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Utilization of broken rice and walnut kernels for development of nutritious snacks using extrusion technology

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Abstract

Walnut kernel supplementation increases the nutritional value of starch based expanded snacks. A systematic study was conducted for optimizing the blending level of broken walnut kernels and broken rice for the production of expanded snacks through co-rotating twin screw extruder. Response surface methodology was used to study the effects of feed composition, feed moisture, screw speed and barrel temperature on specific mechanical energy (SME), bulk density (BD), water absorption index (WAI), water solubility index (WSI), expansion ratio (ER), oil loss during extrusion, complexing index (CI) and breaking strength. Response surface regression models were established to determine the responses as functions of process variables. Regression models for all the responses were highly significant ($p<0.01$) with high co-efficient of determination ($R^2>0.83$). The compromised optimum conditions obtained by numerical optimization for development of extruded snacks were broken walnut kernel flour to broken rice flour ratio (10:90), moisture content 14%, screw speed 550 rpm and die temperature 170 ^{0}C.

Keywords: Rice broken, walnut kernel, extrusion, optimization, response surface methodology

Introduction

Extrusion cooking is a process widely used in the food industry to manufacture snacks, crackers and expanded cereals. The degree of expansion in extruded products is an important characteristic which relates to the texture and sensory properties of extrudates (Liu *et al.*, 2000) [25]. Extrusion cooking has an important influence on product quality, emphasing features like expansion, texture, shelf life, colour and flavor.

Extruded products are generally made from starch based raw materials. Rice flour offers very large starch granules that break down easily with definite flavor, excellent swelling and binding power and are best utilized for making extruded products (Kadan *et al.* 2003) [20]. Broken rice-a byproduct of rice milling process has nutritive value similar to whole rice and is readily available at relatively cheaper rates. It could therefore become an attractive ingredient in extrusion industry. In general, extrusion processing of starch based food materials has been very well studied and well commercialized especially in the category of breakfast cereals (Hu *et al.* 1995; Iwe *et al.* 2001) [19, 18]. However, high fat extruded breakfast snacks are not available in the market; hence there is an increasing interest in enhancing the fat component of such products.

Walnut is much prized as dessert and dry fruit and has proved to be nutritionally valuable food (Dogan and Akgul 2005; Tapsell 2010) [12, 41]. On an average walnut kernel contains 60-70% lipids comprising of mono and polyunsaturated fats, 15.2% proteins, 13.7% carbohydrates, 6.5% dietary fibre and 1.5% ash (Dogan and Akgul 2005; Cosmulescu *et al.* 2009) [13,10]. They are also good source of omega-3 oils with linoleic acid (44.2%), oleic acid (25.7%) and alfa linolenic acid (18.2%) as major components (Kuliev *et al.* 1987) [21]. The broken walnut kernels are widely used in confectionary and pastry industries for its good organoleptic, nutritional and healthy characteristics. A possible application of broken walnut kernels could be the production of extruded breakfast food. A balanced fatty acid diet especially in breakfast or lunch is very important for improving the nutritional status in the developing countries. However, high fat content of walnut kernel may cause reduction of starch dispersion and a decrease in product expansion during extrusion processing. Furthermore, use of raw material with high fat content cause oil loss from dough during extrusion processing and subsequently percolation from extruder (Pilli *et al.* 2000) [31].

Extrusion is a complex process involving many variables, among them barrel temperature, screw speed and feed moisture are the most important factors. So far, the extrusion processing of fat rich raw materials has not been studied in detail exploring the relationships between process variables and product characteristics. For this purpose, the present study was planned with an aim to (a) investigate the influence of extrusion process variables on physico-chemical properties of walnut kernel incorporated rice based extrudates using response surface methodology and (b) establish regression models to predict the product responses as a function of the process variables.

Materials and methods

A widely cultivated paddy variety (Jhelum) obtained from Mountain research Station for field crops, Khudwani, Anantnag, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir, India was shelled using Satake rice mill (Satake, Hiroshima, Japan) to obtain brown rice, which inturn was passed through rice polisher. The small rice brokens (<1/8th of actual kernel size) and locally procured broken walnut kernels were ground in a lab mill model 3303 (Perten, Hagersten Sweden) to a fineness that passed through a 200 µm sieve.

Proximate analysis of flours and final product

The contents of moisture, protein, fat, starch and ash were determined according to AACC methods (2000), dietary fiber and energy value were determined by FibreTech (Foss Instrument Denmark) and Bomb calorimeter (Model 6050, parr instruments, USA) respectively.

Extrusion Process

Extrusion was performed in a co-rotating, intermeshing twin screw extruder Model BC21 (Clextral BC-21, Firminy, France), consisting of four independent zones of controlled temperature in the barrel. The barrel diameter and its length to diameter ratio (L/D) were 2.5 mm and 16:1 respectively. Temperature of the first, second and third zone were maintained at 40, 60, and 90 ^{0}C respectively throughout the experiment, while the temperature at last zone (compression and die section) was varied according to the experimental design. The diameter of die opening was 3 mm. The extruder was equipped with a torque indicator, which showed percentage of torque in proportion to the current drawn by the drive motor. Raw material was metered into the extruder with a single screw volumetric feeder (D.S and M, Modena, Italy). The extruder was thoroughly calibrated with respect to the combination of feed rate and screw speed to be used. The feed rate was varied for optimum filling of the extruder barrel corresponding to the screw speed. The moisture content of feed was varied by injecting water (approximately 50 ^{0}C) into extruder with water pump. A variable speed die face cutter with four bladed knives was used to cut the extrudates.

Experimental Design

A central composite rotatable design (CCRD) (Draper, 1982) was used to incorporate these three variables and walnut kernel incorporation. The CCRD-coded levels and experiment ranges of the four independent variables are shown in Table-1; these were selected based on preliminary trials. Dependent variables were specific mechanical energy (SME), bulk density, water absorption index (WAI), water solubility index (WSI), expansion ratio, oil loss, complexing index and breaking strength. Experiments were randomized in order to minimize the systematic bias in observed responses due to extraneous factors. Both individual effects and interactive effects of independent variables on product responses were determined. All the extrusion experiments were repeated twice.

