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Formulation and Optimization of Value-added Barnyard Millet Vermicelli using Response Surface Methodology

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ABSTRACT

Background: Vermicelli is a traditional Indian food product, commonly known as 'Sewai' or 'Jave'. The present study aims at the value addition of vermicelli enriched with iron and beta-carotene.

Methods: Barnyard millet flour (BMF) and rice flour (RF) along with malt flour from whole green gram, carrot powder, fenugreek powder and xanthan gum (XG) are used to develop nutritionally enriched barnyard millet vermicelli (BMV). Response Surface Methodology (RSM) was employed to optimize the formulation by analyzing the effect of BMF, RF and XG levels on the sensory attributes like hardness, stickiness, color, flavor and masticability.

Result: Results revealed that the independent variables have a significant effect on the dependent variables. The moisture, protein, ash, fat and carbohydrate content in optimized product was found to be 6.40%, 10.07%, 1.44%, 1.72% and 80.31% respectively. The optimized product is nutritionally enriched having 3.81mg/100g of iron and1039µg/100g of beta-carotene present in it.

Key words: Barnyard millet flour, Response surface methodology, Rice flour, Xanthan gum.

INTRODUCTION

Vermicelli is one of the traditional and commonly consumed pasta products. Traditionally, vermicelli is prepared by using whole or refined wheat flour. Since wheat flour is deficient in lysine, the protein quality remains poor. Refining of wheat further reduces its nutritional quality (Jones *et al*., 2020).

Millets are small-seeded annual grasses (Tadele, 2016). There are various varieties of millets grown in India which includes bajra (pearl millet), jowar (sorghum), ragi (finger millet), jhangora (barnyard millet), kangni (foxtail millet), barri (proso millet), *etc* (Dayakar Rao *et al*., 2017; Malathi *et al*., 2016).

Barnyard millet (*Echinochloafrumentacea*) is a multi-purpose crop which is called by several names like japanese barnyard millet, ooda, oodalu, sawan, sanwa and sanwank. In India, the cultivation of barnyard millet is mainly confined to Tamil Nadu, Andhra Pradesh, Karnataka and Uttarakhand (Gomashe, 2016). It is a good source of protein (10.50%), which is highly digestible (81.13%) and is an excellent source of dietary fiber (12.60%) with good amount of soluble (4.20%) and insoluble fractions (8.40%). Its carbohydrate (68.80%) content is low and slowly digestible (25.88%), which makes it a nature's gift for the sedentary lifestyle (Ugare *et al*., 2014). The major fatty acid present is linoleic acid followed by palmitic and oleic acid. It is most effective in reducing blood glucose and lipid levels (Dayakar Rao *et al*., 2017).

Millets being a store house of nutrients, its utilization as food is limited because of its appearance and fewer cooking options (Prakash *et al*., 2018). Majorly the products are made using wheat flour or in combination with other cereals like rye, barley, sorghum and maize (Yadav and Chandra, 2015; Saini and Yadav, 2018) because millets lack in a protein named gluten which is responsible for the visco-elastic properties of dough and so making it a challenge to develop solely millet based products (Padalino *et al*. 2016). Thus, to improve the sensory qualities, hydrocolloids or gums like Xanthan gum, which is an important exo-polysaccharide, need to be incorporated (Lopes *et al*. 2015).

In addition, recent trends in micro-nutrient deficiency portend to a future public health crisis in India irrespective of various policies initiated to tackle these concerns (Gonmei and Toteja, 2018 and Pingali *et al*., 2019). Thus, the present study is employed to develop barnyard millet vermicelli (BMV) from nutritious ingredients to solve the problem of nutrient deficiencies and to save its delicacy.

MATERIALS AND METHODS

Raw material

Barnyard millet flour (BMF) and rice flour (RF) (procured from local market, Lakshmi Nagar, India), were taken as major ingredients. Whole green gram (procured from local market, Lakshmi Nagar, India), carrots and fenugreek leaves (Lady Irwin College, India) were used as enriching ingredients. Xanthan gum (XG) (Lady Irwin College, India) was used as structure setting agent. The study was carried

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out during the period of July 2018 to March 2019, in the Department of Food and Nutrition, Lady Irwin College, University of Delhi, New Delhi.

