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EFFECTS OF XANTHAN GUM ON THE QUALITY OF GLUTEN-FREE BORA RICE AND CORN FLOUR NOODLES USING D-OPTIMAL MIXTURE DESIGN APPROACH

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ABSTRACT

Bora rice found in Assam contains a significant amylopectin concentration (i.e., > 95%) and has a waxy, branched polymer, indicating physical durability and resistance to enzymatic action. This category of rice starch hydrates and expands when exposed to cold water, generating sols that contribute to its bio-adhesive characteristics. Due to glutinous nature, it poses a challenge in making extruded products. Now, xanthan gum has the ability to replace the gluten network of bora rice and blended with corn flour to develop noodles by using extrusion technology. The study was based upon the experiments for three independent variables using a D-optimal mixture design (DOMD). Different responses viz. cooking time, cooking loss, swelling power and solubility were studied. Numerical optimization was done and the optimum values were found to be rice flour (82.3%), corn flour (15%), and xanthan gum (2.6%). The developed noodle product was then analyzed for physiochemical, sensory, and storage properties. The recorded readings were swelling index (37gg^{-1}), solubility (36.5%), cooking loss (27%) and cooking time (209 s). The moisture, protein and ash content were found as approximately 2.5%, 30% and 0.213% respectively. Therefore, based on DOMD optimization technique, a good balance between the bora rice, corn flour and xanthan gum led to the development of extruded noodle with characteristic physicochemical property, storage stability and satisfactory sensory quality.

1. Introduction

Rice, also known as *Oryza sativa lour*, is a staple food in the majority of nations (Verma and Srivastava, 2020).It is the most extensively consumed staple meal in the world for a substantial portion of the human population, particularly in Asia and Africa (Marti et al., 2013).Non-glutinous and glutinous rice are two types of rice that differ in their amylose concentration (also termed as non-waxy and waxy or sweet rice) (Belitzet al., 2009) (Marti et al., 2010) (Devi et al., 2020). While eating food containing wheat, rye, or barley, certain individuals with a particular genetic disposition suffer celiac disease or non-tropical sprue. For those with such problems with wheat gluten allergies, using rice instead of wheat to manufacture rice-based extruded items would be effective (Barbiroli et al., 2013). Traditional rice noodles are produced with long-grain rice flour with an amylose concentration that is between intermediate and high (>22 g/100 g), which is essential for the development of a starch network in rice noodles (Kohlwey, Kendall, &Mohindra, 1995) (Marti et al., 2011).Rice noodles have traditionally been made by a lengthy process of gelatinization, extrusion/slitting, cooking, retrogradation, acid-pickling, drying, packaging, and sterilizing (Li et al.., 2021)(Marti &Pagani,2013).Several research has evaluated the effectiveness of noodles prepared from various rice types. Huang et al., (2021) found out that brown rice noodles had 12–19% higher yield than that of white rice noodles but cooking loss rate was 5-10% higher in brown rice noodles. Also, for economic reasons, it is expanded in many nations where wheat is not a significant local crop by adding other flours. Moreover, amylose has been identified in maize noodles as the element responsible for maintaining their textural integrity after cooking.Dexter and Matsuo, (1979) showed that in corn blends, the lower the amylose content, the lower the noodle cooking quality. *Xanthomonas campestris* is a bacterium that secretes xanthan gum, an extracellular polysaccharide. It is produced commercially using a fermentation procedure and cold water makes xanthan gum soluble, and solutions show strong pseudoplastic flow and an interaction with galactomannans and glucomannans that works synergistically (Sworn, 2021) (Sozer 2009). Kaur et al., (2015) studied the effects of xanthan gum on noodle-making properties and found that the addition of the gum improved hot paste viscosity and final viscosities while decreasing peak viscosity for mung and corn starches.

