

## Modified Low Glycemic Index Ingredients in Noodle Processing: Rheology and Microstructural Characteristics

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### ABSTRACT

Low glycemic index ingredients are now getting attention due to their effect on human nutrition and health. Modification of these ingredients further enhances the beneficial properties of food products. Objective of the study was to modify some of the low GI ingredients such as *rajma*, guar, guar seed and oats with different chemical treatments. These chemical treatments were earlier used for the modification of starches. Studies on the modification of complex foods having both starch and proteins were scanty. These modification techniques yielded some ingredients which had improved rheological behavior and also enhanced product quality parameters. Modification of ingredients has become a new innovation in food technology, with ease of preparation and utilization. These ingredients can be used in a variety of foods from bakery to pasta products. These are having worthy nutritive principles which are beneficial for several health related issues. Further study is needed to understand the molecular changes during modification.

**Keywords:** Modified low glycemic index ingredients, Chemical modification, Succinic anhydride, Rheology, Scanning electron microscope

### Erişte Üretiminde Modifiye Düşük Glisemik İndeksli Bileşenlerin Kullanımı: Reoloji ve Mikroyapı Özellikleri

#### ÖZ

Düşük glisemik indekse sahip gıda bileşenleri insan beslenmesi ve sağlığı üzerindeki etkileri nedeniyle son yıllarda dikkat çekmektedir. Bu bileşenlerin modifikasyonu, ürünün yararlı özelliklerini daha da iyileştirmektedir. Bu çalışmanın amacı, *rajma*, guar, guar tohumu ve yulaf gibi bazı düşük glisemik indekse sahip bileşenlerin farklı kimyasal işlemlerle modifikasyonudur. Bu kimyasal işlemler daha önce nişastaların modifikasyonu için kullanılmıştır. Nişasta ve protein içeren kompleks gıdaların modifikasyonu üzerine çalışmalar oldukça yetersizdir. Bazı bileşenlere uygulanan modifikasyon teknikleri, reolojik davranışları iyileştirdiği gibi ürün kalite parametrelerini de geliştirmiştir. Gıda bileşenlerinin modifikasyonu, hazırlanma ve kullanma kolaylığı ile gıda teknolojisinde bir yenilik haline gelmiştir. Söz konusu bileşenler fırıncılık ürünlerinden makarna ürünlerine kadar birçok gıdada kullanılabilir. Bunlar sağlık ile ilgili birçok konuda faydalı olan değerli besleyici özelliklere sahipler. Bileşenlerin modifikasyonu sırasında ortaya çıkan moleküler değişiklikleri anlamak için daha fazla çalışmanın yapılması gereklidir.

**Anahtar Kelimeler:** Modifiye düşük glisemik indeksli bileşenler, Kimyasal modifikasyon, Süksinik anhidrit, Reoloji, Taramalı elektron mikroskobu

## INTRODUCTION

Glucose is one of the major energy sources for human body. Glucose is used by brain, muscle and other organs as a fuel to perform their regular action. Glycemic index of glucose is set at 100 and all other food groups are compared to this and classified as low medium and high glycemic index (GI) foods. Foods having GI of less than 55, 55-69 and more than 70 are known as low, medium and high GI respectively. Low GI foods affect blood glucose and also insulin sensitivity, with slow digestion and absorption properties. Low GI foods are boon for the diabetics, as this assists in maintaining their blood glucose levels for a normal living [1]. Low GI ingredients occur in all food groups, in pulses pea, lentil, rajma, chickpea. In vegetables all high fiber vegetables, among which cluster bean (guar) stands first. Green leafy vegetables are also known to be low GI [2]. Some earlier studies reported tubers also show low GI after consumption [3].

Modification of low GI ingredients helps in improving the physico-chemical and organoleptic characteristics of the products. With modification there was improvement in texture and sensory characteristics of the noodles [4]. Plenty of studies emphasized on the influence of modified starches on the product quality features. Modified starches have shown positive effect in product structure, flavour and also nutritional aspects [5]. To improve the nutritional properties of the products different modification techniques like chemical and enzyme methods were used. Some of the earlier study reported the modification of a complex matrix (cereal flours), which consists of starch and proteins [6].

Even though there are enormous sources of low GI ingredients there lays a lacuna in utilizing these food groups in routine life. Some of the ingredients are not consumed by majority of the population. So, a carrier is needed to ensure the delivery of these beneficial ingredients for the people in need. In this background, noodle is selected as carrier because of its increasing popularity among all the age groups and also for its ease of preparation. Objective of the present study is to modify different low glycemic index ingredients and looking at the aspects of its effect on rheological and microstructural characteristics. It was also planned to use the modified ingredients in noodle processing and observing the effect on its product quality parameters.

## MATERIALS and METHODS

### Procurement and Processing of Raw Materials

Main raw material for noodle processing is *T. durum* semolina. Same was purchased from local market. Low GI ingredients such as rajma bean (*Phaseolus vulgaris* L.), oats flour (*Avena sativa*) and guar (*Cyamopsis tetragonoloba*) were also obtained from local market. Other raw material guar seed was gifted by Lotus Gums & Chemicals (Rajasthan, India). The procured materials (rajma and guar seeds) were cleaned and ground in chakki flour mill to required particle size and stored until further use. Guar was blanched according to

method described by Ranganna [7] and dried in cabinet air drier, until completely dried. Dried guar pods were then powdered and stored. Selection of low GI ingredients was based on the preliminary optimization studies, in which GI of the ingredients were analyzed and formulations were optimized accordingly. Enzymes like pepsin, invertase, amyloglucosidase and pancreatic  $\alpha$ -amylase were procured from Sigma Chemicals, USA. All other chemicals used for modification were of analytical grade unless and otherwise mentioned.