Table 1: Central Composite rotatable design experiment design: actual levels and coded levels

S. No	Composition (R:W)	Moisture content (%)	Screw speed (rpm)	Barrel temperature (ºC)
1	70:30(+1)	18.00(+1)	550.00(+1)	170.00(+1)
2	70:30(+1)	14.00(-1)	400.00(-1)	170.00(+1)
3	70:30(+1)	18.00(+1)	400.00(-1)	130.00(-1)
4.	80:20(0)	16.00(0)	475.00(0)	110.00(-1.682)
5	90:10(-1)	18.00(+1)	400.00(-1)	130.00(-1)
6	90:10(-1)	14.00(-1)	550.00(+1)	130.00(-1)
7	90:10(-1)	18.00(+1)	550.00(+1)	130.00(-1)
8	80:20(0)	16.00(0)	325.00(-1.682)	150.00(0)
9	70:30(+1)	14.00(-1)	550.00(+1)	130.00(-1)
10	80:20(0)	12.00(-1.682)	475.00(0)	150.00(0)
11.	80:20(0)	16.00(0)	475.00(0)	150.00(0)
12.	80:20(0)	16.00(0)	475.00(0)	150.00(0)
13	70:30(+1)	18.00(+1)	400.00(-1)	170.00(+1)
14	90:10(-1)	18.00(+1)	400.00(-1)	170.00(+1)
15.	80:20(0)	16.00(0)	625.00(+1.682)	150.00(0)
16.	80:20(0)	16.00(0)	475.00(0)	150.00(0)
17	80:20(0)	20.00(+1.682)	475.00(0)	150.00(0)
18	90:10(-1)	14.00(-1)	550.00(+1)	170.00(+1)
19.	80:20(0)	16.00(0)	475.00(0)	190.00(+1.682)
20	70:30(+1)	14.00(-1)	550.00(+1)	170.00(+1)
21.	80:20(0)	16.00(0)	475.00(0)	150.00(0)
22.	80:20(0)	16.00(0)	475.00(0)	150.00(0)
23	70:30(+1)	14.00(-1)	400.00(-1)	130.00(-1)
24	60:40(+1.682)	16.00(0)	475.00(0)	150.00(0)
25	100:00(-1.682)	16.00(0)	475.00(0)	150.00(0)
26	90:10(-1)	14.00(-1)	400.00(-1)	170.00(+1)
27	90:10(-1)	14.00(-1)	400.00(-1)	130.00(-1)
28	70:30(+1)	18.00(+1)	550.00(+1)	130.00(-1)
29	90:10(-1)	18.00(+1)	550.00(+1)	170.00(+1)
30.	80:20(0)	16.00(0)	475.00(0)	150.00(0)

*(R) Rice flour
(W) Walnut kernel flour

Determination of system response

Specific mechanical energy (*Wh/kg*) Specific mechanical energy (Wh/kg) was calculated from rated screw speed (682 rpm), motor power rating (8.5 kW), actual screw speed (rpm), percent motor torque and mass flow rate (Kg/h) using the following formula.

$$\mathrm{SME} = \frac{\text{Actual Screw Speed(rpm)}}{\text{Rated Screw Speed(rpm)}} \times \frac{\text{\% motor torque}}{100} \times \frac{\text{motor power rating(kW)}}{\text{mass flow rate }\left(\frac{\text{kg}}{\text{h}}\right)} \times 1000 \tag{1}$$

Determination of product responses

Bulk density Bulk density (BD) was measured using displacement method (Seker 2005) [35], Extrudates were cut into 25 mm long strands and about 15 g of strands were weighed ($M_{ext.}$) and put in a 100 ml cylinder, yellow millet particles were then added to fill up the cylinder. The extrudates were taken out, and volume of the yellow millet particles was measured (V_{ym}). BD was calculated as

$$\mathrm{BD} = \frac{\mathrm{M_{ext}}}{100-\mathrm{V_{ym}}} \quad (2)$$

Water absorption and solubility indices Water absorption and solubility indices of extruded products were determined by a modification of the method outlined by Anderson and Griffinl (1969). The extrudate samples were ground and sieved through 500 µm sieves. 0.5 grams of sample (extrudate flour) was weighed into a centrifuge tube along with 10 ml of distilled water at 25°C and thoroughly mixed to produce smooth dispersion. Samples were allowed to settle for 30 min with intermittent shaking for every 5 min then centrifuged (SIGMA 3-18K, SciQuip, U.K.) at 1800×g for 15 min. The supernatant was decanted into a tared aluminum pan and dried at 105 ^{0}C to constant weight. The weight of the gel remaining in the centrifuge tube was noted. The results were expressed as the average of two measurements.

$$\text{Water absorption index, g/g} = \frac{\text{Weight gain by gel}}{\text{Dry weight of extrudate}} \quad (3)$$

$$\text{Water solubility index, \%} = \frac{\text{Weight of dry solids in supernatant}}{\text{Dry weight of extrudate}} \times 100 \quad (4)$$

Expansion ratio To determine the expansion ratio (ER), the cross-sectional diameter of the extrudates was measured with a digital Vernier caliper. The ratio of diameter of extrudate and the diameter of die was used to express the expansion of extrudate (Meng *et al.* 2010) [26]. The ER values were obtained from 15 random samples for each extrusion condition

Oil loss and complexing index Oil extraction was done by Soxhlet (Soxtec Avanti, 2050, Sweden) using n-hexane and oil loss percentage was calculated as difference between oil content in raw material and oil content in extrudates. The complexing index was determined using the method described by (Guraya *et al.* 1997) [15].

Breaking strength Breaking strength was measured using TA-XT 2i texture analyzer (stable micro systems, surrey, UK). A three point breaking test (Zasypkin and Lee 1998) [42] was used to measure the maximum force required to break the extrudate samples. Ten measurements were made in each product and average value was used.

Data Analysis

Second order polynomial regression models were established for the dependent variables to fit experimental data for each response using statistical software Design-Expert 9 (Stat-Ease Inc, Minneapolis, MN, USA).

$$yi = b_0 + \sum_{i=1}^{4} b_i x_i + \sum_{i=1}^{4} b_{ii} x_i^2 + \sum_{i=1}^{4} \sum_{i=1}^{4} b_{ij} x_i x_j \quad (5)$$

Where, x_i (i = 1, 2, 3, 4) are independent variables (composition, moisture, screw speed and barrel temperature, respectively) and b_0, b_i, b_{ii} and b_{ij} are coefficient for intercept, linear, quadratic and interactive effects respectively. Data was analyzed by multiple regression analysis and statistical significance of the terms was examined by analysis of variance (ANOVA) for each response. The adequacy of regression model was checked by correlation coefficients. The lack of fit test was used to judge the adequacy of model fit. To aid visualization of variation in responses with respect to process variables, series of dimensional response surface plots were drawn.

Process Optimization

Optimization is the process which maximizes the desired quantities or minimizes the undesired ones. The values of the processing variables that produce the desired optimum value are called optimum conditions (Myers and Montgomery 2002). System parameter-SME and product responses such as BD, WAI, WSI, ER, complexing index, oil loss and breaking strength are the major parameters which can determine the quality of high fat extruded snacks. Therefore, optimum conditions for extrusion of rice-walnut kernel blended flour were determined to obtain minimum BD and breaking strength and maximum SME, WAI, WSI, ER, oil loss and complexing index. To determine the optimum processing conditions, response surface of desirability function was used for numerical optimization. Desirability function is one of the useful approaches to optimize the multiple responses. The general approach is first to convert each response y_i into an individual desirability function d_i that varies over the range $0 \leq d_i \leq 1$, where, if response y_i is at its target value, then $d_i = 1$, and if it is outside an acceptable region, $d_i = 0$. The design variables were then chosen to maximize the overall desirability as,

$$\mathrm{D_0} = (\mathrm{d_1 d_2}, \ldots \mathrm{d_m})^{1/m} \quad (6)$$

where, m is the number of responses and D_o is the overall desirability. Design-Expert uses direct search method to maximize the desirability function, D_o. Because the individual desirability functions are not differentiable, overall desirability was computed by Design-Expert for evaluation of optimized processing conditions (Myers and Montgomery 2002).

