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Research Article

Formulation and Optimization of Multigrain Fermented Noodles: A Healthy and Palatable Convenience Food Option

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In the present study, multigrain fermented noodles were prepared using seera (fermented wheat starch), green gram, sorghum, and finger millet flours with different proportions. Then, the optimized formulation was developed, and cooking characteristics, sensory attributes, nutritional composition, and *in vitro* protein digestibility (IVPD) were evaluated. The prepared noodles showed better cooking characteristics, sensory attributes, and overall acceptability. Compared to commercial and control noodles, the optimized multigrain fermented noodles exhibited higher fiber, total phenol content, ash, iron, reducing sugar, and protein content. At the same time, the IVPD ($92.5 \pm 0.29\%$) of multigrain fermented noodles was comparable to control as well as commercial noodles. The XRD pattern showed a sharp peak at 15 and 20°, and the overall crystallinity was 34.12% observed. The ready-to-cook multigrain fermented noodles, prepared from the fermented wheat starch base, can be used as a healthy choice to refine wheat flour-based noodles, reducing chronic diseases.

1. Introduction

The global trends of consumer food mood shifting to fast foods, ready-to-cook foods like noodles, pasta, and breakfast cereal flakes, have increased worldwide. However, they are not health sustainable; parallelly, increased wellness and healthy food demand can be tackled by infusion of new gastronomic trends and bioactive ingredients. This study brings a solution from junk food to a shift to a healthy food culture. These fast foods are primarily prepared using refined wheat flour due to the presence of fiber; vitamin B complexes including thiamine, pyridoxine, and riboflavin; and some macro- and microelements like zinc, iron, and calcium [1]. Refined wheat flour poses an elevated risk of chronic diseases such as heart disease, diabetes, and obesity [2].

Seera, traditionally prepared in hilly areas of India, is considered beneficial to pregnant women. It has the potential to be an alternative to refined wheat flour. To prepare seera, wheat grains are fermented for 5 days with microorganisms like *Cryptococcus laurentii*, *Torulaspora delbrueckii*, and *Saccharomyces cerevisiae* among yeasts and bacteria such as *Lactobacillus amylovorus* and *Leuconostoc* sp. [3, 4]. It helps maintain a healthy gut microflora and reduces the risk of gastrointestinal problems. Apart from that, it also contains a high amount of reduced sugar and low gluten content. On the other hand, fermented wheat flour is also utilized for preparing jalebi, bhatooru, and pasta [5–7].

Other than cereals, legume flours such as green gram, sorghum, and pulses are suitable for ready-to-cook food items. Green grams have a high protein content (~21 to 31%) and an excellent amino acid profile, reducing the risk of chronic diseases [8]. Sorghum contains moderate to high levels of macronutrients, micronutrients (calcium, iron, magnesium, phosphorous), thiamine, niacin, and phylloquinone content [9, 10]. Furthermore, it has an abundance of bioactive compounds like phenolic compounds, flavonoids, proanthocyanidins, or procyanidins; phytochemicals such as tannins, phytosterols, policosanols, and anthocyanins; and dietary fiber [9]. In addition, sorghum can remarkably regulate blood glucose levels [11]. Finger millets are rich in calcium (~3 times higher than milk), which helps in bone mineralization, improves bone density, and reduces the risk of diabetes [12].

Several studies have been reported on the development of multigrain and fermented grains/flours (black chickpea, pigeon pea, green gram, millet, and sorghum), pasta, noodle, and bakery products [2, 13–20]. However, no study has been reported on developing ready-to-cook multigrain products using seera. Therefore, the study is aimed at developing a healthy and nutritionally rich ready-to-cook noodle using traditional domestic culinary methods, substituting refined wheat flour with fermented wheat starch, sorghum, finger millet, and green gram flour. Furthermore, the effect of various nutritional ingredients on physiochemical and nutritional composition and sensory attributes was also investigated.

2. Material and Methods

2.1. Raw Materials. Green gram, sorghum, finger millet, and wheat grains were procured from the Narela market (Delhi, India). The control noodle samples prepared from wheat grains were powdered finely into flour and passed through a 250 μm sieve. Further, the seera (fermented wheat starch) with *Cryptococcus laurentii*, *Lactobacillus amylovorus*, and *Leuconostoc* sp. was prepared in the laboratory using the procedure represented in Figure 1 and sun-dried from 9:30 AM to 4:30 PM performed 5-6 days, as suggested by Ahmad et al. [3]. Therefore, guar gum was used in preparing instant multigrain fermented noodles.

2.2. Formulation Optimization. In response surface methodology, a 3-factor-5-level central composite design with the quadratic model was used to optimize the instant noodles, which obtained 17 formulations. In optimization, green gram, sorghum, and finger millet were taken as dependent variables, whereas seera, guar gum, and salt concentration were kept fixed. After that, cooking weight, cooking loss, cooking time, overall acceptability, and hardness were considered responses.

To set up a statistical model, we deemed $Y1$,$Y2$,$Y3$,$Y4$, and $Y5$ as cooking weight, cooking loss, cooking time, hardness, and sensory analysis, overall acceptability responses, respectively, and determined coded factor levels as A (green gram, 15–30 g), B (sorghum, 15–25 g), and C (finger millet, 5–10 g). Primary tests were conducted to obtain levels of factors that can develop instant noodles with acceptable attributes.

All response data were fitted into a second-order polynomial equation. These aid in obtaining responses as a result of independent variables. The model that links the independent factors and the chosen responses is mentioned as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{12} X_1 X_3 + \beta_{23} X_2 X_3 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2. \quad (1)$$

From the above equation, Y depicts the response variable while β and X terms indicate regression coefficients and independent factors, respectively. ANOVA was used to test the statistical significance at probability value $p \leq 0.05$ to verify model accuracy. Three-dimensional response graphs were plotted by varying the two factors and another constant factor [21]. Numerical optimization was implemented after the regression analysis to identify optimized formulations. The experiments were conducted for noodles developed from optimized formulations, and the resulting data has been compared with predicted values.

2.3. Proximate Analysis. The proximate analysis, such as the fat, moisture, protein, fiber, and ash content of all flour samples and the optimized samples, was determined according to standard methods [22]. The carbohydrate content was determined by subtracting all proximate values from 100.

2.4. Cooking Characteristics. The cooking properties were evaluated according to Yadav et al. [23] with slight modifications. The cooking time was measured when the outer core of noodles was removed by squeezing cooked samples between glass plates, and the cooking weight was evaluated once the noodle was cooked for preestimated time, followed by cooling for 1 min and measuring the water gained by noodles during cooking. Cooking loss (g/100 g) was calculated by boiling 5 g sample in 150 mL of water, draining the excess water, and drying at 105°C. The cooking loss was calculated as a ratio of the dried weight of residue to the initial weight of noodles.