2. Materials and methods

2.1. Materials

Traditionally grown in Assam, India, Assam Bora rice (*Oryza glutinosalour*) was purchased from a neighborhood market in Tezpur. Gluten-free corn flour was obtained from a seller on the e-commerce website i.eAmazon. Xanthan Gum was purchased from Himedia® Laboratories Pvt. Ltd.

2.2. Methods

2.2.1. Preparation of Noodles

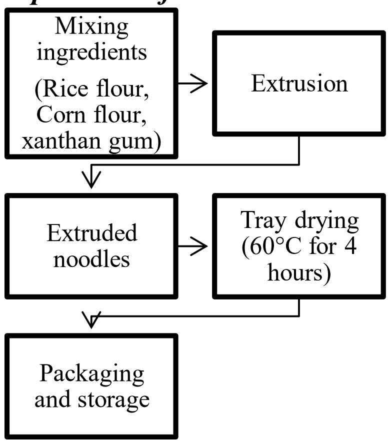

Figure 2.1. Flowchart for the preparation of Rice Noodles

The noodles were developed by using a laboratory model extrusion machine (Mini Dolly Pasta machine, LA MONFERRINA, Italy). On the basis of preliminary trials to obtain well shaped noodles, noodles were prepared by addition of rice flour, corn flour, xanthan gum with 45 ml water addition in 100g. The noodle samples were made by varying the quantity of the three components by using Mixture design in the Design Expert Software. The prepared noodles were then stored in Resealable Zip Lock Cover Pouch bags.

2.2.2. Experimental design for preparation of noodle using D-optimal Mixture Design

The experiment was carried out with various settings using the D-optimal mixture design. The measured response in a combination experiment is presumed to be solely dependent on the relative quantity of ingredients or components present, which typically add to 100%. The present work employed a mixture experiment with three components: Rice Flour (A), Corn Flour(B), Xanthan gum(C). Parameters ranges for D-optimal mixture design in preparing noodles were prepared and the levels of various input variables were selected as follows: Rice Flour (80-85%), Corn Flour (10-15%) and Xanthan gum (1-5%). The three variables generated 16 formulations of noodles with different composition of each ingredient as shown in Table 2.1. Different responses were carried out on the noodles to select the best combination of input variables which could result in most suitable form of noodles. The examined responses were cooking time, cooking loss, swelling index, solubility.

Traditional Scheffe type models for the mixture variables and response surface models for the design variables are typically combined to create models for interpreting data from mixture designs (Scheffe, 1958). The cubic model was fitted as suggested.

Table 2.1. Experimental design showing different formulation for developing noodles

Std No	A:Rice Flour	B:Corn Flour	C:Xanthan Gum
1	82.449	12.551	5.00
2	82.370	15.000	2.630
3	85.000	13.751	1.249
4	80.002	14.998	5.000
5	83.678	14.735	1.587
6	80.002	14.998	5.000
7	83.575	13.508	2.916
8	82.370	15.000	2.630
9	84.957	11.127	3.915
10	85.000	13.751	1.249
11	81.604	14.146	4.250
12	85.000	10.002	4.998
13	85.000	10.002	4.998
14	83.787	12.214	3.999
15	85.000	12.210	2.790
16	82.449	12.551	5.000

Using a statistical package, computations were carried out, including the selection of experimental points, randomization, analysis of variance, fitting of the models, and graphical displays (Design-Expert Version 7.0). On cooking characteristics and starch qualities, descriptive statistics were used. Analysis of variance (ANOVA) was performed on the data to find variations across formulations that were statistically significant ($p<0.05$).

2.2.3. Characterization of Rice Noodles

2.2.3.1. Proximate Analysis

To measure the moisture and protein of the noodle samples, the
Association of Official Analytical Chemists' standard techniques were employed AOAC (2000).

