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Development of Extruded Functional Snack Foods from Plants and Dairy Ingredients Employing Response Surface Methodology

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Abstract

Although food fortification has been practiced for many years in some countries in the Asian region, notably the more affluent ones, national food-fortification programmed have yet to be fully implemented in areas where this problem abounds. In this paper, we highlighted the development of extruded products based on ICMR recommendations for school going children of age 9-18 year to combat hunger deficiency related disorder. In this regard, corn and rice flour, Defatted soy flour (DFSF), Soy protein isolate (SPI), dairy whitener (DW), mango and spinach were taken as raw materials for the study. The result indicated that there was significant difference between protein, fat, carbohydrate and energy content of extruded products. Protein content increased being maximum (24.5%) at 20% of DFSF for DW based product at constant amount of SPI and DW. The significant changes in fat content may be attributed to defatting soy flour that increased the protein solubility and water and oil absorption capacities of the extruded products. High degree of starch gelatinisation at pre-setted machine parameters may be resulted in formation of large insoluble complexes or Maillard compounds causing lesser availability of carbohydrate compounds at higher level of rice and corn flour. Upon model fitting, all the independent variables followed linear model (P<0.001) except carbohydrate content for mango. High R^2 values (R^2>0.92) and non-significant lack of fit between variables and responses indicated good fits and adequacy for the models. Storage study revealed that there was non-significant increase in moisture and hardness of extruded products.

Keywords: Hardness; Cohesiveness; Stickiness; Springiness; Chewiness; Gumminess; Adhesiveness; Carbohydrates; Proteins; Fat; Minerals; Archidonic acid; Linolenic acid; Obesity; Spinach powder; Mango; Papaya; Calcium

Abbreviations: DFSF: Defatted Soy Flour; SPI: Soy Protein Isolate; DW: Dairy Whitener; FFSF: Full Fat Soy Flour; CIAE: Central Institute of Agricultural Engineering

Introduction

It has been estimated that 800 million malnourished people exist in developing countries. Development of nutritious foods has been suggested by FAO to combat malnutrition among children for maintaining good health. Snacks contribute an important part of daily nutrient and calorie intake for many consumers. Extruded snack foods have been increasingly gained popularity for providing safe, nutritious, and wholesome food for poor and undernourished populations for the developing world [1-3]. Reasonably low protein content (2.44 to 11.06%) in market snacks has been reported by several workers. Thus, high consumption of such snacks could lead to malnutrition in children and obesity, which leads to several diseases in adults [4]. Consumption of snacks as a meal could be applicable if it could either provides protein of 2.5–3.0 g per 100Kcal; or if 10–12% of total calories are obtained from pro tein; or if the calories gained from consuming the snack was from carbohydrate (55–65%), fat (20–30%) and protein10–15%). One means for rendering fast food items more nutritious is to fortify them with protein, vitamins, minerals etc. [5].

Cereals mainly rice flour have been popular raw materials for extrusion for food uses mainly because of functional properties, low cost, bland taste, attractive white color, hypoallergenicity and ease of digestion [6]. However, rice is limiting in lysine, the essential amino acid needed for growth but is high in methionine and cystine availability. In contrast, soy protein is high in lysine but low in methionine and cystine. Soy protein contains essential amino acids, most of which are present in amounts that closely match those required for humans. Owing to high protein content, soybean can be effectively utilized for nutritional improvement of cereal based extruded foods [7,8]. Currently, there is considerable and increasing interest in the health benefits of soy-containing foods; in the role of soy protein in lowering the incidence of certain cancers. Several food products were developed to add up protein content by a combination of cereal and soybean flour [9]. Hence, an optimal incorporation of full fat soy flour (FFSF, 43.6% protein, 18% fat) or defatted soy flour (DFSF, 47.2% protein, 1.0% fat) in snacks could increase protein quality [10,11]. Several researchers developed ready-to-eat fortified products by blending cereals with vegetables and fruits. The incorporation of cauliflower trimmings into ready-to-eat expanded products up to 10% level was suggested by Stojceska et al. [12]. Altan et al. [13,14] processed the blends of barley flour and tomato pomace; barley flour and grape pomace, corn flour and tomato pomace in a co-rotating twin-screw extruder. Upadhyay et al. [15,16] reported the use of carrot pomace, gram flour and rice flour-based formulation for extrusion studies. However, the range of process variable was too wide.

Among fruits, mangoes contain 10-20 percent sugar and are an important source of vitamin A. Among vegetables, spinach is much richer in protein than other vegetables and it also has high vitamin A content. It is a good source of minerals, but the high content of oxalate leaves the calcium unavailable in diets. So, enabling calcium richness in fortified products, milk is one of the alternatives as a major source of calcium besides other useful properties like easy in digestibility, protein content, linoleic acid (2.1%), linolenic acid (0.5%) and archidonic acid (0.14%).

The main objective of the present investigation is to provide soy-based protein-rich, low-fat nutritious snacks and food. The products have been designed and developed based on ICMR recommendations for school going children of age 9-18 years. This study will provide an additional source of utilization of soy flour in extruded food formulations. The products developed would provide an opportunity for enhancing the use of quality soy protein through popular snack/food products for the school children.

Materials and Methods

Raw Materials

Corn, rice and wheat flour, oil, skim milk powder and salt were procured from local market of Bhopal. Soy flour (DFSF, FFSF, SPI) were prepared at ICAR-Central Institute of Agricultural Engineering (CIAE), Bhopal. Mango, papaya, and spinach powder were prepared in food processing laboratory of CIAE. The raw materials were cleaned by sieving and proper amount of the materials were taken by weights. Required amount of water was added to make the feed moisture to required level (10-15%). All the materials were mixed properly after addition of salt. The mixture was kept 1 hr for pre-conditioning. The twin screw extruder (make BPTL Kolkata) was set with screw speed 400 rpm and temperature of heaters at 70 °C and 120 °C for extruder barrel and die. The pressure was maintained between 2059 and 4119 kg/cm^2. The mixture was feed and extruded after which the product was kept in dryer for 1.5h to remove moisture. The raw material combinations and their proportions were selected by design expert 7.6 software for different treatment combination of extruded products. Three types of extruded products were extruded based on DW, fruit (mango) and vegetable (spinach) keeping another variables constant in each product.

Some important chemical composition (nutritional values) of all these raw materials taken for the development of extruded snack foods and noodles are given in Table 1.

Table 1: Chemical composition of raw materials used for the development of extruded snack.

Raw materials	Moisture (%)	Protein (%)	Fat (%)	CHO (%)	Energy (kcal/100 g)
Corn flour	14.9	11.0	3.6	66.0	342
Rice flour	13.7	6.8	0.5	78.0	345
Wheat flour	12.2	12.1	1.7	69.0	341
Soybean	10.0	40.0	20.0	30.0	446
DFSF	7.0	50.0	1.0	47.5	430
Guava	77.0	1.1	0.2	14.4	68
Papaya	90.7	0.5	0.3	11.0	43
Mango	81.0	0.6	0.4	15.0	60
Carrot	86.0	0.9	0.3	9.6	41
Spinach	92.1	2.9	0.5	3.6	23
Dairy whiteners	4.1	38.0	0.1	51.0	357
SPI	-	90.0	0.1	6.0	411
Refined wheat flour	-	11.0	0.9	73.9	349

Response Surface Methodology

Response surface methodology (RSM: Mixture Design) was employed to evaluate the effect of different combination with proportion of raw ingredients and their interaction on the nutritional qualities parameters namely protein, fat, carbohydrate and energy content of the extruded snack foods. Corn flour, rice flour, soy flour (DFSF, FFSF, SPI), dairy whitener, mango, papaya, spinach powder etc. were taken as independent (input factor) and quality attributes such as protein content, fat, carbohydrate and energy were considered as dependent parameters.

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Accordingly, mathematical models would be developed to predict the quality parameters of extruded snack foods and noodles under different inputs parameters. Mathematically this can be represented as shown in equation (1)

$$y = f(x1, x2 - - - xn) \qquad (1)$$

Where 'f' is the response surface function, 'y' is dependent variable (quality parameters) and x1, x2, ...xn are input factors.