### Optimization Studies

Initially noodles were formulated using different low GI ingredients such as rajma flour (GI-32), oats flour (GI-52), guar flour (GI-32) and guar seed flour (GI-41) with base material *T. durum* (GI-75). These low GI ingredients were blended with *T. durum* flour at different proportions. Blends were subjected to rheological characterization. Noodles were prepared with the blends utilizing the method of Bharath Kumar and Prabhasankar [8]. Prepared noodles were analyzed for its physico-chemical, sensory and *in vitro* digestibility properties. Results of the above products were analyzed and an optimized formulation was finalized for further modification to improve product quality characteristics. On basis of this, 20% rajma flour, 30% oats flour, 10% guar powder and 7.5% guar seed powder was taken for the modification study.

### Rheological Characteristics of Modified Flour Blends

Rheological study of the unmodified and modified optimized blends were carried out using Farinograph (AACC, 54-21) reports water absorption, dough development time and dough stability which plays a vital role in product quality. Amylograph (AACC, 22-10.01) to understand the pasting properties and amylase enzyme activity of the modified flour blends. Alveograph (AACC, 54-30A) to recognize the visco-elastic properties of the dough. Rheological properties were determined according to the standard AACC methods [9].

### Modification of Ingredients and Noodle Formulation

Optimized levels of the low GI ingredients were set and taken for modification. Modification was carried out by altering pH to alkaline condition using sodium bicarbonate, esterification with succinic anhydride, octenylsuccinic anhydride and treating with potassium permanganate solution. Modification procedure was adopted by Bharath Kumar and Prabhasankar [6] with some variations. In brief; optimized blends were brought to respective alkaline pH while mixing in the Spar mixer with the addition of sodium bicarbonate, while dough was checked frequently for the pH with dough pH analyzer. For esterification [6,10] octenylsuccinic anhydride (3.0% of the weight of starch in the sample) and succinic anhydride (4% starch basis) were added, by maintaining the pH of the dough at 8.5. Another modification using potassium permanganate solution was also carried out by adopting the method used by

Takizawa [11], with some minor modification for this 0.01% of potassium permanganate was used in acidic condition during dough forming. Use of all the chemicals for modification is according to Food and Drug Administration (FDA) regulations. Noodles were formulated according to the method followed by Bharath Kumar and Prabhasankar [8]. Modified dough was rested for 5-10 min and later it was sheeted and cut into noodles using lab scale noodle making machine (Imperia Restaurant, Italy). Then noodles were dried at 50°-55°C for 2 h in a cabinet tray drier. The dried noodles were cooled and packed until further utilization in poly propylene packages.

### Chemical Composition

Noodles were analysed for protein and dietary fiber according to the AOAC methods [12]. Micro-Kjeldahl method was used to determine nitrogen contents noodles [13]. In order to calculate protein content from nitrogen determination a conversion factor 5.7 was used for control noodles and a contribution of nitrogen from non-wheat ingredients was calculated using factor of 6.25. All the values were reported on dry basis.

### Cooking Quality of Noodles

Prepared noodles both unmodified and modified were subjected for cooking quality evaluation adopting the method from AACC (66-50) [9]. Noodles were cut to 5cm approximately by length. Weighed amount of sample (25g) was put in 250mL of boiling water and examined the time until noodles were completely cooked. Gruel was drained and collected for the solid

leach out analysis. Cooked samples were analyzed for its texture, colour and sensory properties.

### Sensory Analysis using Quantitative Descriptive Analysis (QDA)

Prepared products were evaluated for their quality characteristics and for its acceptance. Panelists who regularly participate in evaluating the noodles were selected (Male and Female; 10-15). QDA method to analyze the products was used for the study. This methodology was developed by Stone and Sidel [14]. Method for the sensory evaluation was followed according to Bharath Kumar and Prabhasankar [8]. Later obtained results were correlated and graphically represented as sensory profiles.

### Percentage of Starch Gelatinization

Percentage starch gelatinization was estimated using the method of Bharath Kumar and Prabhasankar [15]. In brief, cooked noodles were freeze dried and approximately 2g of the powdered samples was taken in 100mL of distilled water and mixed for 2min using magnetic stirrer at room temperature (27°C). Suspension was centrifuged at 1500g for about 10min. 1 mL of supernatant was mixed with 1mL of iodine solution (4% potassium iodide and 1% resublimed iodine). This solution mixture was made upto 10mL with distilled water and absorbance was read at 600nm immediately ( $A_1$ ). 1mL iodine solution made upto 10mL was served as a blank ( $A_2$ ). Absorbance was taken in triplicates. Percentage starch gelatinization was calculated using the equation-1;

$$\text{Percentage starch gelatinization (\%)} = \frac{A_1}{A_2} \times 100 \quad (1)$$

### Instrumental Colour Measurement of Noodles

Cooked noodles were analysed for its colour attribute using Lab scan-XE (Reston, USA) equipped with a D65 illuminant with a 2° view angle and slit width of 2 mm. The 10g samples were placed in a quartz container provided with the equipment and placed on the slit opening. Surface colour of the noodles was measured. Measurement was carried out in triplicates and average value of the same was reported. The parameters  $L^*$ ,  $a^*$  and  $b^*$ , indicating lightness ( $L=100$ ) /darkness ( $L=0$ ) dimensions, redness (+ve) to greenness (-ve) and yellowness (+ve) to blueness (-ve) of the samples respectively were recorded for the samples [16].

### Instrumental Firmness of Noodles

Firmness of unmodified and modified noodles was measured using Texture analyzer model TA-XDi (Stable Micro Systems, UK) equipped with Warner Bratzler Blade for shear. Analysis was carried out with the procedure followed as Bharath Kumar and Prabhasankar [15]. The data thus obtained were analyzed statistically.