2.5. Texture Analysis. A texture analyzer (CT3, Brookfield Engineering Laboratories, USA) was used to determine the hardness of the cooked fermented noodles. The samples were penetrated by TA-PFS-C knife edge cut probe with 10% deformation. Initially, samples were cooked only a few minutes before testing. Before launching the test, 5 strands of 2 cm long cooked noodles were positioned centrally under the probe, on the base of the analyzer. The texture analysis's pretest, test, and posttest speeds were set at 2 mm/s with 75% strain and 5 kg load cell. Results of hardness were generated from the force-time curve and were obtained in N.

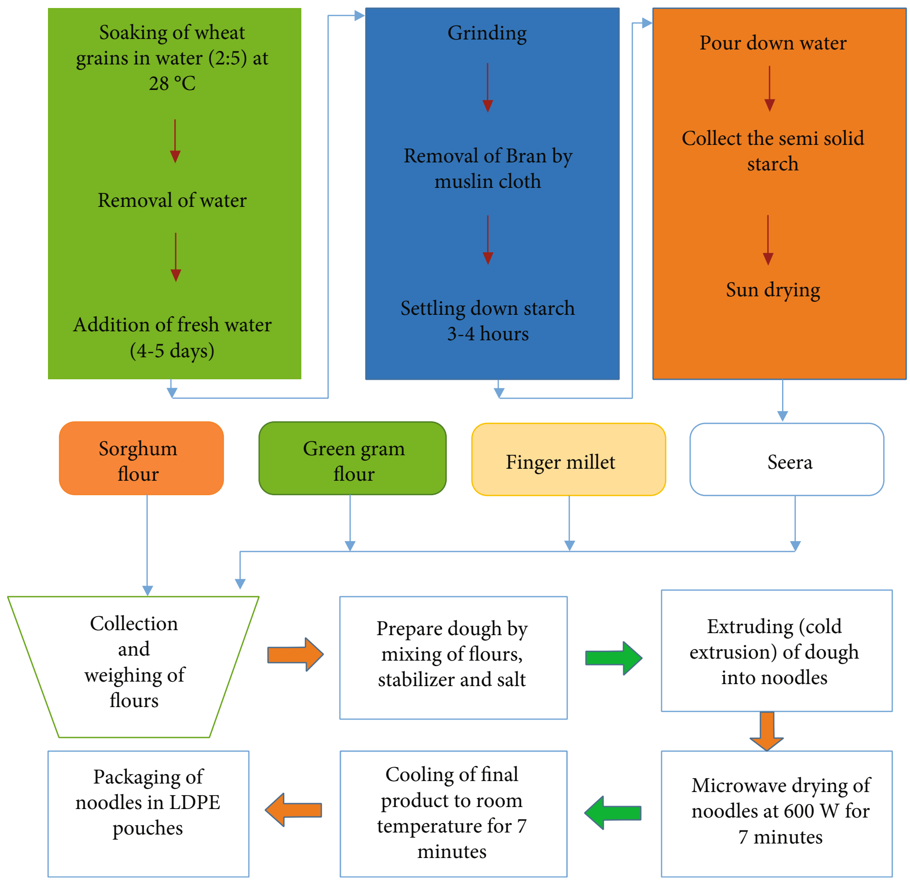


Figure 1: Flow diagram of preparation and processing multigrain fermented noodle.

2.6. Overall Acceptability. The sensory panel of 20 semi-trained members comprised 12 females and 8 males, age group 28-35 years. Each member's consent was taken to be involved in the panel, and the organoleptic properties of the cooked noodles were determined by conducting sensory analysis, according to Kamble et al. [18]. The 9-point hedonic scale method was employed; however, before scaling, panelists asked for rank intensity as per samples. Moreover, the panelists analyzed the product's overall acceptability based on taste, aroma, texture, and color attributes.

2.7. Total Dietary Fiber. An integrated method of determination of total dietary fiber was employed by complying with the standard of AOAC [24]. Sample (1 g) was incubated with 2 kilo units of pancreatic α-amylase and 0.14 kilo units of amyloglucosidase for 16 h at 37°C and maintained the pH (6) to hydrolyze the starch. After that, the residual protein was denatured by heating at 95°C and maintaining a pH of 8.2. Therefore, the denatured sample was hydrolyzed with proteases after cooling to 60°C and reducing pH to 4.2. Then, 78% ethanol was added to precipitate soluble dietary fiber (SDF). Insoluble fractions were retrieved by filtration, washing, drying, and weighing. These dried fractions were analyzed for ash and protein to determine high molecular weight dietary fiber (HMWDF) by subtracting protein and ash weights. An aliquot part of the alcoholic filtrate was concentrated and redissolved in water and then desalted to analyze the SDF by chromatography on an HPLC column. The total dietary fiber was calculated by adding HMWDF and SDF.

2.8. Iron Content. To determine the iron content of the noodles, samples were first charred by placing them in a muffle furnace at 450°C for 5 hours. The cooled samples were then added to a magnesium nitrate solution. 1 mL of hydroxylamine hydrochloride solution was mixed with the samples and incubated for 10 minutes. 5 mL of buffer was added, followed by 2 mL of dipyridyl solution. The absorbance was measured at 510 nm. The standard curve of iron was prepared using the standard methodology of FSSAI (Govt. of India, 2015 Metals).

2.9. Total Phenolic Content. The total phenolic content (TPC) of noodle samples was analyzed using the Folin-Ciocalteu (FC) phenol reagent. First, extraction was carried out using a methanolic and water (80 : 20) solution and kept in a shaking incubator (Innova 42, New Brunswick Scientific Eppendorf, Denmark) at 50°C for 2 hours. Then, 100 μL of extract was mixed with 2.5 mL of FC reagent (10%) and sodium carbonate. The mixture was then incubated at room temperature, and the absorbance was measured using a UV spectrophotometer (UV-2600, Shimadzu, Japan) at 750 nm, as described by Kheto et al. [25]. Gallic acid (GAE) was used as a standard, and the results were expressed in mg GAE/100 g.

2.10. Reducing Sugars. To determine the reducing sugars in the multigrain fermented noodles, 5 g of sample was dissolved in hot water in a volumetric flask and the solution was filtered [26]. Then, titration was performed by adding Fehling A and B solutions to the filtered solution. A few drops of methylene blue indicator and brick red were also added. The reducing sugar content was calculated using

$$\text{Reducing sugars (\%)} = \frac{\text{dilution Fehling factor (g)}}{\text{weight of sample} \times \text{titrate value}} \times 100. \quad (2)$$

2.11. In Vitro Protein Digestibility. The in vitro protein digestibility (IVPD) of multigrain fermented noodles was determined using the method described by Kamble et al. [18]. In brief, 1 g of sample extract was mixed with 15 mL of HCl (0.1 M) and 1.5 mg of pepsin and kept for 3 h at 37°C. After that, 7.5 mL of 0.2 M NaOH and pancreatin solution (4 mg added in 7.5 mL of 0.2 M phosphate buffer at pH of 8.0) was added to the mixture successively. Then, 1 mL of toluene was added to inhibit the growth of microorganisms, and the solution was shaken for 1–2 min and kept for 24 h at 37°C in an incubator. Therefore, the prepared mixture was treated with 10 mL of TCA to separate the undigested protein and large peptides, followed by centrifugation at 3,000 rpm for 20 min. Finally, the protein percentage in the sample was determined using the Kjeldahl method to calculate the IVPD using

$$\text{IVPD (\%)} = \frac{\text{nitrogen (in residue)} - \text{nitrogen (in blank)}}{\text{nitrogen (in sample)}} \times 100. \quad (3)$$

2.12. FTIR. The functional groups in multigrain fermented noodles were analyzed using FTIR spectrophotometer (Alpha E, Bruker, UK), according to the method reported by Kheto et al. [27].