To approximate the function 'f', second order polynomial equation of the following form was assumed (equation 2).

$$y = b_0 + b_1x_1 + b_2 x_2 + b_{11}x_1^2 + b_{22}x_2^2 + b_{12}x_1x_2 \qquad (2)$$

Where, y is the predicted response (dependent variables); b0, b1, b2, b11, b12 and b22 are the regression coefficients; and x1, x2, ...xn are the coded value of independent variables which are linearly related by the following equation (3) with the original values [17-19].

$$x_i = \frac{2(X_i - X_i^m)}{X_i^d} \qquad (3)$$

Where, X_i is actual value in original units, Xi^m is mean of maximum and minimum values, Xi^d is the difference between maximum and minimum values, x_i is the coded values of independent variables.

Mixture Design for Development of Extruded Products

Mixture design was used for optimization of different proportion of raw materials namely corn flour, rice flour, DFSF, SPI, fruits, vegetable and dairy whiteners for development of extruded functional food. The range of the percentage of materials taken mixture design has been given in Table 2.

Table 2: Range of independent parameters.

Constraints		Lower Limit	Upper Limit
Name	Goal		
A: Corn	is in range	30	50
B: Rice	is in range	30	50
C: DFSF	is in range	10	20
D: SPI	is in range	5	10
Fruits, Vegetable, DW	is in range	5	15

Extrusion Process

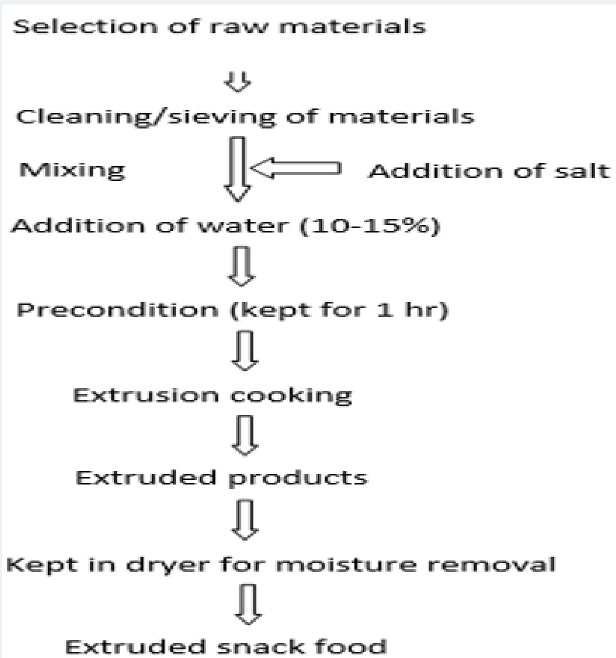

Figure 1: Flow chart for the development of extruded food product.

The twin screw extruder (make BPTL Kolkata) was started 1 h before the start of experimentation to heat the barrel and die. The flow chart is given in Figure 1. The mixture was fed to the extruder and extruded (Figure 2). The product obtained was kept in dryer for one a half hour to remove moisture. The feed rate was calculated by dividing the raw material fed through feeder and the amount of material fed in 1 min is collected. The extruded products developed using various combination and proportion of raw ingredients (S-1: corn + rice + DFSF + DW + SPI; S-2: corn + rice + DFSF + carrot + SPI; S-3: corn + rice + DFSF +spinach + SPI; S-4: corn + rice + DFSF + mango + SPI and control: corn + rice) are shown in Figure 3. The extrusion processing parameters were set to produce extruded functional foods is mentioned in Table 3.

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Figure 2: Feeding sample in the extruder.

Figure 3: Developed extruded products.

Table 3: Extrusion processing parameters for development of extruded snack foods.

Parameters	Values
Screw speed	400rpm
Temperature (barrel)	Heater-1 (Extruder Barrel): 70 °C
Temperature (die)	Heater-2 (Die): 120 °C
Pressure	2059-4119 (kg/cm^2)
Moisture	10-15%

The different combination with proportion of experimental trials produced by the response surface modelling for the development of extruded products using corn flour, rice flour, DFSF, SPI, dairy whiteners, fruits and vegetables as well as the output parameters are shown in (Table 4-6).

Product Characteristics

The moisture, fat, protein and ash were estimated using standard AOAC methods (2005) Determination of carbohydrates and calories. A carbohydrate and calories were calculated by subtracting the percentage of moisture, ash, crude protein, fat from 100 and by using factors 4.0, 4.0, and 9.0 to calculate the energy provided by protein, carbohydrates and fat, respectively.

Results and Discussions

Protein Content

The protein content of the extruded product ranged between 17.3 and 24.5 % for DW, 17.6 and 25.9% for mango, and 13.8and 22.0 % for spinach-based products. Protein content of mango-based products, keeping other variables at respective levels was 5.8 and 17.5% higher than DW and spinach-based products. Using t-test, it was found that mean value of products between DW and mango are statistically significant ($P<0.05$, $t_{stat}=2.00$). However, for other two products (mango and spinach; DW and spinach), the mean values were significant at 1% level which indicated larger effect on protein content. Higher protein content was due to high level of SPI and DFSF. The models were adjusted for the extruded protein content is presented in the in ANOVA (Tables 7-9) using design expert 7.6. The model is significant ($P<0.001$) with high coefficient of determination R^2 (>0.95). There was only a 0.01 per cent chance that a model F-Value this large could occur due to noise. Lack of fit is non-significant ($P>0.49-0.85$) showed that model was adequate to fit into independent variables for getting desirable parameter of high accuracy. The regression equation describing the effect of the process variables on protein of extruded product in terms of actual level of the variables are given as:

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Table 4: Treatment combinations using Design Expert 7.6 (DW based combinations).

Input parameter					Output parameter			
Corn (g)	Rice (g)	DFSF (g)	SPI (g)	Dairy Whiteners (DW)	Protein (g)	Fat (g)	CHO (g)	Energy kcal
30.00	39.68	15.30	5.00	10.00	19.31	2.16	65.19	357.54
30.84	30.20	20.00	8.93	10.03	24.50	2.22	60.15	358.58
30.00	36.62	13.45	9.92	10.00	22.66	2.14	62.09	358.21
41.10	30.00	10.00	8.89	10.00	20.89	2.46	62.93	357.45
30.00	30.02	19.98	5.00	14.99	21.73	3.12	62.03	363.18
35.77	30.00	19.22	5.00	10.00	20.98	2.374	62.94	357.09
30.00	42.97	10.00	7.02	10.00	18.71	2.12	65.73	356.86
30.00	42.24	10.00	5.00	12.76	17.41	2.64	66.59	359.76
44.99	30.00	10.00	5.00	10.00	17.68	2.87	65.51	358.62
30.00	35.48	15.37	6.75	12.39	20.97	2.88	63.18	362.56
30.00	37.69	10.00	9.17	13.14	20.93	2.97	63.22	363.42
30.77	34.87	11.42	7.93	15.00	20.65	3.35	63.05	365.08
30.77	34.87	11.42	7.93	15.00	20.65	3.35	63.05	365.08
35.11	34.06	10.27	10.00	10.54	21.49	2.65	62.53	359.97
42.00	30	10.00	5.00	12.98	17.85	3.28	65.09	361.35
30.00	30	15.93	9.98	14.07	24.02	3.13	59.98	364.26
33.12	38.29	11.00	7.56	10.00	19.60	2.45	64.52	358.60
35.92	31.94	13.85	5.49	12.78	19.52	3.08	63.95	361.67
38.91	33.68	10.46	5.08	11.84	17.82	2.98	65.50	360.16
30.00	30.01	19.98	5.00	14.99	21.62	3.35	62.03	364.85
37.11	37.87	10.00	5.00	10.00	17.30	2.58	66.45	358.28
42.15	30	12.83	5.00	10.00	18.66	2.75	64.72	358.35
30.00	30	15.93	9.98	14.07	24.09	3.13	59.98	364.54
30.00	42.24	10.00	5.00	12.75	17.37	2.71	66.59	360.36
30.00	39.68	15.30	5.00	10.00	19.13	2.24	65.19	357.54

Table 5: Treatment combinations using Design Expert 7.6 (mango based combinations).

