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Optimization and evaluation of multigrain gluten-enriched instant noodles

Savita Rani[1] · Rakhi Singh[1] · Barjinder Pal Kaur[2] ·
Ashutosh Upadhyay[1] · Dinkar B. Kamble[1]

Abstract Central composite design was employed to optimize the cooking, textural and overall acceptability score of the instant dried noodles prepared with multigrain flour and gluten incorporation. Sorghum flour (X_1, 10–50%), soy flour (X_2, 10–20%) and gluten (X_3, 2–4%) were the independent variables investigated with respect to five response variables including cooking time (Y_1), cooked weight (Y_2), cooking loss (Y_3), hardness (Y_4) and overall acceptability (Y_5). The optimum level was found to be 24.61% sorghum, 13.23% soy and 2.95% gluten resulting in cooking time = 9 ± 0.60 min, cooked weight = 17.30 ± 0.17 g, cooking loss = 11.46 ± 0.64 g/100 g, hardness = 36.65 ± 3.2 N with overall acceptability score of 7.3 ± 0.71, respectively. Optimized noodles showed higher ash ($3.40 \pm 0.11\%$), protein ($16.63 \pm 0.55\%$), fiber ($4.78 \pm 0.04\%$) as well as iron content (4.53 ± 0.02 mg/100 g) than the control ($0.83 \pm 0.02\%$, $13.13 \pm 0.84\%$, 0.00 and 2.38 mg/100 g) and Maggie noodles ($3.19 \pm 0.01\%$, $10.53 \pm 0.30\%$, $0.41 \pm 0.50\%$ and 0.22 ± 0.00 mg/100 g) made with refined wheat flour. Optimized noodles also revealed good total phenolic content (84.57 ± 1.42 mg GAE/100 g DW) and 1,1-diphenyl-2-picrylhydrazyl scavenging activity ($19.64 \pm 0.20\%$). Hence, optimized noodles have substantial potential as a protein–fiber-rich complementary food to improve the nutrient delivery of mid-day meal scheme and satisfying the protein requirement of primary class children (12 g/child/day) as laid down by MHRD (India) under the scheme.

Keywords Cooking and textural attributes · Sorghum flour · Soy flour

Introduction

Instant noodles have been recognized as a global food among the people of different age-groups, gender and regions. Noodles industry supplies 97.5 billion servings throughout the world in 2016, and this demand is still on rise [1]. The key ingredients of instant noodles preparation include wheat flour, alkaline reagent and water. Additional ingredients can be added during their preparations for improvement in structure, flavor and texture of the final product [2]. Based on the method of moisture removal, instant noodles are classified into two main groups, i.e., instant dried noodles (8–12% moisture) and instant fried noodles (2–5% moisture). Air-dried noodles contain lower fat content (3%) as compared to fried noodles (15–20%), resulting in longer shelf life of the product along with the advantages of reduced risk of heart diseases [3]. Refined wheat-based noodles are a rich source of carbohydrate but lack essential minerals and dietary fiber components as most of them are lost during the wheat flour refinement process [4]. Previously researchers had used different types of composite flour from alternative sources to improve the nutritional quality of the noodles, meanwhile maintaining the cooking, textural and sensory properties of the product [4–9]. However, none of the work has been carried out for

✉ Rakhi Singh
  rakhi117@gmail.com

1 Department of Food Science and Technology, National Institute of Food Technology Entrepreneurship and Management, Kundli 131028, India

2 Department of Food Engineering, National Institute of Food Technology Entrepreneurship and Management, Kundli 131028, India

optimizing the level of sorghum flour and soy flour with gluten incorporation during instant dried noodles formulation.

Sorghum (*Sorghum bicolor*) is a major staple food consumed by a millions of the people lives in semi-arid regions of Africa, Asian and Latin America [10]. It contains 1.34% ash, 8.47% protein, 1.50% fiber [10] and also known for its rich phytochemicals profile including tannins, phenolic acids, phytosterols which can significantly enhance the human health possibly due to their antioxidant potential [11]. Various studies have been carried out to study the effect of sorghum flour incorporation in noodles and other food products [12–15]. It was reported by Suhendro et al. [7] that noodles with 10% dry matter loss could be prepared through preheating of fine particle size sorghum flour in a microwave oven and dehydrated using two-stage methods (60 °C/100% RH/2 h and 60 °C/30% RH/2 h). Furthermore, Chinese egg noodles with higher firmness and tensile strength could be formulated with sorghum flour of fine particle size (2–5 μm) and higher damage starch (2.78–3.29%) that would be the result of harder kernel characteristics [14].

Soybean (*Glycine max.*) along with its higher protein (40%) and essential amino acid profile also contain adequate carbohydrate (23%) and fat (20%) content. Apart from this, the reasonable amount of dietary fiber, vitamins, minerals, omega-3 fatty acids, antioxidants and other beneficial compounds like phytosterols, lecithin and phenolic acids are also present in soybean [16]. Therefore, it can be used to supplement the cereal-based foods, which are deficient in essential amino acids, particularly lysine [13]. Collins and Pangloli [17] reported that noodles prepared with substitution of wheat flour with defatted soy flour showed higher protein content without having any adverse effect on the overall acceptability score. Adegunwa et al. [18] also reported similar findings for the wheat flour noodles supplemented with soybean and carrot at 10% replacement level.