2.2.3.2. Starch properties

Starch properties such as solubility and swelling power will be determined according to the method of Crosbie et al., (1992)with slight modification. In centrifugal tubes, 0.5g (dwb) of flour samples were combined with 25 ml of water. The mixture was then heated to 85°C and maintained there for 30 min. The samples were centrifuged at 5000 x g for 15 minutes after being cooled to room temperature. It was then kept overnight at 130°C, after that the supernatant was evaporated and weighed. The weight of the dried supernatant to the initial weight of the dry flour is used to calculate solubility. The following formula was used to determine the samples of rice flour's solubility and swelling power.

$$Swelling\ Power\ (gg^{-1}) = \frac{weight\ of\ the\ wet\ sediments}{weight\ of\ dry\ flour} \quad (1)$$

$$Solubility\ (\%) = \frac{Weight\ of\ dried\ supernatant}{Initial\ weight\ of\ dry\ flour} \quad (2)$$

2.2.3.3. Cooking attributes

Cooking Time

Following (ISO, 7304), the ideal cooking period was determined, by removing a long strand of noodle and cutting it using a cutter until the continuous white line visible at the center of the cut section disappears. 25g of noodles were cooked in 300 ml of distilled water that was boiled. A timer was set, and the product was taken out every 30 seconds to determine how much cooking had taken effect.

Cooking Loss

Each sample, which weighed 25g, was cooked to perfection in 300ml of boiling distilled water. The leftover cooking liquid was collected and dried by evaporation in a 100°C oven for 24 hours. Weighted solids were used to report cooking loss as a proportion of the raw sample.

$$Cooking\ loss = \frac{Weight\ before\ cooking - Weight\ after\ cooking}{Weight\ before\ cooking} * 100 \quad (3)$$

2.2.3.4. Modelling of experimental data

The statistical significance of the response was checked through analysis of Variance (ANOVA) and the coefficient of determination (R^2) values were checked.

2.2.3.5. Proximate analysis of optimized noodle sample

Parameters like moisture content, protein content and ash content of the optimized noodle sample were measured following the methods provided by the AOAC (2000).

2.2.3.6. Rheology

On a controlled stress rheometer, dynamic rheological measurements were made. The spacing between the parallel 50 mm-diameter plates on which the rice dough was laid was set to 2 mm. With a constant tension of 2 Pa and 30 °C, a frequency sweep from 0.01 to 10 Hz was carried out. The dough was allowed to rest for 5 minutes to allow residual stresses to release. The applied strain was 1%. By contrasting log plots of the storage modulus (G′) and loss modulus (G″) with frequency, the dough structure was assessed.

2.2.3.7. Sensory evaluation

Panel consisting of 9 judges from the Department of Food Engineering and Technology evaluated the cooked pasta samples. The judges scored the sample in terms of appearance, flavor, color, texture, aroma and overall acceptability using a 9-point hedonic scale where 9 - extremely likely, 8 – like very much, 7-like moderately, 6-like slightly, 5-neither like nor dislike slightly, 4 – dislike slightly, 3 – dislike moderately, 2 – dislike moderately, 2 – dislike very much, 1 – dislike extremely.

2.2.3.8. Effect of storage on moisture content of the optimized noodle sample

The optimized sample's increased moisture content was observed for 15 days at 5-day intervals.

3. Results and discussions

3.1 Moisture and Protein Content

Table 3.1. Moisture and protein content of Rice noodles

Sl No.	Moisture Content (%)	Protein Content (%)
1	2.3	36.0
2	1.2	29.1
3	1.6	26.0
4	2.4	36.8
5	1.5	28.0
6	2.6	36.3
7	1.2	29.0
8	1.7	28.0
9	2.8	26.0
10	1.9	25.0
11	3.4	29.0
12	1.4	35.8
13	2.7	35.8
14	1.3	24.6
15	2.4	34.3
16	2.8	35.9

In the above table, it is seen that the moisture content of the 16 noodle samples lies in the range of 1-3%. Protein content was estimated using the Lowry’s method and the range varies from 25-35%

3.2. Starch Properties

The relative strengths of the bonding within the granules are determined by evaluating the solubility of starches at various temperatures (Schoch, 1964). According to reports, tests for swelling and solubility at an oven temperature of 80°C serve as a decent simulation of the actual process for creating noodles and have been utilized as quick, small-scale ways to forecast the eating quality of wheat and starch noodles (Crosbie et al., 1992).

