Chapter 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

5.1. Introduction

Asian countries like India (Assam in particular) mostly rely on polished rice consumption as the primary staple food. Prolonged consumption of white rice many times a day is associated with higher cases of obesity and type II diabetes [8], because the rice-based diet is rich in starch and low in proteins, fats and fibers that consequently increases the postprandial blood glucose. Thus, the demand for healthy and convenient rice products is on the rise [21]. Noodle-based diet is one of the nutritious and convenience foods with wide acceptance by consumers of all age groups. Rice noodle also or rice pasta or rice vermicelli is an alternative and good choice for diabetic patients, celiac patients as well as normal individuals as it can be processed to have high SDS and RS content to exhibit lower GI values and low RDS. The cooling process of the steamed dough in the noodle making process is modified to increase RS or SDS and lower the GI [22].

In Chapter 3B, gluten free rice noodles from medium broken rice flour of *Ranjit* variety were prepared which exhibited acceptable range of sensory attributes. However, the brokens rate and cooking losses were comparatively higher than the market rice noodle. Due to lack of gluten in rice flour, developing noodle with properties similar to wheat noodles is challenging. Gluten gives wheat noodles their cohesiveness and elasticity, which are not found in rice.

Many studies in literature have suggested that rice noodle quality can be improved by using modified rice starches (by physical and chemical methods) [3, 7, 15, 23-24]. It was observed in Chapter 4 that rice starches modified by single HMT and OPT and dual treatments (HMT-OPT and OPT-HMT) have exhibited low swelling power, solubility, and higher heat stability, as well as higher amylose content and gel hardness which have been reported to be desirable for manufacturing rice noodles [1-2]. Moreover, increase in dietary fractions of starches i.e. SDS and RS was also evident. Specific advantages of RS include its ability to prevent diabetes, obesity, inflammation, and maintain gut health [26]. It can help stop the onset and progression of diabetes by slowing down the rise in postprandial glucose, lowering body weight, promoting insulin production, and improving insulin sensitivity. Short-chain fatty acid synthesis and the diversity and number of helpful bacteria in the colon can both be influenced by RS.

The current study, for the first time, utilized OPT rice starch and its dual modified forms with HMT rice starch on rice noodle development. In this investigation, OPT starch, HMT starch, and dual modified HMT-OPT and OPT-HMT starches added to raw rice flour were used in the production of noodles and a comparative study of cooking, texture, *in vitro* digestibility and sensory properties was made.

5.2. Materials and methods

5.2.1. Preparation of rice flour

Medium broken rice was washed with tap water, air dried for 1 h and made into flour using a mixer grinder (Philips, model HL7505/00). Rice flour was sieved through a 150 μm sieve and dried at 40 ^{o}C for 24 h in a hot air oven until below 12% moisture content was reached. The flour was then packed zipper pouch in airtight container and stored in the refrigerator until further use.

5.2.2. Isolation of starch

Starch was isolated by alkaline steeping method from medium broken rice of *Ranjit* variety of Assam. The procedure of the starch isolation is same as given in section 3C.2.1. of Chapter 3C.

5.2.3. Heat moisture treatment of starch

Heat moisture treated starch (HMTS) was prepared as per the procedure as described in the section 4.2.2.1. of Chapter 4.

5.2.4. Osmotic pressure treatment of starch

Osmotic pressure treated starch (OPTS) was prepared as per the procedure as described in section 4.2.2.2. of Chapter 4.

5.2.5. Preparation of dual modified starch

Two dual modified starches were produced. To obtain HMT-OPT starch (HMT-OPTS), sstarch was modified by HMT followed by OPT. For OPT-HMT starch (OPT-HMTS), starch was modified by OPT followed by HMT. Detail procedure is described in the section 4.2.3. of Chapter 4.

5.2.6. Preparation of rice noodle

Composite rice noodles were prepared using medium broken rice flour and modified rice starch blends as per the composition listed in Table 5.1. The procedure is described in section 3B.2.7 in Chapter 3B. Rice noodle prepared with only rice flour (RFN) was used as the test control. Market rice noodle (MRN), a proprietary brand was used as the market control for comparison.

Table 5.1 The nomenclature of composite rice noodles based on the type and quantity of starches added.

Flour/Starch (g/100g)	Rice flour (g/100g)	Rice noodle code
Rice flour (RF)	100	RFN
Native rice starch (NRS)		
10	90	NSN10
20	80	NSN20
30	70	NSN30
Heat moisture treated starch (HMTS)		
10	90	HSN10
20	80	HSN20
30	70	HSN30
Osmotic pressure treated starch (OPTS)		
10	90	OSN10
20	80	OSN20
30	70	OSN30
Dual modified starch (HMT-OPTS)		
10	90	HOSN10
20	80	HOSN20
30	70	HOSN30
Dual modified starch (OPT-HMTS)		
10	90	OHSN10
20	80	OHSN20
30	70	OHSN30

N = Noodle

5.2.7. Physical properties of dry noodles

The water absorption (WA) and soluble loss (SL) of dry noodles were evaluated by the method described in [11]. Briefly, 3 g noodles were dried in an oven at 110 °C for 24 h followed by cooling in a desiccator, and then weighed. In a pre-weighed Petri plate, 2 g of dried noodles was soaked in distilled water for 24 h at ambient temperature. Following that, the noodles were precisely weighed and the WA of dry noodle samples was determined. After that, the weighed wet noodles were dried at 110 °C for 24 h and reweighed. The difference in weight between before and after soaking of the dry noodles was calculated as the percentage SL of dry noodles. The WA (%) and SL (%) were calculated by the given formulae,

$$WA\ (\%) = \frac{Weight\ of\ wet\ noodles}{Weight\ of\ dry\ noodles} \times 100 \qquad \text{Eq. (5.1)}$$

$$SL\ (\%) = \frac{Weight\ of\ loss}{Weight\ of\ dry\ noodles} \times 100 \qquad \text{Eq. (5.2)}$$

5.2.8. Cooking quality

The cooking quality of noodles was measured according to the method described in AACC approved methods of analysis, 66-50.01 with little modification. Detail procedure is described in section 3B.2.7.1. of Chapter 3B.