### Microstructural characterization

Cooked and freeze dried fresh and dried noodle samples were scanned under scanning electron microscope according to the method described in Prabhasankar [17]. The samples were mounted on the specimen holder and sputter-coated with gold. Then, each sample was transferred to electron microscope (LEO 435 VP, USA) and observed for microstructural characteristics.

### Statistical Analysis of Data

The mean scores ( $n=4$ ) of individual attributes of all the tests were calculated. Duncan's new multiple range test [18] was applied to the data to find the significance difference between mean values of the samples.

## RESULTS and DISCUSSION

### Rheological Properties

Unmodified and modified flour blends were subjected to different rheological analysis using amylograph, farinograph and alveograph. Results of the same are

given in Table 1 and Fig.1, Fig.2. Amylograph analysis (Table 1) indicated that peak viscosity increased and also decreased with the modification of ingredients. This indicates the action of chemicals in both improving and inhibiting the pasting properties of the flour blends. Increase in peak viscosity may be due to inhibition of the amylase enzyme activity in the samples with the modification. Amylograph expresses the pasting characteristics and also amylase enzyme activity of the samples. It is clearly seen that with the increase in pH for rajma blends, swelling of the starch granules reduced with delay in the start of gelatinization time and temperature, which was 68.7°C (10.25min) for unmodified and increased to 80.7°C (12.17) for modified blends. Also there was a significant increase in the peak viscosity from 390 to 434BU, this is mainly because of the inhibited enzyme activity in the blend. Hot paste and cold paste viscosity indicates the pasting behavior, which was changed after modification. In case of potassium permanganate treated blends there was a reduction in stability of the paste compared to unmodified blends, indicated by the reduced hot paste viscosity from 379 to 292BU. The instability may be because of the oxidation of the starch and other protein molecules in the blends. The initiation of gelatinization also delayed compared to unmodified samples, as the oxidation of starch reduces the swelling power of starch molecules [19,20]. Even though CBSP has the highest

peak viscosity among all the samples, its stability was quite low. Hot paste viscosity reduced from 542 to 418BU, cold paste viscosity also followed the same trend with reduction from 884 to 621BU. Hot paste and cold paste viscosity of the unmodified blends was the highest among all the samples. This is due to its galactomannan content in guar seeds, which has high viscosity compared to any other ingredients [21]. Modified samples of CBP with OCT showed delayed gelatinization time from 9.80min (64.5°C) to 11.25min (78.4°C) with increase in gelatinization temperature. Also with modification there was a drastic reduction in peak viscosity from 392 to 285BU. Hot paste viscosity (292BU) and cold paste viscosity (411BU) was the lowest for this modified sample among all the samples. This may be correlated with the results of earlier study where jack beans starch was modified and observed changes in the peak viscosity [22]. Sample (oats) modified using SUCC showed higher initial gelatinization temperature from 63.5°C to 68.3°C. Also peak viscosity increased from 467 to 484BU and the paste was relatively stable compared to other pastes [23]. Stability of the paste is due to the high soluble fiber content in the sample. Cold paste viscosity reduced from 741 to 694BU, which shows the degradation of starch molecules after modification. Results were in line with earlier study where on modification with SUCC, the starch was reasonably stable [24].

Table 1. Amylograph analysis results

Samples	Beginning of gelatinization		Peak viscosity (BU)	Hot paste viscosity (BU)	Cold paste viscosity (BU)
	Time (min)	Temperature (°C)			
RF	10.25 <sup>b</sup> ±1.01	68.7 <sup>bc</sup> ±0.2	390 <sup>b</sup> ±10	381 <sup>b</sup> ±11	763 <sup>d</sup> ±21
RF 9.0	12.17 <sup>c</sup> ±1.11	80.7 <sup>e</sup> ±0.5	434 <sup>c</sup> ±8	464 <sup>cd</sup> ±20	542 <sup>b</sup> ±11
CBSP	9.64 <sup>a</sup> ±0.69	63.2 <sup>a</sup> ±0.9	498 <sup>c</sup> ±11	542 <sup>cd</sup> ±14	884 <sup>d</sup> ±14
CBSP KMnO <sub>4</sub>	10.41 <sup>b</sup> ±1.01	69.1 <sup>c</sup> ±0.4	451 <sup>c</sup> ±9	418 <sup>c</sup> ±15	621 <sup>c</sup> ±19
CBP	9.80 <sup>a</sup> ±0.98	64.5 <sup>b</sup> ±0.1	392 <sup>b</sup> ±7	379 <sup>b</sup> ±14	689 <sup>c</sup> ±17
CBP OCT	11.25 <sup>b</sup> ±1.25	78.4 <sup>d</sup> ±0.7	285 <sup>a</sup> ±6	292 <sup>a</sup> ±19	411 <sup>a</sup> ±15
OATS	9.71 <sup>a</sup> ±1.21	63.5 <sup>a</sup> ±0.5	467 <sup>c</sup> ±9	451 <sup>c</sup> ±22	741 <sup>d</sup> ±15
OATS SUCC	10.24 <sup>b</sup> ±1.11	68.3 <sup>bc</sup> ±0.4	484 <sup>c</sup> ±11	444 <sup>c</sup> ±14	694 <sup>c</sup> ±11

Values are mean±SD, n=4, Means in the same column with different letters differ significantly (p<0.05), RF - 20% rajma flour with T. durum in noodles; RF 9.0 - RF modified with pH9.0; CBSP - 7.5% guar seed powder with T. durum in noodles; CBSP KMnO<sub>4</sub> - CBSP treated with potassium permanganate; CBP - 10% dried guar powder with T. durum in noodles; CBP OCT - CBP treated with octenyl succinic anhydride, OATS - 30% oats with T. durum in noodles; OATS SUCC - OATS treated with succinic anhydride.

