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Effect of Pretreatments and Extrusion Variables on the Quality of Pearl Millet Noodles

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ABSTRACT

Noodles are commercially prepared from wheat flour, as its gluten helps in producing its best quality. However, the product lacks fibre, lysine, essential micronutrients and antioxidant activity. A large proportion (5%) of the total population suffering from celiac disease, wheat allergy and gluten intolerance are also avoiding it. Millets, especially pearl millet, are one of the potential solutions to such problems with the abundance of millet production in the country. Investigating the effect of incorporating other ingredients is the way forward for the development of gluten-free products. Primarily, pearl millet was used to prepare noodles by optimizing various pretreatments and extruder variables. This resulted in high solid loss, low hydration capacity and disintegration after cooking due to the absence of gluten in the millet. Cooking quality, especially solid loss, is considered the most important characteristic for the development of gluten-free noodles, which could be improved with guar gum (2%) and boiling water addition before processing. To obtain the best quality of noodles, the extrusion processing variables were found to be optimum at 74°C barrel temperature, 34.7% moisture content and 178 rpm screw speed.

Keywords: Extruder, Gluten free, Nutritious noodles, Pearl millet

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INTRODUCTION

Noodle is one of the variants of pasta, which differs from spaghetti, penne, tortellini, ravioli, macaroni, fettucine, lasagna and vermicelli in shape. It is continuously penetrating the Indian market due to ease of cooking, palatability and the taste associated with it. Noodle is usually prepared from wheat flour through its secondary processing, and thus, it inherits all its advantages and limitations. Gluten available in wheat flour helps in preparing dough for noodle making. However, traditional noodles are poor in nutrition in terms of fibre, phenolics, minerals and vitamins. In addition, a large proportion (5%) of the total population has been reported to suffer from celiac disease, wheat allergy or nonceliac gluten intolerance (Elli *et al*., 2015). Hence, the core of recent studies includes the identification of potential alternatives to wheat flour for the development of noodles and their covariants.

Pearl millet (*Pennisetum glaucum*) is a small grain cereal grass in semiarid and arid zones and is suited for varying climatic factors (Kaur *et al*., 2018). The crop is resistant to common pests and diseases. India holds the top position in the production of the crop among other producing countries. Pearl millet is rich in energy and nutrition, especially in terms of micronutrients. It is gluten-free and remains alkaline after cooking, which makes it appropriate for populations with gluten or wheat intolerance. The lower value of the glycaemic index (Kaur *et al*., 2018) is another attraction among diet-conscious people, especially for the diabetes-prone part of the population.

Substitution or replacement of wheat has been kept under active consideration for the development of noodles and their covariants while retaining acceptable quality of the product. In this way, pearl millet has been incorporated successfully for the development of various pasta variants (Yadav *et al*., 2014a & b). Nutritious pasta of acceptable quality from 50:50 blends of wheat semolina and pearl millet flour was developed by Jalgaonkar and Jha (2016). Thus, pearl millet has been identified as a nutritious alternative for the development of noodles and their covariants. Nevertheless, noodles prepared from pearl millet do not have enough strength to retain their shape after cooking. It requires study on the effect of various treatments to improve the quality of noodles after cooking.

Extrusion is the method of preparing noodles where variables, viz. the barrel temperature, ingredient moisture and screw speed affect the product quality appreciably (Prakash *et al*., 2021, Yadav *et al*., 2014a & b). Petitot *et al*. (2009) mentioned pressure to cause compactness of extruded product during extrusion. It was thus supposed to minimize disintegration after cooking. Although studies on the incorporation of millet as a minor ingredient are available, studies on noodles containing pearl millet as a major ingredient are scarce. Hence, this study aimed to investigate the effect of

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pretreatments and optimize the extrusion variables for the preparation of pearl millet noodles. Gluten-free functional products can be developed by investigating the effect of other treatments and the incorporation of minor ingredients.

MATERIALS AND METHODS

Procurement of raw materials

Pearl millet grain (*Pusa Composite* 1201 variety) was collected from the farm of the Indian Agricultural Research Institute, Pusa, New Delhi (India). Subsequently, the grain was cleaned, dried and stored safely.

Grain milling

Pearl millet grains were milled to flour with an average particle size of 425 microns using a hammer mill (Sanco, India) and cooled before processing through extrusion.

Pretreatment

The preweighed flour sample was mixed thoroughly with guar gum (2%), and the quantity of boiling water was calculated as per the experimental design. These powdered additives were purchased from local suppliers. The distribution of gum and moisture was ensured to be uniform through manual mixing and sieving of the blend while keeping the same for 24 h at 5°C in the refrigerator.