Processing of raw material

Raw ingredients were undergone pre-processing treatments to improve their nutritional qualities (Oghbaei and Prakash, 2016). Grains were cleaned and milled to fine flour using KALSI domestic grinding mill. Fenugreek leaves (80°C for 5 minutes) and carrot (80°C for 2 minutes) were blanched and then dehydrated (60°C for 6-10 hours) to the moisture content of 11.00% and 11.50% respectively. Malt flour was prepared using whole green gram after germination (37°C for 48 hours) and drying (50-55°C for 8 hours) to a final moisture content of 10.50%.

Experimental design

Response surface methodology was employed for the optimization of variables. A central composite rotatable design (CCRD) was used to study the effect of factors (independent variables) BMF(X_1), RF(X_2) and XG(X_3) at five different levels on responses (dependent variables) of hardness (Y_1), stickiness (Y_2), color (Y_3), flavor (Y_4) and masticability (Y_5) and to determine the optimum combination of variables. The experimental design in the coded (x) and actual (X) levels of variables is shown in Table 1.

The equation (Eq. 1) is represented as second order polynomial for three factors:

$$Y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_{12}x_1x_2 + a_{13}x_1x_3 + a_{23}x_2x_3 + a_{11}x_1^2 + a_{22}x_2^2 + a_{33}x_3^2$$

The coefficients for the above equation were represented by a_0(constant term), a_1, a_2 *and* a_3 (linear effects), a_{12}, a_{13} and a_{23} (interaction effects) and a_{11}, a_{22} and a_{33} (quadratic effects).

Optimization

Optimization was carried out in two phases: preliminary trials to optimize level of additional ingredients (malt flour, carrot powder and fenugreek powder) and the use of Response surface methodology (RSM) for optimization of BMF, RF and XG levels. The processing parameters were optimized based on the sensory evaluation carried out as by semi-trained panel of 30 members using 9-point hedonic scale with scores ranging from 9 to 1, where, 1= extremely unacceptable and 9= extremely acceptable (Sunil *et al*., 2019).

Numerical optimization technique of Stat-Ease Software (Design Expert Version 11) was used and the desired goal for each dependent variable was selected. Response surface graphs were generated which showed the effect of variation in independent variables on the dependent variables (Aggarwal *et al*., 2018). Completion of both phases of optimization resulted in optimized flour mix formulation of dry ingredients (BMF, RF, XG, malt flour, carrot powder and fenugreek powder).

Statistical analysis

The experimental data was analyzed for regression analysis and analysis of variance (ANOVA) to evaluate the statistical significance of the model terms using GraphPad Prism8 version 8.2.1 for windows (www.graphpad.com). The model adequacy was determined using model analysis, lack of fit test and coefficient of determination (R^2) analysis (Mudgil *et al*., 2016).

Preparation of Control Vermicelli and BMV

Control vermicelli was prepared from 100% refined wheat flour using traditional method of hand extrusion. BMV was prepared using BMF, RF, malt flour, carrot powder, fenugreek powder and XG to replace 100% refined wheat flour. Flour mix was sieved through the mesh size no. 30 (aperture of 0.500 mm) and the tight dough was kneaded with water. Dough was kept for resting (15-20 minutes at 25°C) and then fed in to the hand extruder to get the vermicelli. Vermicelli was dried in a hot air oven (60°C for 1-2 hours) to the moisture of 5-7%. Dried vermicelli was roasted (80°C for 2-3 minutes), cooled at room temperature, packed in metalized LDPE pouches (20.87µm thick) and stored at 37°C for further analysis.

Proximate analysis

Moisture, protein, fat and total ash contents were estimated using AOAC (2016), carbohydrate content using IS1656 (2006) whereas iron and beta-carotene content using AOAC 999.10 (2000) and AOAC 2016.13 (2016) respectively.

RESULTS AND DISCUSSION

Experimental design and statistical analysis

The experimental design and corresponding response values as a function of different independent variable with coded variables are summarized in Table 1. Lack of fit test for all the models were observed insignificant which describe the adequacy of models to predict responses (Table 2). CV was < 6% in case of all the responses, indicating that the experiments were carried out with adequate precision. Fig 1 represents the response surface graphs obtained from experimental data.