Farinograph results (Fig. 2) showed that with modification there was an increase in the water absorption except in case of RF and its modified variants. Increase in water absorption from 68% to 73% was the highest in case of oats sample and reduction of water absorption from 64.9% to 60.4% was the lowest. Increase in the water absorption is mainly because of the dilution of gluten, which is one of the key factors to determine the water absorption and also water holding capacity of the dough. As the starch and also gluten component in the flour is modified with chemicals, dough development time significantly increased reaching close to 20 min, which is the maximum time for the test. Results of the study mimic the earlier study where addition of different edible fiber to the flour blend increased the water absorption and dough development time [25]. With the modification there exists a competition between starch and protein for water. Due to this dough will lose the property to hold water and lose its stability. Stability of modified flour differed

significantly from the unmodified flour samples. With the highest variation in CBP samples, where stability increased from 2.9 to 10.5, which was due to increase in insoluble fiber content in the CBP sample. Stability of the dough is mainly dependent on the gluten content in the dough. But here with the modification of RF with pH 9.0 increased the stability of the dough, which is because of the interference caused by the alkaline agent to the degradation of gluten [26]. It can be seen that with the modification of flours, time of breakdown for the dough increased significantly, this may be because of the modification which makes the dough to form gluten in the slower rate compared to the unmodified flour blends. Results can be comparable with the earlier study where addition of some hydrocolloids delayed the formation of gluten in the flour [27].

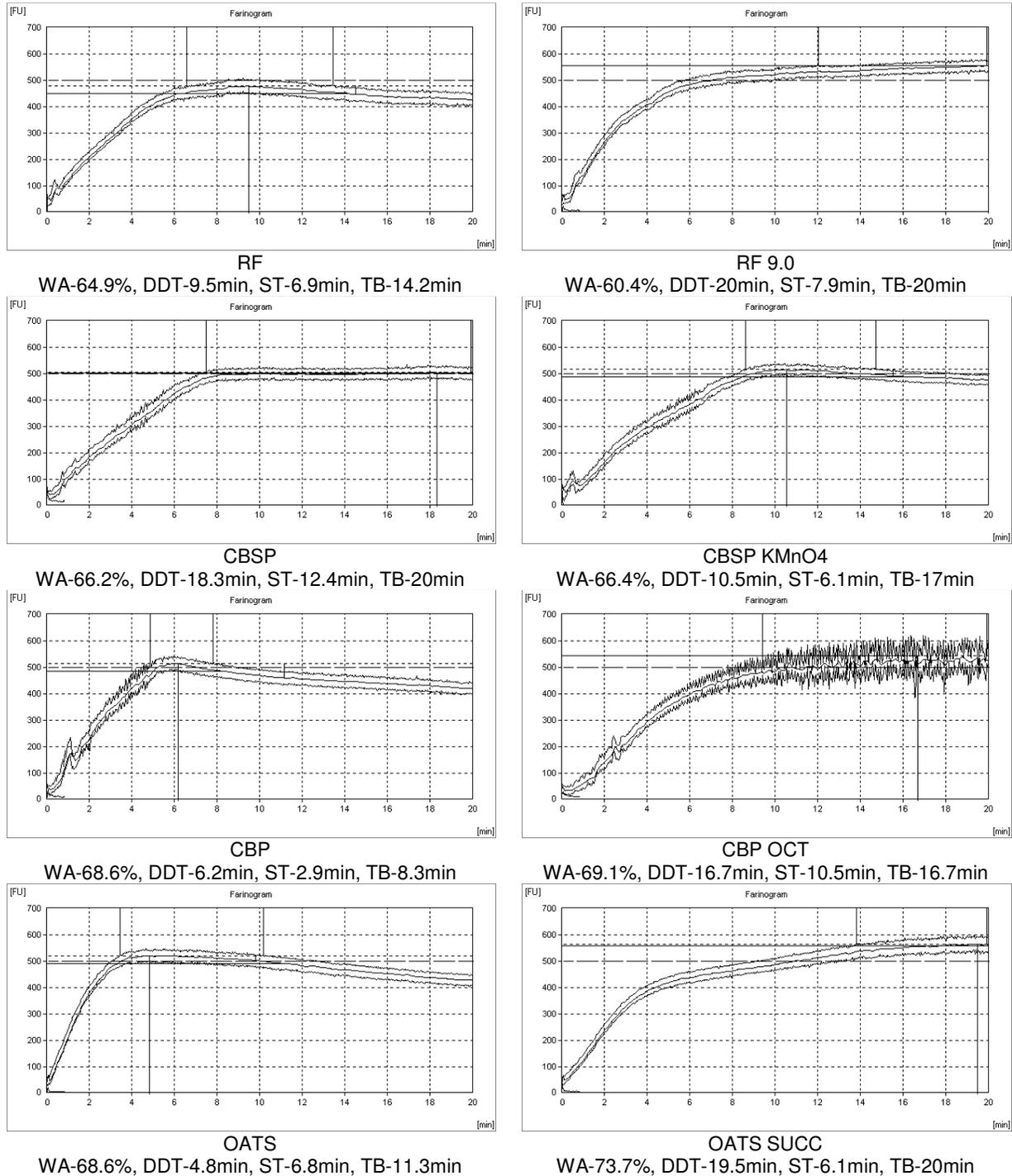


Figure 1. Farinograph characteristics of modified and unmodified flour blends (Sample name abbreviations are as per Table 1; WA-water absorption, DDT-dough development time, ST-stability, TB-time to breakdown)

Results of the alveograph (Fig. 3) revealed that with the modification 'P' value increased significantly which can be correlated with the results of farinograph, where stability of the dough increased with modification in flour blends. This may be because of the more pressure required for the dough to make it swell. But on the other hand index of swelling 'G' was reduced in the modified flour blends, this may be due to under-formation and

also breakdown of gluten in the dough with the modification. Also during modification using pH 9.0, there forms a polymeric complex in the sample, which is hard to break. So the instrument is blowing air to break the structure with increasing the maximum over-pressure (P). Deformation energy of the dough 'W' increased significantly, this is due to the deformation of starch and proteins in the dough during modification.