2.13. SEM. The morphological characteristics of control and optimized multigrain fermented noodles were analyzed using SEM (VEGA 3, SBH, TESCAN Brno S.R.O., Czech Republic) at an accelerating voltage in the range of 5–20 kV.

2.14. XRD. The diffraction patterns of native fermented starch and multigrain mixture gel were examined by XRD (Rigaku Miniflex 600, Rigaku Corporation, Japan). The 2θ was varied from 10–55° during the experiment at a step scan of 0.01° and a count time of 2 s.

2.15. Statistical Analysis. For experimental design and optimization, the CCD of Design-Expert version 10.0.2.0 (Stat-Ease, Inc., Minneapolis, MN, USA) was used. In the SPSS software, one-way ANOVA was used, and the significance of each term was determined using Duncan's multiple range test (SPSS, Inc., Chicago, IL, USA).

3. Results and Discussion

3.1. Cooking Attributes. RSM software was used to optimize the cooking properties of fermented wheat noodles using five variables: cooking weight, cooking loss, cooking time, and hardness. Meanwhile, poor cooking attributes were associated with gluten-free noodles, which weaken the interactions between starch and protein [20]. With the trained panel, sensory analysis was carried out on optimized products. The experimental results of cooking weight obtained with a combination of various independent variables are presented in Table 1. In addition, an ANOVA test was performed to assess the model's suitability. All response variable models were statistically significant ($p < 0.05$, $R^2 = 0.83 - 0.98$) and are shown in Table 2. As a result, the second-order regression equation appropriately described the effect of independent variables on the cooking weight of multigrain fermented noodles. Each independent variable's linear and interactive effect on responses was studied using the linear and 3D response surface plots shown in Figures 2 and 3. The interactive effect of two variables was explored by varying one variable while keeping the second variable constant.

3.2. Effect of Independent Variables on the Cooking Weight of Fermented Wheat Multigrain Noodles. Table 1 shows that the cooking weight of multigrain fermented noodles varied from 13.3 to 15.2 g. The maximum cooking weight (15.2 g) was found in noodles containing 30% green gram, 20% sorghum, and 10% finger millet (run 2). However, the minimum cooked weight (13.3 g) was observed in the noodles consisting of 22.5% green gram, 20% sorghum, and 7.5% finger millet-based noodles (run 13). A quadratic model was fitted to the data, which was found to be statistically significant ($p < 0.05$, $R^2 = 0.83$), and there was a nonsignificant lack of fit ($F = 4.17$). Model terms B, A^2, and C^2 were found to be significant, as presented in Table 2. In addition, cooking time was significantly ($p < 0.05$) influenced by sorghum quantity in the linear model, while green gram and finger millet followed the quadratic model. Furthermore, the influence of sorghum flour on cooking weight at the optimized condition of green gram ($A = 29.53$ g) and finger millet flour ($C = 5$ g) is shown in Figure 2(a). Additionally, there was a marginal increase in cooking weight until 25 g of sorghum was added, as shown by the positive regression term B in Table 2. Moreover, adding sorghum flour to multigrain fermented noodles reduced the cooking weight due to the high fiber content and nonuniformity in the gluten network of fermented noodles.

On the other hand, Figure 2(b) shows the effect of green gram flour on cooking weight at optimized points of sorghum flour ($B = 22.93$ g) and finger millet flour ($C = 5$ g). The cooking weight increased as green gram flour increased from 21 to 30 g. Similarly, Figure 2(c) depicts the effect of finger millet flour on cooking weight at the optimum levels of green gram flour ($A = 29.53$ g) and sorghum flour ($B = 22.93$ g). The cooking weight initially decreased as finger millet flour increased from 5 to 7 to 10 g, as shown in Figure 2(c). The reduced cooking weight of multigrain

Table 1: Central composite arrangement for variables *A* (green gram), *B* (sorghum), and *C* (finger millet) and their responses *Y*1 (cooking weight (g)), *Y*2 (cooking loss (g/100 g)), *Y*3 (cooking time (min)), *Y*4 (hardness (N)), and *Y*5 (overall acceptability).

Run	*A*	*B*	*C*	*Y*1	*Y*2	*Y*3	*Y*4	*Y*5
1	15 (-1)	25 (1)	7.5 (0)	13.9	10.4	2.27	2.09	7.4
2	30 (1)	20 (0)	10 (1)	15.2**	11.9**	2.6**	3.1**	6*
3	22.5 (0)	20 (0)	7.5 (0)	13.79	10.4	2.27	2.15	7.4
4	30 (1)	20 (0)	5 (-1)	14.18	7.8	2.36	2.2	8.1
5	22.5 (0)	25 (1)	10 (1)	13.78	9.8	2.6**	2.61	6.7
6	15 (-1)	20 (0)	10 (1)	14.75	9	2.57	2.3	6.5
7	22.5 (0)	15 (-1)	5 (-1)	14.6	9.1	2.1	2*	7
8	22.5 (0)	20 (0)	7.5 (0)	13.8	10.2	2.15	2.01	7.4
9	22.5 (0)	25 (1)	5 (-1)	14.4	7*	2.5	2.1	8
10	22.5 (0)	15 (-1)	10 (1)	14.9	9.2	2.39	2.35	6.8
11	15 (-1)	15 (-1)	7.5 (0)	14.55	9	2	2.1	7
12	22.5 (0)	20 (0)	7.5 (0)	13.71	10.3	1.95*	2.07	7.5
13	22.5 (0)	20 (0)	7.5 (0)	13.3*	10.4	2.27	2.15	7.4
14	15 (-1)	20 (0)	5 (-1)	14	9.1	2.57	2.1	6.5
15	22.5 (0)	20 (0)	7.5 (0)	13.75	9.9	2.27	2.05	7.2
16	30 (1)	15 (-1)	7.5 (0)	14.74	11	2.03	2.19	7.5
17	30 (1)	25 (1)	7.5 (0)	14.18	7.9	2.36	2.25	8.2**

A = green gram (g); *B* = sorghum (g); *C* = finger millet (g); *Y*1 = cooking weight (g); *Y*2 = cooking loss (g/100 g); Y3 = cooking time (min); *Y*4 = hardness (N); *Y*5 = overall acceptability. *Significant at $p < 0.05$. **Significant at $p < 0.01$.

fermented noodles could be responsible for weakening the gluten network and increased gruel losses.