Hardness

Hardness is a measure of firmness of the vermicelli. The hardness value was observed in the range from 5.70 to 8.30 (based on 9-point hedonic scale) as shown in Table 1. The results of the regression model showed that the hardness first decreases with increase in BMF and RF level up to 59.18% and 14.84% respectively, whereas further increase showed the opposite results as shown in Fig 1(a).

BMF and RF had a negative significant ($p<0.05$) effect at quadratic level (Table 2). Shukla and Srivastava (2014) also reported a reduction in hardness of noodles fortified with millet flour. The hardness effect due to the amylose component of rice starch as observed by Araki *et al*. (2016) which bind to each other to form a matrix and thus increases hardness whereas lower amylose content causes less retrogradation of starch during gel formation and

Table 1: Experimental design matrix and response values of barnyard millet vermicelli.

Run	Independent variables			Dependent variables				
	Barnyard millet flour (%) X_1 (x_1)	Rice flour (%) X_2 (x_2)	Xanthan gum (%) X_3 (x_3)	Hardness Y_1	Stickiness Y_2	Color Y_3	Flavor Y_4	Masticability Y_5
1	52.088	7.364	2.67	5.70	4.40	7.40	6.60	5.10
2	71.118	14.842	2.285	6.30	6.40	7.50	8.30	7.30
3	59.184	14.842	2.285	8.20	7.00	8.40	7.80	8.10
4	59.184	14.842	2.285	8.20	7.00	8.40	7.80	8.10
5	59.184	14.842	2.285	8.20	7.00	8.40	7.80	8.10
6	59.184	14.842	2.932	8.30	6.30	8.30	6.80	6.00
7	47.249	14.842	2.285	7.40	5.60	6.50	6.30	5.50
8	52.088	22.32	2.67	6.70	5.60	7.80	7.20	6.40
9	59.184	27.418	2.285	6.40	7.30	8.00	8.40	6.60
10	66.28	22.32	2.67	6.60	6.20	7.30	8.20	5.60
11	66.28	22.32	1.9	6.20	6.40	8.50	7.60	5.70
12	66.28	7.364	2.67	7.40	5.70	7.90	6.70	5.90
13	66.28	7.364	1.9	7.50	7.40	7.50	7.20	7.30
14	59.184	14.842	2.285	8.20	7.00	8.40	8.20	8.10
15	59.184	2.265	2.285	6.10	5.80	7.70	6.60	5.30
16	59.184	14.842	2.285	8.20	6.00	7.60	7.40	7.30
17	59.184	14.842	1.637	7.50	6.80	8.50	8.20	6.10
18	52.088	22.32	1.900	7.10	6.40	7.90	6.10	6.30
19	52.088	7.364	1.900	7.20	6.60	7.20	6.00	5.30

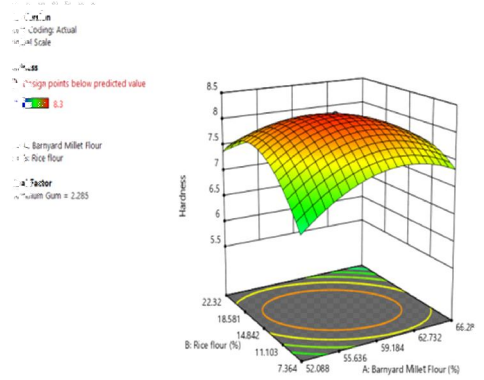
Table 2: Analysis of regression and variance of the second order polynomial models for dependent variables (coefficient values in terms of coded factors).

Source	Hardness	Stickiness	Color	Flavor	Masticability
Regression model (F-value)	7.01	3.48	5.22	3.45	12.45
Intercept	2.86	2.61	2.87	2.80	2.82
X_1	-0.0117	0.0615	0.0350	0.0984	0.0647
X_2	-0.0086	0.0488	0.0262	0.0759	0.0404
X_3	-0.0053	-0.0858	-0.0132	-0.0063	-0.0259
X_1*X_2	-0.0728	-0.0397	-0.0165	0.0268	-0.1070
X_1*X_3	0.0541	0.0328	-0.0201	-0.0401	-0.0337
X_2*X_3	0.0396	0.0751	-0.0426	0.0369	0.0394
X_1^2	-0.0927	-0.0682	-0.0808	-0.0523	-0.1073
X_2^2	-0.1335	-0.0272	-0.0251	-0.0388	-0.1384
X_3^2	-0.0239	-0.0292	0.0091	-0.0380	-0.1299
ANOVA					
R^2 (%)	0.8751	0.7769	0.8392	0.7751	0.9257
Adj R^2 (%)	0.7502	0.5538	0.6784	0.5501	0.8514
Pred R^2 (%)	0.0449	-0.2454	0.2696	-0.5541	0.5579
Adequate precision	7.4715	7.1995	8.2552	5.5193	10.7554
Std. dev.	0.0796	0.1015	0.0560	0.0986	0.0794
Mean	2.68	2.52	2.80	2.70	2.55
Coefficient of variation	2.97	4.03	2.00	3.65	3.12
PRESS	0.4363	0.5174	0.1281	0.6051	0.3374
Lack of fit	1.74^{NS}	1.61^{NS}	0.6089^{NS}	6.03^{NS}	1.93^{NS}