Higher P and W value indicates the strength of the dough. Among all the samples, oats flour modified with succinic anhydride showed higher 'P' value, indicating its strong fiber network, especially of soluble dietary

fiber. Upon esterification with succinic anhydride and octenyl succinic anhydride, a strong network was formed which has resisted the pressure applied.

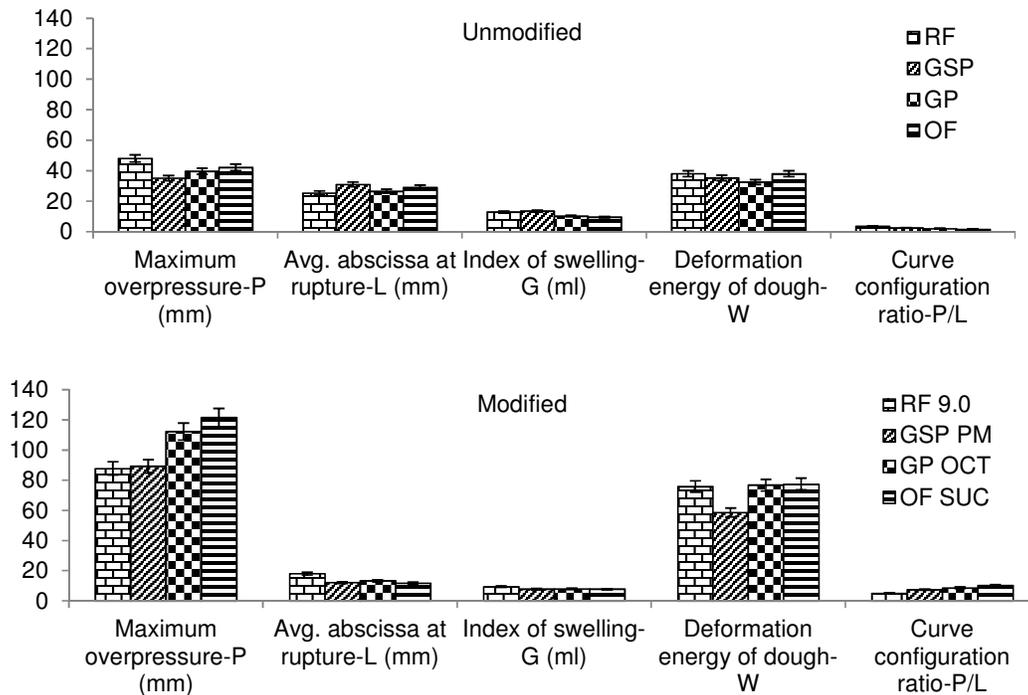


Figure 2. Alveograph characteristics of modified and unmodified blends (Sample name abbreviations are as per Table 1)

In a study Wang [25] observed that decrease in dough height expressed a decrease in extensibility and increased resistance to measurement. According to Van Vliet [28], a too high resistance can cause a limited and slow expansion, which can be suitable for the preparation of extrude products. Where, retention of gas cells and maximum expansion of the dough is not necessary. With SUC modification for oats sample there was highest P value among all the samples, may be due to high content of both soluble and insoluble fibers contributes to the increase in maximum overpressure. Results can be correlated with the earlier study of Dapcevic Hadnadev [24].

### Chemical Composition

Chemical composition of modified and unmodified samples (Table 2) did not show any significant difference in terms of proteins. With highest protein content of 14% in RF incorporated samples and lowest in CBP containing samples (10.5%). Highest protein content in RF samples is due to the addition of pulse samples, usually pulses are rich source of proteins [29]. Lowest was seen on CBP samples, as this is a vegetable and having very less amount of proteins. Other samples like CBSP and oats also showed protein

content of around 13.9% and 11.2% respectively. Upon modification of samples there was no significant difference regarding protein content. Due to modification there were changes in dietary fiber content, which is evident by rheological analysis. Samples with RF showed reduced insoluble and enhanced soluble fiber content after modification (from 12.8% to 10.5% / from 1.5% to 2.1%). This may be due to action of alkali on fiber content of the noodles [30, 31]. There was some degradation of soluble dietary fiber in case of CBSP samples due to action of alkali. As CBSP is rich in soluble dietary fiber (galactomannans) action of alkali has reduced the soluble dietary fiber content in the sample from 4% to 2.5%. This may be due to entanglement of the fibers during modification and later on drying the properties of the fiber are reducing [32]. Apart from these two samples from CBP and oats did not show any significant difference in dietary fiber content. This shows oxidation of samples using potassium permanganate did not have any effect on the dietary fiber content of the samples. All the samples were having higher soluble dietary fiber content before and after modification. So, these samples will be beneficial for the people with different life style disorders [33].

