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Optimization of Extrusion Parameters for Pearl Millet- Soy Noodles

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Abstract

Noodle is one of the wheat-based pasta, encompassing variants such as macaroni, spaghetti, and vermicelli. Pearl millet (Pennisetum glaucum) noodle is alternative to wheat with enhanced nutrition and offers gluten free alternative to wheat noodles with low glycemic index. It exhibited inadequate structural integrity with high solid loss and reduced water absorption capacity. Their cooking and textural quality were improved through substituting 50% pearl millet flour with defatted soy flour. It was produced through flour mix subjected to extrusion followed by drying for safe storage, cooling at ambient condition, packaging and storage. Following Central Comosite Rotatable Design, optimum condition was obtained as 71°C barrel temperature, 34.4% moisture content and 178rpm screw speed of extrusion processing. The solid loss, hydration capacity, cooking time and density were determined at optimized level of extrusion processing conditions. Their respective values were 12.5%, 1.84g/g, 240sec and 1155kg/m^3 with desirability of 0.70. The gluten free noodles can be promoted to upgrade the nutritional content of popular snacks amongst youth and children.

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Introduction

Noodles are pertaining to the pasta group of products together with vermicelli,spaghetti, macaroni etc. The convenience, low cost, storage stability, ease of preparation, palatability and sensorial quality are behind noodles in gaining popularity. Pasta

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variants are the second most consumable form of wheat products in the world. Indian Market has been speculated for pasta products to grow with 16% compound annual growth rate. Demand for pasta products has been growing consistently in the Indian Market and expected to reach US$2,062 million in 2028 from US$785 million in 2022.[1]

Pasta is generally prepared using wheat semolina (*Triticum aestivum*)[2,3] due to desirable textural characteristics as result of its gluten content.[4] Durum wheat semolina (*Triticum durum*) exhibits unique flavour and colour with favourable cooking qualities and thereby preferred as ingredient. It has widely been used in preparation of pasta.[2,3,5,6] The reason behind preference to wheat is its gluten content assisting in preparation of firm noodles. But, the population is ever increasing in search of the nutritional and functional qualities in their diet. Celiac disease, sensitivity to gluten or wheat allergy affects approximately 8.4% of the world population.[7] Considering the facts, developing gluten free noodles has been kept as the core idea in preparing nutritious noodles with functional qualities. Alternatively, millet grains have now emerged out of stigma as nutria cereal from 'poor man's cereal'with functional characteristics and may be helpful in creating better alternative for health conscious consumers. The most common and abundantly available millet in Asia and Africa is pearl millet, which is is gluten free and associated to phytochemicals, phenolic compounds, minerals and vitamins. Pearl millet (*Pennisetum glaucum*) maintains alkalinity after cooking and therefore suitable for population with wheat or gluten intolerance. Hence, some of the researchers attempted for millet incorporation into pasta. Such studies have been reported for finger millet,[8] barnyard millet and proso millet,[9] kodo millet and little millet[10] and foxtail millet.[11] Moreover, defatted soy flour is also gluten free and considered nutritionally superior with adequacy of protein, calcium, phosphorus, vitamins and essential amino acids.[12]

Accordingly, pearl millet flour yielded best suited gluten free blend at 50% level of substitution with defatted soy flour[13] relative to the same from 100% pearl millet flour.[14] Noodle quality was evaluated in terms of in terms of their cooking and textural quality. Both the ingredients are low in glycemic index and therefore also suitable for population prone to diabetes. The effect of replacing wheat flour with protein sources has also been reported to enrich noodles with dietary fiber and essential amino acids.[15]

Noodle has been prepared through the extrusion cooking process at desired temperature in short time for performing kneading followed by cooking and shaping in the desired shape and size of product. Extrusion process yields puffed products following hot extrusion[16] or pasta like products following cold extrusion.[16,17] Finally, dried form of the noodle is cooled under ambient condition prior to subjecting it to packaging. However, noodle quality varies with the extruder variables viz. moisture content, barrel temperature and screw speed. Their values at optimum level depends upon composition of raw ingredients.[16] Hence, the study was aimed to optimize extrusion processing variables for preparation of noodles from gluten free blend of PMF and DSF.

Materials and Methods

Pearl millet (var. PC 1201) was received from research field of ICAR-Indian Agricultural Research Institute (IARI) Pusa, New Delhi after harvesting in the kharif season. The grains were cleaned and dried in the laboratory of Food Science and Postharvest Technology Division at IARI prior to keeping the same in storage container for periodical use. It was subjected to milling through hammer mill (Make: Sanco, India) to yield flour with mean particle size of 425 microns. Defatted soy flour and guar gum was procured from the local suppliers and potable water was used after reverse osmosis process. The flour ingredients were cooled, followed by addition of guar gum (2%) and mixing thoroughly with quantified boiling water to attain 34.7% moisture content.[14] The flour sample was sieved and kept under refrigerated condition for 24 hours to ensure the mixing uniform.[18] It was allowed to attain room temperature before conducting the experiment.

Preparation of Noodles

The noodle strands were prepared using the twin-screw extruder (Make: BTPL, Kolkata, India) following.[14] Based on the trials conducted prior to the experiment, the range of independent variables were decided. The barrel temperature (X_1), moisture content (X_2) and screw speed (X_3) were kept in the range of 53°C-87°C, 28%-38% and 116 rpm-

284rpm respectively. Experiment was conducted with 20 experimental runs as determined through trial version of design expert software. The ratio of feeder and screw speeds was maintained as 1:10 throughout the experiment.[19] The noodle strands prepared through extrusion were placed inside the tray dryer (Make: MSW-216 of Macro Scientific Works at New Delhi) at 50±2ºC to reduce its moisture content near 8-9% for safe storage. The dried strands of noodle were cooled at ambient condition, packed and stored till analysing the samples for quality (Fig. 1).