Extrusion

The mix powder was fed into the extruder at varying barrel temperatures, moisture contents of the mix and screw speeds. Their levels were as per the points obtained for central composite rotatable design with respective ranges of 53.2-86.8°C, 28.0-38.0% wet basis and 116-284 rpm. The feeder speed was kept at one-tenth of the screw speed throughout the experiment (Jalgaonkar *et al*., 2019).

Dehydration of Pasta

The collected noodle strands were dried at 50°C in a tray dryer (MSW-216, Macro Scientific Works, New Delhi) until attaining a moisture level below 8%. Finally, the dried noodles were stored for analysis after cooling and packaging.

Cooking quality

Cooking refers to placing the raw noodles in boiling water until the disappearance of the white core when compressed between two glass plates. Cooking quality was determined by the standard method (BIS, 2010). Cooking time was estimated as the time elapsed in cooking after which noodle strands retain their structures. The gruel was placed in a preweighed beaker before drying to determine the solid loss. It was presented as the weight of dry residue per unit weight of uncooked noodles. Cooking causes weight gain in raw noodles due to hydration and was measured in terms of hydration capacity. Its excess resulted in a sticky texture, whereas lower values may lead to a hard texture. However, pearl millet noodles were found to have a hydration capacity of lower values, and thereby, maximization of the same was desirable.

Water absorption index and water solubility index

The water absorption index (WAI) and water solubility index (WSI) were determined through centrifugation of fine powders of noodles in centrifuge tubes as suggested by Singha *et al*. (2018) with slight modification. A powder sample of 2.5 g was suspended in a preweighed centrifuge tube of 50 ml with 25 ml water. It was subjected to centrifugation at 3000 × g for 10 min. The supernatant obtained was transferred into preweighed beakers and dried at 105°C until a constant weight was obtained. Thus, indices of water absorption and water solubility were calculated using the following equation:

$$WAI = W_s / W_{ps} \quad \ldots (1)$$

$$WSI\,(\%) = (W_{ds} / W_{ps}) * 100 \quad \ldots (2)$$

Where

W_s: Weight of supernatant; gram

Wps: Weight of powdered sample; gram

Wds: Weight of dried soluble; gram

Degree of gelatinization

The extrudates obtained as noodles were analysed for the degree of gelatinization by using a preweighed centrifuge tube filled with ground sample (40 mg) dispersed in 40 ml of 0.06 N KOH (Chen *et al*., 2017). It was slowly agitated (20 min) and centrifuged (10 min) at 3200 g. An aliquot (1 ml) of the supernatant was taken with 0.06 N HCl (1 ml) and distilled water (8 ml) in an amber coloured container. The absorbance reading of the test group was noted as A_1 at 600 nm after adding 1% KI-I_2 solution (0.1 ml) against the reagent blank prepared without sample. The procedure was repeated while replacing the normality of KOH and HCl from 0.06 to 0.1 N. It yielded an absorbance reading of the control group and was noted as A_2. The degree of starch gelatinization was thus calculated as the ratio of A_1 and A_2.

Statistical Analysis

The effects of boiling water and additives were studied in a completely randomized design. It was analysed statistically using Web Agri Stat Package 2.0 available on the website of ICAR-Central Coastal Agricultural Research Institute, Goa-403402. Subsequently, the optimization experiment was analysed using the trial version of Design Expert Software 12.

RESULTS AND DISCUSSION

Effect of pretreatments

The noodle strands of pearl millet flour were found to have poor cooking quality, viz. solid loss and hydration capacity as well. This may be due to the absence of gluten, which is helpful in retaining the shape of noodles after cooking. Boiling water application improved the cooking quality appreciably. It yielded a reduction in solid loss from 35.4 to 20.1% with an increase in hydration capacity from 0.49 to 0.70 gram/gram. However, the cooking time did not change significantly. Subsequently, the cooking quality of noodle strands was studied while incorporating various additives in the flour. Based on preliminary trials, the levels of additives were kept constant at 2% of the flour weight. The least solid loss was obtained with karaya gum (16.1%), which was statistically similar to guar gum (16.2%). However, the incorporation of guar gum resulted in a greater value for hydration capacity, i.e., 1.92 g/g compared to 1.64 g/g with karaya gum. The cooking time varied from 236 to 380 sec and was linked largely to the strengthening of noodle strands. However, cooking time with too high a value is discouraged as indicative of hard texture and difficulty in cooking. Hence, boiling water-treated flour was used with guar gum (2%) for subsequent study.