5.2.9. Texture measurement

The noodle strands were cooked for optimum cooking time. Cooked noodle strands were transferred to a strainer and cooled by immersing in cold water. The cooled noodle strands were used for the texture measurement. Detail procedure is described in section 3B.2.7.2. in Chapter 3B.

5.2.10. Sensory evaluation

A nine-point Hedonic scale was employed for the evaluation of sensory attributes and the procedure for the same is described in section 3B.2.7.3 of Chapter 3B.

5.2.11. *In vitro* digestibility of rice noodles

5.2.11.1. Preparation of enzymes

Pepsin solution: Pepsin solution was freshly prepared by dispersing 5 mg/ml pepsin and 5 mg/ml guar gum in 0.05 M HCl; guar gum was added to adjust the viscosity so as to maintain the sample in suspension form by preventing their sedimentation.

Enzyme mixture: Briefly, 300 mg pancreatin was dispersed in 20 ml water using magnetic stirrer for 10 min followed by centrifugation at 4000 rpm for 5 min. The cloudy pancreatin supernatant ≈15 ml was poured into a reagent bottle and 0.70 ml of amyloglucosidase (1200 U/ml and 1 ml invertase (3000 U/ml) were added and mixed.

5.2.11.2. Determination of free glucose (FG), G_{20}, G_{120} and total glucose (TG)

In vitro starch digestibility of the rice noodles was analyzed as per the method of Englyst et al. [5-6] and Ren et al. [17] with slight modification. The dry rice noodles strands were cooked at their respective optimum cooking time and mashed using a spatula. Then, 500 mg of mashed noodles was taken in 50 ml centrifuge tubes. To this, 25 ml 0.1 M acetate buffer (pH 5.2) and 3 glass balls were added, tubes were capped and the content was mixed vigorously using a vortex shaker. The tubes were kept at 100 ^{o}C for 30 min followed by vigorous vortexing to disrupt the content completely and cooled to 37 ^{o}C. To this, 0.3 ml invertase (3000 U/ml) was mixed and the tubes were incubated in shaking water bath at 37 ^{o}C for 30 min. From each sample, 0.2 ml hydrolysate was taken out and added to 4 ml absolute ethanol and vortexed. FG of the noodle samples was analyzed from this portion.

Similarly, 200 mg cooked and mashed noodle samples were weighed and taken in 50 ml centrifuge tubes. To this, 10 ml pepsin-guar gum solution was added and capped the tubes. Three glass tubes were added to the content in the tubes, vortexed and incubated in shaking water bath at 37 ^{o}C for 30 min to hydrolyze the proteins. Thereafter, 10 ml 0.1M acetate buffer (pH 5.2) was added to the tubes and gently mixed and incubated at 37 ^{o}C for 5 min. One sample was taken out from the water bath at one time and 5 ml enzyme mixture was added, capped, mixed gently and placed back in the water bath and incubation continued at 37^{o}C for exactly 120 min. Enzyme mixture was added to other samples as well in the similar way as above. Exactly after 20 min, the sample tubes were taken out from the water bath one by one (in the same sequence as the addition of enzyme mixture) and 0.2 ml hydrolysate was taken out and added to 4 ml absolute ethanol in centrifuge tubes, vortexed and G_{20} portions were determined. The tubes were placed back in the water bath and the incubation was continued at 37 ^{o}C. After 100 min (total incubation time is 120 min from the addition of enzyme mixture), 0.2 ml hydrolysate was taken out in the same way as above and mixed with 4 ml absolute ethanol; G_{120} portions were determined from these aliquots.

After the hydrolysates for G_{120} portions were collected, the tubes were vigorously mixed using a vortex mixer and placed at 100 ^oC for 30 min. The tubes were mixed manually followed by cooling in ice water for 15 min. Then, 10 ml 7M potassium hydroxide was added, mixed by inverting the tubes and the ice water incubation was continued for another 30 min, and 0.2 ml hydrolysate from each tube was added to 1 ml 1M acetic acid taken in centrifuge tubes. 40 µl amyloglucosidase (100 U/ml) was added to each tube, mixed and incubated at 70 ^oC for 30 min and then at 100 ^oC for 10 min. Tubes were cooled to ambient temperature and 12 ml absolute ethanol was added. These portions were used to determine the TG.

The hydrolysates of samples collected above for FG, G_{20}, G_{120} and TG were centrifuged at 4000 rpm for 5 min. Supernatant was used for determination of glucose content by phenol sulphuric acid method. Stock solution of standard glucose was prepared with a concentration of 2000 µg/ml. From the stock solution, glucose solutions were prepared with concentrations of 100, 200, 400, 500, 700, 1000, 2000 µg/ml and subjected to phenol sulphuric acid test. A standard curve was plotted from the absorbance readings taken at 490 nm.

The amount of glucose determined in the above experiments were used to calculated the following starch fractions in the rice noodle samples

$$RDS = (G_{20} – FG) \times 0.9 \quad \text{Eq. (5.3)}$$

$$SDS = (G_{120} - G_{20}) \times 0.9 \quad \text{Eq. (5.4)}$$

$$RS = (TG - G_{120}) \times 0.9 \quad \text{Eq. (5.5)}$$

5.2.12. Statistical analysis

All analyses, unless otherwise noted, were performed in several replicates, and the mean data are given. DMRT was used in the SPSS (28.0.1.1) to determine statistical differences between the means at a significance level of $p < 0.05$.

5.3. Results and discussion

5.3.1. Physical properties of dry noodles

The WA and SL of the rice noodles were significantly different ($p < 0.05$) as shown in Fig. 5.1. Noodles made from rice flour and native rice starch blends absorbed more water than the test control (RFN). WA increased as the amount of native starch was increased. On the other hand, noodles made from rice flour and modified starch blends absorbed less water than RFN. However, the extent of WA was much lower in the noodles made by incorporating HMT starch and dual modified starches than OPT starch incorporated noodle. Interestingly, the WA decreased as the amount of modified starch increased from 10% to 30%. Modified starches had low swelling power which might be the reason for decreased water absorption by the noodles produced using those starches. In comparison, MRN had the lowest water absorption percentage than all the prepared noodles.