3.3. Effect of Independent Variables on the Cooking Loss of Fermented Wheat Multigrain Noodles. Cooking loss indicates the ability to retain structural integrity and strongly influences the organoleptic properties of cooked items. Table 1 shows the cooking loss of multigrain fermented noodles ranging from 7 to 11.9 g/100 g. Maximum cooking loss (11.9 g/100 g) was observed in noodles prepared from 30% green gram, 20% sorghum, and 10% finger millet (run 2). On the other hand, the noodles comprising 22.5% green gram, 25% sorghum, and 5% finger millet had the lowest cooking loss (7 g/100 g) (run 9). The fitted model for cooking loss was quadratic and found significant ($p < 0.05$, $R^2 = 0.96$) and nonsignificant lack of fit ($F = 5.48$), with the terms *B* ($p < 0.05$), *AC*, *BC*, and B^2 found significant ($p < 0.01$) shown in Table 2.

Sorghum flour possessed an inverse effect on cooking loss, as shown in Figure 2(d). At the optimum points of green gram flour ($A = 29.53$ g) and finger millet flour ($C = 5$ g), the cooking loss decreased as the sorghum flour level increased from 15 to 25 g. Furthermore, Figure 2(e) shows the effect of finger millet flour on cooking loss at optimal levels of green gram flour ($A = 29.53$ g) and sorghum flour ($B = 22.93$ g). The cooking loss increased since the proportion of finger millet flour increased from 5 to 10 g. Millets are gluten-free, which weakens the gluten-starch network and improves solid leaching into the cooking water, resulting in an increased cooking loss [14, 15, 19]. Hymavathi et al. [15] and Marengo et al. [20] reported similar results for finger millet noodles and pasta, respectively.

The synergistic effect of green gram flour (*A*) and sorghum flour (*B*) on the cooking loss of multigrain fermented noodles at the optimum point of finger millet flour ($C = 5$ g) is shown in Figure 2(f). The cooking loss decreased from 9 to 8 g/100 g as the proportion of green gram flour increased from 18 to 27 g. Similarly, increasing the amount of sorghum flour from 19 to 25 g reduced cooking loss from 8 to 6 g/100 g. Furthermore, Figure 2(g) depicts the effect of green gram flour (*A*) and finger millet flour (*C*) on the cooking loss of multigrain fermented noodles at optimum sorghum flour ($B = 22.93$ g) levels. Also, Figure 2(h) depicts the combined influence of sorghum flour (*B*) and finger millet flour (*C*) on cooking loss at green gram flour ($A = 29.53$ g) optimum points. Cooking loss decreased from 10 to 8 g/100 g as sorghum flour concentration increased from 17 to 21 g, while cooking loss increased from 5 to 10% as finger millet flour proportion increased. The gluten-free nature of finger millet flour might be responsible for increased cooking loss. Because the gluten-protein network is responsible for maintaining the structural integrity of the noodles during cooking, a weak structure enables more granules to leach out, increasing the cooking residues [2, 16, 17, 19]. On the other hand, lower cooking loss of multigrain fermented noodles could be attributed to forming a complex network with protein and starch molecules, reducing amylose leaching [14, 20]. In contrast, Rosa-Sibakov et al. [28] reported also that pasta prepared with faba bean and fermented faba bean flours had higher cooking loss (10.8–11.5%) and lower water absorption (130–160%) than semolina pasta (6 and 193%).

3.4. Effect of Independent Variables on Cooking Time of Fermented Wheat Multigrain Noodles. In Table 1, the

Table 2: Analysis of variance for effect of variable on cooking weight, cooking time, hardness, and over all acceptability.

Source	Cooking weight			Cooking loss			Cooking time			Hardness			Overall acceptability		
	β	F-value	p value	β	F-value	p value	β	F-value	p value	β	F-value	p value	β	F-value	p value
Model		3.82	0.05**		20.78	0.0003***		5.39	0.02**		9.45	0.004***		42.25	0.0000282
Intercept	13.67			10.24			2.18			2.09			7.38		
A	0.14	1.46	0.27	0.14	1.20	0.309	-0.01	0.03	0.86	0.14	12.86	0.009***	0.3	48.93	0.0002***
B	-0.32	7.70	0.03**	-0.4	10.19	0.015**	0.15	13.90	0.007***	0.05	1.74	0.23	0.25	33.98	0.0006***
C	0.18	2.53	0.16	0.86	47.37	0.0002***	0.08	3.77	0.09*	0.24	38.02	0.0005***	-0.45	110.10	0.00002***
AB	0.02	0.02	0.89	-1.12	40.29	0.0004***	0.01	0.07	0.80	0.01	0.07	0.80	0.075	1.53	0.26
AC	0.07	0.17	0.69	1.05	35.10	0.0006***	0.06	1.09	0.33	0.17	9.70	0.02**	-0.52	74.93	0.00005***
BC	-0.23	2.04	0.20	0.67	14.50	0.007***	-0.05	0.68	0.43	0.04	0.51	0.50	-0.27	20.56	0.003***
A^2	0.39	6.25	0.04**	0.005	0.001	0.98	0.05	0.98	0.36	0.12	4.56	0.07*	-0.10	3.01	0.13
B^2	0.28	3.18	0.12	-0.67	15.04	0.006***	-0.07	1.67	0.24	-0.04	0.62	0.46	0.25	17.53	0.004***
C_2	0.47	8.96	0.02**	-0.79	21.18	0.002***	0.29	26.48	0.001***	0.22	16.43	0.005***	-0.50	72.25	0.0001***
Lack of fit		4.17	0.10		5.48	0.07		0.24	1.56		6.26	0.05		1.53	0.34
Fit statistics															
Std. dev.		0.32			0.35			0.11			0.11			0.12	
Mean		14.21			9.55			2.31			2.22			7.21	
R^2		0.83			0.96			0.87			0.92			0.98	

A = green gram; B = sorghum; C = finger millet. The asterisk symbols ***, **, and * are significant at 1, 5, and 10% level of significance, respectively.