Input parameter					Output parameter			
Corn	Rice	DFSF	SPI	Mango	Protein	Fat	CHO	Energy kcal
32.81	31.52	10.66	10.00	14.99	21.96	1.42	60.67	343.41
30.00	43.72	10.00	5.00	11.26	17.65	1.35	67.46	352.74
30.00	42.31	14.46	5.00	8.22	19.63	1.39	67.56	361.33
30.15	30.10	20.00	9.99	9.73	25.93	1.41	60.50	358.47
31.04	38.38	20.00	5.33	5.23	22.36	1.46	66.80	369.87
30.00	38.77	16.66	9.55	5.00	24.50	1.39	65.09	370.97
30.01	30.00	19.98	5.00	14.99	21.87	1.40	61.21	344.98
30.01	30.00	19.98	5.00	14.99	21.58	1.40	60.46	340.84
32.81	31.52	10.66	10.00	14.99	22.12	1.40	59.92	340.84
30.94	35.29	13.78	9.65	10.32	23.29	1.37	62.04	353.76
36.07	34.11	16.29	7.01	6.50	22.56	1.56	64.83	363.70
40.77	33.39	10.74	10.00	5.07	23.11	1.66	65.01	367.49
40.77	33.39	10.74	10.00	5.07	23.11	2.00	65.01	370.57
30.00	49.98	10.00	5.00	5.00	18.19	1.68	67.56	358.22
35.24	39.38	11.94	7.384	6.035	21.12	1.85	65.66	363.81
39.41	30.00	12.34	7.49	10.74	21.26	1.97	62.02	350.98
30.00	41.29	10.00	9.70	8.99	21.86	1.66	63.43	356.17

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49.18	30.00	10.00	5.80	5.00	20.12	2.178	66.63	366.63
45.78	30.00	10.00	5.00	9.20	19.05	2.07	65.09	355.22
31.03	34.61	18.45	8.16	7.73	24.53	1.66	61.92	360.80
41.30	38.69	10.00	5.00	5.00	19.11	1.93	69.50	371.93
30.00	43.721	10.00	5.00	11.26	18.24	1.58	67.01	355.30
39.56	30.40	20.00	5.00	5.02	23.06	1.95	65.71	372.69
30.00	49.98	10.00	5.00	5.00	18.63	1.58	68.85	364.25
44.57	30.00	15.41	5.00	5.00	21.43	2.07	66.95	372.25

Table 6: Treatment combinations using Design Expert 7.6 (spinach based combinations).

Input parameter					Output parameter			
Corn	Rice	DFSF	SPI	Spinach	Protein	Fat	CHO	Energy kcal
44.38	35.59	10.02	5.00	5.00	14.77	2.15	68.20	351.31
30.00	30.00	20.00	5.00	14.98	17.69	1.80	58.43	320.72
30.00	45.30	10.00	9.67	5.00	18.04	1.69	66.27	352.49
36.33	32.72	10.79	5.15	15.00	14.38	1.93	61.21	319.79
30.24	30.00	16.72	8.29	14.73	19.13	1.98	57.32	323.69
37.74	42.25	10.00	5.00	5.00	14.48	2.16	69.00	353.41
38.50	35.20	13.49	5.00	7.80	15.65	2.21	65.42	344.22
39.97	30.00	10.00	9.99	10.01	18.36	2.21	61.05	337.66
30.00	47.29	10.00	5.00	7.69	13.89	1.92	67.90	344.54
32.77	33.84	13.99	7.63	11.74	17.61	2.03	60.87	332.30
30.00	38.45	15.06	5.00	11.47	15.75	1.96	63.04	332.90
45.08	30.00	10.00	5.00	9.90	14.43	2.3	64.43	337.04
36.61	30.00	15.79	7.89	9.69	18.81	2.11	61.04	338.47
39.97	30.00	10.00	9.99	10.01	18.36	2.17	61.05	337.23
49.13	30.00	10.00	5.85	5.00	15.34	2.46	66.97	351.42
32.00	32.60	20.00	9.99	5.39	22.05	1.98	61.51	352.15
36.33	32.72	10.79	5.15	15.00	14.04	2.09	61.21	319.89
30.00	45.30	10.00	9.67	5.00	17.69	1.85	66.27	352.58
30.00	45.76	14.21	5.00	5.00	15.51	1.90	68.25	352.16
30.33	34.51	10.15	9.99	15.00	17.56	1.88	58.40	320.81
32.70	40.86	10.00	7.31	9.11	15.66	1.87	64.70	338.32
45.08	30.00	10.00	5.00	9.90	14.23	2.26	64.43	335.06
34.58	32.94	20.00	6.73	5.73	19.44	1.99	63.50	349.73
45.04	30.00	14.95	5.00	5.00	16.45	2.28	66.16	351.09
32.00	32.60	20.00	9.99	5.39	22.06	1.90	61.51	351.44

Table 7: ANOVA for Linear Mixture Model (DW).

	Response 1 Protein				
	Mixture Component Coding is L_Pseudo				
Source	Squares	Df	Square	F-Value	Prob> F
Model	111.8898	4	27.97245	5392.277	< 0.0001***
Linear Mixture	111.8898	4	27.97245	5392.277	< 0.0001***
Residual	0.10375	20	0.005188		
Lack of Fit	0.07965	15	0.00531	1.10166	0.4983
Pure Error	0.0241	5	0.00482		
Cor Total	111.9935	24			

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*** Significant at 1% level

Table 8: ANOVA for Linear Mixture Model on protein content (Mango).

ANOVA for Linear Mixture Model							
*** Mixture Component Coding is L_Pseudo. ***							
Analysis of variance table [Partial sum of squares - Type III]							
	Sum of		Mean	F	p-value		
Source	Squares	Df	Square	Value	Prob> F		
Model	112.3298	4	28.08244	682.0435	< 0.0001	Significant	
Linear Mixture	112.3298	4	28.08244	682.0435	< 0.0001		
Residual	0.823479	20	0.041174				
Lack of Fit	0.501625	15	0.033442	0.519517	0.8504	not significant	
Pure Error	0.321854	5	0.064371				
Cor. Total	113.1532	24					

Table 9: ANOVA for Linear Mixture Model on protein content (Spinach).

*** Mixture Component Coding is L_Pseudo. ***						
Analysis of variance table [Partial sum of squares - Type III]						
	Sum of		**Mean**	**F**	**p-value**	
Source	Squares	Df	Square	Value	Prob> F	
Model	131.6551	4	32.91377	1535.909	< 0.0001	Significant
Linear Mixture	131.6551	4	32.91377	1535.909	< 0.0001	
Residual	0.42859	20	0.02143			
Lack of Fit	0.292059	15	0.019471	0.713043	0.7210	not significant
R^2						
Pure Error	0.136532	5	0.027306			
Cor Total	132.0837	24				

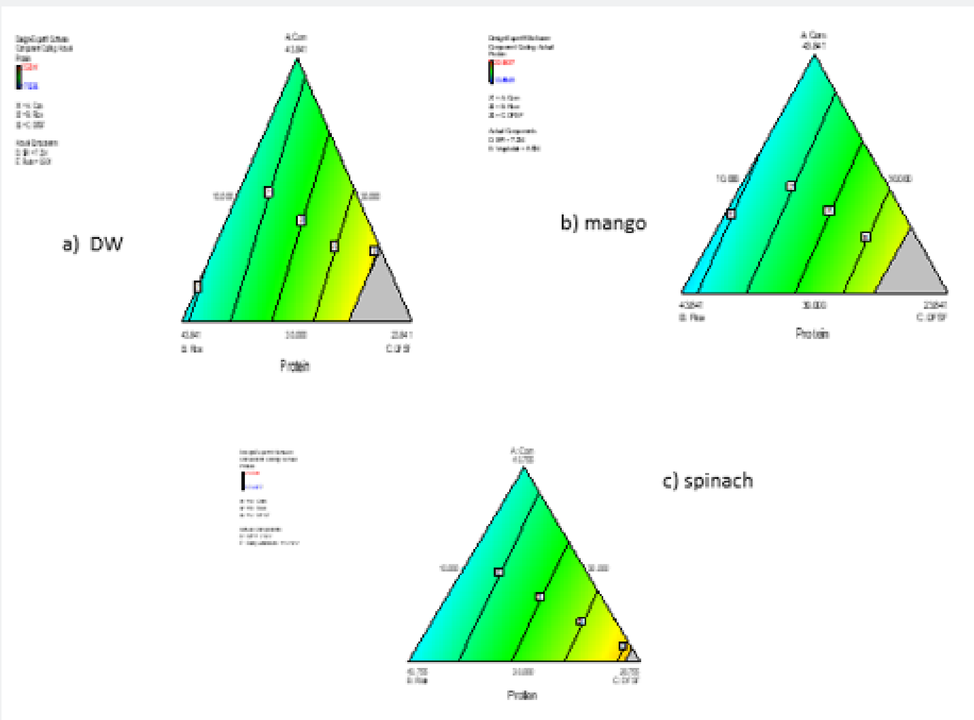

Figure 4: Effect of rice, DFSF and corn on protein content of extruded product.