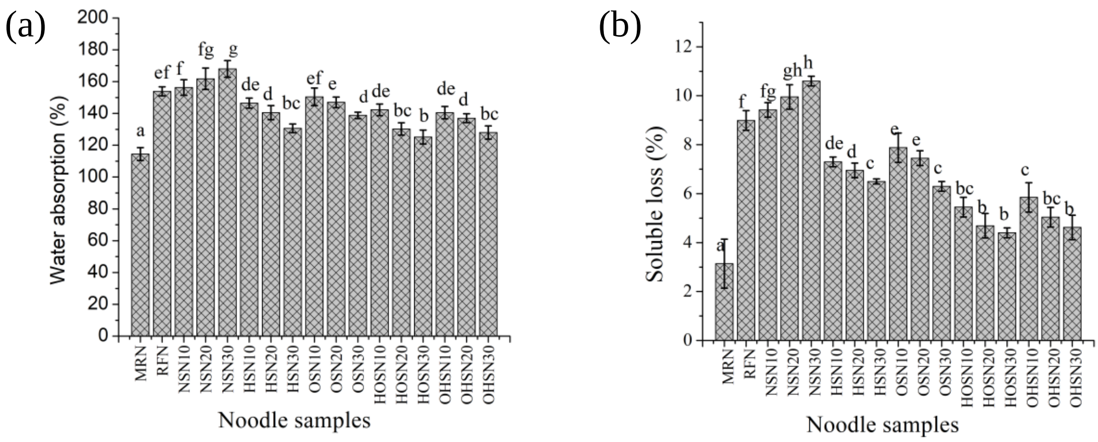


Fig. 5.1 Physical properties of dry noodles viz. water absorption (a), and soluble loss (b). Results presented in the bar diagram are the means of duplicate determinations. The error bars indicate the standard deviation of the mean. Significant difference ($p \leq 0.05$) exists between the mean values with different letters (a-h) on the bars.

SL of noodles made from rice flour and native starch blends were higher than RFN and the losses increased with increasing amount of native starch. This might be because of higher exudation of amylose as the amount of native starch increased in the noodle flour composite [11]. Noodles made from flour blends with modified starches showed lower soluble loss than RFN. The noodles made using OPT starch showed higher soluble loss than noodles made by incorporating HMT starch. Dual modified starches incorporated noodles showed much lower soluble loss than the noodles made using OPT and HMT starches. This might be explained by the low solubility of the modified starches (discussed in Chapter 4) that led to decreased amylose exudation and thus noodle soluble loss decreased. Moreover, the amylose must have reacted with the lipids present in the rice flour to form amylose-lipid complex that reduced the amount of free amylose.

5.3.2. Cooking properties

The results of cooking properties of noodles are presented in the Fig. 5.2. No significant difference was found in the cooking time of noodles containing native rice starch. There was little difference in the cooking time of noodles when 10-20% HMTS, 10-30% OPTS and 10-20% dual modified starches were used ($p > 0.05$). Significant rise in cooking time was noted in the noodles produced with 30% HMTS and dual modified starches (HOSN30 and OHSN30) as compared to the control, RFN. Noodle cooking times might vary depending on the gelatinization temperature of the individual starches or combinations of rice flour and starches [25]. The cooking time was positively correlated to the results of pasting time (results not shown) and pasting temperature of the starches (i.e. noodles containing starch with high pasting temperature took more time to cook) and RS content as discussed in Chapter 4. MRN cooked in significantly short time than all the other noodle samples. Cooking of RFN yielded broken rate of 8.33 ± 3.20% and the noodles prepared from blends of rice flour and native rice starch showed broken rate in the range 6.01-8.27%. Lack of a continuous network of retrograded starch in the noodle may be the cause of the development of broken strands [16]. Out of all the noodles prepared from blends of different modified starches, only OSN10 (1.8 ± 0.06%) and HOSN10 (1.3 ± 0.05%) showed some broken strands, which were significantly lower than the RFN. MRN and noodles other than OSN10 and HOSN10 did not generate brokens during cooking, indicating lower rigidity of the OPT starch. Lower broken rate in other samples might be attributed to the rigidity and strength of the gels formed at the level of incorporation of the modified starch [24].

Substitution with modified rice starches resulted in the formation of noodles with lower rehydration as compared to the control. The results are in positive corelation with the WA of the noodles (Fig. 5.1a). On the other hand, substitution with native rice starch resulted in high rehydration in the noodles and the cooked noodles appeared more swollen and sticky in texture. Significant decrease in rehydration was noticed when 20 and 30% single modified starches were incorporated in the noodles. OPTS substitution at 10% level showed higher rehydration than MRN. More reduction in rehydration was observed in noodles prepared with dual modified starches. The rehydration of MRN and the experimental noodles HSN30, HOSN10, HOSN20, OHSN20 and OHSN30 were not significantly different. The difference in rehydration is ascribed to the difference in the swelling power of the flours and starch blends used for the noodles [20]. Moreover, the moidified rice starches have lower swelling power than the native starch as a result of their respective physical modification processes due to the molecular restructuring, formation of amylose-lipid complex and amylopectin disruption (amylopectin portion is associated with swelling) [14]. Consequently, with the increase in the amount of modified starches, overall swelling power of the blends decreased and this factor affected noodle rehydration.