Quality Analysis of Noodle Strands

The noodle samples (10g) were poured in a beaker (pre-weighed) having boiling water (100ml) inside. Cooking was continued till the disappearance of white cores within the strands as evident through compressing them between two glass plates.[20,21] The percentage of solid materials lost in cooking water relative to the weight of raw sample was presented as solid loss. The lost solid material was determined as the constant weight achieved after placing the gruel in tared beaker overnight in a hot air oven (105°C). Hydration capacity of the strands was defined as the ratio of their weight after and before cooking process. Cooking time was presented as time elapsed for disappearing the white cores of noodle strands after placing raw samples in boiling water.[20]

Solid loss (%)=(Weight of solid material lost)/(Weight of raw noodle sample)

Hydration capacity=(Weight of noodles after cooking)/(Weight of raw noodle sample)

Water absorption index (WAI) was evaluated through centrifugation 3000g (10min) of noodle powder (2.5g) after pouring in 50ml centrifuge tube (pre-weighed) filled with deionized water.[22] It was presented as ratio of weight of gel to weight of powdered sample. Water solubility index (WSI) was determined as the constant weight achieved after placing beaker containing the supernatant in oven (105°C) until achieving contant weight.[22] Thus, water absorption index and water solubility index were determined as follows:

WAI=(Weight of the gel)/(Weight of the powdered sample)

WSI (%)=(Weight of the dried soluble)/(Weight of the powdered sample)*100

Degree of gelatinization (DG) was determined through taking 40mg ground sample and 0.06N KOH (40 ml) in a pre-weighed centrifuge tube.[23] The suspension was agitated slowly for 20 min followed by centrifugation for 10 min. An amber coloured container was filled with 1ml supernatant having 0.06N HCl (1ml) and 8ml of water after distillation. This suspension was used for recording absorbance (A_1) at 600nm upon adding 0.1 ml of 1% KI-I_2 against reagent blank prepared without sample. This process was replicated for absorbance noted as A_2, while altering normality of HCl and KOH as 0.5. Thus, ratio of A_1 and A_2 was reported as degree of gelatinization.

DG=(Absorbance of the sample with 0.06N HCl and KOH at 600nm)/(Absorbance of the sample with 0.5N HCl and KOH at 600nm)

The density (D) has been calculated as mass-volume ratio of noodle strand, while considering it cylindrical in shape and presented as the average of 10 observations.

D=(Mass of noodle strands)/(Volume of noodle strands)

Statistical Analysis

The optimization experiment was conducted following the central composite rotatable design and analysed using response surface methodology. Design expert 12 software was used for optimization of processing variables in extruder, while preparing the noodle samples at various conditions.

Results

The gluten free composition for noodle strands has been identified as pearl millet flour substituted with 50% defatted soy flour.[13] Extrusion processing variables viz. barrel temperature, feed moisture and screw speed are function of raw ingredients and their composition. Hence, experiment was conducted to optimize extruder variables for preparation of noodle strands using selected blend.

The experiment was conducted following Central Composite Rotatable Design for optimizing the extruder variables. Noodle strands were prepared using PMF (pearl millet flour) at 50% level of substitution with DSF (defatted soy flour). Samples were subjected to analysis for optimizing the process variables and determining the values of dependent variables at optimum level. Dependent variables were solid loss, hydration capacity, cooking time, water absorption index, water solubility index, degree of gelatinization and density.