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Final Equation in Terms of Actual Components:

Protein= 0.104533* Corn+0.064893* Rice+0.472722* DFSF+0.903641* SPI+0.174343*Dairy whiteners. (4) for DW.

Protein =0.14925 * Corn+0.089042* Rice+0.49009 * DFSF+0.87187 * SPI +0.02722 * Fruits (5) for mango.

Protein= 0.089208* Corn+0.049002* Rice+0.446145*DFSF+0.86918* SPI+0.009491* Vegetable (6) for spinach.

Model graph (Figure 4) shows the response plot of rice, DFSF and corn on protein content by taking a constant amount of SPI (7.12) and dairy whitener (12.12). As DFSF and SPI were the main contributor of protein, it is revealed from the graph (1, a) that with the increase in DFSF, protein content increased being maximum (24.5%) at 20% of DFSF for DW based product. Similar behavior was also found for mango and spinach-based products. The result agrees with the report by Jha and Prasad & Sudha et al. [20,21] who revealed that inclusion of soy flour and whey protein concentrate in instant vermicelli not only enhanced their protein content and in vitro protein digestibility but also reduced the fat uptake in noodles. As SPI and DFSF are the main source of protein in the product, as described above, high protein content of the products is also reflected in respective regression coefficients [SPI (>0.85) and DFSF (>0.45)] (eq. 4-6). It was found that protein content was maximum at 31 and 34 % of rice and corn flour after which it decreased (as per table, but not revealed in graphs).

Fat Content

Fat content varied from 2.7 to 3.1% for DW, 1.3 to 2.1 % for mango and 1.6 to 2.4% for spinach based extruded product. There were little variations in fat content because the entire ingredient had lower amount of fat. Using student's t-test, it was found that mean value of products was statistically significant (P<0.001, t_{stat}=11.21). Similar behaviors were also found for mango and spinach-based products. The model was adjusted for fat content in this mixture design are presented in ANOVA (Tables 10-12) revealed that all models were significant (P<0.001) with high R^2 (>0.82). The non-significant (0.27) F-value (1.75) of the lack fit indicated the model is adequate for describing the independent parameters for fat content with better accuracy. The regression equation describing the effect of the process variables on the fat content of product in terms of actual level of the variables are given as:

Table 10: ANOVA for Linear Mixture Model on fat content (DW).

	Response1 Protein				
	Mixture Component Coding is L_Pseudo				
Source	**Squares**	**Df**	**Square**	**Value**	**Prob> F**
Model	3.876466	4	0.969117	94.25765	< 0.0001***
Linear Mixture	3.876466	4	0.969117	94.25765	< 0.0001***
Residual	0.205631	20	0.010282		
Lack of Fit	0.172781	15	0.011519	1.753236	0.2783
R^2	0.9464				
Pure Error	0.03285	5	0.00657		
Cor Total	4.082097	24			

Table 11: ANOVA for Linear Mixture Model on fat (mango).

ANOVA for Linear Mixture Model						
*** Mixture Component Coding is L_Pseudo. ***						
Analysis of variance table [Partial sum of squares - Type III]						
	Sum of		**Mean**	**F**	**p-value**	
Source	Squares	df	Square	Value	Prob> F	
Model	1.408263	4	0.352066	22.82692	< 0.0001	Significant
Linear Mixture	1.408263	4	0.352066	22.82692	< 0.0001	
Residual	0.308466	20	0.015423			
Lack of Fit	0.219779	15	0.014652	0.826046	0.6487	not significant
Pure Error	0.088687	5	0.017737			
Cor Total	1.716729	24				

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Table 12: ANOVA for Linear Mixture Model on fat content (spinach).

Response	**3**	**Fat**				
ANOVA for Linear Mixture Model						
***** Mixture Component Coding is L_Pseudo. *****						
Analysis of variance table [Partial sum of squares - Type III]						
	Sum of		**Mean**	**F**	**p-value**	
Source	Squares	Df	Square	Value	Prob> F	
Model	0.740237	4	0.185059	27.35852	< 0.0001	Significant
Linear Mixture	0.740237	4	0.185059	27.35852	< 0.0001	
Residual	0.135284	20	0.006764			
Lack of Fit	0.095863	15	0.006391	0.810596	0.6583	not significant
Pure Error	0.039421	5	0.007884			
Cor Total	0.875521	24				

Final equation in terms of actual components:

Fat=0.029013* Corn-0.01306* Rice-0.01349 * DFSF-0.00466* SPI+0.206028* Dairy whiteners. (7) for DW

Fat=0.041727* Corn+0.007691* Rice+0.001702DFSF-0.00603* SPI-0.00622*Fruits (8) for mango

Fat=0.039179* Corn+0.008926* Rice+0.012931*DFSF+0.007637* SPI+0.011969* Vegetable (9) for spinach

From regression curve (eq. 7-9), it was found that the rice flour, DFSF and SPI (for DW), SPI and fruit (for mango) had negative effect and corn flour and dairy whitener had positive effect on fat content. As fat content mostly depends on dairy whitener as described above is also evident from the regression equation (eq. 4). Fat are generally affected by the corn flour and DFSF but the role was meagre as evident from regression equation. Generally, the protein content is believed to play a role in oil absorption in extruded product. In a qualitative study, Moss et al. (1987) reported that noodles made from high-protein wheat flour absorbed less oil than noodles made from low-protein flour. They proposed that the high oil absorption in low-protein flour noodle was due to the formation of coarse globules during steaming, allowing oil to penetrate easily through the noodle. In our study products having high protein contents were due to protein rich SPI which showed more oil absorption than the low protein samples. Protein content is not the sole factor influencing oil uptake, protein quality also significantly affects free oil absorption in instant noodles [22]. Again, defatting increases the protein solubility and water and oil absorption capacities of the extruded products.

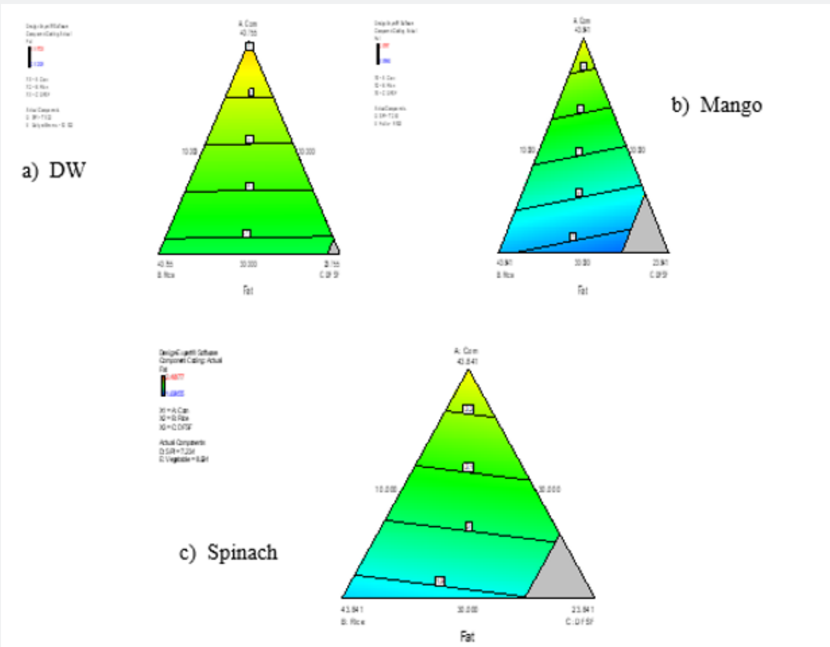

Figure 5: Effect of rice, DFSF and corn on fat content of extruded product.