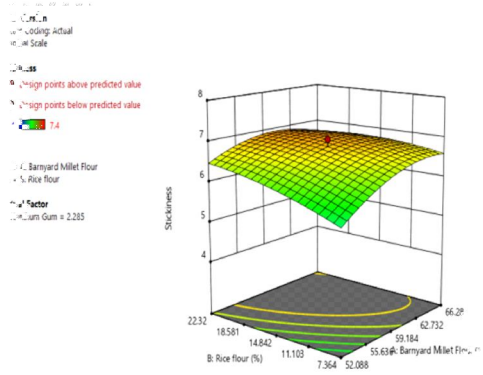
NS: Non-significant.

Significant at 0.05 level.

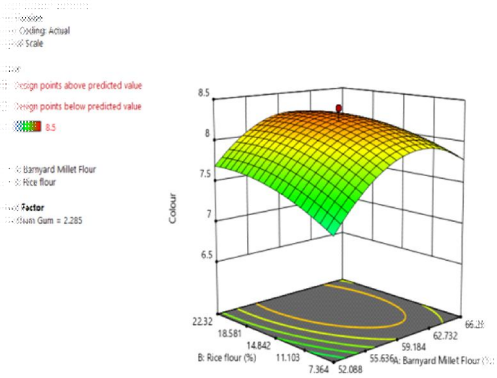
X_1=Barnyard Millet Flour, X_2=Rice Flour, X_3=Xanthan gum.



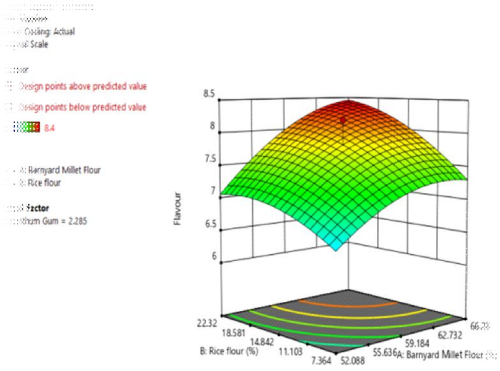
(a) Response for Hardness



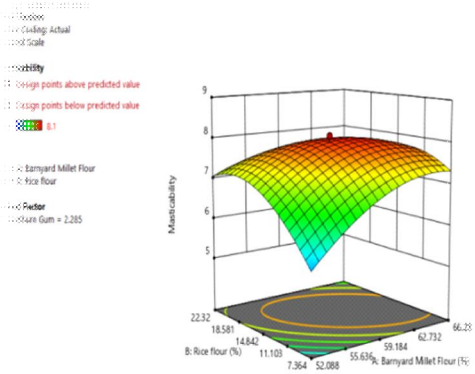
(b) Response for Stickiness



(c) Response for Color



(d) Response for Flavor



(e) Response for Masticability

Fig 1: Response surface relating to sensory score of barnyard millet vermicelli.

consequently weaker gel structure (Afifah and Ratnawati, 2017). The interactive effect showed slight negative significant ($p<0.05$) for BMF and RF (Table 2).

Stickiness

Stickiness is a measure of adhesiveness of vermicelli and is negatively related to vermicelli quality. The stickiness value was observed in the range from 4.40 to 7.40 (based on 9-point hedonic scale) as shown in Table 1. The results of the regression model showed that stickiness decreases with increase in BMF level up to 66.28%, while further increase showed the opposite results, whereas increase in RF level showed the decrease in stickiness (Fig 1b).