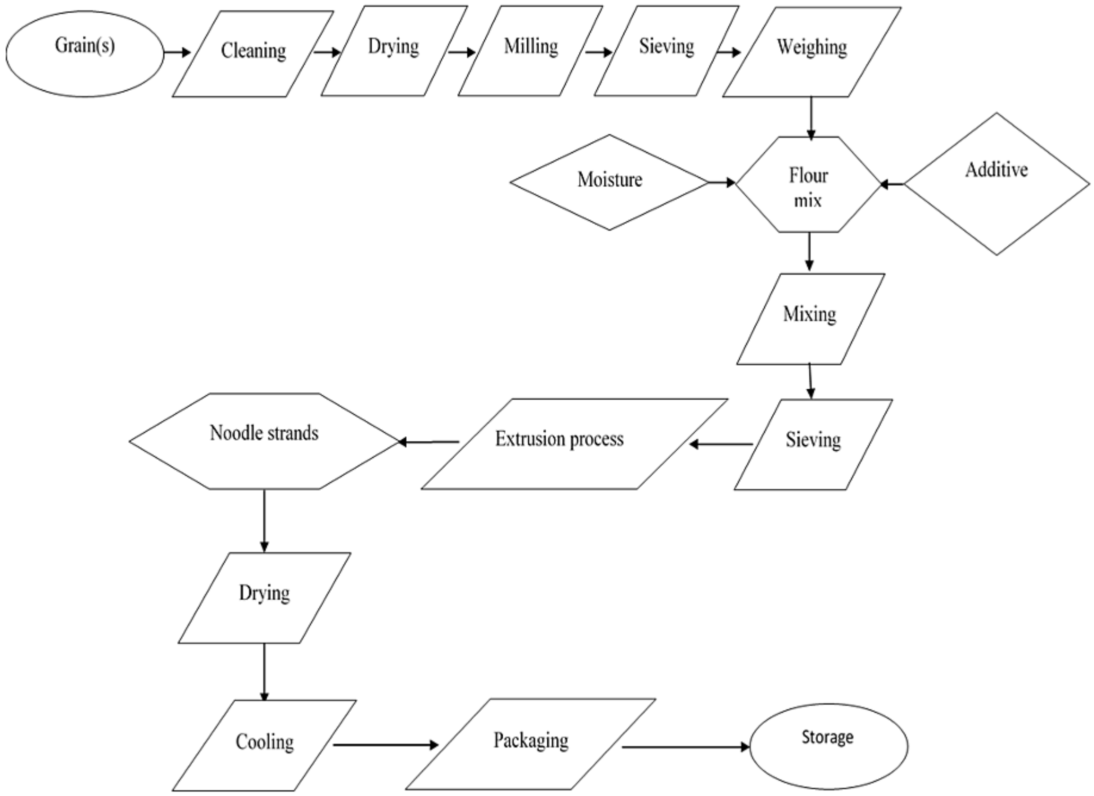

Fig. 1: Process flow chart for preparation of noodle strands through extrusion processing

Solid Loss

The loss of solids (SL) occurs during cooking as result of loosely adhered starches solublising from product surface. It was obtained as 10.8-22.4% in the optimization experiment using PMF substituted with 50% DSF (Table 1). The regression equation 1 generated for solid loss had high values for R^2 (0.974), adjusted R^2 (0.951), predicted R^2 (0.867) and signal-noise ratio (16.5>4) as evident from Table 2. The model was significant ($p<0.0001$) having lack of fit non-significant ($p=0.3384$) with respective F-values of 41.5 and 1.5.

$$SL=11.64 + 2.10X_1-0.605X_3\ X_1+ 2.01X_1^2+ 2.80X_2^2+ 2.24X_3^2 \quad ...(1)$$

Hydration Capacity

Hydration capacity (HC) is the compass for absorption level of water upon cooking varied in the range of 1.45-2.10 in the present experiment (Table 1). The regression equation 2 for HC had R^2 of 0.910 with its adjusted and predicted values as 0.828 and 0.367 respectively (Table 2). The difference between adjusted R^2 and predicted R^2 was more than 0.2, which was linked to the large block effect. Model was significant ($p=0.0004$) with lack of fit non-significant ($p=0.0141$) with respective F-values of 11.2 and 9.4.

$$HC=1.89+0.077X_1-0.077X_2+0.059X_3-0.049X_1\ X_2-0.084X_2\ X_3-0.094X_1^2-0.068X_3^2 \quad ...(2)$$

Table 1: Quality parameters of noodle strands prepared from pearl millet flour substituted with 50% defatted soy flour

X_1 °C	X_2 %wb	X_3 Rpm	SL %	HC g/ g	CT sec	WAI g/ g	WSI %	DG	D kg/ m³
60	30	150	15.86	1.45	251	2.86	13.6	0.36	1272
80	30	150	21.83	1.73	280	3.11	12.9	0.39	1026
60	36	150	16.90	1.62	294	3.00	13.8	0.39	1275
80	36	150	22.38	1.68	285	3.11	12.6	0.47	1210
60	30	250	16.84	1.75	190	2.67	15.9	0.26	1112
80	30	250	20.73	2.10	169	3.25	15.2	0.34	0951
60	36	250	17.33	1.56	186	3.57	14.2	0.30	1152
80	36	250	20.05	1.74	200	3.61	13.3	0.41	1006
53	33	200	13.77	1.57	248	2.78	10.7	0.37	1240
87	33	200	20.06	1.68	201	3.49	10.4	0.48	1086
70	28	200	18.84	2.02	176	3.26	12.5	0.28	0963
70	38	200	19.42	1.65	196	2.87	10.9	0.43	1157
70	33	116	16.69	1.66	276	2.64	16.6	0.34	1293
70	33	284	18.43	1.74	152	3.34	18.7	0.17	0946
70	33	200	11.48	1.92	239	2.94	15.8	0.25	1046
70	33	200	12.11	1.86	226	3.18	15.3	0.27	1116
70	33	200	10.87	1.93	226	3.20	14.3	0.28	1155
70	33	200	12.69	1.88	228	3.12	15.9	0.28	1105
70	33	200	12.07	1.88	234	3.02	15.6	0.28	1123
70	33	200	10.76	1.86	236	3.11	14.9	0.28	1118

X_1: barrel temperature (°C); X_2: moisture content (% wb); X_3: screw speed (rpm); SL: solid loss (%); HC: hydration capacity (g/g); CT: cooking time (second); WAI: water absorption index (g/g); WSI: water solubility index (%); DG: degree of gelatinization; D: density (kg/m³)

Cooking Time

Cooking time (CT) indicates strength for strands of noodle withstanding their structures following optimal period of cooking. It was therefore desirable to have its maximum value. Cooking time was varying in the range of 152-294seconds (Table 1). The CT value had significant ($p<0.01$) inverse relation with screw speed (Equation 3). Regression model for CT was found significant ($p<0.0001$) with F-value of 22.5. It was associated with high values of R^2 (0.809), adjusted R^2 (0.773) and predicted R^2 (0.660) respectively. The regression equation yielded linearly varying inverse relation of cooking time with screw speed. The signal-noise ratio of 16.3 (>4) revealed the adequacy of fit.