Table 3.2. The swelling index and solubility for the noodle samples are shown

Sl No.	Swelling Index(gg^{-1})	Solubility (%)
1	26.8	24.8
2	37.1	36.0
3	37.9	35.8
4	26.8	24.8
5	37.8	35.8
6	26.8	24.8
7	37.3	36.0
8	37.1	36.0
9	36.0	26.0
10	37.9	35.8
11	25.9	23.0
12	26.5	24.1
13	26.5	24.1
14	36.0	26.0
15	37.2	36.0
16	26.8	24.2

3.3. Cooking Attributes

Table 3.3. Table showing data for the cooking time and cooking loss for the noodle samples

Sl No.	Cooking Time(s)	Cooking Loss (%)
1	254	26.1
2	210	27.0
3	180	30.8
4	252	26.2
5	193	30.5
6	250	25.9
7	223	27.0
8	210	27.0
9	235	26.5
10	180	30.8
11	243	26.1
12	248	26.3
13	248	26.3
14	235	26.5
15	218	27.0
16	250	26.1

In the above table, it can be seen that as the xanthan gum content in the product increases the cooking time increases and vice versa. The cooking loss however decreases when the xanthan gum content in the sample is comparatively more.

3.4. Modelling of experimental data

The experimental design and the corresponding responses are shown in the Table 3.4. The statistical significance of the response was checked through analysis of Variance (ANOVA) and was presented in Table 3.6 – 3.10. The value of determination coefficient (R^2) should be 0.8 and above for the good fit of model (Joglekar&May, 1987). The coefficient of determination (R^2) of all responses in the present study was above 0.8, which implied that the independent variables were highly attributed for the noodle making formulations.

Table 3.4. Experimental design for noodle development

	Factors			Responses			
Run No	**A: Rice Flour(g)**	**B: Corn Flour(g)**	**C: Xanthan Gum(g)**	**Cooking Time(s)**	**Cooking Loss (%)**	**Swelling Index(gg^{-1})**	**Solubility (%)**
1	82.449	12.551	5.00	254	26.1	26.8	24.8
2	82.370	15.000	2.630	210	27.0	37.1	36.0
3	85.000	13.751	1.249	180	30.8	37.9	35.8
4	80.002	14.998	5.000	252	26.2	26.8	24.8
5	83.678	14.735	1.587	193	30.5	37.8	35.8
6	80.002	14.998	5.000	250	25.9	26.8	24.8
7	83.575	13.508	2.916	223	27.0	37.3	36.0
8	82.370	15.000	2.630	210	27.0	37.1	36.0
9	84.957	11.127	3.915	235	26.5	36.0	26.0
10	85.000	13.751	1.249	180	30.8	37.9	35.8
11	81.604	14.146	4.250	243	26.1	25.9	23.0
12	85.000	10.002	4.998	248	26.3	26.5	24.1
13	85.000	10.002	4.998	248	26.3	26.5	24.1
14	83.787	12.214	3.999	235	26.5	36.0	26.0
15	85.000	12.210	2.790	218	27.0	37.2	36.0
16	82.449	12.551	5.000	250	26.1	26.8	24.2

A high R^2 value does not, however, guarantee that the regression model is always a fit one. A decent statistical model should have comparable adjusted and unadjusted R^2 values. A CV more than 10% typically denotes substantial mean value variation and a failure to meaningfully establish an acceptable response model. For the model and parameters to be significant, p values of 0.05 or below must be acquired, but for lack of fit, p values greater than 0.05 ($p>0.05$) must be produced. The cubic model was determined to be the best model for cooking time, cooking loss, and solubility when these rules for physical parameters were followed.

