodle containing 20% dual modified starches. Addition of dual modified starch at 30% level of substitution in the noodle blends caused highest increase in the RS content ($p < 0.05$).
- Thus, single modified starches by OPT and HMT up to 30% level and dual modified starches by OPT-HMT and HMT-OPT up to 20% level incorporation in medium broken rice flour can be effectively used to enhance the overall quality of rice noodle.

6.2. Future scope of the present study

- The present research work can be the basis for studies on the size fractionation of broken rice of other indigenous rice varieties of Assam with wide range of amylose content for quality evaluation.
- Utilization of medium brokens as well as smaller brokens to develop other convenience food products may be explored.
- Molecular level change of rice starches as a result of modification methods may be elucidated.
- Glycaemic index of the noodles produced by substituting the rice flour with modified starches may be investigated.