Consumer Acceptance Test

A consumer panel of 400 un-trained judges evaluated the acceptability of the optimized product in terms of colour, flavor, texture, appearance and overall acceptability using 4 point scale (poor = 1, fair = 2, good = 3, excellent = 4) (Refrah *et al.* 2009) [33]. The product was prepared one day prior to testing and stored under ambient conditions in sealed low density polyethylene bags. All the samples were randomized using 3 digit codes. The test panelists were 200 male and 200 female adults (> 18 years of age) from district Srinagar, Jammu and Kashmir, India.

Results and Discussions

The nutrient profile of rice flour and walnut kernel flour are given in table 2. Among the two flours, the moisture and starch contents of rice flour were higher than walnut kernel flour, whereas protein, fat, ash and dietary fiber contents were higher in walnut kernel flour. The energy value of walnut kernel flour was about 1.96 times higher than that of rice flour. The reason could be the higher amount of protein and fat content in walnut kernels.

Table 2: Nutrient profile of rice flour and walnut kernel flour (mean values plus standard deviation in parenthesis)

Flours	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Dietary Fibre (%)	Starch (%)	Energy (Kcal/100g)
RF	11.92 (0.58)	8.09 (0.04)	0.23 (0.02)	0.47 (0.04)	0.96 (0.08)	64.09 (0.82)	348 (1.49)
WF	2.05 (0.02)	15.2 (0.32)	65 (0.45)	1.81 (0.09)	6.9 (0.11)	0.95 (0.96)	682 (2.08)

RF = Rice flour
WF = Walnut kernel flour

The data on mean values of system and product responses along with their standard deviations are summarized in Table-3. Analysis of variance is summarized in Table-4. Models for all parameters were highly significant (p<0.01) with high coefficient of determination (R^2> 0.83). Thus, models developed could be used to navigate the design space and to predict the responses correctly. The predicted R-square was found in reasonable agreement with adjusted R-square for all the parameters. Coefficient of variation being less than 8.95% suggests that the experiments were reasonably accurate and models are reproducible. Adequate precision compares the range of predicted values at the design points to average the prediction error. The adequate precision value of > 4 indicates adequate model discrimination. All the parameters showed highly desirable adequate precision (Table 4). None of the models showed significant lack of fit, indicating that all second order polynomial models correlated well with the measured data.

Table 3: Physico-Chemical properties of the extruded products (mean values plus standard deviation in parenthesis)

S. No	SME	BD	WAI	WSI	ER	CI	OL	BS
1	84.78 (3.4)	265 (7.88)	5.27 (0.93)	10.93 (1.10)	1.078 (0.12)	68 (2.8)	7.7 (0.35)	191.1 (6.12)
2	76.47 (3.2)	199 (7.12)	5.06 (0.74)	10.56 (1.07)	1.042 (0.10)	65 (2.9)	7.4 (0.32)	126.1 (7.13)
3	82.53 (3.3)	288 (7.68)	5.7 (0.95)	7.58 (1.02)	0.98 (0.140	36 (2.4)	3.8 (0.12)	210.5 (7.12)
4	95.76 (4.2)	195 (7.11)	5.14 (0.92)	9.68 (1.08)	1.265(0.01)	15 (0.78)	2.16 (0.08)	205.1 (7.12)
5	72.32 (3.1)	270 (7.64)	5.62 (0.95)	7.21 (1.02)	1.233 (0.01)	25(0.21)	3.2 (0.11)	228.4 (7.15)
6	107.2 (4.7)	129 (7.07)	5.38 (0.93)	13.72 (1.13)	1.589 (0.01)	23 (1.2)	2.6 (0.08)	94.7 (5.75)
7	86.59 (3.4)	245 (7.54)	5.62 (0.95)	10.13 (1.10)	1.266 (0.01)	24 (1.2)	2.7 (0.09)	225.3 (7.14)
8	76.19 (3.3)	241 (7.51)	5.34 (0.93)	7.62 (1.08)	1.117 (0.14)	54 (2.7)	5.5 (0.21)	178.2 (6.73)
9	81.56 (3.2)	161 (6.24)	4.6 (0.53)	14.18(1.14)	1.265 (0.01)	32 (1.7)	3.5 (0.11)	111 (5.93)
10	80.78 (3.2)	172 (6.32)	4.89 (0.73)	12.31 (1.11)	1.312 (0.02)	47 (1.8)	4.8 (0.71)	120.7 (6.14)
11	59.78 (2.8)	154 (6.12)	5.21 (0.93)	10.42 (1.07)	1.269 (0.03)	34 (2.4)	4.1 (0.22)	69.9 (5.14)
12	54 (2.8)	154 (6.12)	5.21 (0.93)	10.42 (1.07)	1.269 (0.03)	34 (2.4)	4.1 (0.22)	69.9 (5.14)
13	81.56 (3.2)	267 (7.6)	5.41 (0.95)	8.72 (1.02)	0.955 (0.04)	69 (2.9)	8 (0.42)	176.9 (^.34)
14	62.66 (2.8)	202 (7.15)	5.77 (0.96)	7.15 (1.03)	1.317 (0.04)	59 (2.8)	7.1 (0.31)	176.5 (6.34)
15	82.32 (3.6)	167 (6.18)	5.04 (0.93)	13.55 (1.13)	1.361 (0.04)	52 (2.7)	5.2 (0.22)	107.3 (6.01)
16	74.3 (3.2)	154 (6.12)	5.21 (0.93)	10.42 (1.10)	1.269 (0.03)	34 (2.4)	4.1 (0.22)	69.9 (5.14)
17	60.2 (2.8)	364 (8.7)	5.83 (0.98)	7.8 (1.02)	0.955 (0.04)	57 (2.8)	6.6 (0.41)	305.6 (8.09)
18	88.78 (3.9)	82 (5.51)	5.1 (0.92)	14.42 (1.15)	1.702 (0.05)	50 (2.7)	6 (0.31)	50 (4.12)
19	76.48 (3.2)	131 (6.31)	5.02 (0.86)	11.44 (1.11)	1.427 (0.01)	72 (3.1)	8.6 (0.41)	104 (6.03)
20	84.32 (3.8)	150 (6.42)	4.71 (0.63)	13.69 (1.11)	1.287 (0.01)	67 (2.9)	7.3 (0.31)	62.5 (5.12)
21	79.49 (3.2)	154 (6.12)	5.21 (0.93)	10.42 (1.10)	1.269 (0.02)	34 (3.1)	4.1 (0.22)	69.9 (5.14)
22	61.14 (2.8)	154 (6.12)	5.21 (0.93)	10.42 (1.10)	1.269 (0.02)	34 (2.9)	4.1 (0.22)	69.9 (5.14)
23	81.56 (3.87)	206 (7.18)	4.94 (0.84)	9.76 (1.9)	0.974 (0.03)	34(2.4)	3.7 (0.21)	207.8 (7.14)
24	82.89 (3.84)	223 (7.28)	4.98 (0.84)	10.92 (1.98)	1.089(0.13)	53 (2.4)	6.3 (0.24)	126.7 (7.32)
25	86.12 (3.88)	130 (7.21)	5.58 (0.95)	9.45 (1.78)	1.898 (0.7)	23 (2.4)	2.8 (0.09)	81.2 (5.38)
26	69.98 (2.92)	152 (6.12)	5.14 (0.92)	11.9 (1.98)	1.546 (0.7)	51 (2.7)	6.1 (0.210	90.8 (5.68)
27	92.55 (4.2)	193 (6.19)	5.5 (0.95)	9.57 (1.87)	1.519 (1.02)	22 92.3)	1.5 (0.01)	166.7 (6.34)
28	63.23 (2.92)	288 (8.34)	5.11 (0.92)	10.62 (1.88)	0.941 (0.04)	33 (2.7)	3.6 (0.12)	235.2 (7.48)
29	85.48 (3.3)	182 (6.17)	5.64 (0.95)	10.66 (1.88)	1.468 (0.06)	59 (2.34)	6.5 (0.21)	205.6 (7.13)
30	56.28 (2.72)	154 (6.12)	5.21 (0.93)	10.42 (1.82)	1.269 (0.15)	34 (2.41)	4.1(0.22)	69.9 (5.14)