Since refined wheat flour is necessary for making noodles of good quality characteristics [4], this study instead of focusing on gluten-free trends concentrates specifically on the supplementation of wheat with sorghum and soy flour along with gluten incorporation to improve the nutritional profile as well as rheological, textural, cooking and sensory qualities of the noodles determined to a large extent by added wheat gluten [19–22]. Wheat gluten isolated by aqueous washing contain 70–80% protein and important for the rheological property of dough which depends basically on the interaction between its two sub-components, namely gliadin and glutenin. Gliadin imparts viscous properties, whereas glutenin is responsible for providing strength and elasticity in the developed dough [20]. Gluten incorporation is essential for improving the dough sheeting

properties, better cooking and textural properties of white salted noodles. Incorporation of gluten isolated from soft wheat flour also reported to reduce the cooking loss significantly during salted noodles formulation [21]. Zhou et al. [22] reported that addition of gluten enhanced the cooking (reduced cooking loss and broken ratio), textural (tensile strength, breaking strength and firmness) as well as sensory properties of noodles from the composite flour of oat, wheat and tapioca starch. Therefore, the present study aimed to examine the impact of three independent factors including sorghum flour, soy flour as well as gluten addition on the cooking, textural and overall acceptability of the noodles and finding out their optimum level using response surface methodology (RSM). This study will enhance the usage of underutilized sorghum grain together with soy flour incorporation in formulation of nutritionally enriched functional food products. Developed noodles as a protein–fiber-rich complementary food might offer the substantial potential to overcome the nutritional deficiency among school children through their inclusion in Mid-day Meal scheme of Government of India. Moreover, these noodles are developed particularly for primary and upper primary school children that rely on the gluten-enriched diets such as *Roti-sabji, Dal-roti, Dal-poori* to fulfill their protein and energy requirements; therefore, gluten incorporation can be taken as an advantage to improve the final product quality without having any adverse effect on the targeted consumers.

Materials and methods

Materials

Refined wheat flour (Sharbati), soybean flour (Ahilya 3), sorghum flour (Pant Chari 5) and common salt (NaCl) of Tata brand used for noodles formulation procured from local market of Noida, Uttar Pradesh (India). All flours were sifted through 250 micron (μ) sieve, packed in low-density polyethylene (LDPE) packets and kept in airtight containers at 10 °C. Additives/chemicals used during the study were, boric acid (H_3BO_3), Bromocresol, copper sulfate ($CuSO_4$), gluten, guar gum, methyl red, potassium sulfate (K_2SO_4), sodium hydroxide (NaOH), sulfuric acid (H_2SO_4), obtained from Sisco Research Laboratories Pvt. Ltd. (Mumbai, India) and Fisher Scientific (Mumbai, India).

Noodles preparation

Instant dried noodles were prepared as per the 20 combinations prescribed by 3-factor-5-level CCD (Table 2). Wheat flour was replaced with composite flour of sorghum,

soy and gluten and mixed in an electric mixer (PLANE-TARY, B10F-1) for 2 to 4 min. Dough was made by adding 0.2% guar gum, 2% NaCl and 1% NaOH salts at a water absorption rate of 54–60% on the basis of flour weight. The prepared dough was kept in a plastic bag (25–27 °C/1 h) and sheeted by passing it several times over the roller of pasta maker machine (Marcato Ampia 150 Pasta Maker, Italy) until it achieves a final thickness of 1.2 mm. The sheeted dough was finally extruded through the die to get the desired noodles strand. The extruded noodles was then steamed for 3 min at 100–102 °C and dried in hot air oven (85 °C/90 min). The dried noodles were cooled, packed in LDPE and stored at room temperature for further analysis.

Analysis of cooking quality

Cooking properties of the noodles viz. cooking time, cooked weight and cooking loss were analyzed as per the method of Yadav et al. [4] with minor alteration. Noodles (5 g) was boiled in 200 ml of distilled water in a glass beaker using hot plate (IKA, Rh Basic 1). Optimal cooking time was estimated by noticing the time at which white core of the noodles disappeared completely on pressing between two glass slides.

For the estimation of cooked weight, noodles were cooked for their respective cooking time, followed by rapid cooling under running tap water for about 1 min. The gain in noodles weight observed after cooking was recorded as final cooked weight (g). For calculation of cooking loss or mass of solid matter left in cooking water, noodles sample (5 g) was cooked in 200 ml of boiling water. Water remained after cooking was collected in a previously weight glass beaker and dried in hot air oven (Alfa Instruments) at 105 °C till the complete evaporation occurs. Cooking loss was then displayed as a percentage of dry matter lost during cooking to dry sample weight.

$$\text{Cooking loss } (\%) = \frac{\text{Weight of dried residue}}{\text{Noodles weight before cooking}} \times 100$$

Evaluation of noodles hardness

Texture profile of cooked noodles was determined with slight modification of method suggested by Choy et al. [6] with Texture Analyser, TA-XT2i (Stable Micro Systems, Survey, UK). Before performing the analysis, calibration settings were done using the 5 kg load cell with a return trigger path at 15 mm. The measurement mode settings for compression (pre-test, test and post-test) were fixed to a speed of 2.0 mm/s; strain was at 75%; trigger type at auto-10 g, and P/75 (75 mm compression platen) probe was employed. Three noodles strands (2 cm length) were placed parallel on a flat metal plate and analyzed within 5 min after the cooking. Results have been expressed as noodles harness in newton obtained from the texture profile/force–time curve generated by the software.

Evaluation of overall acceptability score

The dried noodles were cooked in hot water and served immediately for the sensory evaluation. Sensory analysis of the noodles was done by 30 semi-trained panelists comprising staff as well as students of National Institute of Food Technology Entrepreneurship and Management (NIFTEM), India. The panelists were asked to evaluate the overall acceptability of noodles using a nine-point hedonic rating scale ranging from 1 to 9, where 1 indicated "dislike extremely" and 9 represented "like extremely."