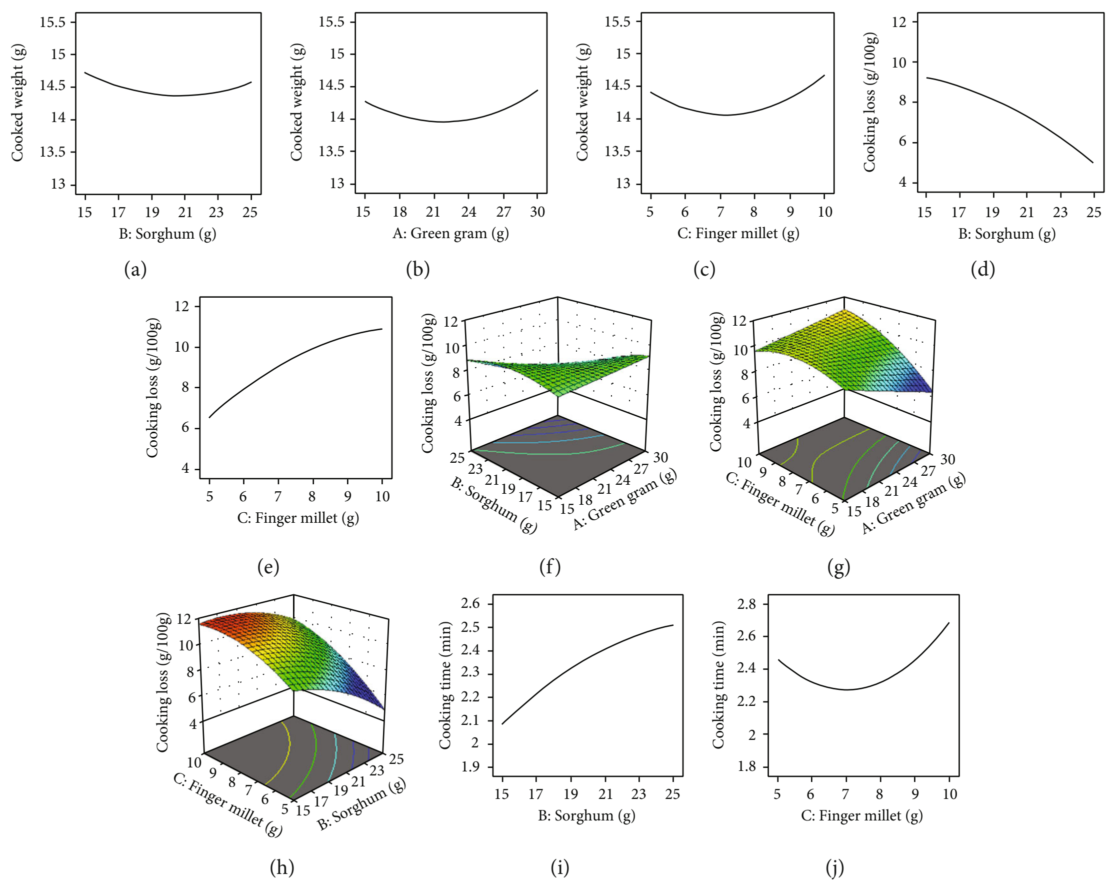


FIGURE 2: Effect of independent variables on cooking weight, cooking loss, and cooking time of multigrain fermented noodles.

cooking time for multigrain fermented noodles ranged from 1.95 to 2.6 min. The maximum cooking time (2.6 min) was obtained at run 2, consisting of 30% green gram, 20% sorghum, and 10% finger millet-based noodles, compared to run 5 (22.5% green gram, 25% sorghum, and 10% finger millet). The minimum cooking time (1.95 min) was recorded at run 12, which comprised 22.5% green gram, 20% sorghum, and 7.5% finger millet. As shown in Table 2, the quadratic model was found significant for cooking time ($p < 0.05$, $R^2 = 0.87$) with lack of fitting ($F = 1.56$), and terms B and C^2 were found significant ($p < 0.01$). The impact of independent variables on cooking time for multigrain fermented noodles was linearly dependent on sorghum proportion. Based on the results, it can be concluded that sorghum had the strongest effect on cooking time. These phenomena might be associated with sorghum's higher gelatinization temperature and the formation of an amylose-lipid complex, eventually improving cooking time [13, 21]. Furthermore, longer cooking times might have induced the degradation of amylose networks, reducing cooking loss [13]. However, finger millet had a significant effect at the 5% level.

The effect of sorghum flour on cooking time at the optimum points of green gram flour ($A = 29.53$ g) and finger millet flour ($C = 5$ g) is shown in Figure 2(i). As the proportion of sorghum flour increased from 15 to 25 g, the cooking time increased from 2.1 to 2.5 minutes. Benhur et al. [13] observed comparable results for sorghum flour-extruded pasta. Similarly, Figure 2(j) shows the effect of finger millet flour on the cooking time of multigrain fermented noodles at optimal levels of green gram flour ($A = 29.53$ g) and sorghum flour ($B = 22.93$ g). The amount of finger millet flour increased from 5 to 7 g, reduced the cooking time from 2.2 to 2.4 min, and then continued to increase as the amount of finger millet flour increased from 7 to 10 g. Jyotsna et al. [17] concluded that samples with a high protein concentration delay the hydration rate by causing complex starch networks. It might be due to the weakening of the protein-starch network, which could have accelerated water absorption and reduced cooking time.

3.5. Effect of Independent Variables on the Hardness of Fermented Wheat Multigrain Noodles. Hardness is an indicator of noodle firmness that is inversely associated with the water retention capacity of flour [21]. In this study, the hardness of multigrain fermented noodles ranged from 2 to 3.1 N, as shown in Table 1. Noodles containing 30% green gram, 20% sorghum, and 10% finger millet possessed the highest hardness value (3.1 N) (run 2). The lowest value was found in noodles comprising 22.5% green gram, 15% sorghum, and 5% finger millet (run 7). As shown in Table 2, the hardness of noodles fitted significantly with a quadratic model ($p < 0.05$, $R^2 = 0.92$); terms A, C, and C^2 significant ($p < 0.01$); and AC significant ($p < 0.05$). Adding green gram and finger millet flours significantly ($p < 0.01$)