SME = Specific mechanical energy (Wh/kg)
BD = Bulk density (kg/m^3)
WAI = Water absorption index (g/g)
WSI = Water solubility index (%)
ER = Expansion ratio
CI = Complexing index (%)
OL = Oil loss (%)
BS = Breaking strength (N)

Table 4: Analysis of Variance for the fit of experimental data to response surface model.

Regression	Sum of Squares							
	SME	**Bulk Density**	**WAI**	**WSI**	**Expansion Ratio**	**Oil Loss**	**Complexing Index**	**Breaking Strength**
R-Square	0.83	0.99	0.84	0.94	0.98	0.98	0.99	0.99
Adjusted R Square	0.68	0.99	0.82	0.93	0.96	0.96	0.98	0.98
Predicted R Square	0.57	0.98	0.76	0.90	0.89	0.88	0.94	0.95
C.V (%)	8.94	1.35	2.45	4.99	3.46	7.59	5.03	6.13
Adequate Precision	9.06	151.8	20.1	32.8	30.6	28.0	40.5	44.75
Lack of Fit	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s

SME = Specific Mechanical Energy
WAI = Water Absorption Index
WSI = Water Solubility Index
n.s = Non Significant.

Various physico-chemical attributes have been studied in different extruded products. Pilli *et al.* 2008 [32] studied the effects of barrel temperature, dough moisture and screw speed on specific mechanical energy, oil loss, complexing index, break strength, porosity and expansion ratio of extrudates developed from almond and wheat blend. Normell *et al.* 2009 studied the physical and micro-structural properties of native corn starch-soy protein concentrate extrudates. Liang *et al.* 2012 studied the expansion ratio, BD, breaking stress, WSI and rehydration ratio of the extruded products developed from corn flour and soy protein isolate blends. The influence of process variables on physico-chemical properties of extrudates have been shown to be generally significant in all these studies.

Specific mechanical energy (SME) The fitted model for SME is shown below in equation (7) indicating quadratic effects only with composition (i.e walnut kernel incorporation).

$$SME = 64.17 - 1.50\,C - 4.35M + 3.11S - 3T + 5.29\,C^2 \quad (7)$$

Figure 1(a) and 1(b) shows the response surface plots of SME vs two independent variables with third and fourth taken at midpoint levels (code 0). Figure 1(a) is SME vs composition and moisture content in which screw speed and barrel temperature were controlled at 475rpm and 150 ^{0}C (code value 0). Figure 1(b) is SME vs barrel temperature and screw speed with the composition (walnut kernel level) and feed moisture set at 20% and 16% respectively. The calculated SME observed in this experiment ranged from 54 to 107.2 Wh/kg (table-3). Although the effect of moisture content on SME seems dominant in equation 7, but the maximum (107.2 Wh/kg) and minimum (54 Wh/kg) SME values for run 6 and 12 in table- 2 and 3 indicates that the combined effect of all the four independent variables was more prominent and important on SME. In equation 7 the negative coefficients of the linear terms of moisture, temperature and composition indicates that SME decreased significantly ($p<0.01$) with the increase in these variables, while positive coefficient for screw speed indicated that SME increased significantly ($p<0.01$) with the increase in screw speed.