Experimental design for optimization of noodles formulation

In the current study, central composite design (CCD) of response surface methodology was used for studying the impact of three independent factors: sorghum flour (X_1), soy flour (X_2) and gluten (X_3) on the cooking time (Y_1), cooked weight (Y_2), cooking loss (Y_3), hardness (Y_4) as well as overall acceptability score (Y_5) of the noodles. The upper and lower limits for these variables (X_1: 10–50%, X_2: 10–20%, X_3: 2–4%) were selected on the basis of available literature as well as by taking preliminary trials, and coded levels are shown in Table 1. A total of 20 experimental combinations with seven center point replication were performed with respect to the three independent factors and five response variables (Table 2). Experimental data of all responses were fitted to a second-order polynomial equation for expressing the selected responses as a function of independent factors. The proposed quadratic model relating the selected dependent responses and independent factors is as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2$$

where Y is the response variable, β_0, β_1, β_2, β_3, β_{12}, β_{13}, β_{23}, β_{11}, β_{22}, β_{33} represent the regression coefficients, X_1, X_2, X_3 are the independent factors [23]. The analysis of variance (ANOVA) was used for determining the significant difference between linear, quadratic and interaction terms of independent factors. The statistical significance of polynomial model terms was judged using F-statistic at a probability (P) of 0.1, 0.05 and 0.01 along with a non-significant lack-of-fit value. To visualize the concept more clearly, three-dimensional response surface plots were created by putting single factor constant at the central point

Table 1 Coded level of independent variables used in central experimental design

Independent variables	Symbols		Coded levels				
Actual		Coded	$-\alpha$	-1	0	$+1$	$+\alpha$
Sorghum flour (%)	X_1	x_1	10.00	18.11	30.00	41.89	50.00
Soy flour (%)	X_2	x_2	12.03	12.03	15.00	17.97	20.00
Gluten content (%)	X_3	x_3	2.00	2.41	3.00	3.59	4.00

Table 2 Central composite design matrix with estimated values of responses

Run	Processing parameters			Measured responses				
	X_1 (x_1)	X_2 (x_2)	X_3 (x_3)	Y_1	Y_2	Y_3	Y_4	Y_5
1	30.00 (0)	20.00 (+ 1.68)	3.00 (0)	8 ± 0.52	17.62 ± 0.72	15.40 ± 0.91	26.15 ± 2.16	6.4 ± 0.85
2	41.89 (+ 1)	12.03 (− 1)	3.59 (+ 1)	12 ± 0.20	15.60 ± 1.08	19.86 ± 0.47	30.92 ± 3.05	6.8 ± 0.73
3	41.89 (+ 1)	17.97 (+ 1)	2.41 (− 1)	10 ± 0.60	16.40 ± 0.98	20.00 ± 2.43	35.58 ± 6.19	6.7 ± 0.89
4	18.11 (− 1)	12.03 (− 1)	2.41 (− 1)	9 ± 0.62	18.09 ± 1.19	15.40 ± 1.40	37.65 ± 10.4	7.3 ± 0.71
5	50.00 (+ 1.68)	15.00 (0)	3.00 (0)	11 ± 0.57	16.24 ± 0.67	24.46 ± 0.75	38.66 ± 1.98	5.7 ± 1.36
6	41.89 (+ 1)	17.97 (+ 1)	3.59 (+ 1)	10 ± 0.64	15.95 ± 0.62	17.73 ± 4.80	46.46 ± 12.6	6.3 ± 1.32
7	30.00 (0)	15.00 (0)	3.00 (0)	8 ± 0.76	17.05 ± 1.07	12.26 ± 0.80	39.06 ± 8.90	7.3 ± 0.79
8	30.00 (0)	15.00 (0)	3.00 (0)	9 ± 0.68	17.01 ± 0.46	14.26 ± 1.52	39.06 ± 3.25	6.8 ± 1.10
9	30.00 (0)	15.00 (0)	3.00 (0)	8 ± 0.57	16.80 ± 1.51	11.93 ± 0.83	39.52 ± 14.8	7.2 ± 0.88
10	30.00 (0)	15.00 (0)	2.00 (− 1.68)	8 ± 0.20	16.16 ± 1.58	11.80 ± 2.42	37.93 ± 1.21	6.8 ± 1.40
11	18.11 (− 1)	17.97 (+ 1)	3.59 (+ 1)	10 ± 0.41	17.79 ± 0.31	12.46 ± 1.52	43.21 ± 5.70	5.8 ± 1.47
12	41.89 (+ 1)	12.03 (− 1)	2.41 (− 1)	10 ± 0.20	18.84 ± 1.63	13.20 ± 1.58	35.23 ± 3.11	6.8 ± 1.59
13	30.00 (0)	15.00 (0)	3.00 (0)	7 ± 0.20	17.85 ± 1.41	13.06 ± 3.44	36.83 ± 9.62	7.2 ± 1.53
14	10.00 (− 1.68)	15.00 (0)	3.00 (0)	10 ± 0.15	17.43 ± 0.73	12.53 ± 0.78	40.80 ± 6.05	6.9 ± 1.67
15	30.00 (0)	15.00 (0)	4.00 (+ 1.68)	8 ± 0.60	16.16 ± 0.65	7.53 ± 1.15	37.19 ± 2.04	6.4 ± 1.54
16	30.00 (0)	15.00 (0)	3.00 (0)	7 ± 0.70	16.78 ± 1.28	8.86 ± 3.36	40.07 ± 7.65	6.7 ± 1.18
17	30.00 (0)	15.00 (0)	3.00 (0)	8 ± 0.55	16.97 ± 1.54	9.13 ± 0.80	45.15 ± 2.19	7.3 ± 1.50
18	18.11 (− 1)	17.97 (+ 1)	2.41 (− 1)	9 ± 0.50	17.61 ± 1.61	10.86 ± 1.52	42.60 ± 2.05	6.3 ± 1.37
19	30.00 (0)	15.00 (0)	3.00 (0)	8 ± 0.50	17.10 ± 1.08	10.26 ± 1.28	41.12 ± 7.02	7.2 ± 1.72
20	18.11 (− 1)	12.03 (− 1)	3.59 (+ 1)	9 ± 0.75	16.25 ± 1.32	9.13 ± 0.70	28.82 ± 7.87	6.6 ± 1.75

All the values are mean ± SE of three independent determinations

X_1 (sorghum flour, %), X_2 (soy flour, %), X_3 (gluten, %), Y_1 (cooking time, min), Y_2 (cooked weight, g), Y_3 (cooking loss, g/100 g), Y_4 (hardness, N), Y_5 (overall acceptability)

while changing the other two variables within the experimental range [24]. After regression analysis of the experimental data, numerical optimization technique was employed to find out the optimum values of processing parameters. The optimal noodles preparation was achieved by combining set goals of all quality parameters into an overall desirability function. For confirming the validity of the model, experiment was conducted at optimum values of processing variables and obtained responses were then compared with predicted values of the responses.