Effect of extrusion process variables

Effect of extrusion processing variables, viz. barrel temperature (X_1), moisture content (X_2) and screw speed (X_3) were investigated for product characteristics of noodle strands through response surface methodology. Product responses were presented as second-order polynomial models in terms of process variables along with statistical validity (Table 1).The models were significant (*P<0.01*) for solid loss (SL), hydration capacity (HC), water absorption index (WAI), water solubility index (WSI) and degree of gelatinization (DG) with high values for the coefficient of determination (Table 1). Low values of CV (coefficient of variation) were also meant for reasonable accuracy of the experiment and reproducible models. All these parameters yielded significant *(p<0.01)* models with a nonsignificant *(p≥ 0.1)* lack of fit. Models had higher F values with least chances of noise to cause this as depicted from their respective p values. Table 1 comprises the coefficients for predicting the responses as coded values indicating the relative effect of factors, their interactions and quadratic terms depending upon the magnitude of the corresponding terms (Table 1).

Table 1: ANOVA and regression coefficients of the second order polynomial model for product responses

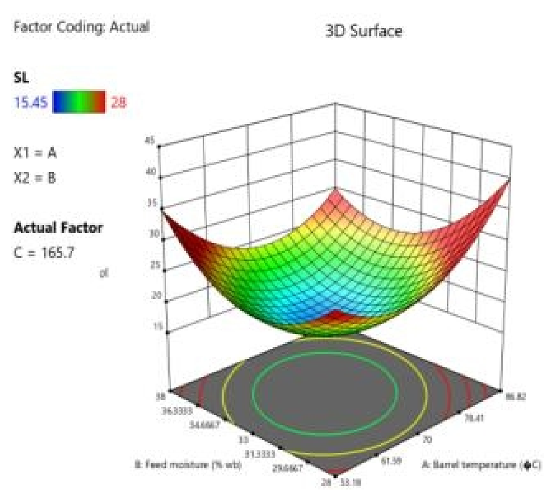
Parameters	SL (%)	HC	CT	WAI	WSI (%)	DG
Intercept	17.025	1.916	462.5	2.725	8.869	0.761
X_1	0.965**	0.022	-35.7***	0.134***	-1.113***	0.059***
X_2	0.038	0.027	33.2***	0.011	-0.209	0.019
X_3	0.717*	-0.118***	18.4***	0.076***	-0.702**	-0.066***
X_1X_2	-1.332**	0.044	-3.1	0.022	0.165	0.012
X_2X_3	1.172**	-0.009	-20.6***	-0.102***	0.265	0.047*
X_3X_1	0.290	0.014	6.9	-0.040*	-0.475	-0.01
X_1^2	2.933***	-0.240***	-45.6***	-0.013	-0.982***	-0.184***
X_2^2	3.011***	-0.178***	-59.8***	0.015	-1.534***	-0.063***
X_3^2	1.293***	-0.108***	-37.7***	0.049**	-0.353	-0.090***
R^2	0.947	0.954	0.979	0.930	0.912	0.944
Adjusted R^2	0.900	0.913	0.959	0.867	0.834	0.894
Predicted R^2	0.702	0.766	0.910	0.715	0.641	0.874
Adequate precision	11.134	12.040	21.658	13.854	9.530	13.456
F-value (Model)	19.99***	23.18***	51.00***	14.83***	11.57***	18.80***
p-value (Model)	<0.0001	<0.0001	<0.0001	0.0001	0.0003	<0.0001
F-value (Lack of fit)	2.03	1.41	0.7986	0.7337	0.732	0.1534
p-value (Lack of fit)	0.2280	0.3566	0.5945	0.6289	0.6299	0.9668
CV (%)	5.74	5.41	4.56	2.14	11.95	12.26

X1: barrel temperature; X2: moisture content; X3: screw speed; SL: solid loss; HC: hydration capacity; CT: cooking time; WAI: water absorption index; WSI: water solubility index and DG: degree of gelatinization

***significant at 1% (p≤0.01); **significant at 5% (p≤0.05) and *significant at 10% (p≤0.10).

Solid loss (SL)

Solid loss refers to solids in water solubilized during cooking and is thereby known as gruel loss and cooking loss. Cooking performance is mainly indicated through the leaching of solids in cooking water and is termed solid loss or cooking loss. BIS: 1485 recommended it to be below 8% for pasta and its variants prepared from wheat. However, it goes beyond the limit for non-wheat ingredients. The experimental study yielded a value in the range of 15.45-27.26%. It was found to increase with the addition of millet flours in durum wheat semolina (Gull *et al*., 2015a & b). The coefficient table exhibited only quadratic terms of the variables to have a significant (p<0.01) effect on SL (Table 1). However, X_1 and the interactions of X_2 with X_1 and X_3 also had a significant (0.01<p≤ 0.05) effect on SL at the 5% level of significance. The coded factors yielded equation (1) for solid loss exhibiting SL to be