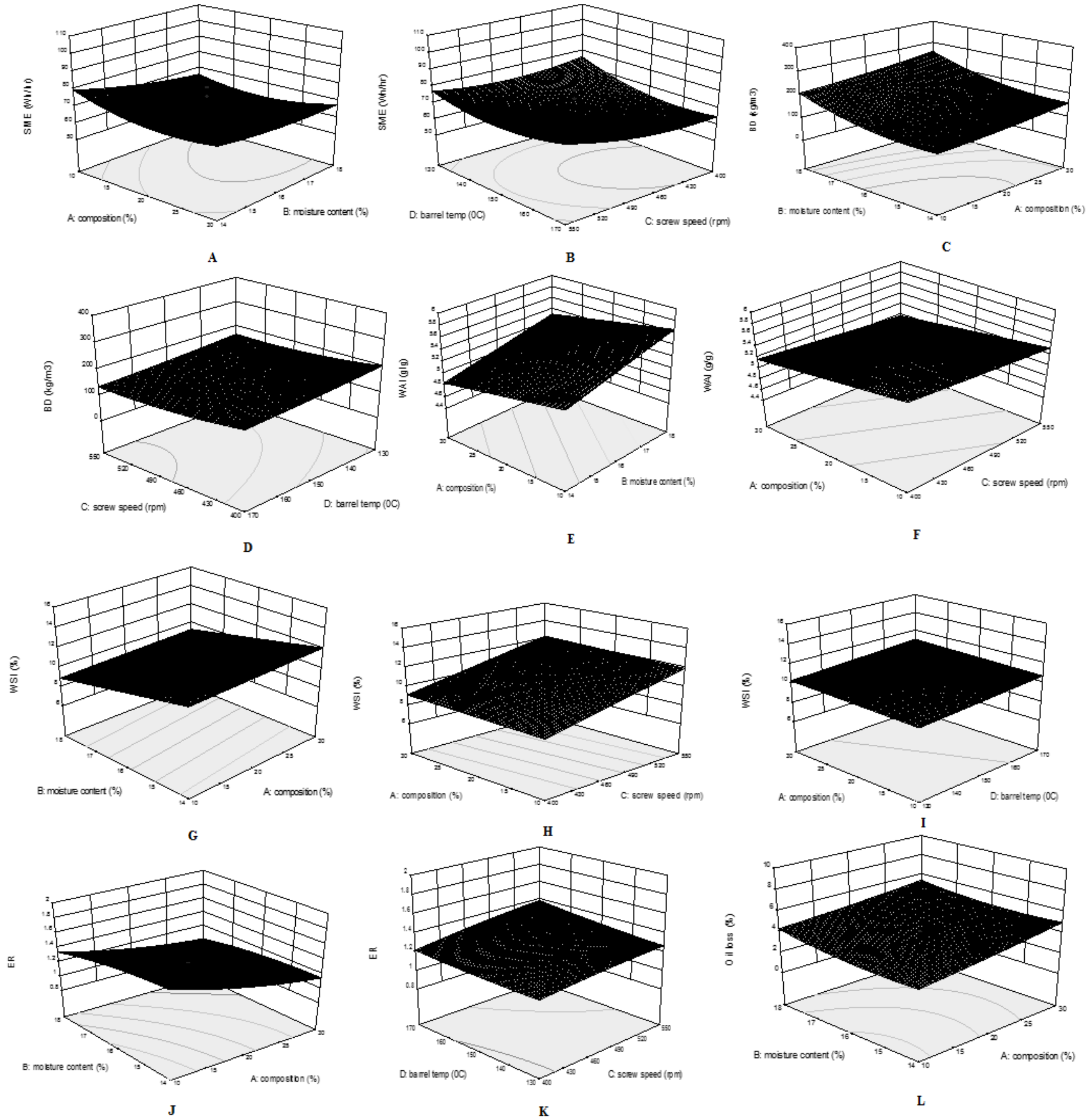
Any variable affecting the viscosity of the food melt in the extruder could correspondingly affect SME (Akdogan 1996) [2]. High moisture produces a lubricating effect resulting in less energy use and subsequently reduced SME. Higher temperature facilitates the transformation from solid flow to viscoelastic flow and starch gelatinization and reduces the melt viscosity which results in decreased SME. This phenomenon could also be attributed to increase of lipid fraction migration outside (Lerici *et al.* 1980) [22]. Increase in SME with increasing screw speed could be attributed to higher shear rates and is well documented in various extrusion based studies (Dogan and Karwe 2003; Altan *et al.* 2008) [12]. The fitted model and response surface plots shows that SME decreased slightly with the addition of walnut kernel level. Material with high lipid content lowers the SME value because of the lubricant role of lipid (Pilli *et al.* 2008) [32]. However, the quadratic effect of walnut kernel level had a significant ($p<0.01$) positive effect on SME. At higher levels of walnut kernel, the protein interaction effects may have had an increased contribution, therefore countering the effects of fat.

Bulk density The fitted regression model for BD is shown in equation 8 indicating quadratic effects with composition, moisture, screw speed and interactive effect with moisture and screw speed.

$$BD = 154 + 23.21\,C + 46.62M - 17.63S - 17.04\,T + 11.31MS + 5.97C^2 + 28.84M^2 + 12.84S^2 \quad (8)$$

Figure 1(c) and 1(d) shows the response surface plot of BD vs two independent variables with third and fourth taken at midpoint levels. The data depicted in table-3 indicates that BD ranged from 82 to 364kg/m^3. Feed moisture was the most dominant factor affecting the BD. The effect of feed moisture on extrusion process has been observed to complex. In this study, a quadratic effect of feed moisture on BD was found and the maximum BD (364kg/m^3) was observed when feed moisture was maximum (20%) (Table -3). The equation 8 indicates that BD increased significantly ($p<0.01$) with the increase in feed moisture and walnut kernel incorporation. The high dependence of BD on feed moisture reflects its influence on elastic characteristics of the material. High feed moisture content during extrusion reduces the elasticity of the dough through plasticization of the melt, resulting in reduced SME and therefore reduced gelatinization, decreasing the expansion and increasing the BD of extrudates (Mercier and Feillet 1975). The significant positive effect of walnut kernel incorporation on BD could be due to high protein (15.20%) and fat (65%) contents in walnut kernels which may have affected the extent of starch gelatinization and thus the rheological properties of the melted material in the extruder. Further, the dietary fiber content of walnut kernels is high (6.9%) compared to rice (0.96%). Therefore, walnut kernel incorporation reduces expansion during extrusion. The NSPs in fiber might bind water more tightly during extrusion than the starch. This binding might inhibit water loss at the die and thus reduce expansion and increase the bulk density. The other possible reason can be that as the walnut kernel incorporation increases during extrusion, the starch may not gelatinize fully due to high dietary fiber content in walnut kernels which reduces the expansion and thereby increases bulk density (Camire and King, 1991).

BD relationship with temperature and screw speed was somewhat flat showing minimum, but significant (p<0.01) interactions with both barrel temperature and screw speed contributing to a lower BD (equation 8). Seker 2005 [35]; Hagenimana and Fang 2006 reported similar results. High screw speed and barrel temperature results in more gelatinization of starch during extrusion. Case *et al.* 1992 reported that with the increase in starch gelatinization, the volume of the extrudates increases the BD decreases. Higher temperature provides higher potential energy for flash-off of super-heated water from extrudates as they may leave the die. The extrudates thus exiting from die hole become lighter in weight due to moisture loss. Increase in screw speed increases the shearing effect which stretches apart the starch and protein molecules causes more puffing of the extrudates with lower BD. However, Sun and Muthukumarappan 2002 found an increase in BD with an increase in screw speed but no explanation was provided. The significant (p<0.01) positive interactive effect of screw speed and moisture content (equation 8) indicates that effect of moisture content was dominating over screw speed. The quadratic effects of walnut kernel level, feed moisture and screw speed also had significant (p<0.01) positive correlations with BD.