Nutritional composition and antioxidant activity of control, optimized and Maggie noodles

Chemical analysis including moisture, ash, fat, protein, fiber percentage and iron content of control, optimized noodles and Maggie noodles was carried out using the standard method [25]. Total carbohydrate was estimated by the difference method (100 − moisture + ash + fat + protein + fiber). For calculating the total phenolic content and 1,1-diphenyl-2-picrylhydrazyl (DPPH) scavenging activity, extraction of the phytochemicals was carried out using the method of Sreeramulu et al. [26] Powdered sample (2 g) was mixed vigorously with 20 ml of 60% methanol comprising 0.1% HCl and extracted vigorously (4 h/27 °C) in a shaking incubator. The suspensions were centrifuged at 10,000 g for 15 min/ 10 °C, and supernatant was collected by filtration through Whatman #1 filter paper. The filtrates were stored at deep freezer (− 20 °C) until analysis.

Total phenolic content was evaluated using Folin–Ciocalteu reagent as described by Dordević et al. [27]. Briefly,

100 µl of each extract was mixed with 500 µl of FC reagent and 6 ml distilled water in a test tube. After the shaking of mixture for 1 min, 2 ml of 15% sodium carbonate was added and mixture was shaken once again for 0.5 min. Finally, volume was made up to 10 ml with distilled water and after incubation for 2 h; absorbance was read at 750 using UV/visible spectrophotometer against experimental blank. Standard gallic acid curve ranging from 1 to 1500 µg/ml was used to represent the results as mg of GAE/100 g of dried extract.

Antioxidant activity of the noodles was calculated using 1,1-diphenyl-2-picrylhydrazyl (DPPH) assay according to the protocol of Gull et al. [28]. About 0.1 ml of sample extract was treated with 3.9 ml of 0.1 mm methanolic DPPH solution (4 mg DPPH/100 ml methanol). After 30 min of incubation in dark, absorbance was recorded immediately at 517 nm using methanol as blank. A control sample comprising 0.1 ml methanol and 3.9 ml 0.1 mm DPPH solution was also prepared, and reading for the same was taken immediately (0 min) at 517 nm against experimental blank. Antioxidant activity or %DPPH inhibition was calculated using the following formula;

%DPPH Inhibition

$$= \frac{\text{Absorbance of control} - \text{Sample absorbance}}{\text{Control absorbance}} \times 100$$

In vitro protein digestibility of noodles

In vitro protein digestibility (IVPD) was determined according to the method given by Afify et al. [29]. About 1 g of sample was added to HCl (15 ml, 0.1 M), containing 1.5 mg pepsin and incubated for 3 h at 37 °C. The obtained suspension was neutralized with 7.5 ml of 0.2 NaOH and treated with 4 mg of pancreatin in 7.5 ml 0.2 M phosphate buffer (pH 8.0). To this mixture, 1 ml of toluene was added to prevent microbial growth, gently shaken and incubated for further at 37 °C for 24 h. Thereafter, 10 ml of 10% TCA was added to separate undigested protein and larger peptides and centrifuged (50,000 g/20 min). Protein in the supernatant was estimated by Kjeldahl method (AOAC, 2000). The % protein digestibility was calculated using the following equation;

Protein digestibility %

$$= \frac{\text{Nitrogen (in supernatent)} - \text{nitrogen (in blank)}}{\text{Nitrogen (in sample)}}$$
$$\times 100$$

Statistical analysis

CCD of Design-Expert version.10.0.2.0 (Stat-Ease, Inc., Minneapolis, MN, USA) was used for experimental designing and optimization purpose. Experimental data of triplicate observation were analyzed and judged statistically using one-way analysis of variance (ANOVA), and significance of each term was evaluated with Duncan's multiple range test in the SPSS software (SPSS, Inc, Chicago, IL, USA).

Results and discussion

Influence of the independent factors on the cooking qualities of noodles

Cooking time, cooked weight and cooking loss are the important cooking parameters that decide the quality as well as consumer acceptability of the noodles. The cooking time of the noodles ranged from 7 to 12 min depending upon the level of independent variables used (Table 2). The minimum cooking time was observed for run no. 13 (30% sorghum, 15% soy and 3% gluten) and maximum for run no. 2 (41.89% sorghum, 12.03% soy and 3.59% gluten). Quadratic model established for cooking time was significant ($P < 0.05$, R^2 0.80) with X_1, X_1^2 as significant model terms (Table 3). Concentration of sorghum flour positively and significantly affected the cooking time in both linear ($P < 0.1$) and quadratic manners ($P < 0.01$). Response surface graphs displaying the effects of sorghum and soy flour on the cooking time of noodles are presented in Fig. 1A. Cooking time of the noodles increased with increased level of sorghum flour as also shown by the positive sign of its regression term X_1 (Table 3) and could be ascribed to the higher gelatinization (onset, mid- and end) temperature as well as enthalpy value of flour. Further, development of sorghum starch–soy lipid complex that restrict starch granules leaching and hinder entry of water into the granule could also be the reason of higher cooking time of the noodles as reported by Pilli et al. [30] for oat flour supplemented spaghetti. Similar observation has been reported earlier by Benhur et al. [12] for the sorghum-based pasta developed with extrusion technology. However, soy flour incorporation did not affect the cooking time significantly ($P > 0.1$) and optimum range for cooking time was observed between 13.5 and 15% level of soy flour. These findings are contrary to the work done by Choy et al. [6] who reported the opposite trends in case of buckwheat fortified noodles. It has been observed that replacement of wheat flour with other ingredients leads to discontinuity of gluten network, which was responsible for higher moisture penetration, thereby, reducing cooking time. Figure 1B shows that gluten incorporation did not affect the cooking time significantly ($P > 0.1$), and optimal range of cooking time was observed at a gluten level of 2.7–3.0%.