$$CT=224.6-42X_3 \quad ...(3)$$

Water Absorption Index

Water absorption index (WAI) was 2.6-3.6g/g in the present experiment for optimizing extruder variables (Table 1). Water absorption index is governed by starch gelatinization and the extent of thermal treatment. The equation representing the variation of WAI with extrusion parameters have been found with low values of R^2 and adjusted R^2 as 0.526 and 0.437 respectively (Table 2 and equation 4).

$$WAI=3.11+0.159X_1+0.161X_3 \quad ...(4)$$

Water Solubility Index

Water solubility index (WSI) is deliberated as undesirable characteristic for noodle samples and was evaluated by centrifuging the powdered noodle in water. It was related directly to the degree of solubility in water or inability of forming gel and thus the content of un-gelatinized starch in the noodle sample. The WSI value was found in the range of 10.4-18.7% in the present experiment (Table 1). Significant ($p<0.0001$) model and non-significant ($p=0.415$) lack of fit were obtained for WSI with 21.7 and 1.23 as respective F-values. Moreover, the model was obtained with adequacy of signal-noise ratio with the value as 19.2 (>4). The regression equation revealed it depending maximum upon X12 with negative correlation (Table 2 and equation 5). This equation was found with R^2, adjusted R^2 and predicted R^2 of 0.951, 0.908 and 0.766.

Table 2: ANOVA of the model for responses of noodle strands prepared from pearl millet flour substituted with 50% defatted soy flour

	SL, %	HC, g/g	CT, sec	WAI, g/g	WSI, %	DG	D, kg/ m³
Intercept	11.64	1.89	224.6	3.11	15.27	0.2728	1117.60
X_1	2.10***	0.077***	-4.84	0.159**	-0.293**	0.0355***	-64.22***
X_2	0.1739	-0.077***	7.95	0.054	-0.468**	0.0346***	44.54***
X_3	0.0664	0.059***	-42***	0.161**	0.676***	-0.0429***	-83.88***
X_1X_2	-0.2075	-0.0487**			-0.0875	0.0100	
X_2X_3	-0.2225	-0.0837***			0.0375	0.0100	
X_3X_1	-0.6050*	0.237			-0.4375*	0.0000	
X_1^2	2.01***	-0.0944***			-1.52***	0.0569***	
X_2^2	2.80***	-0.0201			-1.112***	0.0322***	
X_3^2	2.24***	-0.0679***			0.99***	-0.0032	
R^2	0.974	0.910	0.809	0.526	0.951	0.974	0.834
AR^2							
0.951	0.828	0.773	0.437	0.908	0.951	0.802	
PR^2	0.867	0.367	0.660	0.149	0.766	0.839	0.717
AP	16.47	12.11	16.34	8.21	19.19	23.96	18.21
F(M)	41.53***	11.19***	22.53	5.92***	21.72***	41.69***	26.72***
p(M)	<0.0001	0.0004	<0.0001	0.0064	<0.0001	<0.0001	<0.0001
F(L)	1.48	9.37	17.03	5.76	1.23	3.33	2.08
p(L)	0.3384	0.0141	0.0029	0.0330	0.4146	0.1065	0.2156
CV(%)	5.15	3.86	8.61	6.57	4.54	5.37	4.23

X_1: barrel temperature (°C); X_2: moisture content (% wb); X_3: screw speed (rpm); SL: solid loss (%); HC: hydration capacity (g/g); CT: cooking time (second); WAI: water absorption index (g/g); WSI: water solubility index (%); DG: degree of gelatinization; L: lightness; a: redness; b: yellowness; d: noodle thickness (mm) and D: density (kg/m³); AR^2: Adjusted R^2; PR^2: Predicted R^2; AP: Adequate precision; F(M): F-value (Model); p(M): p-value (Model); F(L): F-value (lack of fit); p(L): p-value (lack of fit); *significant at 10% ($p≤0.10$); **significant at 5% ($p≤0.05$) and ***significant at 1% ($p≤0.01$)

$$WSI=15.27-0.293X_1-0.468X_2+0.676X_3-0.437X_3 X_1-1.52X_1^2-1.11 X_2^2+ 0.99X_3^2 \quad ...(5)$$

$$DG=0.273+0.035X_1+0.035X_2-0.043X_3+0.057X_1^2+0.032X_2^2 \quad ...(6)$$

Degree of Gelatinization

Degree of gelatinization (DG) was varying from 0.17 to 0.48 in the present experiment on optimization of extruder variables for preparation of noodle strands using PMF substituted with 50% DSF (Table 1). Regression equation 6 was obtained for DG with high values of R^2 (0.974), adjusted R^2 (0.951) and predicted R^2 (0.839). The model was significant with lack of fit non-significant having F-value as 41.7 for model and 3.33 for lack of fit.