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The capacity of protein to absorb water and oil is determined by its polar and non-polar amino acids composition, respectively [23]. At high moisture content, the viscosity of the starch would be low, allowing for extensive internal mixing and uniform heating which, in turn, would account for enhanced starch gelatinization; it also may lead to increased water absorption causing high fat absorption also. The high mechanical shear caused breakdown of macromolecules to small molecules with higher solubility. It is clear from the response surface (Figure 5) that oil content in rice, corn and DFSF simultaneously increased the fat content in the products and the extent was more than the individual effects, indicating a synergy. This agrees with the report by Murthy. While elasticity may be critical for finished product qualities, it causes issues in industrial production of dough products, where large heaps of doughs are shaped into thin sheets using sheeting rolls. Increasing the ratio of starch to protein leads to formation of a continuous starch matrix that enables water vapour to expand because starch melt viscosity is lower than protein melt viscosity [24-26]. During moisture removal process, the spaces of water vapour may filled by fat globules causing more fat content in extruded products.

Energy Content

The energy content of the products ranged from 356 to 365 kcal/100g for DW, 340 to 372 kcal/100g for mango and 319 and 353 kcal/100g for the extruded product. Using student'st-test, it was found that mean energy content of products using DW and mango were statistically non-significant (P<0.61, t_{stat}= 0.5) while the same was significant using DW and spinach(P<0.001, t_{stat}= 8.36) and spinach and mango (P<0.001, t_{stat}= 6.25).This indicated that mango could be used as energy replacer for DW with reduced cost of final product as the unit cost of DW is much higher than mango. For all the mixtures whatever the level, energy content was significant (<0.001) as shown in (Tables 13-15) with high coefficient of determination R^2 (>0.92). The non-significant (P>0.22) indicated good accuracy of chosen model. The regression equation describing the effect of the process variables on energy content in terms of actual level of the variables are given as:

Table 13: ANOVA for Linear Mixture Model on energy content (DW).

	Response1 Protein				
	Mixture Component Coding is L_Pseudo				
Source	**Squares**	**Df**	**Square**	**Value**	**Prob> F**
Model	180.0435	4	45.01088	78.34945	< 0.0001
Linear Mixture	180.0435	4	45.01088	78.34945	< 0.0001***
Residual	11.48977	20	0.574489		
Lack of Fit	9.876124	15	0.658408	2.040121	0.2214
Pure Error	1.61365	5	0.32273		
Cor Total	191.5333	24			

*** Significant at 1% level

Table 14: ANOVA for Linear Mixture Model on energy content (mango).

Response	2	Calorie				
ANOVA for Linear Mixture Model						
*** Mixture Component Coding is L_Pseudo. ***						
Analysis of variance table [Partial sum of squares - Type III]						
	Sum of		**Mean**	**F**	**p-value**	
Source	Squares	Df	Square	Value	Prob> F	
Model	2216.672	4	554.1679	60.97904	< 0.0001	Significant
Linear Mixture	2216.672	4	554.1679	60.97904	< 0.0001	
Residual	181.7569	20	9.087843			
Lack of Fit	143.6609	15	9.577392	1.257008	0.4305	not significant
Pure Error	38.09598	5	7.619195			
Cor Total	2398.429	24				

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Table 15: ANOVA for Linear Mixture Model on energy content.

ANOVA for Linear Mixture Model						
*** Mixture Component Coding is L_Pseudo. ***						
Analysis of variance table [Partial sum of squares - Type III]						
	Sum of		Mean	F	p-value	
Source	Squares	Df	Square	Value	Prob> F	
Model	3399.636	4	849.9089	1107.479	< 0.0001	Significant
Linear Mixture	3399.636	4	849.9089	1107.479	< 0.0001	
Residual	15.34853	20	0.767427			
Lack of Fit	13.03031	15	0.868688	1.873612	0.2523	not significant
Pure Error	2.318217	5	0.463643			
Cor Total	3414.984	24				

Final equation in terms of actual components:

Energy =3.455244* Corn+3.398012* Rice+3.433454 * DFSF+3.700634* SPI+4.767625* Dairy whiteners (10) for DW

Energy=3.846363* Corn+3.693403* Rice+4.073597* DFSF+3.817815* SPI+1.168505* Fruits (11) for mango

Energy=3.637284* Corn+3.684187* Rice+3.716799* DFSF+3.825296* SPI+0.541524* Vegetable (12) for spinach

From the regression equation (7), regression coefficient is highest for DW (4.767) indicating its larger effect on energy content of the DW which is also corroborated to its high fat content. However, mango-based products; DFSF (4.073) had more effect on energy value rather than mango. While for spinach-based product, except spinach all variable ad almost equal importance for energy value of the products (regression coefficient: 3.63-3.82). From the response plot (Figure 6), it may be seen that energy content was highest at 30, 34 and 11.42% of corn flour, rice flour and DFSF beyond which the value decreased.

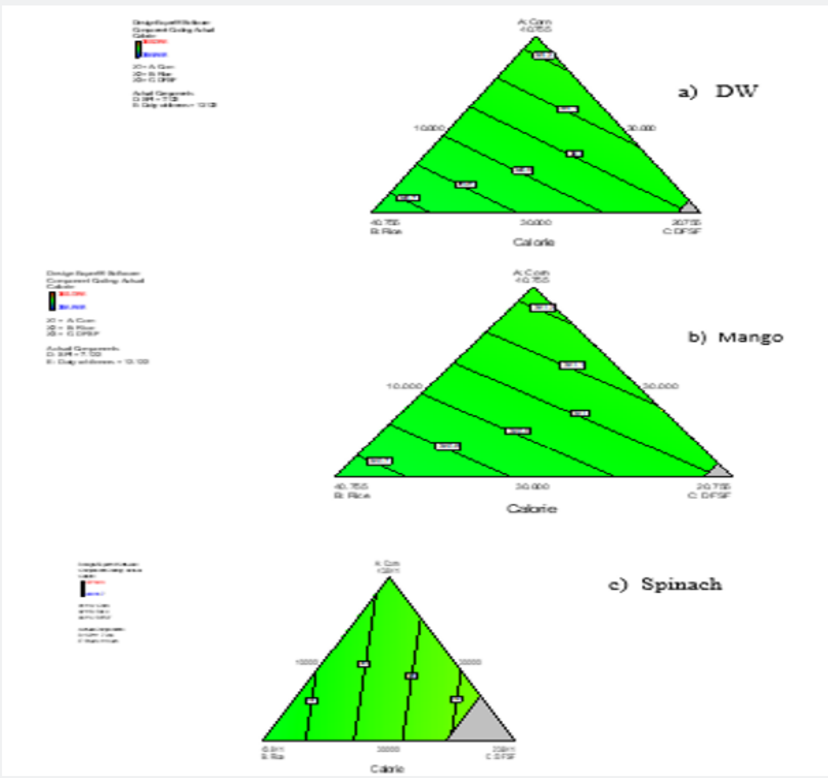

Figure 6: Effect of rice, DFSF and corn on fat content of extruded product.