Table 3 Analysis of significance of regression model selected for different responses

Regression coefficient	Cooking time	Cooked weight	Cooking loss	Hardness	Overall acceptability
Intercept	7.84**	17.08**	11.39**	39.99**	7.10**
X_1	0.49*	− 0.36**	3.15***	− 0.56	− 0.10
X_2	− 0.29	− 0.15	0.37	3.33**	− 0.30**
X_3	0.22	− 0.39**	− 0.55	− 0.21	− 0.17*
X_1X_2	− 0.38	-0.39**	0.74	− 0.43	0.15
X_1X_3	0.13	− 0.25	1.13	1.85	0.100
X_2X_3	− 0.12	0.60***	− 0.13	3.08**	− 0.025
X_1^2	1.08***	− 0.066	2.57***	0.81	− 0.28***
X_2^2	0.50	0.32*	1.31	− 5.08***	− 0.068
X_3^2	0.19	− 0.30**	− 0.55	0.040	− 0.18*
ANOVA					
Model (F value)	4.30	4.93	4.70	3.04	3.38
Lack of fit (F value)	2.05	3.07	2.55	3.44	2.85
R^2	0.80	0.82	0.81	0.73	0.75

X_1 (sorghum flour, %); X_2 (soy flour, %); X_3 (gluten, %). *significant at $P < 0.1$, **significant at $P < 0.05$, ***significant at $P < 0.01$
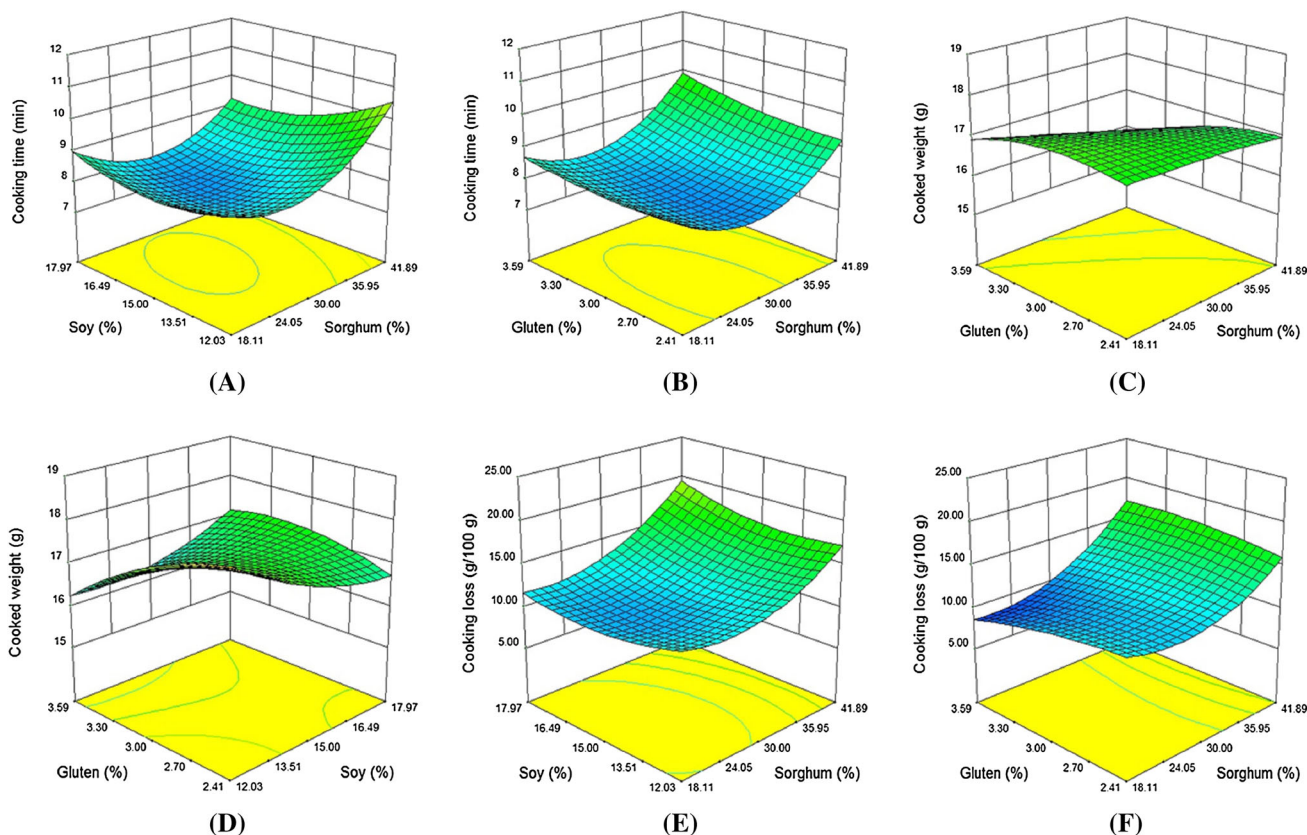

Fig. 1 (**A**)–(**F**) Response surface plots showing the effect of sorghum (X_1), soy (X_2) and gluten (X_3) on cooking time (Y_1), cooked weight (Y_2) and cooking loss (Y_3) of the noodles

The cooked weight of the noodles was observed in the range of 15.6 (run no. 2) to 18.84 g (run no. 12) (Table 2). Multiple regression analysis of experimental data showed that model obtained for cooked weight was significant ($P < 0.05$) with satisfactory value of R^2 (0.82) along with a non-significant lack of fit ($F = 3.07$). Between all the model terms, X_1, X_3, X_1X_2, X_2X_3, X_2^2, X_3^2 were reported to have a significant effect on cooked weight of noodles (Table 3). Sorghum flour in their linear (X_1) and interactive term ($X_1 X_2$) exhibited a significant negative ($P < 0.05$)

effect on cooked weight. However, the interactive term of soy with gluten (X_2X_3) cause significant positive variation at a probability (P) of 0.01. From the response surface plots (Fig. 1C, D), it can be seen that both sorghum and gluten had a negative impact on cooked weight, while the effect of soy was not significant ($P > 0.1$). This reduction in cooked weight as a result of sorghum flour incorporation could be ascribed to its higher fiber content that weaken the gluten network as reported earlier by Pilli et al. [30] for oat flour fortified spaghetti. Furthermore, gluten incorporation in noodles lowered the water imbibition which might be the reason of lower cooked weight of the final product [21].