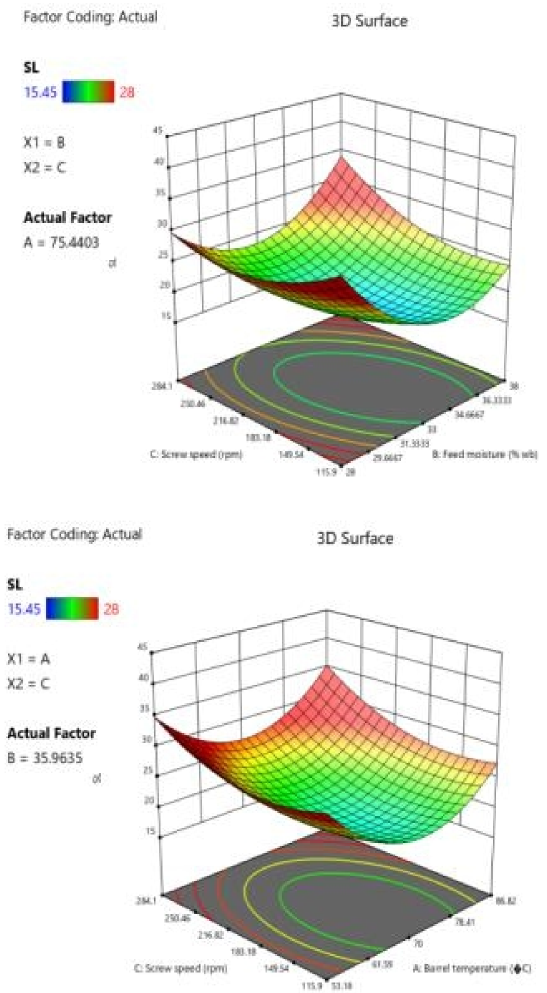


Fig. 1: Effect of extrusion processing variables on solid loss of noodles

influenced maximum by X_2^2 as it was found to have the highest coefficient.

$$SL(\%) = 17.025 + 0.965X_1 + 0.717X_3 - 1.332X_1X_2 + 1.172X_2X_3 + 2.933X_1^2 + 3.011X_2^2 + 1.293X_3^2 \quad (\text{Adjusted } R^2 = 0.900) \ldots (3)$$

It was inferred from the graphs (Fig. 1) that solid loss was least, while reaching lower levels for X_1 along with the same for X_2. It reached a maximum value at high values of X_1 with a low level of X_2. The value also peaked due to the interaction effects of X_2 with X_3 as well as X_3 with X_1. An increase in the losses was linked to starch degradation at the end points.

Solid loss decreased with increasing barrel temperature (X_1) in the range of 53.2-65°C due to a reduction in the melt viscosity of starch. This resulted in low shear stress or friction in the extruder and a reduction in molecular degradation (Wang *et al*., 2012). However, an increase in the losses beyond 65°C was attributed to degrading starch, denaturizing gluten and deteriorating surface conditions, causing ease of release of starch granules (Table 1). Moisture addition caused a decrease in solid loss in the range of 28 to 33% wet basis, which was linked to lowered melt viscosity. Similar results were reported for noodles of pea starch (Wang *et al*., 2012) and pasta of pearl millet-wheat semolina (Jalgaonkar *et al*., 2019). However, an increasing trend was obtained beyond 33% moisture content. This was considered to be a result of stickiness and low mechanical strength, similar to the results of de la Pena and Manthey (2017).

With an increase in screw speed from 116 to 200 rpm, the solid loss decreased slightly but increased thereafter. This might be due to a reduction in melt viscosity with high shear stress or friction in the extruder at higher screw speeds. However, increasing losses were observed beyond 190-200 rpm and were supposed to be in harmony with reduced retention time for extruder cooking and insufficiency of gelatinization. Similar findings have also been reported by Jalgaonkar *et al*. (2019).

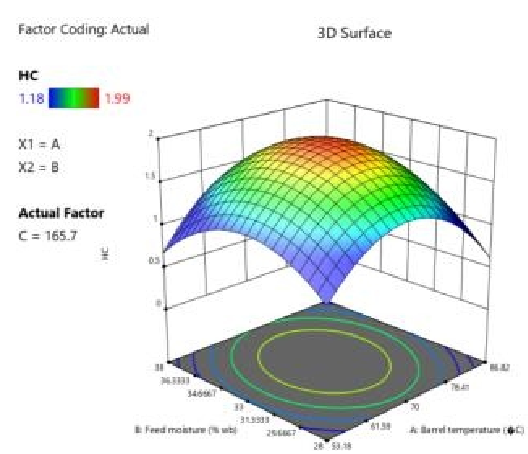
Hydration capacity (HC)

Hydration capacity is the capacity of noodle strands to absorb water during cooking. The coefficient table shows the linear term of X_3 and quadratic terms of all the variables under investigation with a significant ($p<0.01$) effect on HC. It could be presented as regression coefficients in terms of coded values as

$$HC = 1.916 - 0.118X_3 - 0.240X_1^2 - 0.178X_2^2 - 0.108X_3^2 \quad (\text{Adjusted } R^2 = 0.913) \ldots (4)$$

The equation revealed the dependence of the hydration capacity maximum on the quadratic term of barrel temperature (X_1^2).