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Carbohydrate

Generally, carbohydrate content depends on corn flour and rice flour where its value ranged between 59.95 and 66.59% for DW, 59.92 and 69.50% for mango, and57.32and 69.00% for spinach-based products. Using student's t-test, it was found that mean carbohydrate content of all products was statistically non-significant (P<0.19, t_{stat}= 1.3). Carbohydrate contents of the products were highly affected by corn flour and rice flour because corn rice was major source of carbohydrate. To fit the response, quadratic model for mango and linear model for DW and spinach-based products are well represented as shown in ANOVA (Tables 16-18). The model was significant (p<0.001) with highest coefficient of determination (R^2>0.99) of all the dependent parameters. From Table 16, it is observed that the interaction of corn*rice, corn*SPI, rice* DFSF, rice*SPI, DFSF*SPI and SPI*spinach are significant (P<0.05). The regression equation describing the effect of the process variables on the carbohydrate content of product in terms of actual level of the variables are given as:

Table 16: ANOVA for Linear Mixture Model on carbohydrate content.

Response	4	Carbohydrate					
ANOVA for Quadratic Mixture Model							
*** Mixture Component Coding is L_Pseudo. ***							
Analysis of variance table [Partial sum of squares - Type III]							
	Sum of		Mean	F	p-value		
Source	Squares	Df	Square	Value	Prob> F		
Model	192.9912	14	13.78508	50.95376	< 0.0001	Significant	
Linear Mixture	180.2058	4	45.05146	166.5236	< 0.0001		
Corn*Rice	2.074498	1	2.074498	7.667959	0.0198		
Corn*DFSF	0.477679	1	0.477679	1.765642	0.2134		
Corn*SPI	2.721585	1	2.721585	10.05979	0.0100		
Corn*spinach	0.704806	1	0.704806	2.605173	0.1376		
Rice* DFSF	1.496217	1	1.496217	5.530461	0.0405		
Rice*SPI	2.952919	1	2.952919	10.91487	0.0080		
Rice*spinach	0.000447	1	0.000447	0.001651	0.9684		
DFSF*SPI	1.818544	1	1.818544	6.721879	0.0268		
DFSF*spinach	0.124259	1	0.124259	0.459299	0.5133		
SPI*spinach	3.703789	1	3.703789	13.6903	0.0041		
Residual	2.70541	10	0.270541				
Lack of Fit	1.202254	5	0.240451	0.79982	0.5938	not significant	
Pure Error	1.503156	5	0.300631				
Cor Total	195.6966	24					

Table 17: ANOVA for Linear Mixture Model on carbohydrate content.

*** Mixture Component Coding is L_Pseudo. ***						
Analysis of variance table [Partial sum of squares - Type III]						
	Sum of		Mean	F	p-value	
Source	**Squares**	**Df**	**Square**	**Value**	**Prob> F**	
Model	95.2794	4	23.81985	63660000	< 0.0001	significant
Linear Mixture	95.2794	4	23.81985	63660000	< 0.0001	
Residual	0	20	0			
Lack of Fit	0	15	0			
Pure Error	0	5	0			
Cor Total	95.2794	24				

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Table 18: ANOva for Linear Mixture Model on carbohydrate content.

Response	4	Carbohydrate				
ANOVA for Linear Mixture Model						
*** Mixture Component Coding is L_Pseudo. ***						
Analysis of variance table [Partial sum of squares - Type III]						
	Sum of		Mean	F	p-value	
Source	Squares	Df	Square	Value	Prob> F	
Model	268.912	4	67.228	63660000	< 0.0001	Significant
Linear Mixture	268.912	4	67.228	63660000	< 0.0001	
Residual	0	20	0			
Lack of Fit	0	15	0			
Pure Error	0	5	0			
Cor Total	268.912	24				

Final equation in terms of actual components:

Carbohydrate=0.694* Corn+0.814 * Rice+0.416DFSF+0.032* SPI+0.554* Dairy whiteners (13) for DW

Final Equation in Terms of Actual Components:

Carbohydrate=0.56164* Corn+0.352119* Rice-0.9141*DFSF+16.50373Fruits+0.015566* Corn * Rice+0.018329* Corn * DFSF-0.1889* Corn * SPI-0.02553* Corn * Fruits+0.032215* Rice * DFSF-0.1944* Rice * SPI+0.000582 * Rice * Fruits-0.15248* DFSF * SPI-0.01602* DFSF * Fruits-0.22741* SPI * Fruits

(14) for mango

Final Equation in Terms of Actual Components:

Carbohydrate= 0.73196*Corn+0.85196*Rice+0.45396*DFSF+0.06996*SPI+0.09896* Vegetable (15) for spinach

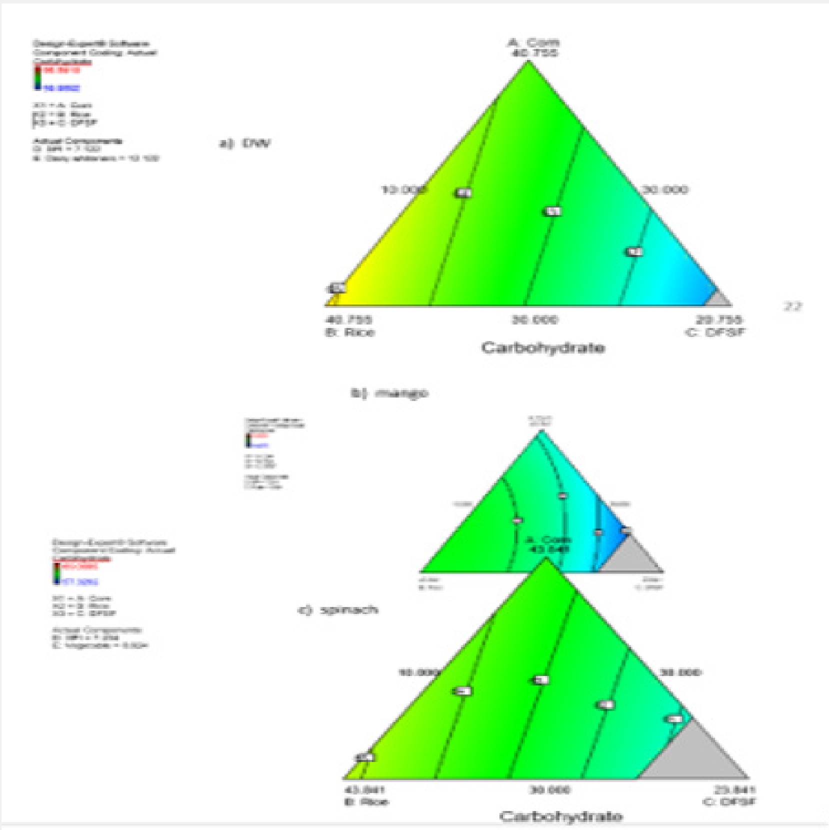

Figure 7: Effect of rice, DFSF and corn on carbohydrate content of extruded product.

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From eq. 13, the regression coefficients of interaction terms corn * SPI, corn * fruits, rice * SPI, DFSF * fruits and SPI * fruits are negative suggested that increase and decrease of these process parameters resulted in decrease and increase of carbohydrate content .it is found that From the response surface graph (Figure 7), it may be seen that increase in corn flour and rice flour enhanced the carbohydrate content, being maximum at 41.8, 31.6 and 10.0 % of corn flour, rice flour and DFSF keeping a constant amount of DFSF and SPI at 12.122 and 7.12 % level indicating minimum carbohydrate content with the combined increase of above variables. The reason may be due to high degree of starch gelatinisation at pre-setted machine parameters beyond which larger fragments of fibre molecules from starch of this flour may be sheared off during extrusion [27] and the fragments could unite to form large insoluble complexes or Maillard compounds generally termed as lignin causing lesser availability of carbohydrate compounds. A similar behaviour was also found for mango and spinach-based products.

Specific Case of Most Acceptable Combinations of Extruded Products

Soy fortified function extruded products were developed using rice flour, corn flour, DFSF, fruit powder, vegetable powder, SPI and dairy whiteners with optimum combination using response surface modeling. Many combinations of the developed products were found acceptable to the consumers; however, some most acceptable combinations from the above ingredients (Table 19) were taken for further analysis and storage study. Addition of 10% moisture was found optimum.

Table 19: Some most acceptable combination of extruded products.