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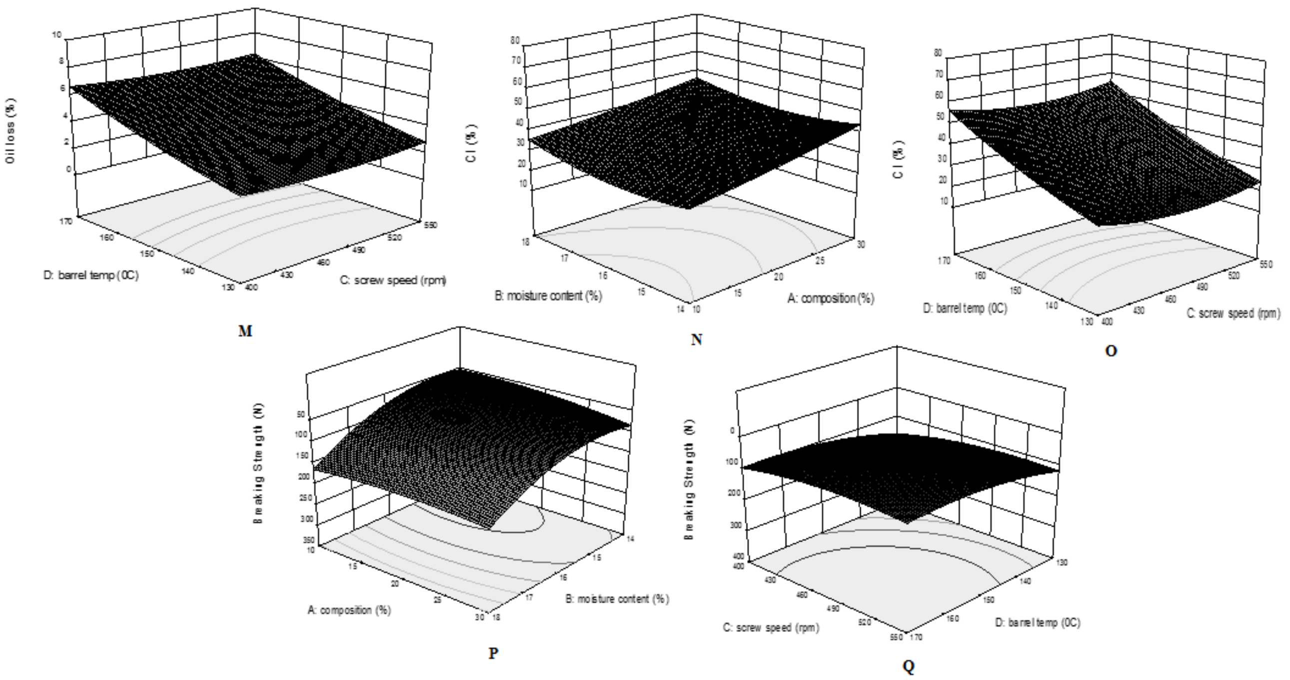

Fig 1: Response surface plots for the effect of composition, moisture, screw speed and barrel temperature on dependent variables

Water absorption index Water absorption index (WAI) indicates the hydrolytic breakdown of starch, swelling ability of starch components and extrusion induced fragmentation and macro molecular complex formations (Dogan and Karwe, 2003) [12]. WAI is an important attribute of extruded products as it determines ability of product to absorb liquid. The fitted regression equation for WAI shown in equation 9 shows that WAI was significantly ($p<0.01$) affected by walnut kernel incorporation, moisture content and screw speed. The effects were however only linear with these variables and no quadratic or interactive effects were observed.

$$WAI = 5.26 - 0.17C + 0.23M - 0.096S \qquad (9)$$

Figure 1(e) and 1(f) shows the response surface plot of WAI vs two independent variables at a time with the third and fourth taken at the midpoint levels. The data given in table-3 shows that WAI ranged from 4.6 to 5.83g/g. Out of four independent variables, the feed moisture was found again the most dominant factor for WAI. Maximum WAI value of 5.83g/g was noticed, when feed moisture was maximum (20%) (Table-3). The equation 9 demonstrates that WAI increased significantly ($p<0.01$) with the increase in feed moisture and decreased significantly ($p<0.01$) with the increase in walnut kernel incorporation and screw speed. Since, WAI is a gelatinization index, highly significant positive effect of feed moisture may be due to low viscosity of starch at high moisture, thereby extensive internal mixing and uniform heating during extrusion which would account for enhanced starch gelatinization (Sibel and Fahrettin 2008). Silva *et al.* (2009) and Baljit *et al.* (2015) also found positive correlation with moisture content and WAI. Decreasing effect of walnut kernel on WAI may be attributed to low starch content of walnut kernel which affects the gelatinization process in the barrel and thereby reduces the WAI. Earlier reports on non-starch component incorporation in extrusion process also showed a negative effect on WAI (Sibel and Fahrettin 2008; Subir *et al.* 2011). The negative correlation between WAI and screw speed (Equation 9) can be attributed to the residence time of feed formulation inside the barrel. Generally, as shear increases the dough becomes increasingly capable of forming a gel. Moreover faster screw speed tends to increase shear rate but decreases residence time leading to less gelatinized product. Sun and Muthukumarappan (2002) and Seker (2005) [35] however, did not find any significant effect of screw speed on water absorption of extrudates. In this study screw speed was found to be least important, but a significant factor for WAI, which is inconsistent with the findings already, reported by Liang *et al.* (2012) [24] for twin screw extrusion of corn flour and soy protein isolate.

Water solubility index (WSI) WSI- an indicator of degradation of molecular components measures the degree of starch conversion during extrusion which is the amount of soluble polysaccharides released from the starch component (Ding *et al.* 2006). The fitted regression model for WSI is shown in equation 10

$$WSI= 10.54 + 0.81C - 1.41M + 1.57S + 0.37T \qquad (10)$$

Figure 1(g), 1(h) and 1(i) shows the response surface plot of WSI vs two independent variables at a time with the third and fourth taken at the midpoint levels. The data depicted in table-3 shows that the WSI values for the extrudates ranged from 7.15 to 14.42 percent. The equation 10 demonstrates the prominent effect of screw speed on WSI, but in table -3, the maximum (14.42%) and minimum (7.15%) WSI values for run 18 and 14 indicate that the combined effect of all the four independent variables was much more severe on WSI than the screw speed alone. The equation shows that the barrel temperature, screw speed and walnut kernel level had significant ($p<0.01$) positive effects on WSI, while the feed moisture had a significant ($p<0.01$) negative effect on WSI. The WSI is contributed by the nature of the major components in the feed i.e. whether the carbohydrates and proteins are present in their native form or in gelatinized/denatured state. At lower feed moisture levels, it is possible that there is greater shear fragmentation of starch during extrusion. The higher feed moisture levels enhance the gelatinized starch percentage and can diminish protein denaturation and starch degradation. Similar effects have been reported by Onyango *et al.* 2004; Sibel and Fahrettin 2008. Higher WSI of extrudates with the increasing screw speed may be related to higher SME. The high mechanical shear causes breakdown of macromolecules to small molecules with higher solubility. Higher temperature would increase the degree of starch gelatinization that could increase the amount of soluble starch resulting in an increase in WSI. This was in concomitance with the trends already reported by Ding *et al.* 2006 and Baljit *et al.* 2015. It is evident from equation 10 that WSI increased with the increase in walnut kernel incorporation which may be due to decrease in starch content in the feed formulation. Similar results were reported by Normell *et al.* 2009 for soya protein fortified extrudates.