3.4.1. Effect of variables on cooking time

The statistical analysis from Design Expert Version 7.0 software suggested a cubic model as the best model.

Table 3.5. Analysis of Variance Table for cooking time

Source	*Sum of squares*	*df*	*Mean Square*	*F value*	*p-value prob>F*	
Model (cubic)	9916.39	9	1101.82	658.17	<0.0001	significant
Linear Mixture	9713.19	2	4856.59	2901.07	<0.0001	
AB	5.36	1	5.36	3.20	0.1238	
AC	29.22	1	29.22	17.46	0.0058	
BC	36.36	1	36.36	21.72	0.0035	
ABC	0.095	1	0.095	0.057	0.8194	
Residual	10.04	1	1.67			
Lack of fit	0.044	1	0.044	0.022	0.8874	Not significant
R^2	0.9990					
R^2_{adj}	0.9975					
C.V. %	0.57					

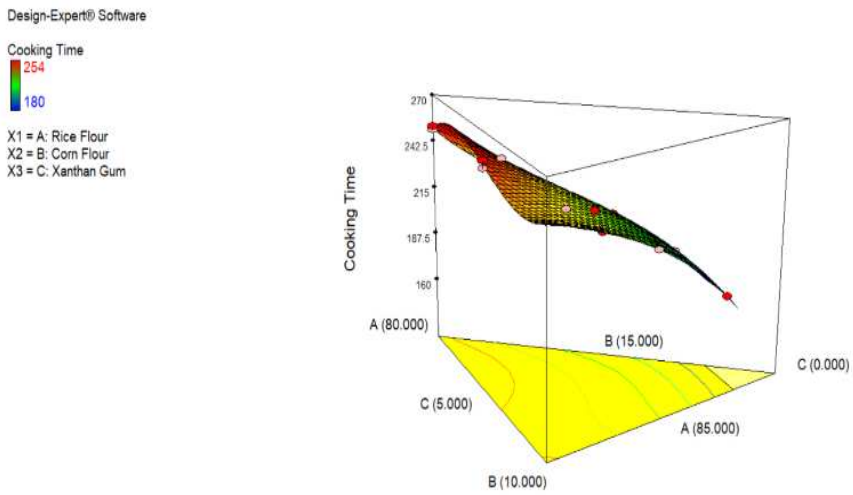

Figure 3.1.3D surface of effects of variables on cooking time

3.4.2. Effect of variables on cooking lossThe statistical analysis from Design Expert Version 7.0 software suggested a cubic model as the best model.

Table 3.6. Analysis of Variance Table for cooking loss

Source	*Sum of squares*	*df*	*Mean Square*	*F value*	*p-value prob>F*	
Model (cubic)	45.76	9	5.08	388.13	<0.0001	significant
Linear Mixture	35.72	2	17.86	1363.37	<0.0001	
AB	6.493E-003	1	6.493E-003	0.50	0.5078	
AC	2.87	1	2.87	219.14	<0.0001	

BC	2.22	1	2.22	169.42	<0.0001	
ABC	0.67	1	0.67	51.09	0.0004	
Residual	0.079	1	0.013			
Lack of fit	0.034	1	0.034	3.73	0.1112	Not significant
R^2	0.9983					
R^2_{adj}	0.9957					
C.V. %	0.42					

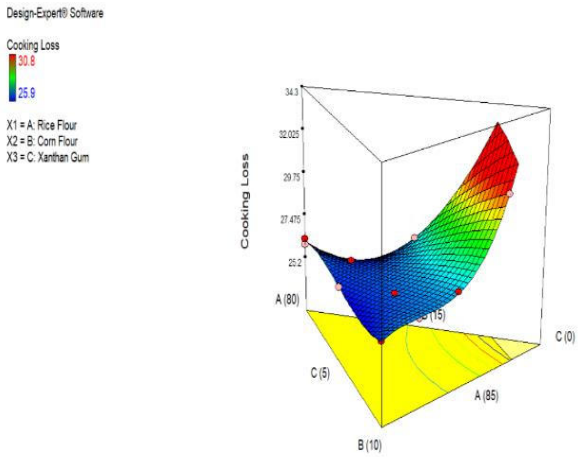

Figure 3.2. 3D surface of effects of variables on cooking loss

3.4.3. Effect of variables The statistical analysis from Design Expert Version 7.0 software suggested a cubic model as the best model.