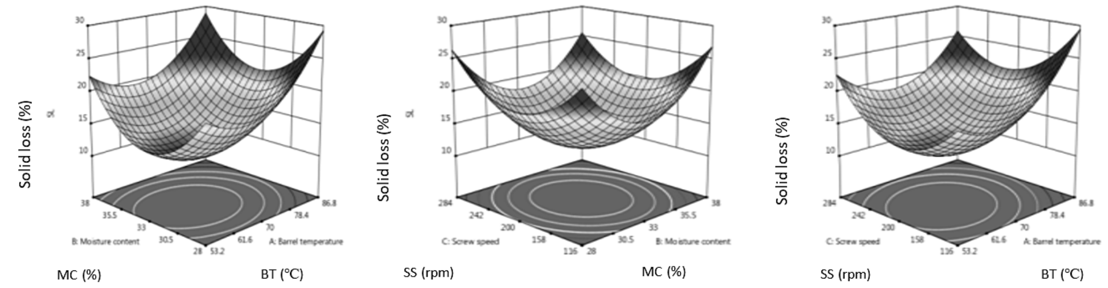

Fig. 2a: Variation in solid loss with extruder variables for noodle strands preapared from pearl millet flour substituted with 50% defatted soy flour

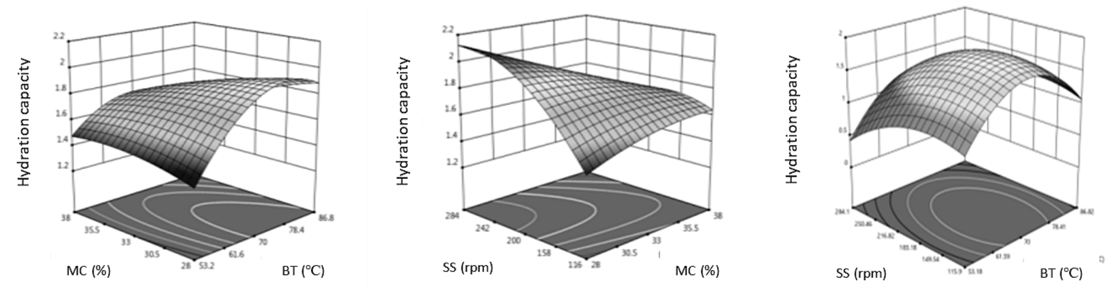

Fig. 2b: Variation in hydration capacity with extruder variables for noodle strands preapared from pearl millet flour substituted with 50% defatted soy flour

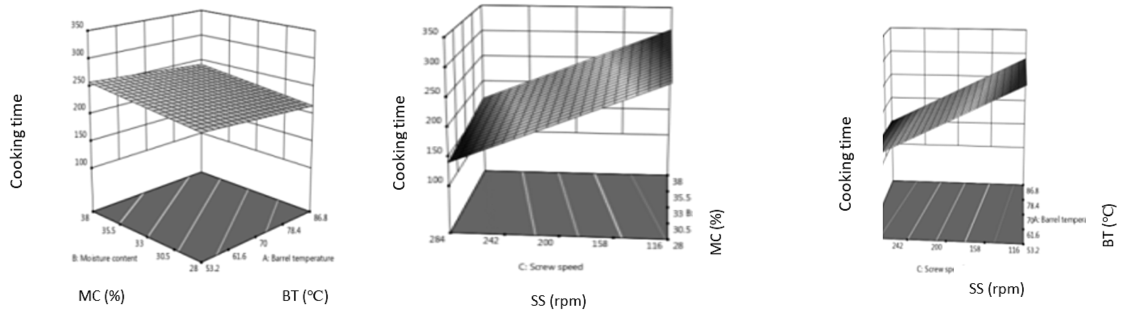

Fig. 2c: Variation in cooking time with extruder variables for noodle strands preapared from pearl millet flour substituted with 50% defatted soy flour

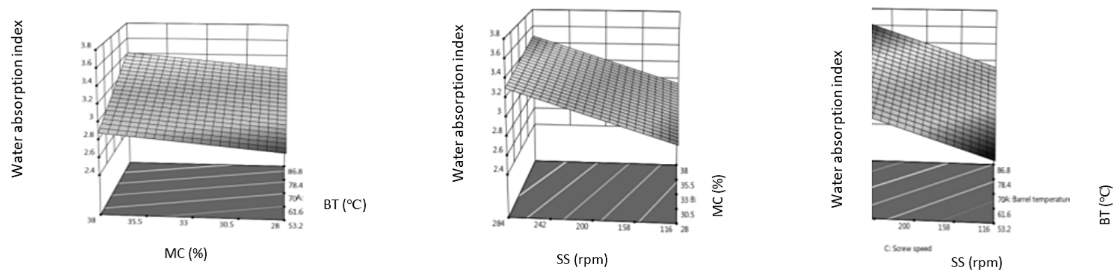

Fig. 2d: Variation in water absorption index with extruder variables for noodle strands preapared from pearl millet flour substituted with 50% defatted soy flour

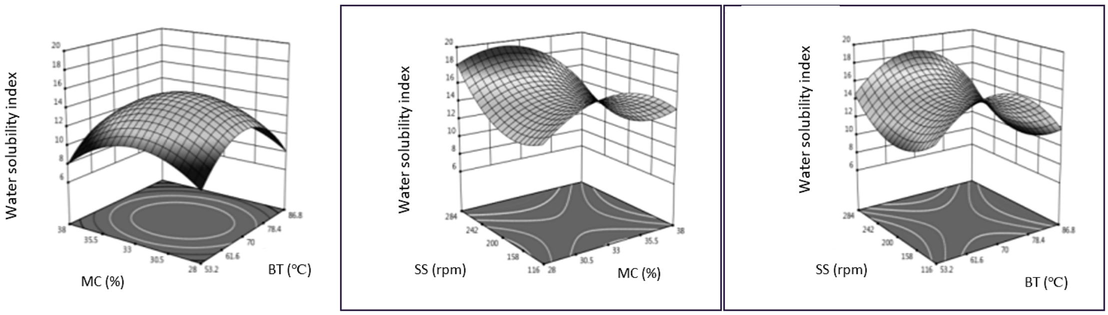

Fig. 2e: Variation in water solubility index with extruder variables for noodle strands preapared from pearl millet flour substituted with 50% defatted soy flour