Trial No	Combinations of raw materials	Ratio	Sample
1.	Corn: Rice: DFSF: DW: SPI	35: 35:15:10:5	S-1
2.	Corn: Rice: DFSF: Carrot: SPI	40: 30:15:10:5	S-2
3.	Corn: Rice: DFSF: Spinach: SPI	35: 40:10:10:5	S-3
4.	Corn: Rice: DFSF: Mango: SPI	38: 32:15:10:5	S-4
5.	Control: Corn: Rice	50:50	C

Nutritive Value of Soy Extruded Snacks based on Chemical Composition

The snacks prepared with different levels of soybean was analyzed for protein, fat, carbohydrates, moisture content, Ash content, and energy values (Table 20).

Table 20: Nutritive values of accepted extruded snack products.

Trial No.	Protein (%)	Fat (%)	MC (%), db	Ash (%)	Carbohydrate (%)	Energy (kcal)
S-1	19.95	7.15	1.8	5.5	61.12	432.18
S-2	18.05	5.32	1.9	6.5	63.22	418.05
S-3	16.45	8.40	1.8	4.5	61.95	451.57
S-4	19.25	4.69	2.1	5	64.29	414.90
Control	10.85	6.55	2.1	4	70.05	440.60

Protein

The observation in respect to protein content of soy extruded snacks is tabulated and graphically represented Fig. 8. It is revealed that, there was increase in protein level by addition the DFSF and SPI level in snacks. Soy powder blended extruded snacks recorded maximum protein 19.95 percent in S-1 sample and minimum protein of 10.85 per cent in control sample.

Fat

The observation in respect to fat content of extruded soy-snacks is presented in Table 20. It is evident that there was increase in fat level by oil frying in snacks. Soy fortified snacks recorded maximum 8% in S-3 sample and 6.55 % in control sample.

Carbohydrates

The observation in respect to carbohydrate content of extruded snacks is presented in Table 20. It is evident that there was decrease in carbohydrate level by increasing the DFSF and SPI level in snacks. The soy fortified snacks recorded minimum 61.12 % in S-1 sample and maximum carbohydrate of 70.05% in control sample. Increased in the carbohydrate was found in S-2 and S-4 sample by adding DFSF and SPI.

Energy value

The data pertaining to energy value content of extruded soy-snacks are presented in the Table 20. It is observed that there was increase in energy value by increasing the soy flour level in snacks. Soy powder blended snacks recorded maximum 451.18 Kcal in

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S-3 sample and minimum energy of 414.9 Kcal in S-4 sample. Increased in the calorie by adding the DFSF and SPI were found in the samples.

Moisture content

From Table 20, It is evident that the moisture content ranges of the samples are varied between 1.8 to 2.1%. Moisture content of product is affected by ingredients.

Ash Content

From Table 20, it is revealed that as the quantity of DFSF added, ash content also was increased. Ash content recorded maximum 6.5% in S-2 sample and minimum 4 % in control sample. The graphical representation of protein, fat, carbohydrate content, energy-value, moisture-content and ash content of different treatments are represented in Figures 8-12.

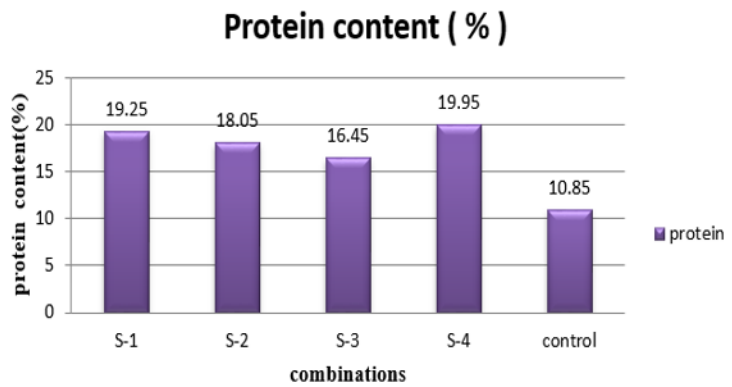

Figure 8: Protein content of extruded soy-snacks.

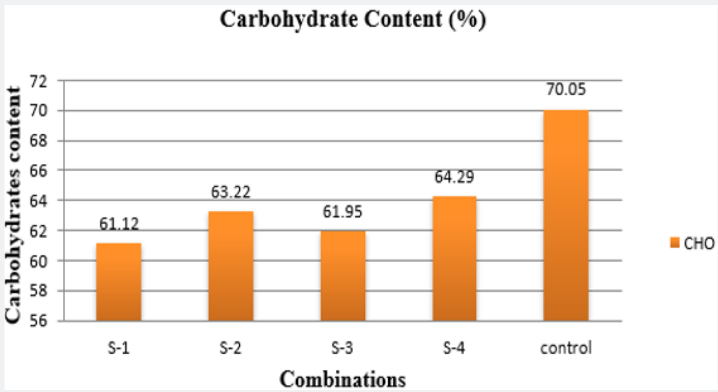

Figure 9: Carbohydrate content of extruded soy-snacks.

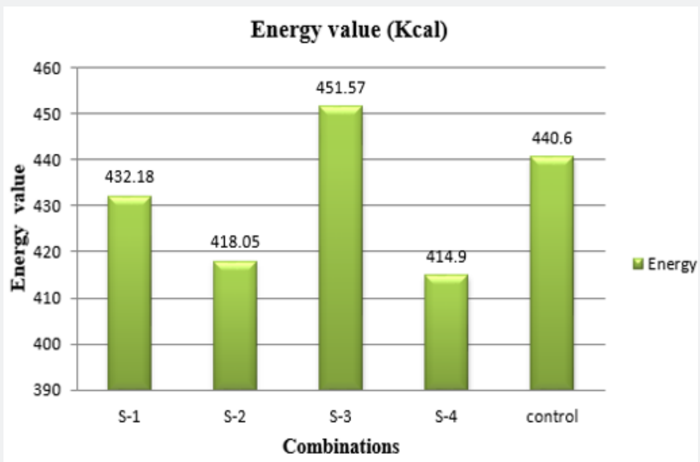

Figure 10: Energy/Calorie value of extruded soy-snacks.

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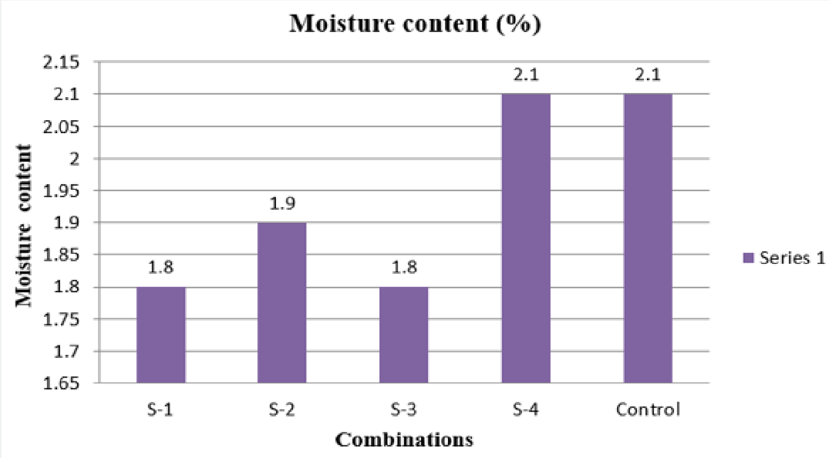

Figure 11: Moisture content of extruded soy-snacks.

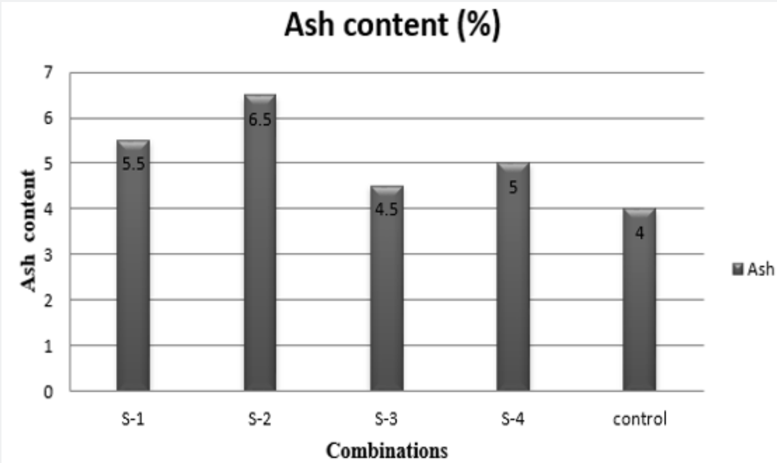

Figure 12: Ash content of extruded soy-snacks. Sensory evaluation of extruded snacks foods.