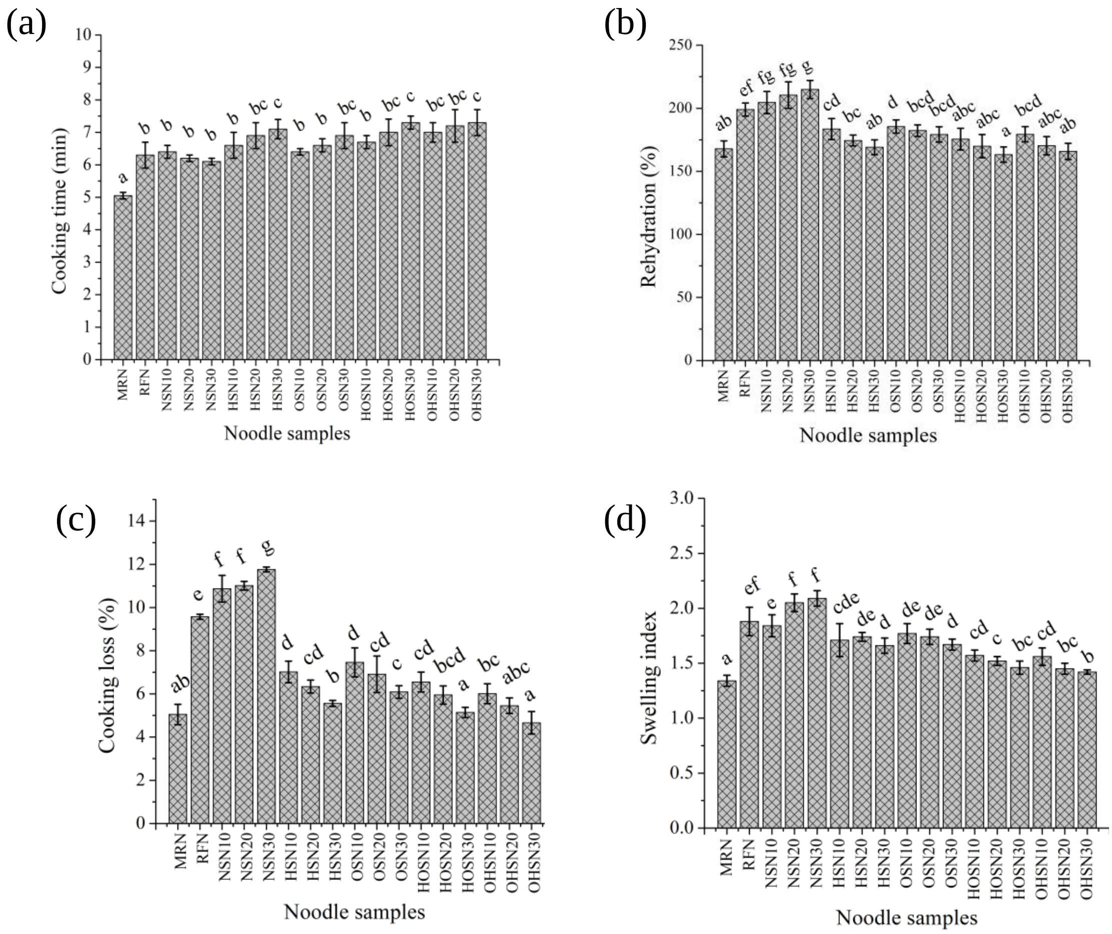


Fig. 5.2 Cooking properties viz. cooking time (a), rehydration (b), cooking loss (c) and swelling index (d) of noodles prepared from blends of rice flour and native, single and dual modified starches. Results presented in the bar diagram are the means of duplicate determinations. The error bars indicate the standard deviation of the mean. Significant difference ($p \leq 0.05$) exists between the mean values with different letters (a-g) on the bars.

Noodles containing native starch showed higher cooking loss. When noodles are cooked, loosely bound gelatinized starch particles are leached into the cooking water resulting in cooking loss. Thus, cooking loss strongly depends on the strength of retrograded starch networks [24]. High cooking loss results in cloudiness in cooking water, and sticky mouthfeel [25]; thus, it is desirable to reduce the cooking loss. The cooking loss decreased significantly when the noodles were produced from blends of rice flour and modified rice starches. Noodles containing OPTS showed relatively higher cooking loss than HMTS containing noodles. Usage of 30% HMTS for noodles significantly reduced cooking loss and the value is comparable to MRN whereas substitution of OPTS up to 30% could not bring the cooking loss percentage down to the level of MRN. Noodles prepared with dual modified starches showed more reduction in cooking loss as compared to single modified starches. Moreover, the reduction of cooking loss was more pronounced when higher percentage of modified starches was used, dual modified starch in particular. Cooking loss of HOSN20, HOSN30, OSHN10, OSHN20 and OSHN30 were comparable with the MRN. The possible reason for the reduction in the cooking loss may be the higher amylose content of modified starches that strongly bound to the other components of the starch and flour such as amylopectin, lipids, and proteins which consequently reduce the exudation of amylose [10]. It is notable to highlight that the cooking loss values of all the noodles prepared from the blends of rice flour and modified rice starches were less than the highest acceptable limit (10%) [25].

Swelling index of rice noodles increased when native rice starch was used in the blends. Substitution of modified starches to rice flour significantly reduced the swelling index. 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. Lower swelling index of the noodles is due to the low swelling power of the flour starch blends used. More reduced swelling index is related to low rehydration and hard texture in the noodles which is an indication of inferior noodle quality and therefore not desirable.