Table 3.7. Analysis of Variance Table for swelling index

Source	***Sum of squares***	***df***	***Mean Square***	***F value***	***p-value prob>F***	
Model (cubic)	440.93	9	48.99	100.05	<0.0001	significant
Linear Mixture	349.48	2	174.74	356.84	<0.0001	
AB	0.19	1	0.19	0.38	0.5605	
AC	2.42	1	2.42	4.94	0.0680	
BC	2.46	1	2.46	5.03	0.0660	
ABC	0.035	1	0.035	0.072	0.7970	
Residual	2.94	6	0.49			
Lack of fit	2.94	1	2.94			
$\mathbf{R^2}$	0.9934					
$\mathbf{R^2_{adj}}$	0.9835					
C.V. %	2.15					

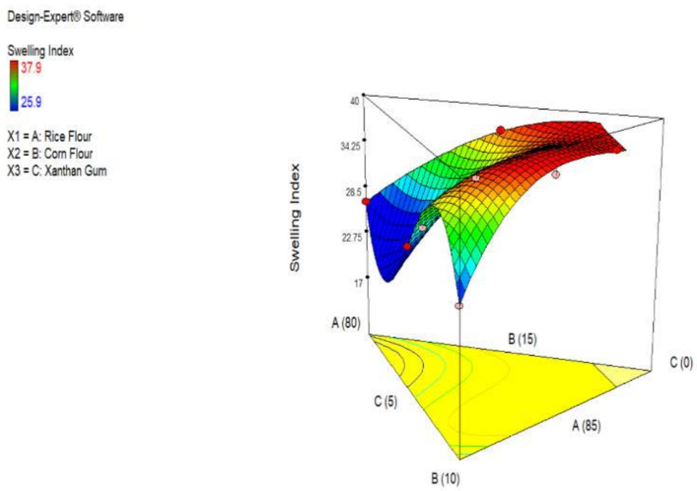

Figure3.3. 3D surface of effects of variables on swelling index

3.4.4. Effect of variables on solubilityThe statistical analysis from Design Expert Version 7.0 software suggested a cubic model as the best model.

Table 3.8. Analysis of Variance Table for solubility

Source	Sum of squares	df	Mean Square	F value	p-value prob>F	
Model (cubic)	505.77	9	56.20	205.36	<0.0001	significant
Linear Mixture	424.87	2	212.44	776.31	<0.0001	
AB	6.705E-004	1	6.705E-004	2.450E-003	0.9621	
AC	70.64	1	70.64	258.15	<0.0001	
BC	60.65	1	60.65	221.62	<0.0001	
ABC	37.33	1	37.33	136.42	<0.0001	
Residual	1.64	6	0.27			
Lack of fit	1.46	1	0.044	0.022	0.8874	significant
R^2	0.9968					
R^2_{adj}	0.9919					
C.V. %	1.77					