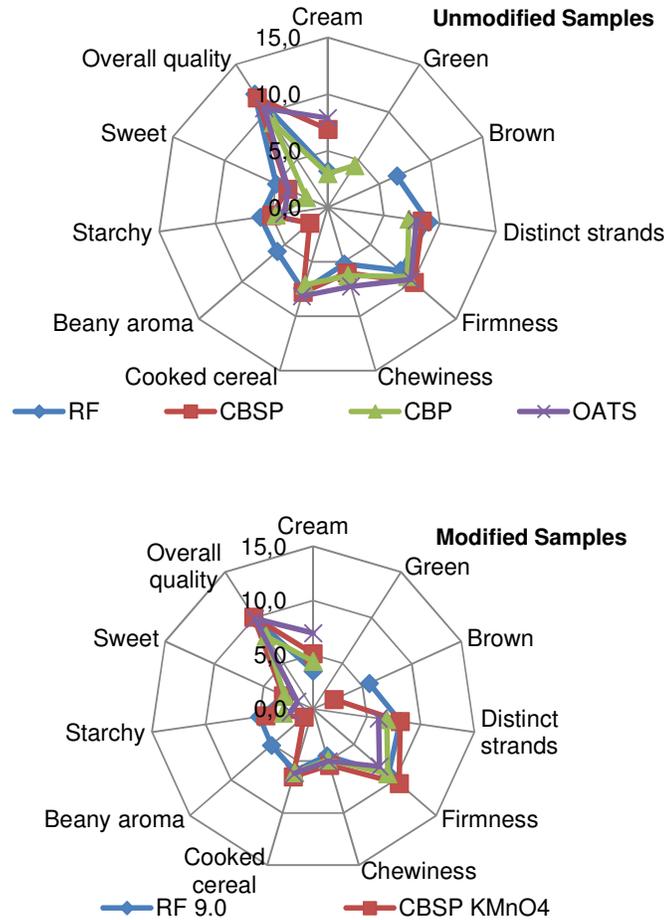


Figure 3. Sensory profile of unmodified and modified noodle samples (Sample name abbreviations are as per Table 1)

Table 2. Chemical composition and product characteristics as influenced by modification of ingredients

Parameter	RF	RF 9.0	CBP	CBP KMnO <sub>4</sub>	CBSP	CBSP OCT	OATS	OATS SUCC
Cooked weight (g)	53.8 <sup>b</sup> ±0.8	42.0 <sup>a</sup> ±1.0	48.4 <sup>a</sup> ±1.5	42.8 <sup>a</sup> ±1.8	57.9 <sup>b</sup> ±1.5	50.0 <sup>ab</sup> ±0.9	54.5 <sup>b</sup> ±1.1	50.8 <sup>ab</sup> ±0.4
Solid leach out (%)	5.0 <sup>b</sup> ±0.7	4.1 <sup>b</sup> ±0.1	6.9 <sup>c</sup> ±0.5	6.1 <sup>c</sup> ±0.0	3.2 <sup>a</sup> ±0.4	4.9 <sup>b</sup> ±0.2	5.5 <sup>b</sup> ±0.0	5.6 <sup>b</sup> ±0.0
Firmness (N)	2.14 <sup>b</sup> ±0.41	2.85 <sup>b</sup> ±0.42	2.43 <sup>b</sup> ±0.40	1.89 <sup>a</sup> ±0.12	3.11 <sup>c</sup> ±0.31	2.54 <sup>b</sup> ±0.20	2.99 <sup>bc</sup> ±0.11	2.11 <sup>b</sup> ±0.09
Colour	L*	53.1 <sup>b</sup> ±1.1	55.2 <sup>b</sup> ±2.1	41.9 <sup>a</sup> ±1.5	38.4 <sup>a</sup> ±1.1	56.2 <sup>b</sup> ±1.5	58.5 <sup>bc</sup> ±1.8	63.1 <sup>c</sup> ±1.5
	a*	5.7 <sup>b</sup> ±0.9	6.1 <sup>c</sup> ±0.5	1.87 <sup>a</sup> ±0.1	6.2 <sup>c</sup> ±0.2	2.5 <sup>a</sup> ±0.7	3.1 <sup>ab</sup> ±0.9	3.5 <sup>b</sup> ±0.2
	b*	12.5 <sup>b</sup> ±1.1	12.6 <sup>b</sup> ±1.5	22.9 <sup>a</sup> ±1.1	18.3 <sup>b</sup> ±0.8	18.4 <sup>b</sup> ±1.1	17.4 <sup>b</sup> ±1.2	17.7 <sup>b</sup> ±0.9
Protein (%)	14.1 <sup>b</sup> ±0.0	14.2 <sup>b</sup> ±0.0	10.5 <sup>a</sup> ±0.2	10.4 <sup>a</sup> ±0.5	13.9 <sup>b</sup> ±0.0	13.5 <sup>b</sup> ±0.7	11.2 <sup>a</sup> ±0.9	11.5 <sup>a</sup> ±0.0
Dietary fiber	Insoluble (%)	12.8 <sup>c</sup> ±0.8	10.5 <sup>b</sup> ±0.5	11.5 <sup>b</sup> ±0.8	10.2 <sup>b</sup> ±0.5	9.2 <sup>a</sup> ±0.2	9.5 <sup>a</sup> ±0.7	10.1 <sup>b</sup> ±0.7
	Soluble (%)	1.5 <sup>a</sup> ±0.3	2.1 <sup>b</sup> ±0.1	2.7 <sup>b</sup> ±0.1	3.0 <sup>c</sup> ±0.8	4.0 <sup>d</sup> ±0.1	2.5 <sup>b</sup> ±0.4	3.8 <sup>cd</sup> ±0.5
Percent gelatinization (%)	31 <sup>b</sup> ±1.2	20 <sup>a</sup> ±0.5	32 <sup>b</sup> ±0.9	21 <sup>a</sup> ±0.1	39 <sup>c</sup> ±0.8	32 <sup>b</sup> ±0.1	49 <sup>d</sup> ±0.4	45 <sup>d</sup> ±0.2

Values are mean±SD, n=4, \* Freeze dried, Means in the same row with different letters differ significantly (p≤0.05), Sample name abbreviations are as per Table 1.