XG and BMF had a significant ($p<0.05$) negative effect on stickiness at linear and quadratic level respectively (Table 2). Mudgil *et al*. (2016) reported that on supplementation of partially hydrolyzed guar gum to noodles bound the free water and thus stickiness decreased in the cooked noodles. Similarly, Low *et al*. (2019) observed that the use of mono-glyceride and amylose molecules inhibit swelling of starch as a result of which stickiness in noodles is substantially reduced.

Color

Color value was observed in the range from 6.50 to 8.50 (based on 9-point hedonic scale) as shown in Table 1.

The results of the regression model showed that with increase in BMF and RF level up to 59.18% and 14.84% respectively, there was increase in acceptability for product color, whereas further increase showed the opposite results (Fig 1c). Chandraprabha *et al*. (2017) reported that barnyard millet vermicelli prepared from barnyard millet flour, whole wheat flour and *Ekanayakam* root barks, showed decrease in sensory score for color with when level of BMF exceeds beyond 40%.

BMF had a significant ($p < 0.05$) positive effect on color at linear level whereas slightly negative effect at quadratic level (Table 2). Gull *et al*. (2015) reported that incorporation of millet decreases the lightness of pasta at linear level due to the pigments present in pericarp, aleuronic layer and in endosperm region.

Flavor

Flavor value was observed in the range from 6.00 to 8.40 (based on 9-point hedonic scale) as shown in Table 1. The results of the regression model showed that with increase in BMF level up to 59.18%, there is increase in product flavor while further increase showed the opposite results, whereas increase in RF level showed increase in flavor (Fig 1d). Similarly, Chandraprabha *et al*. (2017) reported the decrease in sensory score of flavor in barnyard millet vermicelli prepared from barnyard millet flour, whole wheat flour and *Ekanayakam* root barks when BMF level exceeds beyond 40%.

BMF and RF had a significant ($p<0.05$) positive effect on flavor at linear level. XG showed the insignificant ($p>0.10$) negative effect at all three levels (Table 2).

Masticability

Masticability, also defined as chewiness is the energy needed to break down the vermicelli to the swallowing state. Masticabilityvalue was observed in the range from 5.10 to 8.10 (based on 9-point hedonic scale) as shown in Table 1. The regression model showed that masticability increases with increase in BMF and RF level up to 59.18% and 14.84% respectively, while, further increase showed the opposite results as shown in Fig 1(e).

BMF had a significant ($p<0.05$) positive effect on masticability at linear level. BMF, RF and XG showed the significant ($p<0.05$) negative effect at quadratic level (Table 2). The incorporation of XG into a rice starch system mimic the visco-elastic properties of gluten (Hymavathi *et al*., 2019) thereby leading to improved texture of the product as reported by Srikaeo *et al*. (2018) and Low *et al*. (2019). BMF and RF had a significant ($p<0.05$) negative effect at interactive level.

Optimization of product formulation and model validation

Optimum values of processing variable and responses are shown in Table 3. The optimized solutions for the BMV wereobserved as BMF (64.25%), RF (22.32%) and XG (2.36%). The model predicted value (μ_0) and the observed experimental value (μ_1) obtained after manufacturing optimized product are tabulated in Table 4. No significant difference ($p<0.10$) was observed between the predicted and experimental values.

Proximate analysis

Nutrient composition of BMF, RF, flour mix (optimized) and refined wheat flour revealed that the fat, protein and

Table 3: Optimization parameters for barnyard millet vermicelli*.

Responses	Goal	Lower limit	Upper limit	Importance	Optimum value[a]
Barnyard millet flour (%)	Maximize	52.088	66.28	5	64.25
Rice flour (%)	Maximize	7.364	22.32	4	22.32
Xanthan gum (%)	In range	1.9	2.67	4	2.36
Hardness	Minimize	5.7	8.3	2	6.78
Stickiness	Minimize	4.4	7.4	2	6.76
Color	Maximize	6.5	8.5	5	7.93
Flavor	Maximize	6.0	8.4	5	8.17
Masticability	Maximize	5.1	8.1	5	6.78

*Lower and upper weights values were 1 for all the variables.