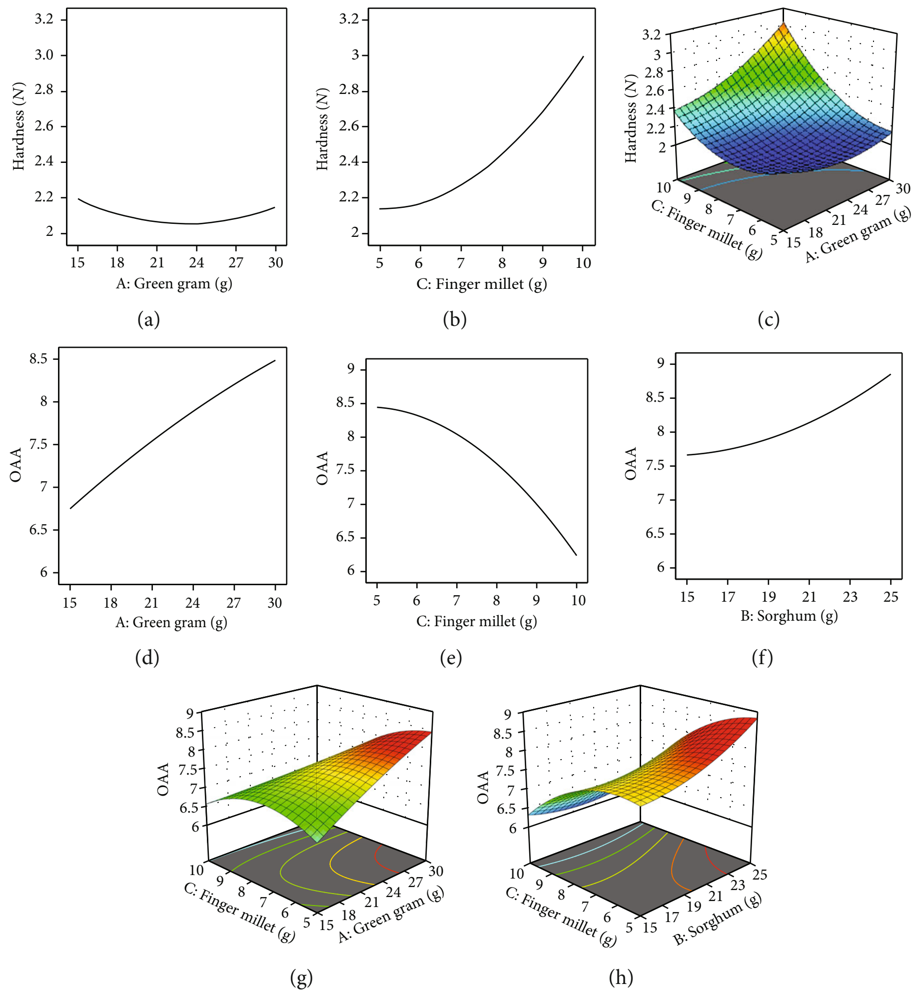


Figure 3: Effect of independent variables on hardness and overall acceptability of multigrain fermented noodles.

influenced the hardness values of multigrain fermented noodles. However, Figure 3(a) showed the effect of green gram flour on hardness at optimal levels of sorghum flour ($B = 22.93$ g) and finger millet flour ($C = 5$ g). Noodles produced from fermented multigrain decreased in hardness from 2.2 to 2.1 N. Jalgaonkar et al. [16] noticed that the stronger protein network in multigrain pasta led to a higher hardness value.

Figure 3(b) depicts the effect of finger millet flour on hardness at the optimal weights of green gram flour ($A = 29.53$ g) and sorghum flour ($B = 22.93$ g). The hardness of the multigrain fermented noodles increased from 2.1 to 3.1 N as the amount of finger millet flour increased from 5 to 10 g. It might be due to the increased fiber content caused by adding finger millet flour, which enhances the ability of noodles made from multiple grains to absorb water. Similarly, Nasir et al. [29] found finger millet flour-based biscuits that were fiber-rich. Fiber-rich materials, such as carrot pomace powder mixed with finger millet flour, increased the hardness value. Furthermore, Figure 3(c) depicts the effect of green gram flour (A) and finger millet flour (C) on the hardness of multigrain fermented noodles at optimum sorghum flour ($B = 22.93$ g) amounts. It can be concluded that an increase in green gram (24–30 g) and finger millet flour (9–10 g) proportions increased the hardness value.

3.6. Effect of Independent Variables on Overall Acceptability of Multigrain Fermented Noodles. Table 1 illustrates that the overall acceptability of multigrain fermented noodles ranged from 6 to 8.2. The noodles with the highest overall acceptability (8.2) had 22.5% green gram, 20% sorghum, and 7.5% finger millets (run 13). The noodles with the lowest overall acceptability (6) had 30% green gram, 20% sorghum, and 10% finger millet (run 2). Table 2 shows the significant models for the overall acceptability of multigrain fermented noodles ($p < 0.05$, $R^2 = 0.98$) and A, B, C, B^2, and C^2 significant models for variation in overall acceptability. Green gram and sorghum have a positive influence on acceptability. The effect of green gram flour on the overall acceptability of multigrain fermented noodles at optimum points of sorghum flour ($B = 22.93$ g) and finger millet flour ($C = 5$ g) is shown in Figure 3(d). As the proportion of green gram flour increased from 15 to 30 g, the overall acceptability of multigrain fermented noodles increased. The effect of sorghum flour on the overall acceptability of multigrain fermented noodles at the optimum points of green gram flour

Table 3: Constraints fixed for numerical optimization of independent variables and response.

Parameters	Control noodles	Optimized noodles	Branded noodles
Moisture (%)	12.1 ± 0.51^a	11.8 ± 0.08^b	8.1 ± 0.12^c
Carbohydrate (%)	72 ± 0.18^a	67.54 ± 0.35^b	63.12 ± 0.00^c
Protein (%)	13.3 ± 0.73^a	12.13 ± 0.46^b	10.1 ± 0.08^c
Ash (%)	0.11 ± 0.02^c	3.54 ± 0.13^a	3.21 ± 0.10^b
Fat (%)	1.93 ± 0.08^a	0.65 ± 0.03^b	0.41 ± 0.04^c
Fiber (%)	0.1 ± 0.06^b	4.34 ± 0.13^a	0.38 ± 0.05^b
IVPD (%)	92 ± 0.21^b	92.5 ± 0.29^b	93 ± 0.39^a
Total phenol (mg GAE/100 g)	61.33 ± 0.25^b	198.67 ± 0.28^a	44 ± 0.34^c
Reducing sugar (w/w %)	1.3 ± 0.03^c	2.23 ± 0.12^a	1.6 ± 0.23^b
Iron (mg/100 g)	2.1 ± 0.13^b	2.92 ± 0.14^a	0.24 ± 0.1^c

Values expressed as mean ± S.D. Mean in rows with different superscripts a, b, c, and d is significantly ($p < 0.05$) different.

($A = 29.53$ g) and finger millet flour ($C = 5$ g) is shown in Figure 3(e). The overall acceptability increased from 7.7 to 8.2 when sorghum flour was increased from 15 to 25 g. The effect of finger millet flour on the overall acceptability of multigrain fermented noodles at optimal levels of green gram flour ($A = 29.53$ g) and sorghum flour ($B = 22.93$ g) is shown in Figure 3(f). As the amount of finger millet flour increased from 5 to 10 g, the overall acceptability of multigrain fermented noodles decreased. According to Hymavathi et al. [15], the overall acceptability of finger millet flour-incorporated noodles decreased as the proportion of finger millet flour increased.