Appearances as well as the acceptability of noodles are affected by the higher cooking loss since it is related with the surface characteristics of cooked noodles [19]. Experimental results showed that cooking loss of the noodles samples ranged from 7.53 to 24.46 g/100 g, lowest for run no. 15 and highest for run no. 5 (Table 2). Model obtained for cooking loss was found to be significant ($P < 0.05$) with a satisfactory coefficient of determination (R^2 0.81) along with a non-significant lack of fit ($F = 2.55$). Between all the model terms, only sorghum flour in their linear (X_1) and quadratic (X_1^2) forms showed significant variation in cooking loss (Table 3). As evident from response surface graph (Fig. 1E, F), cooking loss of the noodles increased with increased level of sorghum flour, being highest at 50% replacement of sorghum flour. These results are in agreement with work done by Aydin and Gocmen [5] who reported that cooking loss of noodles increased with incorporation of oat flour, possibly due to the weakening of the protein–starch network as a result of oat flour incorporation which otherwise forms a strong gluten network. Similarly, Benhur et al. [12] reported increased cooking loss in the range of 7.41–10.12/100 g for the sorghum-based pasta probably due to the degradation of amylose networks as a result of sorghum flour incorporation. Shukla and Srivstava [8] also reported similar findings for the refined wheat-based finger millet blend incorporated noodles (at 30, 40 and 50% level). Similarly, Liu et al. [20] also reported higher cooking loss of 6.08% for the noodles prepared with commercial sorghum as compared to other hybrids. However, the effect of soy and gluten was not statistically significant ($P > 0.1$). A non-significant effect of gluten incorporation up to a level of 3.6% on the cooking loss was also reported by Zhou et al. [22].

Influence of processing variables on textural properties of noodles

Hardness is a measure of noodles firmness, reported to be correlated negatively with water uptake capacity of flours or starches [4]. Hardness of the different noodles samples ranged from 26.15 to 46.46 N (Table 2). Model obtained for hardness was found to be significant ($P < 0.05$), and X_2, X_2X_3, X_2^2 were the terms having notable effect on the

selected responses. 3-D surface plots displaying the effect of soy and sorghum flour on the hardness of noodles are shown in Fig. 2A. Hardness of noodles increased with increased level of soy flour (linear, interactive and quadratic terms) and as indicated by its regression coefficient terms viz. X_2, X_2X_3, X_2^2 (Table 3). These outcomes are in covenant with work done by Jalgaonkar et al. [31] who reported a hardness value of 13..07 to 14.43 N for wheat semolina-pearl millet-based pasta with supplementation of defatted soy flour at different level (5, 15 and 25%), possibly due to the presence of more strong protein network inside the pasta sample. Hardness of the noodles was also found to be negatively associated with both sorghum and gluten level (Fig. 2A, B); however, this effect was not statistically significant ($P > 0.1$). Pilli et al. [30] also reported a lower hardness value for the spaghetti made with oat flour supplementation which could be attributed to both dilution of soft wheat gluten as well as poor availability of water to develop the gluten network.

Effect on the overall acceptability of noodles

Overall acceptability of the noodles samples varied from 5.7 to 7.3 for different noodles samples. The lowest overall acceptability score was observed for run no. 5 (50% sorghum, 15% soy and 3% gluten) and the highest for run no. 16 (30% sorghum, 15% soy and 3% gluten) (Table 2). Model used for overall acceptability was significant ($P < 0.05$), and X_2, X_3, X_1^2, X_3^2 are the significant model terms responsible for variation in overall acceptability score (Table 3). It was clear from the 3-D plots (Fig. 2C, D) that overall acceptability of noodles decreased with increase in level of soy flour and gluten. The optimum value of overall acceptability score was observed at soy and gluten level of 12–15 and 2.4–3%, respectively. However, incorporation of sorghum flour was not found to have any significant effect on the overall acceptability ($P > 0.1$) of the noodles. Collins and Pangloli [17] also reported that sensory acceptability of sweet potato and soy flour incorporated noodles decreased with increased level of soy flour. Similar findings were also reported by Singh et al. [7] for noodles prepared for the noodles prepared with incorporation of conventional soy flour.