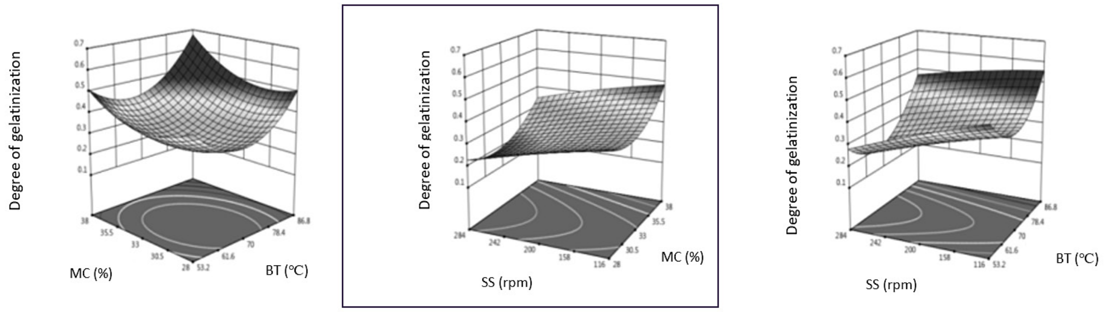

Fig. 2f: Variation in degree of gelatinization with extruder variables for noodle strands preapared from pearl millet flour substituted with 50% defatted soy flour

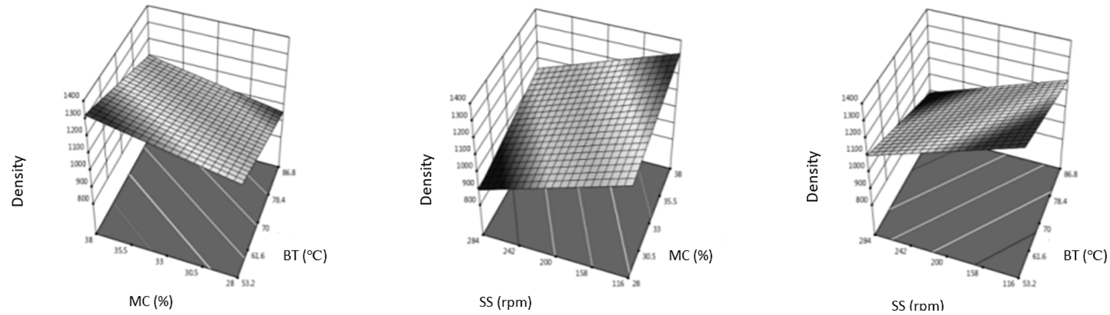

Fig. 2g: Variation in density with extruder variables for noodle strands preapared from pearl millet flour substituted with 50% defatted soy flour

Density (D)

The density indicates compactness of the noodle strands. It has been associated directly to their strength, while allowing it not to disintegrate during cooking. Thus, higher density was considered a desirable attribute. Density of noodles prepared under varying extrusion conditions were in the range of 946-1293kg/m^3

$$D=1117.6-64.2X_1+44.5X_2-83.9X_3 \quad ...(7)$$

The model was found with high value of R^2 as 0.834 with 0.802 and 0.717 as respective values for adjusted and predicted R^2. There was only 0.01% chance for noise to cause the large F-value for model, whereas 21.56% was chance for lack of fit causing F-value to occur due to noise.

Optimization study is based on the constraints and their importance based on which the optimum point is determined. In this study, the details of contraints for independent and dependent variables, their respective goals, ranges and importance in development of noodles have been presented in Table 3. Development of gluten free noodle strands includes solid loss as one of the most critical parameters. It was aimed to achieve firm strands of noodle, while retaining the structure of noodle strands from PMF substituted with 50% DSF after cooking. The analysis using design expert software was performed by setting the constraints to find optimum solution attaining the highest desirability. The optimum extruder condition is barrel temperature of 71^{o}C with flour moisture of 34.4% and screw speed of 178 rpm.

Thus, the noodle strands were prepared at the optimum conditions of extrusion processing. Picture of noodle strands prepared under optimized conditions is presented in Fig. 3. The cooking characteristics of noodles prepared under the optimized extruder conditions are presented in Table 3. The noodles were finally obtained to have 13.1±0.3% solids loss and high density of 1164±7 kg/m^3. The degree of gelatinization was 0.36, indicating adequate starch modification. The cooking time was also sufficiently high to tolerate moderate overcooking while retaining its structure. Considering the benefits of pearl millet and soy flour over wheat noodles, and its gluten free characteristic, slight increase in cooking loss can be tolerated as cooking standards for gluten free pasta products have not yet been set. Noodle quality parameters were validated at optimum extrusion processing variables at optimized condition of independent variables noodle making (Table 3).