Sensory Evaluation of Extruded Snacks Foods

Table 21: Mean score for different characteristics of extruded snack products.

Characters	Combinations,				
	Control	S-1	S-2	S-3	S-4
Taste	7.0±05	6.9±0.5	7.0±0.98	6.7±0.71	6.7±0.5
Texture	7.4±0.69	7.2±0.69	7.1±0.98	7.3±1.14	6.9±0.57
Flavour	7.1±0.41	6.8±0.26	6.7±0.57	6.5±1.1	6.4±0.57
Colour	6.9±0.14	7.0±0.98	6.4±0.12	6.8±1.41	6.9±0.57
Appearance	7.1±05	6.9±.07	6.8±1.64	6.6±0.63	6.5±0.85
Overall acceptability	7.1±0.69	7.0±0.88	6.8±.03	6.7±1.71	6.5±1.06

After seasoning coating the snack with roasted in different flavors, the snack samples were subjected to sensory evaluation. The samples of extruded soy-snacks were evaluated by using the standard scorecard. The assessment was done by studying the characters like color, flavor, taste and overall acceptability. Results revealed that with increase in the level of DFSF and SPI there is variation in sensory score related to colour, flavour, taste, texture/ mouth feel and overall acceptability [28-30]. Amongst various levels of DFSF, and SPI used in blend for the preparation of snacks, the highest overall score obtained was 7.0 for snacks prepared with the level of 10 per cent DFSF and 5 per cent SPI (S-1). The results show that the utilization of soy powder at 10 % DFSF and 5 % SPI level reported maximum scores with respect to all sensory characters (Table 21). The substitution of all soy protein sources

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in snacks gave significant difference (P≤0.05) in terms of general appearance suitability of colour and overall acceptability from control formula. On the other hand, there were no significance difference (P≤0.05) among control sample and DFSF, and SPI formulas in terms of texture/ mouth feel, respectively. The general appearance of soy protein enriched extruded snacks showed no significant difference (P ≤ 0.05) among snacks with any soy protein source.

Textural Properties Analysis of Extruded Snack Products

Textural quality of the snack samples was examined for compression force (CF) by applying a TA-XT2i Texture Analyzer. P50 compression probe (50 mm. dia. cylinder aluminium) was applied to measure compression force required for samples breakage which indicates hardness [31-33]. Testing condition was 5.0 mm/s pre-test speed, 5.0mm/s test speed, 10.0 mm/s post-test speed. Each measurement was conducted on 50% strain of individual. Force–time curves of the TPA, hardness, cohesiveness, stickiness, springiness, chewiness, gumminess and adhesiveness values were determined. The textural properties of all the samples are presented in following Table 22.

Table 22: Textural properties of extruded snack foods.

Sample	Hardness	Springiness	Cohesiveness	Gumminess	Chewiness
S-1	7.14	0.88	0.33	2.39	2.10
S-2	6.72	0.04	0.01	0.07	0.03
S-3	5.44	0.80	0.36	1.96	1.57
S-4	7.46	0.84	0.55	4.17	3.53
Control	7.25	0.30	0.17	1.29	0.39

For S-1 sample, the dairy whiter (DW) effects on the hardness of snacks. It was harder in texture as compare to other samples but less than control. The S-2 sample containing carrot, was low in hardness and other parameters of texture as compare to control, but more in gumminess and chewiness. The S-3 sample containing spinach also low in hardness and other parameters of texture as compare to control but more in gumminess and chewiness. The S-4 sample containing mango bad the highest hardness but less than control. The reason for highest hardness in control sample may be due to combination of only corn and rice which was less in other textural properties. The graphical representation of samples is represented in Figure 13.

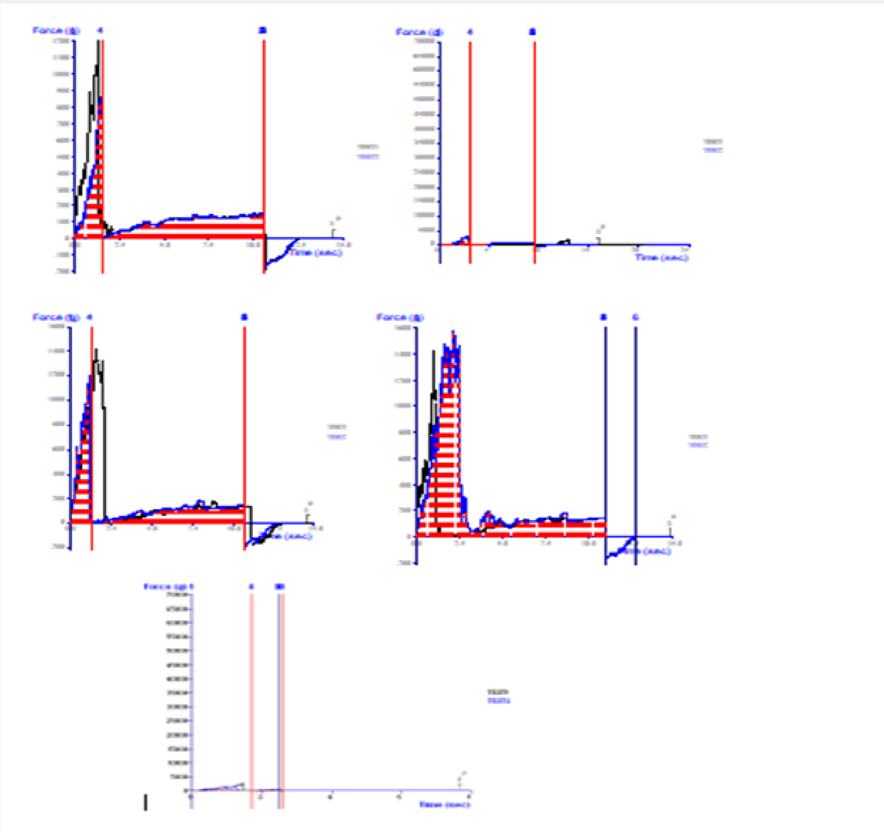

Figure 13: Textural properties of products (S1-S4) and control sample.

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The developed extruded snack foods rich in protein (20% - 87% increase) and low in fat are good protein supplement for school children and others. The products were evaluated using sensory chart with a panel of judges and the panel liked the product very much in terms of its texture, color, crispiness, appearance and taste. The storage study inferred that all the samples were suitable after six months in various packaging system, however, packaging in PET/PET met/LDPE kept the product with superior quality followed by PET met/LDPE and LDPE in terms of moisture content, crispness and sensory data. The developed products were provided to 100 school children of different age (10-18 yrs) group of Bhopal and collected the response for knowing the acceptability level of the product. The products were rated as 'very much liked'.

Conclusion

Extrusion-technology is gaining increasing popularity in the global agro-food processing industry, particularly in the food and feed sectors. In our study, starches and protein of different nature are co-extruded and the product parameters are influenced by synergetic effects. Such inexpensive, high energy value products may be valuable in feeding the hungry across the world as well as in promoting the health benefits of extruded foods. This study focuses to develop the process for production of nutritionally balanced formulated and functional snack foods which are successful in the market and meet the intended nutritional requirements and are also accessible to the vulnerable groups of the society at minimum possible cost. There was non-significant increase in moisture content and hardness of products during three month of storage. It was aimed to achieve this objective through use of abundantly available raw food ingredients having high nutrition such as cereals, soybean, dairy products and horticultural produce to minimize the cost and maximize nutrition.

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