Fig. 2 reveals the hydration capacity decreasing with its peak near central values of X_1 along with the same for X_2. It was favoured by X_2 up to 35% with X_3 below 200 rpm. A similar pattern was obtained for X_3 below 215 rpm with X_1 below 78°C. The value was lowest at extreme levels of X_1, X_2, X_3 and their interactions (Fig. 2). This was attributed to the gelatinization of starch that occurred during extrusion and favoured hydration of the noodles in the process of cooking. The variations were in close agreement with the same degree of gelatinization investigated by Gimenez *et al*. (2013) for pasta of the spaghetti type prepared from corn-broad bean. However, a decrease in the value beyond a certain level of X_1 was attributed to starch damage. The low molecular weight of water was responsible for reduced melt viscosity while acting as a plasticizer during extrusion. Moisture addition favoured granule swelling, gelatinization of starch and thereby hydration.



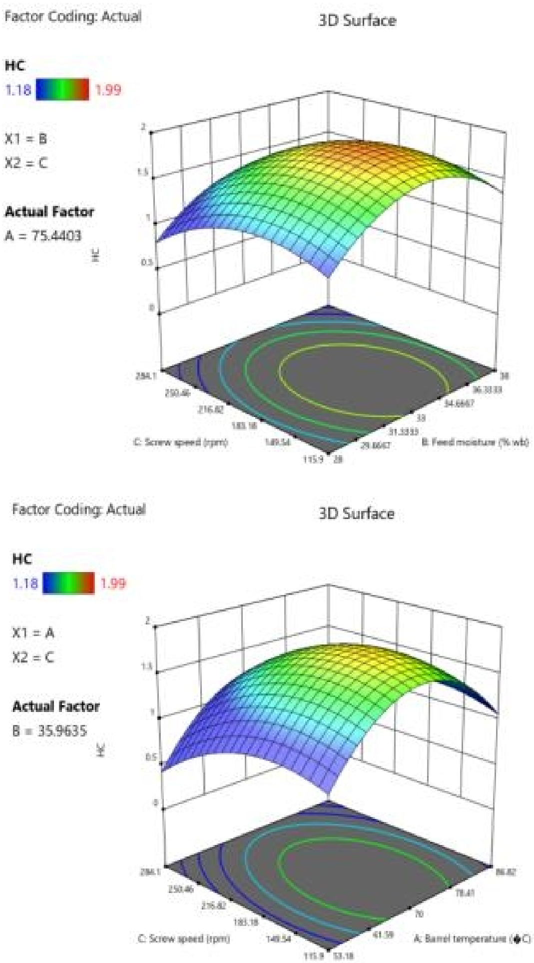


Fig. 2: Effect of extrusion processing variables on hydration capacity of noodles

The increasing screw speed reduced the degree of fill, leading to an increase in specific mechanical energy; thus, a higher degree of starch gelatinization favoured hydration capacity. However, the trend was reversed beyond 215 rpm screw speed (Table 1).

Cooking time (CT)

Cooking time indicates the ability of noodle strands to withstand their structure after moderate overcooking. This fact governs it to maximize, whereas a higher cooking time needs more energy input. Jalgaonkar*et al*. (2019) reported similar results, where the cooking time for pasta of pearl millet-wheat semolina was reported as 309-446 sec. The CT model was obtained with quite high values of R^2, adjusted R^2, predicted R^2 and signal-to-noise ratio of 0.979, 0.959, 0.910 and 21.658, respectively. This equation is presented as

$CT = 462.5 - 35.7X_1 + 33.2X_2 + 18.4X_3 - 20.6X_2X_3 - 45.6X_1^2 - 59.8X_2^2 - 37.7X_3^2$ (Adjusted $R^2 = 0.959$) ... (5)