### Cooking Quality of Noodles

Cooking quality of noodles plays a vital role in deciding the product quality characteristics. Results of the cooking quality are depicted in Table 2. Results revealed that with modification there was decrease in the cooked weight for all the samples, with highest reduction in case of RF incorporated noodles, this can be supported with the farinograph results, with reduced water absorption. Cooked weight reduced from 53.8g to 42g in RF samples. Least reduction is seen in oats and its modified variants (54.5g to 50.8g), this may be due to its difference in the dietary fiber content of the samples. Chemical modification also had an effect on solid leach out. Results revealed that with modification there was

reduction in solid leach out of RF and CBP samples. Reduction was from 5% to 4.1% (RF) and from 6.9% to 6.1% (CBP). This may be due to formation of strong network due to alkali treatment, which is evident from SEM results. Whereas, in case of CBSP and oats samples there was a slight increase was observed. Reduction of solid loss is due to less absorption of water during cooking and also reduced cooking time compared to unmodified samples [34]. Increase in solid loss is attributed to increase in the dietary fiber content in the samples. As the dietary fiber content increases, it disrupts the starch-protein matrix and starch is tending to leach out more. Results can be correlated with the earlier study where, with increase in the pea fiber in the pasta increased the solid loss in the samples [35].

### Instrumental Colour Measurement of Noodles

Colour analysis (Table 2) of the sample revealed that with modification there was some notable changes in the samples. Lightness value ( $L^*$ ) showed significant decrease in case of potassium permanganate treated sample with 41.9 for unmodified to 38.4 for modified. This is due to oxidation reaction, which made to change the colour of the samples. Increased  $L^*$  value was seen in pH modified samples, as alkali reaction reduced the pigments of RF and lightened the samples. Regarding  $a^*$  (redness/greenness), there was a significant change in CBP sample treated with potassium permanganate, which darkened the colour of the noodles.  $a^*$  value elevated from 1.87 to 6.2. Apart from this all other samples did not show any difference in  $a^*$  value. Now to explain  $b^*$  value (yellowness/blueness), again for CBP sample it was reduced after modification, indicating the reaction of permanganate on the sample. All other samples remained with slight change in the value.

### Instrumental Firmness of Noodles

Noodles with good acceptance and palatability should have appealing texture and mouthfeel. Cooking procedure, cooking time and modification techniques also have effect on noodle firmness [36]. Results of the noodle firmness analysis were represented in Table 2. Noodles are analyzed mainly for their firmness property. Firmness of the noodles significantly reduced except in case of RF, where it was increased from 2.1N to 2.8N. Results showed that dietary fiber from the modified RF increased the firmness, which may be due to compact structure formation due to alkali treatment. Compact structure is contributed from protein and dietary fiber present in it. This is evident from the SEM analysis. Maximum reduction of firmness was seen in CBP and its modified variants, with 2.4N for unmodified and 1.9N for modified samples.

### Sensory Analysis

For a product to be acceptable it should have appealing colour, flavour, texture and mainly taste. These parameters decide the quality of a product [37]. Sensory profile of unmodified and modified noodle samples was graphically represented as Fig. 3. Unmodified samples used for the study were optimized earlier to assess its quality parameter. These samples were further modified to improve the product quality and study the influence of modification on it. Upon modification major attributes required to judge the noodle quality remained unchanged. Surface colour of the modified samples slightly differed from the unmodified samples. Strands were distinct even after modification. Firmness score of the noodle strands increased in RF samples from 8.5 to 9.2, which can be correlated with the firmness analysis. As a desirable attribute chewiness did not change significantly still after modification. Overall quality score of the samples were above 7.5, so all the samples were acceptable. Highest overall quality score was obtained by RF (11.9) and lowest was CBP OCT (8.0) on a 15cm sensory scale.

### Percentage of Starch Gelatinization

In cereal based foods like pasta and noodles, starch gelatinization plays a vital role for the depiction of product quality. As the product to be cooked under high heat condition (boiling), it should be kept in mind that product should not lose its structure during cooking. So, here gelatinization is crucial stage during cooking. Over and under gelatinized starches in products have some adverse effect during digestion of the food matrix. In this study it can be seen that with modification percentage of starch gelatinization reduced significantly among all the samples, with maximum reduction in case of RF and CBP treated with pH 3.0 and potassium permanganate respectively. Reduction of gelatinization is a positive sign for its slow releasing property of starch during digestion and absorption. Percentage gelatinization reduced from 31 to 20 (RF) and 32 to 21 (CBP), while for *T. durum* noodles it will be around 60%. So, reduction of percentage gelatinization has shown reducing starch digestibility [15]. In case of CBSP and oats treated with OCT and SUCC respectively, showed reduction to some extent from 39 to 32 (CBSP) and 49 to 45 (oats). Less reduction in gelatinization percentage is mainly due to its high dietary fiber content in the samples. Also in case of CBSP increased protein content can be seen, which also a reason to reduce the gelatinization. Negative effect of proteins on gelatinization was observed in previous study where sorghum was used as a protein source [38].

### Microstructural Characterization

Microstructural analysis has to be carried out to understand the internal changes of the particles due to modification. Correlation of these results with other product quality characteristics gives firm knowledge about what is happening during modification. For example; this can be correlated with water absorption, firmness, starch digestibility and so on. Results of microstructural studies (Fig.4) indicated that with modification of RF using increased pH, there was a formation of polymerized structure. This explains the reduction of water absorption in farinograph analysis. Also reduced swelling of starches can be seen in the modified sample. In case of CBSP unmodified sample fiber matrix can be clearly seen, but with oxidation with potassium permanganate, disruption of the same can be seen. Starch granules and galactomannans from the guar were oxidized and less exposed in the matrix. In case of CBP, fiber matrix can be clearly visible with thread like structure in the unmodified sample. But in modified sample these type of structure is missing due to modification with OCT. As OCT act as emulsifier, a compact structure is seen in the modified samples. In case of oats, modification has disrupted the matrix. In unmodified samples starch granules were exposed and the same is absent in modified samples. These results can be correlated with the results of rheological data. Higher peak viscosity was observed in CBSP sample, here it can be seen that sample is having higher amount of starch granules embedded in protein matrix from both wheat and guar. Stability of modified CBP sample reduction in amylograph also explained here with

disruption of matrix, which losses holding capability. These fiber matrix aid in slow release of glucose during digestion and absorption, this is markedly reported by IVSD results. Also reduction in percentage gelatinization after modification in all the samples is also explained

well from the microstructural results. Results are comparable to earlier study where pea flour incorporated noodles made the structure firm, due to its fiber content [8].