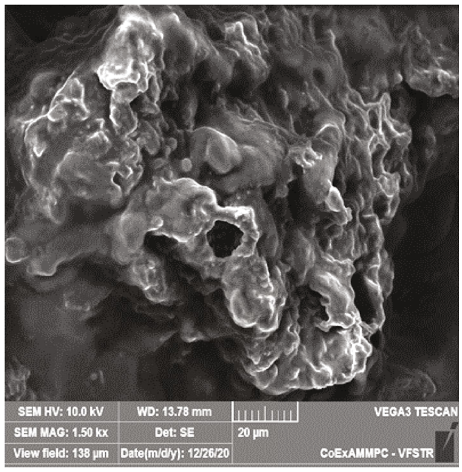
The influence of green gram and finger millet flour at optimum points of sorghum flour ($B = 22.93$ g) is shown in Figure 3(g). The overall acceptability of multigrain fermented noodles increased from 7.5 to 8 when the amount of green gram flour was increased from 21 to 30 g but decreased from 7 to 6.5 when the amount of finger millet flour was increased from 9 to 10. Jyotsna et al. [17] reported a similar kind of observation, where the mouthfeel and flavor of green gram semolina-fortified pasta were acceptable, with up to 60% of green gram semolina-fortified pasta. The influence of sorghum flour and finger millet flour on the optimum points of green gram flour ($A = 29.53$ g) is shown in Figure 3(h). It was found that the addition of sorghum flour (19–25 g) increased the overall acceptability from 8 to 8.5. In contrast, an increase in finger millet flour (7–10 g) proportion in multigrain fermented noodles decreased the overall acceptability from 7.5 to 6.5.

3.7. Comparison and Evaluation of Optimized Fermented Noodles. The highest desirability from the response surface optimization was 0.94 for multigrain fermented noodles prepared from green gram (29.53 g), sorghum (22.93 g), and finger millet (5 g). However, the cooking weight, cooking loss, cooking time, hardness, and overall acceptability were 14.14 ± 0.11 g, 6.22 ± 0.13 g/100 g, 2.43 ± 0.29 min, 2.106 ± 0.15 N, and 8.583 ± 0.41, respectively. In another study, Kamble et al. [18] achieved the desirability (86.20%) for the production of microwave-processed multigrain pasta using 31.96% sorghum, 13.04% finger millet flour, and 3.40% gluten. Similarly, Rizzello et al. [30] reported that 30% replacement level of semolina with fermented faba bean flour markedly improved the nutritional profiles of enriched pasta, including protein quality and starch hydrolysis indexes, without negatively affecting technological and sensory feature.

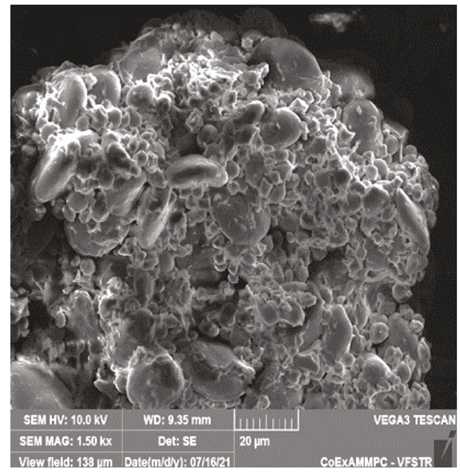
3.8. Nutritional Analysis of the Optimized Fermented Wheat Noodles. The proximate composition (Table 3) of various noodles compared in this study shows that the moisture content remained almost identical in control noodles (12.1 ± 0.51%) and multigrain fermented noodles (11.8 ± 0.08%). The ash and crude fiber content of optimized multigrain fermented noodles was significantly ($p < 0.05$) higher than the control. Adding fermented wheat starch, green gram, sorghum, and finger millet might have improved the nutritional content of multigrain noodles [31]. The present investigation was supported by previous findings by Rani et al. [21], Jyotsna et al. [17], and Khetarpaul and Goyal [31].

An increase in the ash content of multigrain fermented noodles could have been responsible for adding sorghum and finger millets, which contain a high amount of minerals such as calcium, iron, magnesium, and zinc [10]. On the other hand, higher fiber content improves digestion. Multigrain fermented noodles have a higher protein content than traditional noodles, which could be attributed to adding green gram and sorghum. Ojokoh et al. [32] also reported that sorghum supplemented with cowpea, then fermented for 72 hours, could be recommended for improving the protein quality of sorghum. Like fiber and ash, the fat content of multigrain fermented noodles increased significantly ($p < 0.05$). However, the optimized noodles contained less carbohydrates due to fermented wheat starch, which could have reduced the sugar content and improved the digestibility [3]. Contrary to our findings, Park et al. [33] reported reduction in crude protein from 6.8% to 4.1%, crude lipids from 0.2% to 0.1%, ash from 0.3% to 0.1%, and reducing sugars from 0.46 to 0.09% after 72 h of fermentation of rice.

Iron content was found to be higher in optimized fermented starch wheat noodles (2.92 ± 0.14 mg/100 g) than in the control sample. Likewise, the protein content of optimized multigrain noodles was slightly reduced (12.13 ± 0.46%) than the control sample (13.3 ± 0.73%) due to the lower availability



(a)



(b)

Figure 4: SEM images of (a) refined wheat flour noodle (control) and (b) multigrain fermented noodles.

of gluten in the sample [23]. Additionally, the presence of antinutritional factors in sorghum might have bound with proteins, reducing the overall protein content.

The optimized multigrain fermented noodles had a slightly higher IVPD ($92.5 \pm 0.29\%$) than the control noodles ($92 \pm 0.21\%$). Similar findings were reported by Khetarpaul and Goyal [31]. A slight improvement in the IVPD of multigrain noodles might have been responsible for protein denaturation, unfolding, and the degradation of antinutritional factors such as tannin and phytic acids [31]. Furthermore, the presence of more antinutritional factors in raw samples, particularly sorghum, could have suppressed proteolytic enzyme activity in fermented seera, restricting the IVPD of multigrain noodles [18, 27]. Baker et al. [34] reported that cooking of doughs prepared from supplementation of sorghum with soybean showed a high level of IVPD (ranged from 16.6% to 21.8%) compared to unsupplemented cooked sorghum flour, indicating the feasibility of utilizing soybean as a supplement to sorghum. Additionally, the reduced sugar content increased from 1.3 ± 0.03 to $2.23 \pm 0.12\%$ because of the addition of fermented starch, which contains more reducing sugar due to polysaccharide fermentation that could convert to simple sugars. In contrast, Khetarpaul and Goyal [31] reported that reducing the sugar content of noodles (with different ratios of soy, sorghum, maize, rice, and wheat flours) did not bring in any significant ($p < 0.05$) changes compared to the control sample.

Furthermore, the total phenol content of multigrain noodles was significantly ($p < 0.05$) higher (198.67 ± 0.28 mg GAE/100 g) than the control (61.33 ± 0.25 mg GAE/100 g), which could be attributed to the release of bound polyphenol from sorghum and finger millet cell matrixes [6, 19]. According to Khan et al. [19], sorghum-fortified pasta had a higher total phenol content than the control. Fois et al. [6] concluded that higher availability of polyphenol content might have adversely influenced IVPD.