5.3.3. Texture measurement

The results of texture profile analysis of noodles are given in the Fig. 5.3. Noodles prepared with blends of rice flour and modified starches showed significantly different (higher) hardness than RFN and noodles incorporated with native rice starch ($p < 0.05$). Moreover, hardness increased as the amount of modified starch was increased ($p < 0.05$). Substitution of dual modified starches produced noodles with harder texture as evident by the higher hardness than the noodles prepared using single modified starches ($p < 0.05$). Noodles viz. HSN30, OSN30, HOSN10, and OHSN10 showed comparable hardness to the MRN. The amylose content is regarded as a significant component that favourably affects the hardness of noodles [25], which is consistent with the results of hardness (Fig. 5.3a) and amylose content (Fig. 4.1a, Chapter 4). Adhesiveness remains statistically unchanged when noodles were incorporated with modified starches. The market control showed highest adhesiveness ($p < 0.05$) (suggestive of additives usage). Springiness of the test noodles apparently increased when noodles were prepared using higher amount of modified starches (30%) and was statistically similar to the market control. OSN30 and HOSN20 showed relatively higher cohesiveness than the other noodles and test control ($p < 0.05$). However, the MRN showed the highest cohesiveness ($p < 0.05$). The noodles made from the blends of rice flour and modified starches showed higher chewiness [18] possibly due to higher hardness as a result of substitution with modified starches having high amylose content [7]. Native starch did not affect the noodle gumminess ($p > 0.05$). On the other hand, substitution of modified starches showed significant effect on the noodle gumminess as evident by their higher value than RFN. HOSN30 showed similar gumminess values as MRN. The results of tensile test of noodles are given in the Fig. 5.4. Tensile testing assesses the breaking strength of noodle and breaking distance indicating the ability to resist breakdown [7]. RFN showed relatively low tensile strength and breaking distance indicating its low extensibility. Substitution of native starch did not affect the tensile strength and breaking distance. On the other hand, noodles prepared with blends of rice flour and modified starches significantly increased both indices ($p < 0.05$). Moreover, dual modified starches showed more pronounced impact on the tensile strength and extensibility of the noodles than the single modified starches. The tensile strength of MRN is comparable with the noodles made from 30% single modified starches and 20-30% dual modified starches. Interestingly, breaking distance of maximum number of noodles were comparable to MRN. Substitution of dual modified starches at 30% level markedly increased the breaking distance. Thus, the results of noodle texture so obtained suggested that the single HMT, OPT and dual HMT-OPT and OPT-HMT starches could improve the

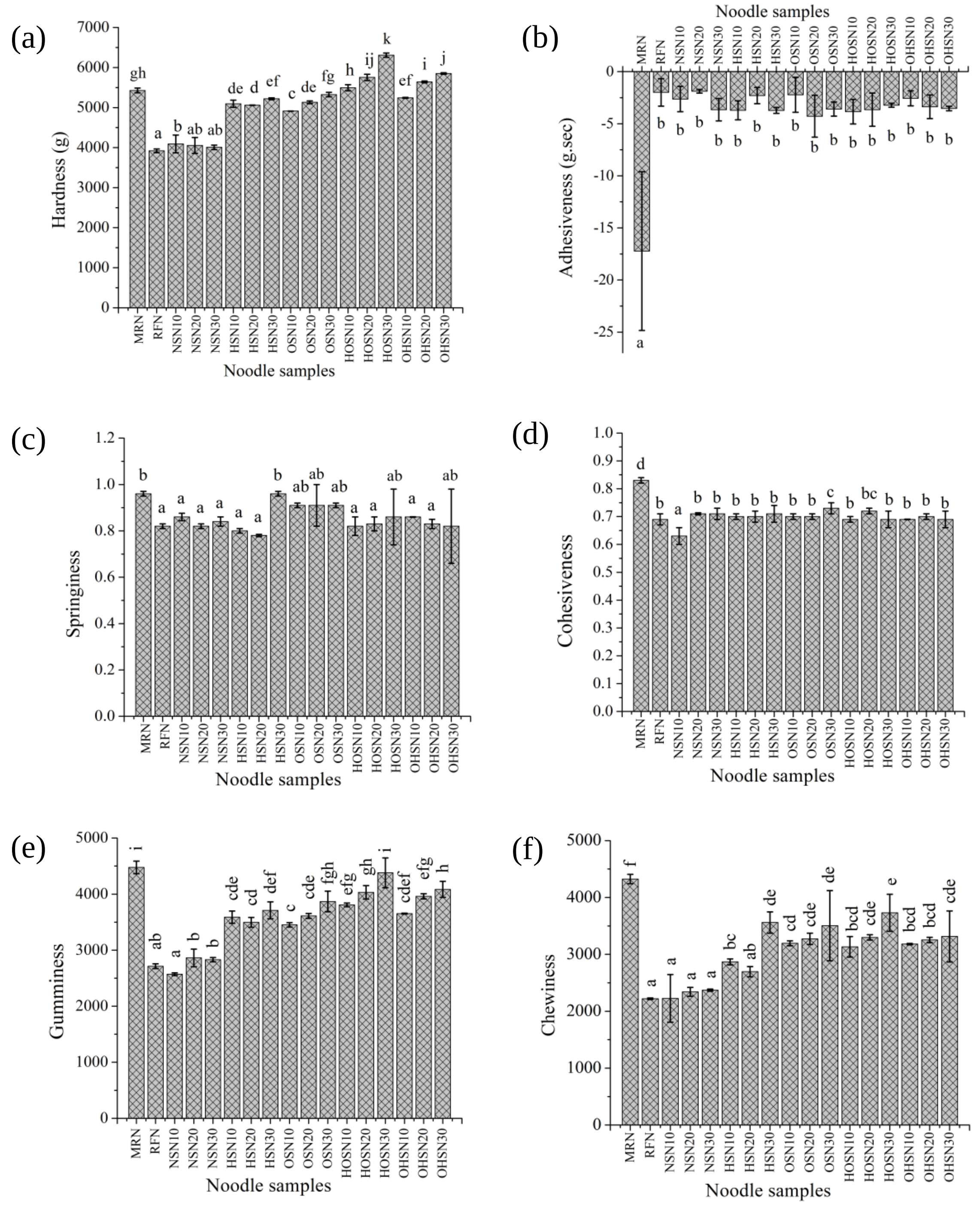


Fig. 5.3 Texture properties of noodles viz. hardness (a), adhesiveness (b), springiness (c), cohesiveness (d), gumminess (e), and chewiness (f). Results presented in the bar diagram are the means of 5 replicates. The error bars indicate the standard deviation of the mean. Significant difference ($p \leq 0.05$) exists between the mean values with different letters (a-k) on the bars.

textural attributes of noodle to be at par with market rice noodle. However, substitution of single and dual modified starches more than 20% led to harder noodles with higher chewiness and gumminess.