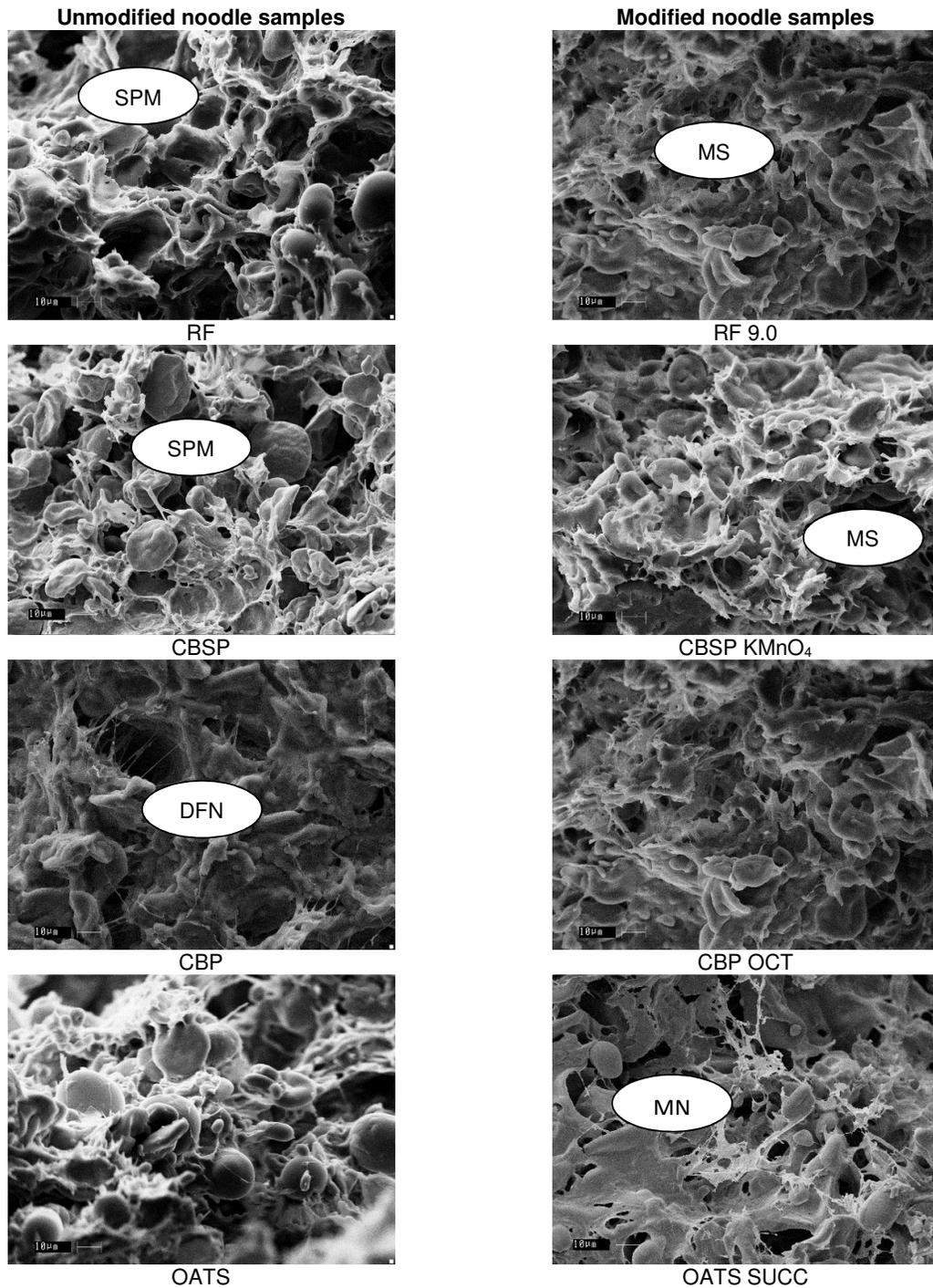


Fig. 4 Microstructural characterization of modified and unmodified ingredients in noodles (Sample name abbreviations are as per Table 1; SPM-starch protein matrix, MS-modified starches, MN-modified network, DFN-dietary fiber network)

## CONCLUSION

Starch plays a vital role in deciding the end product quality. Also along with starch protein and other constituents also helps to improve the quality parameters. Present study aims to understand the relation and influence of chemically modified low GI ingredients on the rheological and microstructural properties on noodle dough. It is observed that upon modification several changes in their structural and functional properties have occurred. There was some changes in amylograph pasting characteristics, farinograph water absorption and alveograph maximum overpressure. These results were strongly evident by the microstructural representation. Also product quality like solid leach out, colour, texture (firmness) also showed some positive changes during analysis of modified samples, compared to their unmodified samples. After modification RF sample increased firmness and also soluble dietary fiber content. Colour of the potassium permanganate treated samples varied significantly due to its oxidative effect. Solid leach out of the modified and unmodified samples were within the acceptable level (<8%). So, these modified samples can be used in different product formulations to aid the people in need.

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