Table 3: Constraints for optimization of extrusion processing of PMF-DSF noodles and their validation for optimized extrusion variables

Variables	Goal	Lower limit	Upper limit	Importance	Optimum value	Actual value	Difference
X_1, °C	In range	53.20	86.80	3	71	71	--
X_2, %w.b.	In range	28.00	38.00	3	34.4	34.4	--
X_3, rpm	In range	116.0	284.0	3	178	178	--
SL, %	Target	10.76	12.50	5	12.5	13.1±0.3	0.6
HC, g/g	Maximize	1.45	2.10	5	1.84	1.79±0.06	0.05
CT, sec	Maximize	180	240	2	240	234±6	6
WAI, g/g	Maximize	2.64	3.61	2	3.10	2.80±0.08	0.30
WSI, %	Minimize	10.4	18.7	2	14.7	15±0.36	0.30
DG	Maximize	0.17	0.48	2	0.31	0.36±0.03	0.05
AD, kg/ m^3	Maximize	946	1293	2	1155	1164±7	9
Desirability	0.70						

X_1: temperature inside barrel; X_2: moisture content of flour; X_3: speed of screw; SL: solid lost to water during cooking; HC: noodle capacity for hydration; CT: optimal cooking time; WAI: index for water absorption during centrifugation; WSI: index for solubility of noodle powder during centrifugation; DG: extent of gelatinization; D: density

Discussion

Solid Loss

The range of solid loss was lower than the values reported for noodles prepared from 100% pearl millet flour.[14] It was also reported with higher values upon adding millet flour in durum wheat semolina.[24,25] Solid loss was decreasing near central values and increasing towards the extreme points of dependent variables. With increase in the levels of X_1 and X_2, initial reduction in losses was associated to the reduced melt viscosity for starch. It yielded reduction in shear stress and thereby reduced friction as well as molecular degradation. Noodles of pea-starch[19] and pasta from pearl millet mixed with wheat semolina[25] had similar results. However, it was favoured at higher values of X_1 (barrel temperature) and X_2 (moisture content). This increase in the solid loss was attributed to degradation of starch at upper extreme points. Increased losses were also reported at higher moisture as consequence of stickiness with lowered mechanical strength.[26] With increased value of X_3, reduction in solid loss was linked to high shear or friction and thereby reduced melt viscosity. However, increase in losses beyond the critical limit of X_3, was associated to insufficient degree of starch gelatinization as a result of less residence time.[19] The solid loss was minimum near 65°C barrel temperature with 33% flour moisture and 200rpm screw speed (Fig 2a). The significant model with non-significant lack of fit was desirable for model to be fitted.

Hydration Capacity

It was reported with quite low value (1.13g/g) for pasta prepared from 10% PMF in wheat flour[27] and at par value (1.71g/g) for wheat flour pasta.[28] The pasta prepared from 50:50 blend of wheat semolina-PMF was reported with 1.96-2.36g/g as HC.[19] Higher value of HC was associated to the strength of noodle strands retaining their structures after absorbing more water during cooking. Differences in hydration capacity were justified as variation in their flour composition. HC was positively affected by barrel temperature and screw speed at 1% level of significance. It was negatively affected by flour moisture content during extrusion. HC attaind its maximum value near 80°C barrel temperature, 28% flour moisture and 280rpm screw speed (Fig. 2b). The least value was depicted at lower values for screw speed and barrel temperature. Gain in its value was attributed to reduction in fill factor resulted as higher specific mechanical energy as well as degree of starch gelatinization. The interactive effects viz. X_1X_2 and X_2X_3 had inverse effect on HC. The coded values yielded regression equation for hydration capacity. HC was revealed depending maximum upon X_{12} with inverse relation. The signal-noise ratio of 12.1 (>4) was desirable for model to be fitted. However, the model was significant (p=0.0004) with lack of fit non-significant (p=0.0141) with respective F-values of 11.2 and 9.4, which was desirable for model to be fitted. Significant model with non-significant lack of fit was desirable for model to be fitted.

Cooking Time

Cooking time of durum wheat semolina pasta has been reported with quite high value of 600-648seconds for,[29] which decreased appreciably to 309-446seconds on incorporating 50% PMF in wheat semolina.[19] Cooking time of noodles from wheat and wheat substituted with lentil (30%) were reported as 620 and 720 seconds respectively.[30] In this experiment, low cooking time was linked to absence of gluten in providing path for water to be absorbed during cooking and thereby reduction in cooking time. Considering the strength of noodle strands, high CT values are preferred, while lower value accounts for ease of cooking and energy saving. Thus, cooking time was maximized with in restricted range of 180-240 seconds. Cooking time decreased steeply with increased screw speed, which was opposite to the results for noodles of pea starch (Fig. 2c).[25] The positive correlation of moisture has also been reported with little effect of barrel temperature on cooking time for noodles of pea starch noodles.

Water Absorption Index

Water absorption index was reported as 2.4-3.1g/g for noodles prepared from 100% pearl millet flour.[14] It was affected by X_1 and X_3 at 5% ($0.01 \leq p < 0.05$) level of significance. The graphs exhibited linear increase in WAI value with X_1, X_2 and X_3. But, the effect of X_1 and X_3 were prominent and at par with each other as evident from Fig. 2d and equation 4. The model was found with adequate signal-noise ratio of 8.2 (>4) with significance (p=0.0064) having model F-value of 5.9, which was desirable for model to fit. However, the significant (p=0.0330) lack of fit (F-value= 5.8) was undesirable for model to be fitted. The increased water absorption was attributed to higher capacity of flour ingredients on subjecting it to high thermal treatment or shear stress.

Water Solubility Index

Water solubility index is indicative of the solubilisation of noodle powder in water after centrifugation of the sample usually increased with the content of ungelatinized starch and thus desired to have its minimum value. WSI was found to increase with high screw speed, implying lesser time for flour modification (Fig. 2e). It decreased with increase in barrel temperature and flour moisture ($p \leq 0.05$). Interaction of screw speed and barrel temperature reduced the WSI ($p < 0.1$). The significant model with non-significant lack of fit was desirable for model to be fitted. The graph inferred maximum value of WSI near 82°C barrel temperature and 33% of flour moisture. The difference between predicted and adjusted R^2 values was less than 0.2, which was normally expected. The model was found with adequate signal-noise ratio of 19.2 (>4), alluding the model useful for navigating the design space.