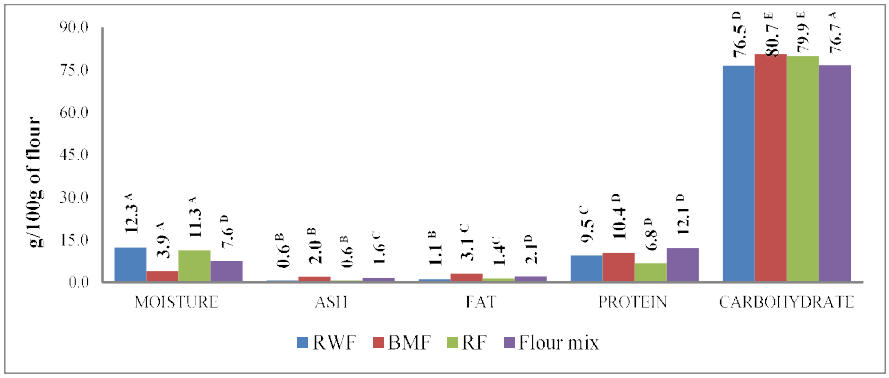
[a]The desirability of the results was 0.931.

Table 4: Optimized formulation of barnyard millet vermicelli*.

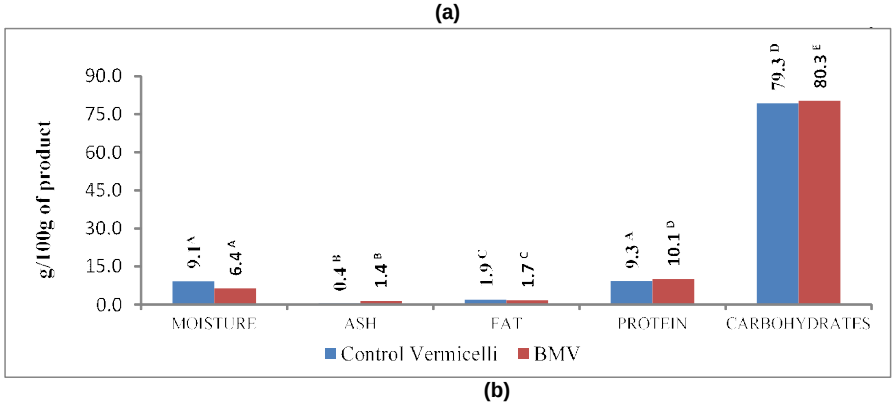
Responses	Predicted value (μ_0)	Experimental value (μ_1)	% Deviation	t_{cal}
Hardness	6.83	7.49	9.512%	0.109
Stickiness	6.88	7.30	6.101%	0.099
Color	8.09	7.88	-2.486%	0.178
Flavor	8.14	8.60	5.687%	0.178
Masticability	6.99	7.98	14.242%	0.022

*H_o: $\mu_0 = \mu_1$, $t_{cal} < t_{table}$ at $p < 0.1$, 'H_o' was accepted.

[a]Mean of five replications.



(a)



(b)

Fig 2: Proximate composition of (a) refined wheat flour (RWF), barnyard millet flour (BMF), rice flour (RF) and flour mix; (b) barnyard millet vermicelli (BMV) and control vermicelli; Data are represented as Mean±SEM (mean of three replicates) on % (w/w) basis; [ABC]Means within a column (for a specific parameter) with at least one similar superscript do not differ significantly (p>0.05).

carbohydrates of the BMF, RF and optimized flour mix significantly differed (p< 0.05) from the refined wheat flour (Fig 2a).

Nutrient composition of control vermicelli and BMV has been presented in Fig 2b. The protein and carbohydrate content in BMV were observed to be differed significantly (p<0.05) from the control vermicelli. The protein was 8.8% higher in BMV whereas, the fat content is reduced by 10.50%. The content of iron and beta-carotene in BMV was found to be 3.81mg/100g and 1039µg/100g respectively.

CONCLUSION

Response surface methodology was effectively utilized for optimization of variables (BMF, RF and XG) for development of value-added BMV.Model validation was performed by analyzing various significant statistical aids that revealed the adequacy of model. Present results suggest that the level of 64.25% BMF, 22.32% RF and 2.36% XG resulted in vermicelli that can replace 100% refined wheat flour. BMV is nutritionally enriched with nutrients like iron (3.81mg/100g) and beta-carotene (1039µg/100g). Thus, the acceptability and nutritional adequacy of the developed vermicelli indicate the ample scope for its commercial utilization.

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