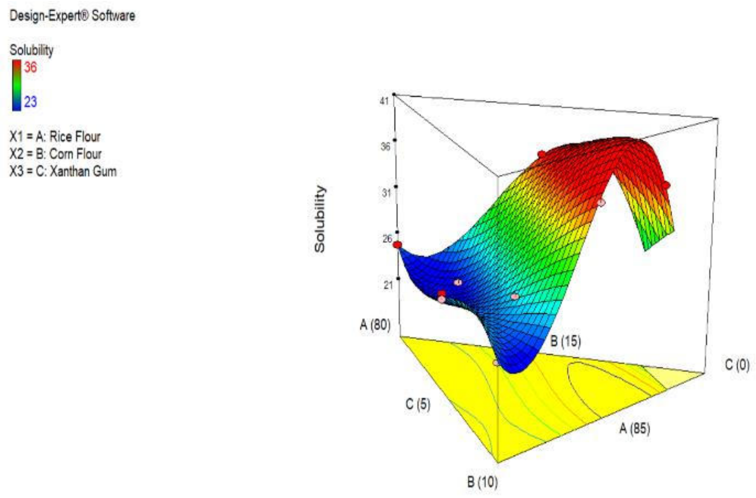

Fig 3.4. 3D surface of effects of variables on solubility

3.4.5. Standardization of Noodle composition

By choosing the responses from cooking time, cooking loss, swelling index, and solubility, the values of the variables were optimized. Based on the observation that the replies directly affected the caliber of the generated noodles, as demonstrated by the corresponding R^2 values, numerical as well as graphical optimization was used. The optimum values were 15% corn flour, 2.6% xanthan gum, and 82.386% rice flour. The standardized combination's validation was completed. The experimental results were discovered to be rather near to the projected results, demonstrating the accuracy of the predicted models.

Table 3.9. Criteria used for the optimization along with predicted value responses

Constraints	Goal	Lower limit	Upper limit	Importance	Standardized Values
Rice Flour	In range	80.0022	85	3	82.386
Corn Flour	In range	10.0018	15	3	15.000
Xanthan Gum	In range	1.24887	5	3	2.614
Cooking time	Minimize	180	254	3	209.776
Cooking loss	Minimize	25.9	30.8	3	27.0488
Swelling index	Maximize	25.9	37.9	3	37.0262
Solubility	Maximize	23	36	3	36

Table 3.10. Validation of the standardized combination

Parameters	*Actual*	*Predicted*
Rice Flour	82.3	82.3
Corn Flour	15.0	15.0
Xanthan Gum	2.6	2.6
Cooking Time	207.5	209.776
Cooking Loss	26.91	27.0488
Swelling Index	36.7	37.0262
Solubility	35.5	36

3.5. Proximate analysis of optimized noodle sample

Table 3.11 summarizes the proximate composition of the optimized noodle sample

Noodle sample	Moisture Db*(%)	Protein (%)	Ash
Optimized	2.5±0.30	29.9±0.97	0.213±0.17

*Values are mean ± SD of three independent analyses (n=3)

A B

Figure 3.5. Optimized (A- Uncooked Noodles) and (B – Cooked Noodles)

3.6. Rheology

Rheological behavior of the optimized sample's dough was studied and compared to that of a plain rice dough, in order to study the effects of addition of corn flour and xanthan gum.

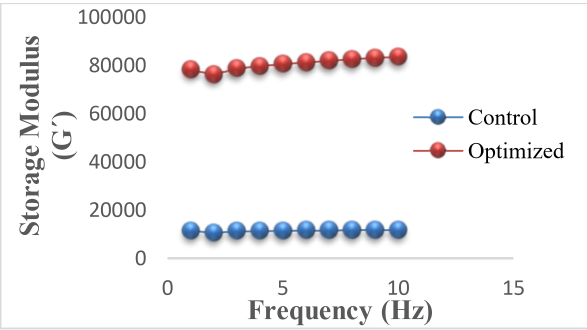

Figure 3.6. Effect of corn flour and xanthan gum incorporation into rice flour on storage modulus of rice dough