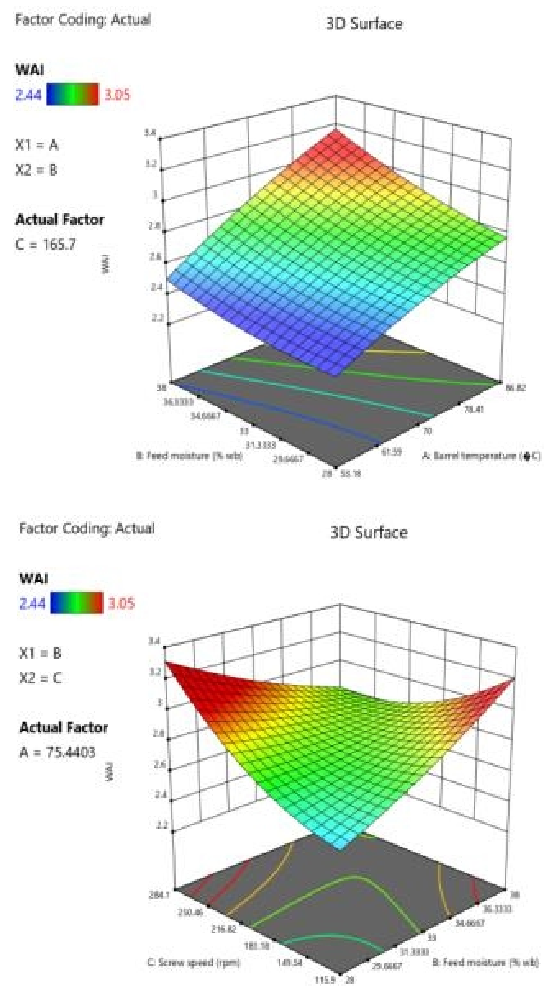
The model was found to be significant ($p<0.0001$) with a nonsignificant ($p=0.5945$) lack of fit, with F values of 51.0 and 0.7986, respectively. It revealed only a 0.01% chance for noise to cause this large F–value, whereas lack of fit had a 59.45% chance for the occurrence of this F value due to noise. In the present study, cooking time varied in the range of 220-481 seconds during the investigation. It exhibits the strength of noodle strands to retain their shape after cooking. Thus, cooking time was excluded from the list of constraints for optimizing extruder variables while preparing noodles using 100% pearl millet (Table 1).

Water absorption index (WAI)

The water absorption index indicates the capacity of extrudates to absorb water. The WAI ranged from 2.44 to 3.05 grams/gram for pearl millet noodles (Fig. 3). Regression analysis clarified that it depended significantly ($p<0.01$) on the linear terms X_1, X_3 and X_2X_3 (Table 1). However, the same was true for X_3^2 at the 5% level of significance ($0.01 \leq p<0.05$) and X_3X_1 at the 10% level of significance ($0.05 \leq p<0.1$).

$WAI = 2.725 + 0.134X_1 + 0.076X_3 - 0.102X_2X_3 - 0.040X_3X_1 + 0.049X_3^2$ (Adjusted $R^2 = 0.867$) ... (6)

The coefficients presented as coded values in the regression equation unveiled the maximum dependence of water absorption on the linear term X_1.The WAI increased linearly with X_1 and X_2 in all conditions except for a decrease in X_2 beyond 200 rpm screw speed, as depicted from 3-dimensional graphs (Fig. 3). The trend was in agreement with the variation in the level of starch gelatinization and thermal treatment during extrusion. It increased with X_3 at low levels of X_2, decreased at higher levels of X_2, and increased beyond 250 rpm



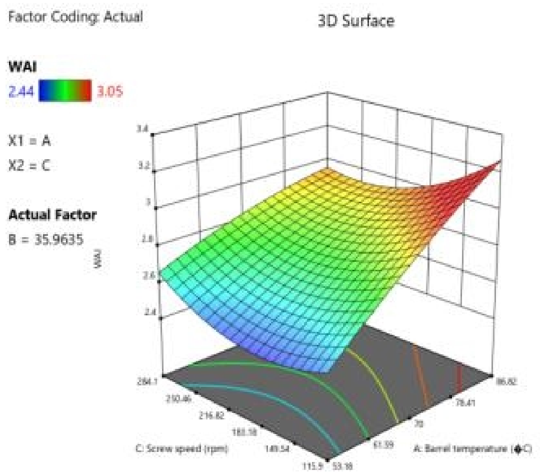
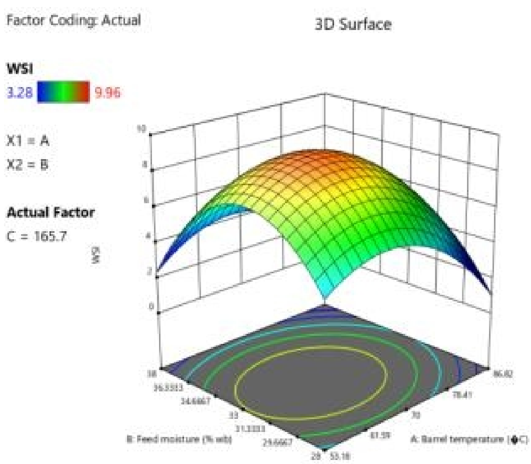
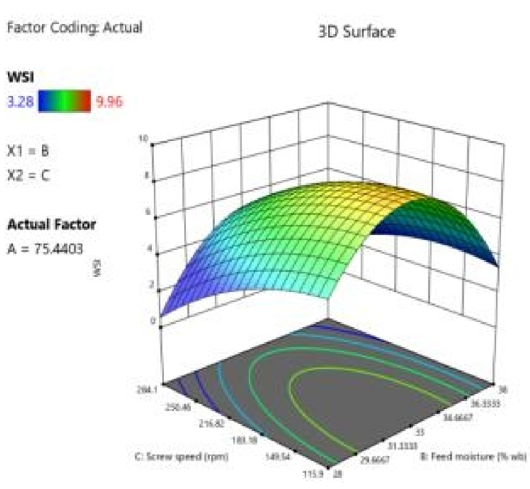