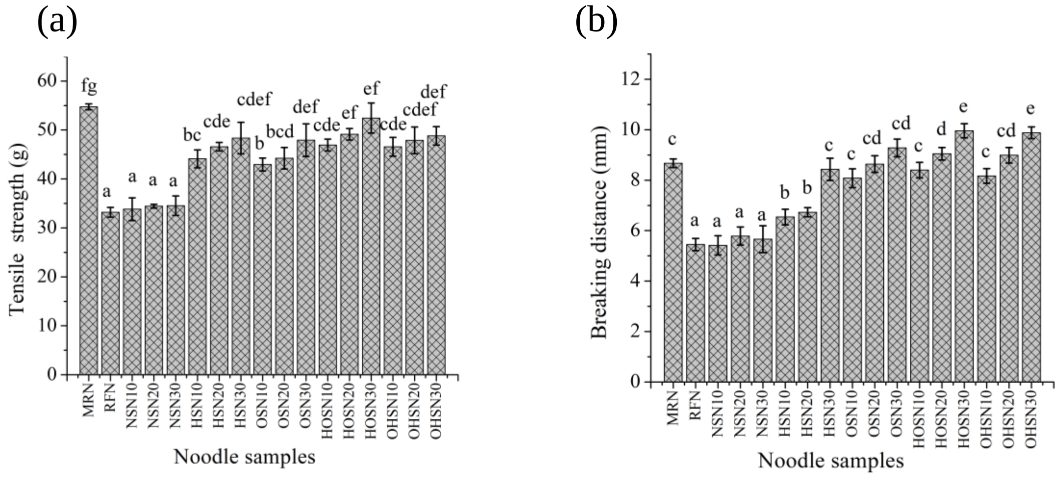


Fig. 5.4 Tensile properties viz. tensile strength (a) and breaking distance (b) of noodles prepared from blends of rice flour with native, single and dual modified starches. Results presented in the bar diagram are the means of 5 replicates. The error bars indicate the standard deviation of the mean. Significant difference ($p \leq 0.05$) exists between the mean values with different letters (a-g) on the bars.

5.3.4. Sensory evaluation

Noodles prep ared from rice flour and blends with native and modified rice starches were evaluated for colour, appearance, firmness, elasticity, tooth packing and overall acceptability and the results are depicted in Fig. 5.5. Colour scores of the noodles containing modified starches were relatively higher than RFN and noodles containing native starches. Higher colour scores indicated more whiteness which is a desirable attribute in rice noodles. Appearance score of RFN and the noodles containing native starch did not differ significantly. There was no significant difference among the appearance of the noodles containing modified starches. However, an apparent increase in appearance score of HSN20, HOSN10 and OHSN20 and their comparability with MRN was noticed. There was no statistical difference in the firmness and elasticity of RFN and noodles containing native starch. MRN scored the highest in firmness and elasticity. Substitution of modified starch (20-30%) in the noodle blends apparently increased the firmness and elasticity as evident by the comparable scores with MRN (p >

0.05). Noodle made from rice flour and blends containing native starch scored low for tooth packing. Application of modified starch in the noodles apparently increased the tooth packing score than RFN ($p > 0.05$). MRN scored significantly high score in tooth packing indicating low amount of masticated noodle stuck in the teeth. Overall acceptability of RFN and noodles containing native starches were not different statistically. Higher overall acceptability score of noodles (7.1-7.7) were noted when 20-30% single and 10-20% dual modified starches were used ($p < 0.05$). Overall acceptability of noodles containing 30% dual modified starches reduced possibly due to harder texture.

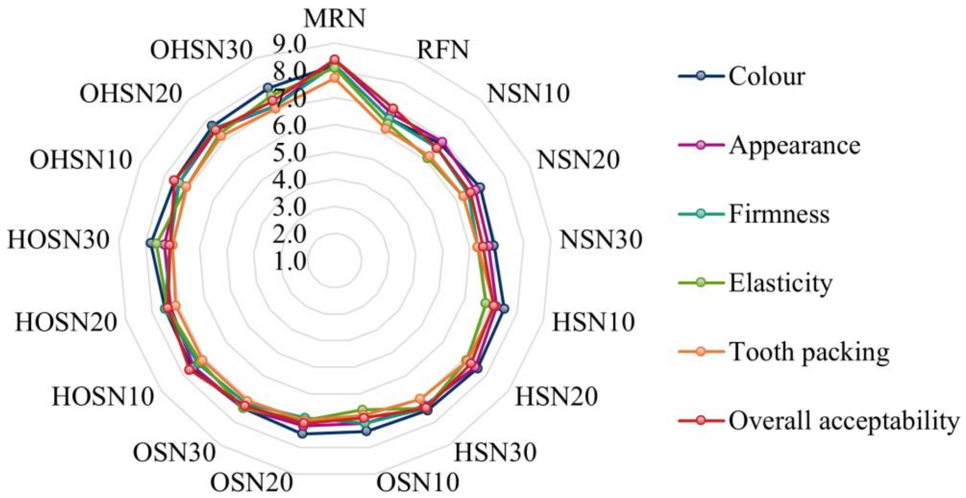
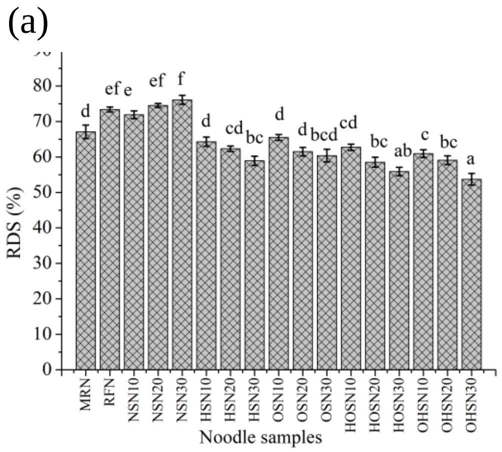


Fig. 5.5 Sensory attributes of noodles prepared from blends of rice flour with native, single and dual modified starches.