Optimized level of variables and verification of model

Design-Expert Software (version.10.0.2.0) was employed for numerical optimization for obtaining the optimum level of variable as well as extrapolative value of responses according to the set goals with maximum desirability function. During the optimization process, all the independent variables were kept in range, whereas responses
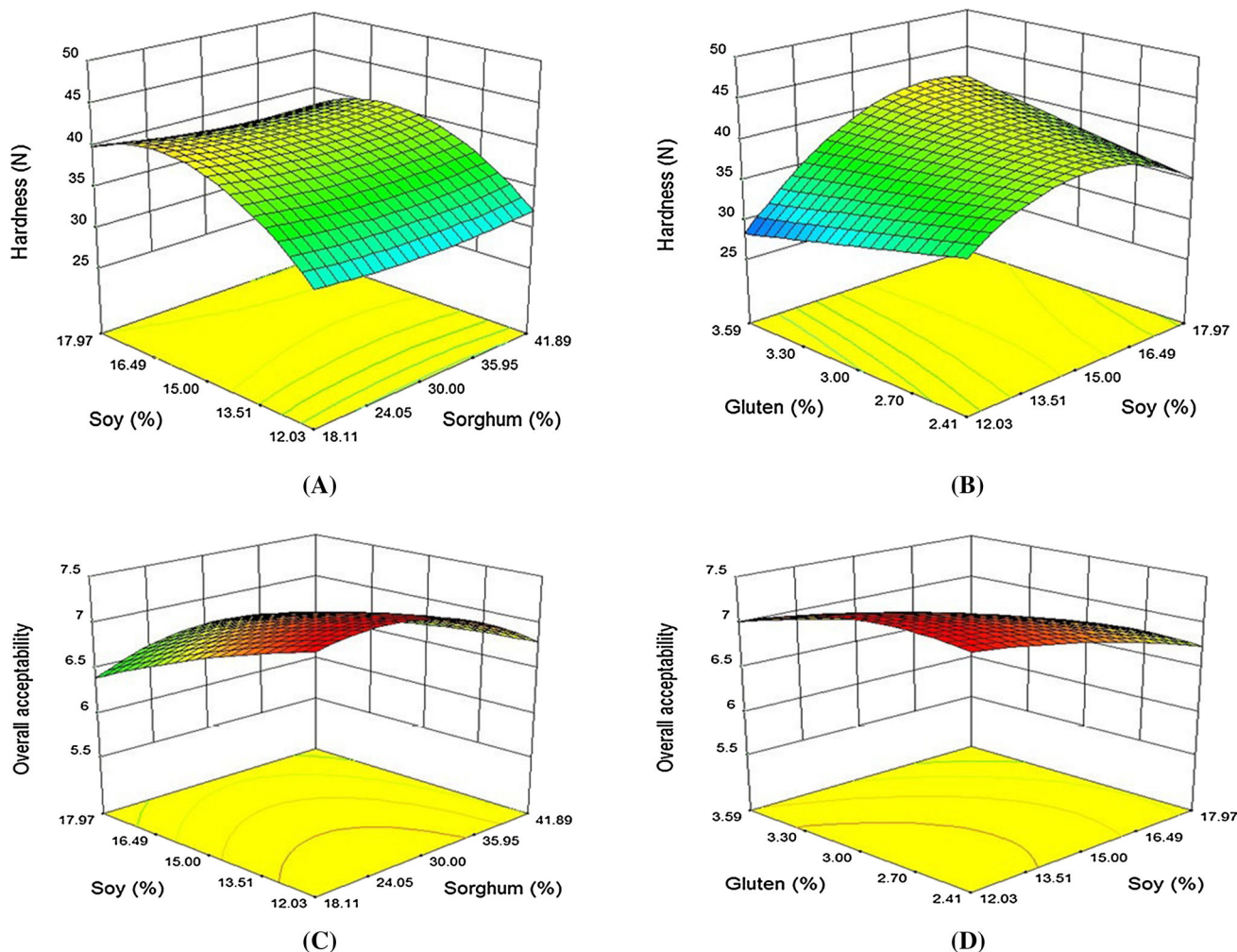
Fig. 2 (**A**)–(**D**) Response surface plots showing the effect of sorghum (X_1), soy (X_2) and gluten (X_3) on hardness (Y_4) and overall acceptability (Y_5) of the noodles

including cooking time, cooked weight and hardness were kept within range, followed by minimization of cooking loss and maximization of overall acceptability (Table 4). Results of numerical optimization suggested that maximum desirability (0.89) could be obtained by formulation of noodles at 24.61% sorghum, 13.23% soy and 2.95% gluten, respectively. At the optimal level, predicted values of responses such as cooking time, cooked weight, cooking loss, hardness and overall acceptability were 8 (min), 17.38 (g), 11.01 (g/100 g), 36.78 (N), 7.3, respectively. Model validity was also confirmed through performing the experiments at optimum levels of independent variables (24.61% sorghum, 13.23% soy and 2.95% gluten). The validation results showed that experimental values were in good agreement with the predicted responses values, thereby confirming the adequacy of selected model (Table 5). Further, experimental data of the responses obtained at optimal level showed good compatibility with the control noodles made with refined wheat flour.

Table 4 Constraints fixed for numerical optimization of independent variables and responses

Variables	Goal	Lower limit	Upper limit
Sorghum (%)	In range	18.11	41.89
Soy (%)	In range	12.03	17.97
Gluten (%)	In range	2.41	3.59
Cooking time (min)	In range	7	12
Cooked weight (g)	In range	15.60	18.84
Cooking loss (g/100 g)	Minimize	7.53	24.46
Hardness (N)	In range	26.15	46.46
Overall acceptability	Maximize	5.7	7.3

Nutritional and antioxidant profile of noodles

Table 6 shows that optimized noodles had significantly higher amount of ash (3.40%), fat (4.66%), protein (16.63%) and crude fiber (4.78%) as compared to the control sample (0.83, 1.93, 13.13 and 0.00%). Ash and

Table 5 Experimental validation of predicted values of responses obtained at optimal level and comparison with control noodles (RWF)

Response variables	Optimized noodles (Sorghum flour; 24.61%, Soy flour; 13.23%, Gluten; 2.95%)		Control noodles (RWF)
	Predicted values	Experimental values	
Cooking time (min)	8 ± 0.37	9 ± 0.60	6.33 ± 1.15
Cooked weight (g)	17.38 ± 0.15	17.30 ± 0.17	18.87 ± 0.55
Cooking loss (g/100 g)	11.01 ± 0.58	11.46 ± 0.64	8.13 ± 0.30
Hardness (N)	36.78 ± 2.43	37.65 ± 3.2	33.19 ± 6.38
Overall acceptability	7.3 ± 0.28	7.3 ± 0.71	7.86 ± 0.81