Degree of Gelatinization

DG has been indicating palatability of the product and was thus desired to have maximum value. The DG value increased significantly with barrel temperature and flour moisture at 1% level ($p \leq 0.01$) of significance as expected. Screw speed was found to have a significantly negative effect on DG. Regression equation has normally been expected to have difference of predicted and adjusted R^2 values less than 0.2. The analysis revealed its maximum and minimum dependence upon X_1^2 and X_2^2 respectively (Table 2). The significant model and non-significant lack of fit were desirable for model to be fitted. It was revealed to be useful for navigating the design space as adequacy of signal-noise ratio (19.2) was higher than 4. The highest degree of gelatinization was observed near 80°C temperature, 36% moisture with screw speed of 150rpm (Fig. 2f). The predicted and adjusted R^2 values were obtained with difference not more than 0.2, which was normally expected. Gelatinization has limiting factors either temperature, residence time or moisture for lowered value.

Density (D)

Bulk density of noodles prepared from wheat substituted with lentil (30%) was reported with 520kg/m^3.[29] It was revealed as 674-739 kg/m^3 with least value for noodles of refined wheat flour and higher values for the same incorporated with insoluble dietary fiber.[31] It was lighter than the pearl millet and protein rich chickpea grains having density in the range of 711.9-827.5 kg/ m^3 and 830-880 kg/ m^3.[32,33] The values were similar to the pearl millet flakes having density in the range of 349.5-590.7.[34,35] It was found depending maximum upon X^3 as revealed from the equation. Density was found to increase with flour moisture ($p<0.01$), while barrel temperature and screw speed affected it negatively ($p<0.01$) as depicted from fig. 2g. The findings on density is on expected lines since higher degree of hydration of flours leads to higher starch-protein binding which reinforces the strength of noodle strands. It indicates the strength for strands of noodles. Difference of predicted and adjusted R^2 was less than 0.2, which was expected. It was found with signal-noise ratio of 18.2 (>4) indicating adequacy of signal and inferred that the model was useful for navigating the design space. Significant model was obtained with lack of fit non-significant, which was desirable for model to be fitted.

The study was to optimize the extruder variables for noodle preparation from gluten free blend using 50:50 mix of pearl millet and defatted soy flour.[36] Optimum extruder process varibles viz. barrel temperature, moisture content and screw speed were 71°C, 34.4% flour moisture and 178 rpm screw speed respectively. Optimum extrusion variables have been reported for the process of pasta preparation using 20% tiger nut in wheat as 70°C temperature and 15% feed moisture.[37] The instant noodles of cocoyam was reported with optimum processing condition of extrusion as 700rpm screw speed with 47.5% moisture of feed and 55°C temperature.[38] The optimum values of extruder variables were revealed as 70°C barrel temperature, 12rpm feeder speed and 30% moisture level with the ratio of screw and feeder speeds as 10 for 50:50 blend of wheat semolina and pearl millet.[19] Yadav *et al*. (2021)[39] reported negative correlation of cooking time and cooking loss or solid loss with the moisture level of feed. The increase in water absorption upon incorporation of legume and heated water has been linked to denatured protein enhancing the available amino group with polarity and hence the water uptake.[40] Considering the facts, some of the researchers have investigated the effect of extruder variables on variation in product quality. Yadav *et al*. (2022)[41] reviewed physico-chemical, thermal, microstructure, pasting, texture, nutritional and cooking characteristics of millet-based products as function of extruder variables. Sobowale *et al*. (2021)[42] studied the effect of composition of ingredients, barrel temperature and moisture level, while optimizing the extruder variables for pearl millet flour based snacks. Kaur *et al*. (2014)[43] also optimized the parameters of extrusion process for development of breakfast cereal using response surface methodology. Thus, optimum extruder variables in the current study will be useful in developing gluten free nutriyious noodles from 50:50 mix of pearl millet and defatted soy flours.

Future Directions

The study may be extended to identify best suited reason/season/variety of raw ingredients for commercializing the product. The noodle quality may subsequently be improved through incorporation of pre-treatments or other ingredients. These results may also lead to development of different products with similar composition.

Fig. 3: Gluten free nutritious noodles prepared from pearl millet substituted with 50% defatted soy flour

Conclusion

The extrusion processing variables are function of raw ingredients and their commposition. Noodle was prepaed using the gluten free composition comprising pearl millet flour substituted with 50% defatted soy flour. Optimization experiment was conducted for process variables of extruder following the central composite rotatable design. Independet variables were 71°C temperature inside barrel and 34.4% flour moisture with speed of screw at 178rpm. The solids lost to the cooking water, noodle capacity for hydration and optimal time of cooking were 12.5%, 1.84g/g and 240sec repectively at optimum condition with desirability of 0.70. Moreover, index for water absorption of noodle powder during centrifugation, index for solubility of noodle powder in cooking water during centrifugation, extent of gelatinization and density were 3.10, 14.7, 0.31 and 1155kg/m^3 respectively. The developed product can be served as gluten-free noodle enriched with protein, fiber, iron and zinc. As both the major ingredients were low in glycemic index, the noodle may be presented as friendly to the population prone to diabetes.

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This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Clinical Trial Registration

This research does not involve any clinical trials.

Permission to Reproduce Material from Other Sources

Not Applicable

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