Expansion ratio The fitted model for ER is shown in equation 11 indicating quadratic effects with only moisture content.

$$ER = 1.27 - 0.20C - 0.10M + 0.063S + 0.040T - 0.041M^2 \qquad (11)$$

Figure 1(j) and 1(k) shows the response surface plot of ER vs two independent variables at a time with third and fourth taken at the midpoint levels. Table-3 shows that ER of extrudates varied between 0.941 to 1.898. Out of four independent variables, the composition was most dominant factor for ER. Maximum ER (1.898) was recorded at 0 percent walnut kernel level (i.e 100% rice flour). Several researchers have demonstrated that the ER of extruded cereals depends on the degree of starch gelatinization. The starch based material like rice is undoubtly an ideal candidate for extrusion processing. Addition of walnut kernel due to its low starch content (0.95%) and high dietary fiber content (6.9%) may affect the gelatinization process and thus expansion of the product (Jin *et al.* 1994). Further while extruding the material high in fat content, torque is decreased as the lipid reduces slip within the barrel and often product expansion is poor, because insufficient pressure is developed during extrusion (Singh *et al.* 2007). The equation 11 shows that feed moisture and walnut kernel level had significant ($p<0.01$) negative linear effects, while screw speed and barrel temperature had significant ($p<0.01$) positive linear effects on ER followed by significant ($p<0.01$) negative quadratic effect of feed moisture.

During extrusion processing the high feed moisture would change the molecular structure of amylopectin in starch based materials, which reduces the melt elasticity and decreases the radial expansion. The increasing effect of barrel temperature on ER could be probably due to more gelatinization of starch at high temperatures. Similar findings have also been reported by Dogan and Karwe 2003 [12] and Meng *et al.* 2010 [26]. Low screw speed, in other way more residence time in a co-rotating twin screw extruder might have induced the degradation of amylopectin networks in the material that changed the melt elasticity characteristics and reduced ER. This is in agreement with the findings reported by Samuel and Chatto padhyay, 1992. As the walnut kernel level was increased, ER was considerably decreased (Equation 11). This may be attributed to high protein (15.20%) and fat (65%) content of walnut kernels which affects expansion through their ability to effect water distribution in the matrix. Further, during extrusion of fat and starch rich blended materials, the formation of starch –lipid complexes is evident.

Oil loss during extrusion During extrusion of fat rich material, there occurs some loss of oil which is measured by difference of fat present in the material before extrusion and the fat present in the product after extrusion.

The fitted regression equation for oil loss is shown below in equation 12

$$\text{Oil loss} = 4.10 + 0.68C + 0.34M - 0.062S + 1.85T \qquad (12)$$

Figure 1(l) and 1(m) shows the response surface plot of oil loss vs two independent variables at a time with the third and fourth taken at midpoint levels. Table-3 shows that oil loss percentage during extrusion was in the range of 1.5 to 8.6. Out of four independent variables, the barrel temperature was most dominant factor for oil loss during extrusion processing. Maximum oil loss percentage of 8.6 was recorded at highest barrel temperature of 190^{0}C. It is expected that at high barrel temperature more lipids are lost at the die as free oils. Another explanation for maximum oil loss percentage can be the melting of starch-lipid complexes at high barrel temperature (Camire 2000). In equation 12, the positive coefficients of the linear terms of walnut kernel level, moisture and barrel temperature indicated that oil loss percentage increased significantly ($p<0.01$) with the increase in these variables; while as negative coefficient of screw speed indicated that oil loss percentage decreased significantly ($p<0.01$) with the increase in screw speed. High moisture produces a lubricating effect resulting in less energy use, reduced SME and subsequently increased oil loss percentage. High temperature reduces melt viscosity and hence SME by facilitating the transformation from solid flow to viscoelastic flow, which results in higher oil loss percentage during extrusion. The oil loss percentage was increased as the walnut kernel level was increased (equation 12). This could be attributed to high fat content (65%) of walnut kernels. Increase in screw speed results in higher shear, which gives higher SME and lower oil loss percentage during extrusion processing. This is in concomitance with the results reported by Pilli *et al.* 2008 [32].

Both oil loss and SME were negatively correlated (equation 7 and 12). The reason could be that lubricating effect of lipid lowers the mechanical energy with the increase of migration of oil outside. This was in concordance with the findings of Pilli *et al.*, 2008 [32].

Complexing index Complexing index (CI) measures the amount of starch which is not complexed with lipids. The fitted models for CI shown below in equation 13 indicates that CI was significantly affected by all the four independent variables.

$$CI = 34 + 6.29C + 2.04M - 0.38S + 15.54T + 0.56CT + 0.94MT \qquad (13)$$

Figure 1(n) and 1(o) shows the response surface plot of complexing index vs two independent variables at a time with the third and fourth taken at the midpoint levels. The data given in table-3 shows that complexing index varied between 15 to 72%. As in oil loss percentage the barrel temperature was the most dominant factor affecting the CI as well (equation 13). The lowest complexing index value of 15% was recorded at lowest barrel temperature of 110 ^{0}C. It could be related to formation of starch-lipid complexes at low temperature which could favour the retention of lipid fraction. However, the highest complex index value of 72% was noticed at highest barrel temperature of 190 ^{0}C (Table 3). It could be expected that high barrel temperature favours the melting of starch-lipid complexes which increases the oil loss percentage and hence CI.

The equation 13 shows that walnut kernel level, feed moisture and barrel temperature had significantly ($p<0.01$) positive linear effects, while screw speed had significantly ($p<0.01$) negative linear effect on complexing index. The interaction of temperature and walnut kernel level and moisture and temperature also had significant ($p<0.01$) positive effects on complexing index. The complexing index like oil loss seems to be influenced by starch-lipid complexes (Pilli *et al.*, 2008) [32]. The CI supported the oil loss results in our study. Similar results were found by Pilli *et al.*, 2008 [32] in almond snacks.