Fig. 3: Effect of extrusion processing variables on water absorption index of noodles

screw speed (Fig. 3). The X_3 value attained its trough near 150 rpm at lower levels of X_1 and 250 rpm at higher levels of X_1. It was found to increase with increasing as well as decreasing screw speed. The decrease in WAI was obtained due to a shortened retention period and thereby a reduction in thermal treatment with an increase in X_3 at high levels of X_1.





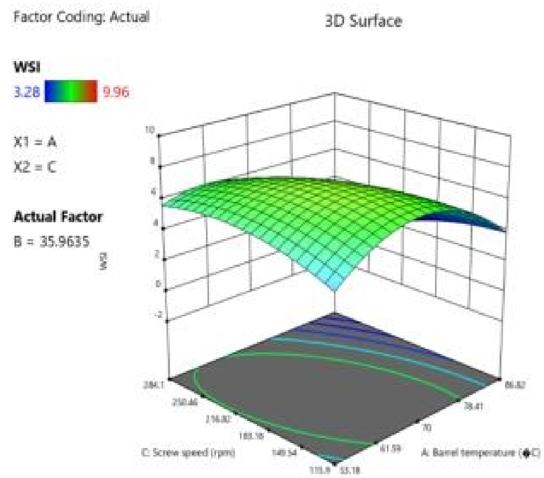


Fig. 4: Effect of extrusion processing variables on water solubility index of noodles

Water solubility index (WSI)

WSI implies the inability of noodle powder to make a gel and instead becomes solubilized in water when subjected to centrifugation. The WSI varied in the range of 3.28-9.96% (Fig. 4). The regression analysis exhibited its dependence significantly ($p<0.01$) on the linear term of X_1 and quadratic terms of X_1 and X_2. Moreover, the linear term of screw speed also affected it at the 5% level of significance ($0.01\leq p<0.05$).

$WSI = 8.869 - 1.113X_1 - 0.702X_3 - 0.982X_1^2 - 1.534X_2^2$
(Adjusted $R^2 = 0.867$) … (7)

The coefficients of the regression equation revealed that it depended on X_2^2. The graphs (Fig. 4) exhibited the highest value of WSI in the central range of X_1 and X_2.

The water solubility index reached its peak near 70°C for X_1 and 33% for X_2. It unveiled the peak near 35% of X_2 with 150 rpm of X_3. It attained its maximum value near 78°C for X_1 and decreased gradually with X_3. WSI followed the trend of starch gelatinization to some extent as an effect of X_1 and X_2. However, the effect of X_3 was seemingly of less importance (Table 1).

Degree of gelatinization (DG)

Gelatinization is a desirable attribute for improved texture, palatability and digestibility of foods. It varied in the range of 0.11-0.87 when investigating the extrusion process variables for the development of pearl millet noodles (Fig. 5). As evident from the regression analysis, terms X_1, X_3, X_1^2, X_2^2 and X_3^2 were found to affect it at the 1% level of significance ($p<0.01$).

$DG = 0.761 + 0.059X_1 - 0.066X_3 + 0.047X_2X_3 - 0.184X_1^2 - 0.063X_2^2 - 0.090X_3^2$ (Adjusted $R^2 = 0.894$) … (8)

The coded values forming equation 6 referenced its maximum dependence on the quadratic term of X_1. The variation in DG with extruder variables yielded the lowest value at extreme levels. The value attained its peak at different levels for the combination of variables. It was near 78°C of X_1 with 33% of X_2, 34% of X_2 with 180 rpm of X_3 or 220 rpm of X_3 with 75°C of X_1 (Fig 5). The lower values were attributed to insufficient moisture, temperature or retention time or degradation in starch beyond a certain level of gelatinization.