3.9. Morphological Properties of Multigrain Fermented Noodles. SEM analysis reveals the structural orientation of macromolecules [14]. Here, the surface morphology of control and multigrain fermented noodles was completely different. For example, control samples showed that the starch granules were closely attached to the protein and have smooth surfaces and compact arrangement (Figure 4(a)). However, higher surface tension and stronger gluten network might have been responsible for the compact structure of control noodles. Jyotsna et al. [17] also reported similar findings, in which starch granules were surrounded by protein matrix. Starch granules of various sizes were visible on the outer layers of multigrain fermented noodles, and the surface became rough and loosely attached to protein. It could be due to the breakdown of the starch protein network, which will eventually reduce hardness and accelerate water penetration. Furthermore, the swelling of starch granules could have reduced the overall gelatinization temperature [35]. Similarly, Rani et al. [21] reported that the surface of refined wheat flour control noodles became more compact than multigrain noodles. They also claimed that the compact structural arrangement of starch and protein might be responsible for lower cooking loss and cooking time.

3.10. FTIR Spectra of Noodle. The FTIR spectra of control (refined wheat flour) and optimized multigrain fermented noodles are shown in Figure 5(a). Both samples showed some common bands at 993, 1652, and 2923 cm^{-1}, indicating similar functional groups. The sharp band observed at 993.14 cm^{-1} is attributed to an amorphous state of starch. The presence of carbohydrates can be confirmed from the fingerprint region in 1200–800 cm^{-1} [18]. The protein region could be confirmed by 1652 cm^{-1} (amide I), attributed to N-H amide bond stretching; the sharp intensity may be due to green gram flour incorporation [21]. However, the spectra of multigrain fermented noodles showed newer bands at 1336 and 2109 cm^{-1} with major changes at 1652, 1743, and 2848 cm^{-1} compared to the control sample. The peak at 1336 corresponds to bending vibrations of aliphatic C-H bonds in organic molecules. Fermentation breaks down the complex carbohydrates to produce alcohol and organic acids. These new compounds could have different

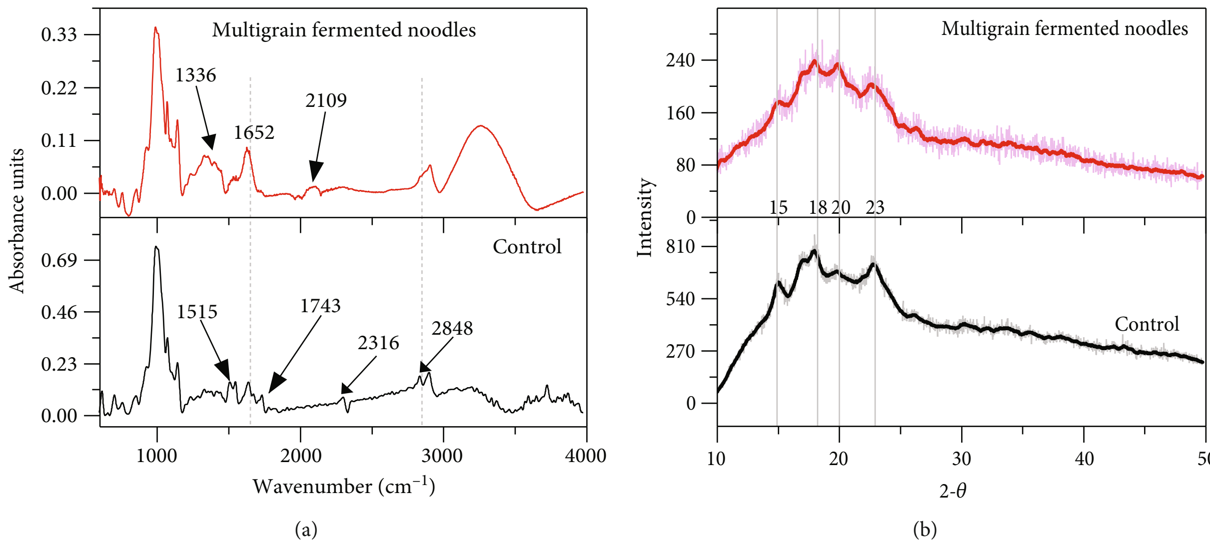


Figure 5: (a) FTIR spectra and (b) XRD pattern of multigrain fermented noodles.

vibrational properties than the initial substrates, leading to shifts or intensity changes in the C-H bending. A peak at 2109 cm^{-1} suggests the formation of the nitrile group (C≡N). This could be confirmed by the disappearance of minor bands near 1743 cm^{-1} corresponding to amide compounds in the control sample. Multigrain fermented noodles also experienced the disappearance of the band at 2848 cm^{-1} (control), which corresponds to the symmetric stretching of the $=CH_2$ (methylene) groups [36]. However, an increase in intensity at 2923 cm^{-1} confirmed the conversion of symmetric stretching of the $=CH_2$ groups to symmetric stretching. The possible reason might be increased carbonyl (C=O) or hydroxyl (-OH) groups interacting with $=CH_2$ groups to change their stretching [37]. The broad peak at 3322 cm^{-1} is attributed to vibrations of phenolic groups O-H bond, possibly due to a significant increase in phenolic compounds [21]. This band was stronger in multigrain fermented noodles than in control due to increased H-bonding. Similar findings have been reported by Rani et al. [21] and Kamble et al. [38].

3.11. XRD. Figure 5(b) depicts the XRD pattern of wheat flour and cooked multigrain fermented noodles. In both samples, two sharp peaks were identified at 15 and 20°. In addition, the medium peak intensity was observed at 18 and 23°. However, both samples had a type A crystallinity pattern, indicating the presence of a shorter amylopectin chain [39]. On the other hand, the degree of crystallinity of the control sample was found to be 36.02% and reduced to 34.12%, indicating that amorphous regions improved. Furthermore, adding sorghum and finger millet flour might have strongly influenced the crystallinity pattern of noodles [18, 40, 41].

4. Conclusions

Experimental studies revealed that incorporating fermented wheat starch, sorghum, green gram, and finger millet flour in multigrain noodles enhanced cooking attributes and nutritional profiles, such as fiber, total phenolic, ash, iron, and reducing sugars content compared to commercial noodles. Moreover, the cooking quality and sensory attributes of multigrain noodles were highly acceptable. The optimum level of independent variables obtained by optimization of responses was green 29.53 g of gram flour, 22.93 g of sorghum flour, and 5 g of finger millet flour. In the present study, optimized noodle samples significantly reduced cooking time and loss compared to commercial noodles. Reducing cooking time would help increase production yield and sustain more heat-sensitive nutrients. This study would help better understand the effect of traditional culinary methods of soaking and fermentation on ready-to-cook noodles. Therefore, fermented wheat starch can be an ingredient for functional and healthy substitutes.

Data Availability

The data used to support the findings of this study are available from the corresponding authors upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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