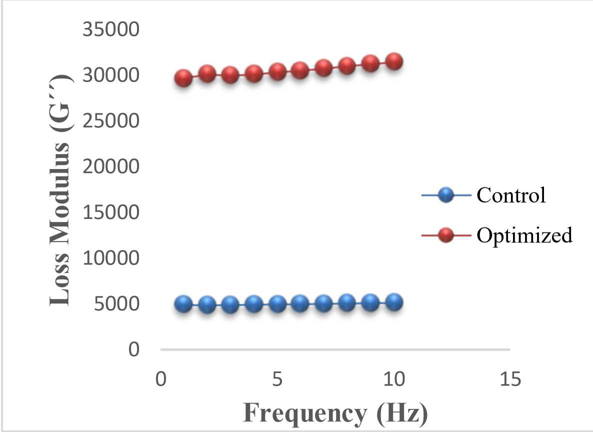

Figure 3.7. Effect of corn flour and xanthan gum incorporation into rice flour on Loss modulus of rice dough

The storage modulus provides information on the degree of structure in a material. It is a representation of the energy held inside the sample's elastic structure. The material can be regarded as predominantly elastic if the storage modulus is larger than the loss modulus and the phase shift is lower than 45ºC. The loss modulus represents the viscous component of the total amount of elasticity. A material is equally elastic and viscous if the phase shift is 45ºc or tanφ=1.

It is considered to be a hard dough if the difference between storage modulus and loss modulus is greater than 1000, and a soft dough if the difference value is less than 1000. The addition of maize flour and xanthan gum enhanced both the elastic modulus (G') and viscous modulus (G"). The rise in modulus value suggests that the dough got stronger.

3.7. Sensory evaluation

The optimized noodle sample was subjected to sensory analysis and there was a total of 20 number of panelists. Each panelist were provided with a sensory analysis sheet and hedonic scale rating was followed. The product received a sensory score of 7.83 and 8.04 respectively for color and aroma.

Table 3.12. Sensory scores of the cooked noodles

Parameters	*Score**
Appearance	7.50 ±0.5
Colour	7.83 ±1.0
Texture	8.33± 0.8
Aroma	8.04 ±1.4
Taste	8.40 ±0.7
Overall acceptability	8.22 ±0.3

*Values are mean SD of three independent analyses (n=9)

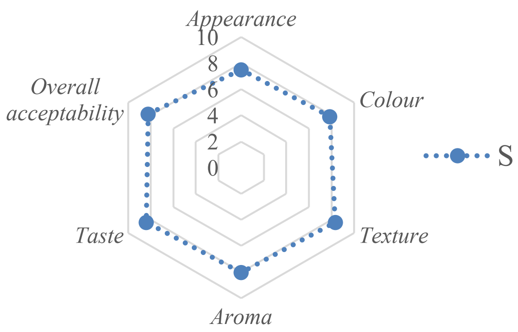

Figure 3.8. Radar graph for sensory data of the noodles

3.8. Effect of storage on moisture content of the optimized noodle sample

The amount of moisture gained by the optimized sample kept in an accelerated shelf-life condition for 15 days is shown in the table below.

Table 3.13. Storage studies of optimizednoodles

No. of days	*Gain of moisture (%)*
0	0
5	1.129
10	6.967
15	7.969

4. Conclusions

From the current research carried out, it can be concluded that the addition of corn flour and xanthan gum in the rice flour alters the rheological behavior, greatly. From the rheological data, it is seen that the dough is hard and possesses viscoelastic nature. Both elastic modulus (G´) and viscous modulus (G´´) were seen to increase with the addition. The magnitude of the modulus increased, which implies that the rice dough became stronger.

The optimized product has a protein content of 30% whereas noodles obtained in the market have a protein content of 11-15%. This considerable amount of protein can be attributed to the presence of both rice flour and corn flour bound together by xanthan gum.

The product has a cooking time of 3-4 minutes and gives off a good aroma thus a sensory score of 8 in average.

However, the cooking loss of 26-27% is a considerable amount of loss of the product and doesn't comply with the acceptable limit (BIS, 1993). The weakening and disruption of the protein-starch matrix is blamed for cooking loss. Disruption of the protein starch matrix may be the cause of an increase in cooking loss. Further research for the stability of the noodles prepared from the Bora Rice Flour can be carried out in the future.

5.References

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