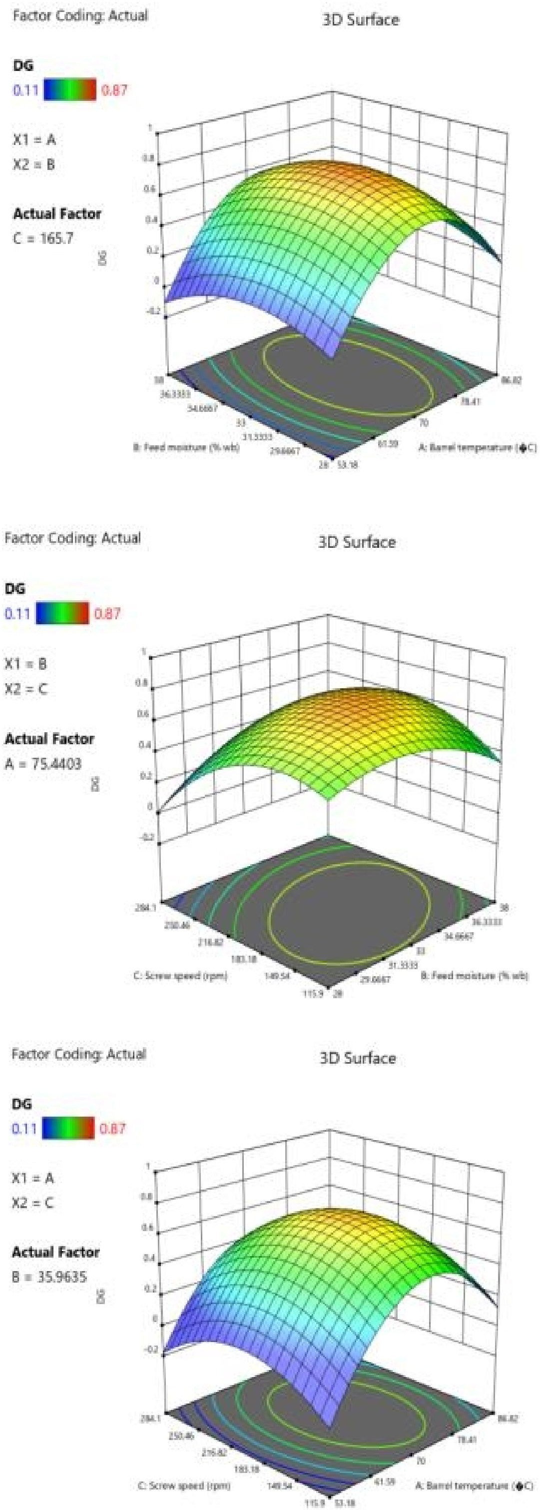


Fig. 5: Effect of extrusion processing variables on degree of gelatinization of noodles

Optimization of extrusion processing variables

The extrusion processing variables were optimized while keeping the constraints as per their importance. Solid loss and hydration capacity were given maximum importance (5) relative to WAI, WSI and DG as 2.The optimum solution comprising extrusion process variables was obtained as a 74°C barrel temperature, 34.7% wet basis moisture content, and 178 rpm screw speed. The corresponding product responses were determined for solid loss, hydration capacity, cooking time, water absorption index, water solubility index and degree of gelatinization. Their respective values were obtained as 18.10%, 1.89 g/g, 429 sec, 2.79, 7.99 and 0.75. In this experiment, the desirability of optimization was 0.7.

CONCLUSIONS

The nutritional and functional qualities are the driving force behind replacing wheat with pearl millet for the preparation of noodles. The objective of the study was to develop millet-based nonwheat noodles with or without incorporation of other ingredients. The process was standardized with pretreatment to retain its structure after cooking. Extrusion processing variables were then optimized for the development of pearl millet noodles, and optimum values were 74°C barrel temperature, 34.7% wet basis moisture content and 178 rpm screw speed. The solid loss, hydration capacity, water absorption index, water solubility index and degree of gelatinization were optimized as 18.10%, 1.89, 429 sec, 2.79, 7.99% and 0.75, respectively. The optimum solution was obtained with a desirability of 0.70, revealing that it could be used for subsequent study. The optimum level would help as a basis to investigate the effect of minor alterations in terms of additional treatments and/or ingredients for the development of functional noodles.

CONFLICT OF INTEREST

All the author both individually and collectively, affirms that they do not possess any conflicts of interest either directly or indirectly related to the research being reported in the publication.

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