Breaking strength The fitted regression equation for breaking strength (BS) is shown in equation 14

$$BS = 69.90 + 7.25C + 46.24M - 14.59S - 25.10T + 36.87M^2 \qquad (14)$$

Figure 1(p) and 1(q) shows the response surface plot of breaking strength vs two independent variables at a time with the third and fourth taken at the midpoint levels. Table-3 shows that breaking strength of extrudates was in the range of 50 to 305.6 newtons (N). Out of four independent variables, the feed moisture was found again the most dominant factor for breaking strength. Maximum breaking strength of 305.6 N was recorded, when feed moisture was maximum (20%) (Table-3). In equation 14, the positive coefficients of the linear terms of composition and moisture indicates that breaking strength of extrudates increased significantly ($p<0.01$) with the increase in these variables, while as negative coefficients of the linear terms of screw speed and barrel temperature indicates that breaking strength of extrudates decreased significantly ($p<0.01$) with the increase in these variables. The quadratic effect of feed moisture also had significant ($p<0.01$) positive correlation with breaking strength. Increase in hardness with the increase in moisture might be due to the reason that water acts as a plasticizer reduces viscosity and mechanical energy dissipation in the extruder and thus the product becomes dense and bubble growth gets compressed. Similar positive relation between moisture and breaking strength was also observed by Ding *et al.* 2006; Altan *et al.* 2008. The increasing effect of walnut kernel level on hardness as found in this study could be attributed to the reduced expansion due to high protein and fat content of walnut kernels. This is the agreement with the findings of Li *et al.* 2005; Normell *et al.* 2009. Hardness decreased with the increase in screw speed and barrel temperature (equation 14). It is expected that increasing screw speed as well as temperature would decrease the melt viscosity, which favours the bubble growth and produces low density products with small and thin cells, thus increasing the crispness of extrudates. This results in a lower BD and hence lowers the hardness of extrudates. The decrease in hardness with the increase in screw speed was also observed by Liu *et al.* 2000 [25]; Altan *et al.* 2008 [33]. In high fat extrudates the decrease in BS for high barrel temperature can be attributed to fusion of starch-lipid complexes (Colonna and Buleon 1994). The decrease in hardness with the increase in temperature has previously been reported by Altan *et al.* 2008 [33]; Liang *et al.* 2012 [24] also.

Optimization and Validation

The desirability function of the response surface for obtaining optimal conditions in extrusion processing of rice-walnut kernel blend is shown in figure 2. By applying the desirability function method, and covering our criteria, the best solution obtained for extrusion cooking of rice-walnut kernel blended flour was selected. The desirability value obtained was 0.71 (Figure 2) and optimum walnut kernel incorporation level, feed moisture, screw speed and barrel temperature were estimated as 10%, 14%, 550 rpm and 170 ^{0}C, respectively. By applying these optimal conditions, the walnut kernel incorporated rice based extruded snacks with BD equal to 82 kg/m^3, WAI 5.1%, WSI 14.4 g/g, ER 1.70, complexing index 50%, oil loss 6%, breaking strength 50 N and SME 88.7 Wh/kg were produced.

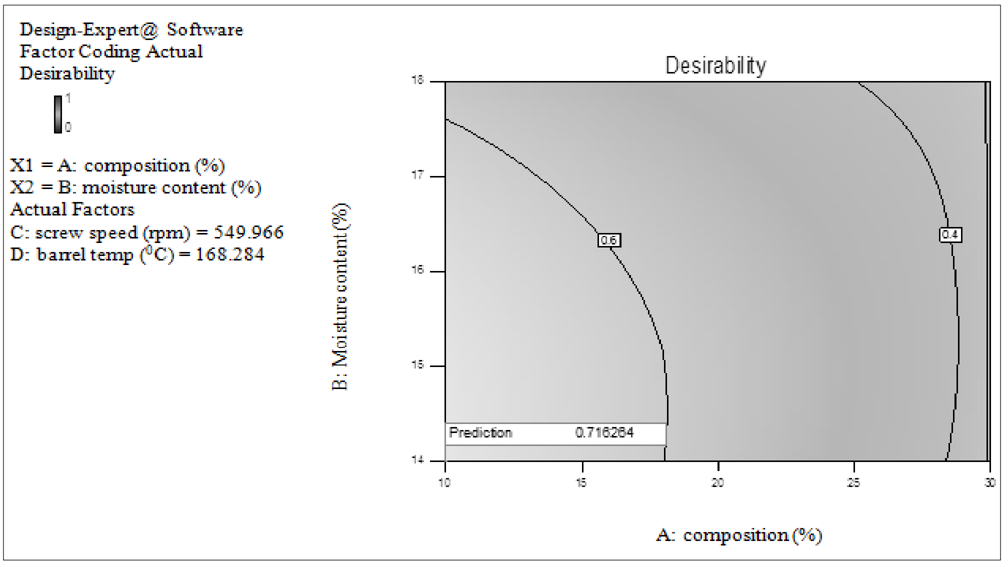

Fig 2: Desirability function response surface for walnut kernel incorporated rice based extrudates

It can be noted from table 5 that predicted response values and actual obtained response values were almost similar and variations were within acceptable limit of 4%. The extruded snack food prepared by using optimized condition was analyzed for proximate composition. The moisture content was found to be 3.42%, protein 9.5%, fat 3.3%, ash 0.6%, starch 58%, and dietary fiber 1.56%. The energy value of the optimized extruded snack food was estimated as 389.2 kcal/kg. The consumer acceptability results depicted in table 6 shows that the mean overall acceptability score of the optimized product was 3.6 (very good) on 4-point scale.

Table 5: Predicted response levels and actual response levels

Values	SME Wh/kg	Bulk density (kg/m^3)	WAI (%)	WSI (%)	Expansion ratio	Complexing index (%)	Oil loss (%)	Breaking Strength (N)
Predicted values	90.3	81.5	5.3	13.9	1.74	48.5	5.8	52
Actual values	88.7	82.0	5.1	14.4	1.70	50.0	6.0	50.0
Variation (%)	1.77	0.61	3.77	3.59	2.29	3.09	3.44	3.84

Table 6: Consumer acceptability score for final product

Color	Flavor	Texture	Appearance	Overall acceptability
3.4	3.6	3.7	3.8	3.6

* on 4 point scale
n= 400, the scores are average values of 400

Conclusion

Response surface methodology revealed significant (p<0.01) effects of all the four independent variables (composition, feed moisture, screw speed and barrel temperature) on the system parameter and product characteristics of twin screw extruded broken rice and walnut kernel flour blends. Further, the regression models for all the responses were highly significant (p<0.01) with high coefficient of determination (R^2>0.83) which confirms the validity of models for providing adequate information regarding the behavior of the responses upon variation in processing variables. Within the experimental range, feed moisture was found a dominant factor for SME, BD, WAI and breaking strength whereas for WSI and ER, the screw speed and feed composition were the dominating factor, respectively. However, out of four independent variables, the barrel temperature was found to be the most dominating factor for oil loss and complexing index. The optimum conditions obtained by numerical optimization for development of walnut-kernel incorporated rice based extruded snacks were found as rice flour:walnut kernel flour (90:10), feed moisture content (14%), screw speed (550 rpm) and barrel temperature (170 ^{0}C).

The present study confirms the feasibility of developing nutritious snack food from walnut kernels by extrusion processing. This will open a new horizon for development of high-energy and nourishing products from locally available fatty flours by extrusion technology. Large scale production of these extruded products could be adopted for improvement of nutritional status in developing countries.

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