Values are expressed as mean ± SD of three triplicate observations

RWF Refined wheat flour

protein level of multigrain soy-enriched noodles was also higher than the popular brand of instant noodles "Maggie" which contains 3.19% ash and 10.53% protein. This increase in nutritional value of the optimized noodles could be the result of incorporation of sorghum and soy flour during noodles formulation as also reported by Khetarpaul and Goyal [13] for the noodles prepared with incorporation of 10% sorghum and soy flour. Higher iron content of sorghum–soy-based noodles could be ascribed to the greater iron content (9.6 mg/100 g) of soybean flour [16]. These noodles can fulfill 41.63% of protein RDA requirement as prescribed by NIN [32] for children between the age-group of 10–12 years. Furthermore, considering the nutritional norms of protein (12 g/day/child), prescribed by MHRD [33] under Mid-Day Meal scheme of Government of India, these noodles could be used to overcome the protein deficiency in primary class child. Developed optimized noodles may be claimed as a fiber-rich product (more than 4% dietary fiber) which further provides various health benefits associated with consumption of dietary fiber-rich product [34].

Total phenolic content of multigrain noodles was significantly ($P < 0.05$) higher (84.57 ± 1.42 mg/100 g GAE and) than the control noodles (59.33 ± 2.18 mg/100 g GAE) and Maggie noodles (40.76 ± 0.82 mg/100 g GAE),

possibly linked with the higher phenolic content of soy flour and sorghum flour used in multigrain formulation [13, 35]. Antioxidant result showed that Maggie noodles had significantly ($P < 0.05$) higher DPPH inhibition activity (37.98 ± 0.06%), compared with multigrain (19.64 ± 0.20%) and control noodles (17.20 ± 0.26%) that might be associated with the presence of natural antioxidants inside the vegetable oil utilized during processing and frying of the noodles [36]. Further, fortification of additives as antioxidant during manufacturing of Maggie noodles could also be the reason of highest antioxidant activity of Maggie noodles. Negative correlation between the total phenolic content and DPPH scavenging activity of Maggie noodles may be due to the fact that TPC that does not comprise all the antioxidant that might occur inside the extract, while the DPPH scavenging assay is not particularly limited to polyphenols [37] as also reported in different research findings [37–39].

In vitro protein digestibility (IVPD)

As shown in Table 6, optimized noodles had highest protein digestibility (95.57 ± 0.33%), followed by control (95.40 ± 0.29%) and Maggie noodles (94.69 ± 0.47%). However, the difference observed between the IVPD of

Table 6 Nutritional composition and antioxidant profile of optimized noodles (g/100 g)

Parameters	Control noodles	Optimized noodles	Maggie noodles
Moisture (%)	11.48 ± 0.65[b]	12.96 ± 0.15[a]	7.08 ± 0.13[c]
Ash (%)	0.83 ± 0.02[c]	3.40 ± 0.11[a]	3.19 ± 0.01[b]
Fat (%)	1.93 ± 0.12[c]	4.66 ± 0.04[b]	15.83 ± 0.08[a]
Protein (%)	13.13 ± 0.84[b]	16.63 ± 0.55[a]	10.53 ± 0.30[c]
Fiber (%)	0.00	4.78 ± 0.04[a]	0.41 ± 0.50[b]
Carbohydrate (%)	72.63 ± 0.29[a]	57.63 ± 0.46[b]	62.93 ± 0.00[b]
Iron (mg/100 g)	2.38 ± 0.02[b]	4.53 ± 0.02[a]	0.22 ± 0.00[c]
Total phenols (mg/100 g GAE)	59.33 ± 2.18[b]	84.57 ± 1.42[a]	40.76 ± 0.82[c]
%DPPH inhibition	17.20 ± 0.26[c]	19.64 ± 0.20[b]	37.98 ± 0.06[a]
IVPD (%)	95.40 ± 0.29[c]	95.57 ± 0.33[c]	94.69 ± 0.47[d]

Values are expressed as mean ± SD ($n = 3$). Means in the rows with different superscripts are differ significantly ($P \leq 0.05$)

IVPD In vitro protein digestibility

optimized and control noodles was not statistically significant ($P > 0.05$) and in covenant with the outcomes of Dhingra and Jood [40] who also reported a non-significant difference between protein digestibility of wheat bread (74.0%) and barley supplemented bread (74.2%). Khetarpaul and Goyal [13] reported similar results for the processed noodles made with refined wheat, soy and sorghum flour ($68.16 \pm 0.54\%$) and refined wheat, soy and maize flour ($67.21 \pm 0.20\%$). Higher protein digestibility of all the noodles samples could be attributed with depolymerization of proteins, structural changes and destruction of anti-nutritional factors as a result of steaming and high temperature drying of instant noodles [41]. Additionally, this improved protein digestibility of the noodles could also be linked with the reduction/elimination of various anti-nutrients (phytic acid, condensed tannins and polyphenols) as results of higher thermal treatment employed during noodles processing [42].

Suggestions

CCD design seemed to be a valuable tool for optimizing the effects of sorghum (X_1), soy (X_2) and gluten (X_3) on the quality attributes of noodles. All the statistical significant terms such as R^2 values, F value and lack of fit had shown the adequacy of the model. It was reported that sorghum flour had a significant impact on the cooking properties (cooked weight, cooking loss), while soy flour exhibited significant effect on the hardness and overall acceptability of the noodles ($P < 0.05$). Current research suggested that noodles with satisfactory cooking loss, adequate hardness and higher overall acceptability score could be developed through the combination of 24.61% sorghum flour, 13.23% soy flour and 2.95% of gluten. Furthermore, due to their high fiber as well as protein level, these noodles can be used as a part of mid-day meal to overcome the problem of malnutrition in primary class children. In addition to the nutritional benefits, these noodles unlike instant fried noodles do not undergo the rancidity problem because they are not deep dried and could be stored for the longer time without having any detrimental effect on human health.

Compliance with ethical standards

Conflict of interest The authors declare that have no conflict of interest.

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