5.3.5. *In vitro* starch digestibility of rice noodles

The results of *in vitro* starch digestibility of rice noodles depicted in Fig. 5.6 showed significantly different RDS, SDS and RS content of noodles. Substitution with native starch progressively increased the RDS of noodle. Noodles made by substituting with modified starches showed significantly different and lower RDS content than the RFN ($p < 0.05$). Apparent decrease in RDS was observed when the amount of modified starches were increased in the noodle blends ($p < 0.05$). However, the RDS of MRN was lower than RFN but higher than most of the test noodles containing modified starches except HSN10, OSN10. Significantly low SDS of noodle than RFN was observed when native starch was used at 30% to the noodle blends. Noodles made from blends containing modified starch showed higher SDS than the control ($p < 0.05$). Moreover, increase in amount of modified starches apparently increased SDS of noodles. OHSN30 showed significantly higher amount of SDS than other noodles. Higher SDS as observed in the noodles is possibly due to the presence of higher amount of amylose and disrupted amylopectin mix [9]. SDS of MRN was higher than the RFN but lower than the noodles containing modified starches ($p < 0.05$).



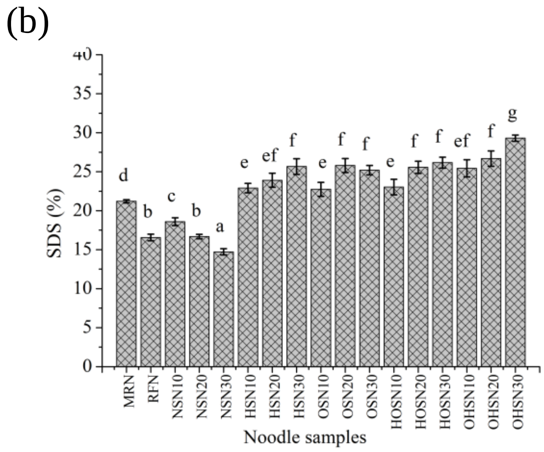
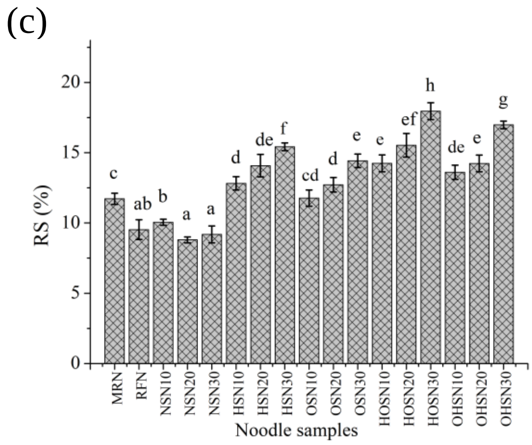


Fig. 5.6 Rice starch fractions viz. RDS (a), SDS (b), and RS (c) of noodles obtained by *in vitro* starch digestibility study. Results presented in the bar diagram are the means of 2 replicates. The error bars indicate the standard deviation of the mean. Significant difference ($p \leq 0.05$) exists between the mean values with different letters (a-h) on the bars.



No significant difference in the RS content was observed between RFN and the noodles containing native starch ($p > 0.05$). Increase in the amount of native rice starch reduced the total lipids and proteins without much variation in the amylose content, which could be the reason for non-significant change in RS. All the other noodles containing single and dual modified starches showed substantial increase in RS content than RFN with an increase in their amount of substitution. There was no significant difference in RS of the noodles containing 10-20% HMT starch and 10-20% OPT starch. When noodles were prepared by blending 30% HMT and 30 % OPT the amount of RS formed in both noodles were significantly different. Addition of dual modified starch in the noodle blends caused highest increase in the RS content at 30% level of substitution ($p < 0.05$). The amount of RS formed at 30% level of substitution with single modified starch is comparable to the noodle containing 20% dual modified starch.

Amylose content is inversely related to RDS and positively related to SDS and RS [12]. Modified starches contain higher amylose content than the native rice starch and rice flour. Substituting rice flour with modified starch must have increased the amylose content of the blends. Amylose can form V-type structure in starch with lipid (amylose- lipid complex), which is more resistant to digestive enzymes. Lipid can interact with amorphous amylose (amorphous amylose-lipid complex, Type I) and crystalline amylose (crystalline amylose-lipid complex, Type II), and the latter is more resistant to enzyme digestion [12]. Furthermore, the noodle processing involved gelatinization and retrogradation, which must have generated retrograded starch [4]. The short-term retrograded starch is formed when gelatinized noodle dough or strands are cooled [13]. This is another possible reason for the high RS content in noodles made from blends containing modified starches, which are more resistant to enzyme hydrolysis. This was possibly due to the formation of more long chain amylopectin that can form a double helix within a compact crystalline structure and also associated with the lipid (crystalline amylose-lipid complex), which resists enzyme access and thus increased RS content [12]. V-type structure is absent in native starch and possibly is the reason for low RS in the noodles containing native starch. Hence, if V-type starch structure is formed in the noodles that would be during noodle processing with the available lipid in the rice flour. On the other hand, modified starches possess significant amount of V-type starch as detected by XRD (discussed in Chapter 4) and retrograded starch as a result of their modification, which must have added up the RS content. Furthermore, steaming during noodle processing process also must have induced RS formation [19].

5.4. Conclusion

The present study revealed the suitability of single and dual modified rice starches in composite rice noodle making. Substitution of modified starches with rice flour had significant effect on the cooking, textural, and sensorial properties, and digestibility of rice noodles. Cooking loss was substantially reduced when noodles were prepared using 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. 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. Surprisingly, almost no broken rate was generated by the noodles containing modified starches. However, the noodles prepared from the blends containing 30% dual modified starches took significantly more time to cook. 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% incorporation and dual modified starches below 20% yielded in noodles with comparable hardness to the market control. Results of sensory study indicated improved sensory attributes as a result of modified starch usage. Noodles made from blends containing 20-30% single and 10-20% dual modified starches scored higher in overall acceptability. Rice noodles prepared using modified starches showed reduced 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 starch. 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 and dual modified starches by OPT and HMT can be effectively used with medium broken rice flour to improve the overall quality of blended rice noodles.

Bibliography

[1] Ahmed, I., Qazi, I. M., Li, Z., and Ullah, J. Rice Noodles: Materials, Processing and Quality Evaluation: Rice Noodles: Materials, Processing and Quality Evaluation. *Proceedings of the Pakistan Academy of Sciences: B. Life and Environmental Sciences*, 53(3):215-238, 2016.

[2] Bhattacharya, M., Zee, S. Y., and Corke, H. Physicochemical properties related to quality of rice noodles. *Cereal Chemistry*, 76(6):861-867, 1999.

[3] Cham, S. and Suwannaporn, P. Effect of hydrothermal treatment of rice flour on various rice noodles quality. *Journal of Cereal Science*, 51(3):284-291, 2010.

[4] Collado, L.S. and Corke, H. Noodles: Starch. In: Encyclopedia of Food Grains, 2nd ed. Wrigley C, Corke H, Seetharaman K, Faubion J eds. Oxford: Academic Press, 64–71, 2016.

[5] Englyst, H. N., Kingman, S. M., and Cummings, J. H. Classification and measurement of nutritionally important starch fractions. *European Journal of Clinical Nutrition*, 46:33-50, 1992.

[6] Englyst, K. N., Englyst, H. N., Hudson, G. J., Cole, T. J., and Cummings, J. H. Rapidly available glucose in foods: an in vitro measurement that reflects the glycemic response. *The American Journal of Clinical Nutrition*, 69(3):448-454, 1999.

[7] Hormdok, R. and Noomhorm, A. Hydrothermal treatments of rice starch for improvement of rice noodle quality. *LWT-Food Science and Technology*, 40(10):1723-1731, 2007.

[8] Hu, E. A., Malik, V. and Sun, Q. White rice consumption and risk of type 2 diabetes: meta-analysis and systematic review. *The BMJ*, 344: e1454, 2012.

[9] Huang, T. T., Zhou, D. N., Jin, Z. Y., Xu, X. M., and Chen, H. Q. Effect of debranching and heat-moisture treatments on structural characteristics and digestibility of sweet potato starch. *Food Chemistry*, 187:218-224, 2015.

[10] Jeong, S., Kim, Y., Ko, S., Yoon, M. R., Lee, J. S., and Lee, S. Physicochemical characterization and in-vitro digestibility of extruded rice noodles with different amylose contents based on rheological approaches. *Journal of Cereal Science*, 71:258-263, 2016.

[11] Kasemsuwan, T., Bailey, T., and Jane, J. Preparation of clear noodles with mixtures of tapioca and high-amylose starches. *Carbohydrate Polymers*, 36(4):301-312, 1998.

[12] Khatun, A., Waters, D. L., and Liu, L. A review of rice starch digestibility: effect of composition and heat-moisture processing. *Starch-Stärke*, 71(9-10):1900090, 2019.

[13] Li, C., You, Y., Chen, D., Gu, Z., Zhang, Y., Holler, T. P Ban, X., Hong, Y., Cheng, L. and Li, Z. A systematic review of rice noodles: Raw material, processing method and quality improvement. *Trends in Food Science & Technology*, 107:389-400, 2021.

[14] Lorlowhakarn, K. and Naivikul, O. Modification of rice flour by heat moisture treatment (HMT) to produce rice noodles. *Agriculture and Natural Resources*, *40*(6 (Suppl.)):135-143, 2006.

[15] Low, Y. K., Effarizah, M. E., and Cheng, L. H. Factors influencing rice noodles qualities. *Food Reviews International*, 36(8):781-794, 2020.

[16] Marti, A., Abbasi Parizad, P., Marengo, M., Erba, D., Pagani, M. A., and Casiraghi, M. C. In vitro starch digestibility of commercial gluten-free pasta: the role of ingredients and origin. *Journal of Food Science*, 82(4):1012-1019, 2017.

[17] Ren, X., Chen, J., Molla, M. M., Wang, C., Diao, X., and Shen, Q. In vitro starch digestibility and in vivo glycemic response of foxtail millet and its products. *Food & Function*, 7(1):372-379, 2016.

[18] Ross, A. S. Instrumental measurement of physical properties of cooked Asian wheat flour noodles. *Cereal Chemistry*, 83(1):42-51, 2006.

[19] Sajilata, M. G., Singhal, R. S., and Kulkarni, P. R. Resistant starch–a review. *Comprehensive Reviews in Food Science and Food Safety*, 5(1):1-17, 2006.

[20] Sandhu, K. S. and Kaur, M. Studies on noodle quality of potato and rice starches and their blends in relation to their physicochemical, pasting and gel textural properties. *LWT-Food Science and Technology*, 43(8):1289-1293, 2010.

[21] Sofi, S. A., Singh, J., Mir, S. A., and Dar, B. N. In vitro starch digestibility, cooking quality, rheology and sensory properties of gluten-free pregelatinized rice noodle enriched with germinated chickpea flour. *LWT-Food Science and Technology*, 133:110090, 2020.

[22] Srikaeo, K. and Sangkhiaw, J. Effects of amylose and resistant starch on glycaemic index of rice noodles. *LWT-Food Science and Technology*, 59(2):1129-1135, 2014.

[23] Wang, L., Zhang, C., Chen, Z., Wang, X., Wang, K., Li, Y., Wang, R., Luo, X., Li, Y. and Li, J. Effect of annealing on the physico-chemical properties of rice starch and the quality of rice noodles. *Journal of Cereal Science*, 84:125-131, 2018.

[24] Wu, F., Meng, Y., Yang, N., Tao, H., and Xu, X. Effects of mung bean starch on quality of rice noodles made by direct dry flour extrusion. *LWT-Food Science and Technology*, 63(2):1199-1205, 2015.

[25] Yadav, B. S., Yadav, R. B., and Kumar, M. Suitability of pigeon pea and rice starches and their blends for noodle making. *LWT-Food Science and Technology*, 44(6):1415-1421, 2011.

[26] Zhang, Z. and Bao, J. Recent advances in modification approaches, health benefits, and food applications of resistant starch. *Starch-Stärke*, 2100141, 2021.