

# Optimization of Extrusion Process Parameters for Red Lentil-carrot Pomace Incorporated Ready-to-eat Expanded Product Using Response Surface

Md. Shafiq Alam<sup>\*</sup>, Sunil Kumar

Department of Processing and Food Engineering, Punjab Agricultural University, India

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**Abstract** For optimization of extrusion process for development of red lentil-carrot pomace incorporated ready-to-eat rice based expanded product, experiments were planned in Box-Behnken design using response surface methodology. The independent process variables for extrusion were feed moisture content (14-20%), die temperature (120-180°C), screw speed (300-500 rpm) and formulation (rice flour: pulse flour; 60-80%: 10-30%) with constant proportion of carrot pomace powder (10%). Second order polynomials were used to model the extruder responses, functional and physical properties as a function of extrusion process variables. The extrusion process was optimized for maximum expansion ratio, water absorption index, overall acceptability and minimum bulk density, water solubility index, specific mechanical energy and hardness with in experimental range. The optimum extrusion process conditions obtained were 80:10:10 (rice flour: pulse flour: carrot pomace powder), 14% feed moisture content, 394 rpm screw speed and 120°C die temperature. An analysis of variance (ANOVA) revealed that among the process variables, feed moisture content followed by screw speed had the most significant effect on all the responses; screw speed had the significantly higher effect on specific mechanical energy. The proportion of red lentil and carrot pomace in rice based expanded product was observed to have significantly lower effect on the selected responses.

**Keywords** Extrusion Technology, Ready-to-eat Snacks, Optimization, Carrot Pomace

## 1. Introduction

Fruit and vegetable wastes are inexpensive, available in large quantities, characterized by a high dietary fibre content resulting with high water binding capacity and relatively low enzyme digestible organic matter (Serena and Knudsen, [33]). A number of researchers have used fruits and vegetable by-products such as apple, pear, orange, peach,

blackcurrant, cherry, artichoke, asparagus, onion, carrot pomace (Nawirska and Kwasnievska, [31]; Grigelmo-Miguel and Martin-Belloso, [20]; Ng *et al.*, [32]) as sources of dietary fibre supplements in refined food.

The total production of carrot and turnips in the world during the year 2011 was estimated as 35.658 million tons (FAO, [19]). The carrot (*Daucus carota*) is a root vegetable, usually orange, purple, red, white or yellow in color, with a crisp texture when fresh. It is a rich source of-carotene and contains other vitamins, like thiamine, riboflavin, vitamin B-complex and minerals (Walde *et al.*, [37]). Carrot pomace is a byproduct obtained during carrot juice processing. The juice yield in carrots is only 60-70%, and even up to 80% of carotene may be lost with left over carrot pomace (Bohm *et al.*, [10]). The carrot pomace has good residual amount of all the vitamins, minerals and dietary fibre. So far the left over pomace, received after juice extraction of carrots, does not find proper utilization. Moreover, vegetable pomace has become a source of environmental problem. The pomace is quite perishable as it contains about  $88 \pm 2\%$  of moisture. However, dried carrot pomace has carotene and ascorbic acid in the range of 9.87 to 11.57 mg and 13.53 to 22.95 mg per 100 g, respectively (Upadhyay, [35]). Due to the high dietary fibre content, carrot pomace can be used to develop products that could supplement fibre in the diet of people. A promising way to store the carrot pomace is in dried form and utilize it in the development of bakery products specifically extrudates, which are becoming more popular than other bakery products in ready to eat food category.

Extrusion cooking is a versatile and efficient method of converting raw materials into finished food products. It can replace many conventional processes in food and feed industry due to its uniqueness, versatility, high productivity, low operating cost, energy efficiency, high quality of resulting products and an improvement in digestibility and biological value of proteins. Extrusion cooking has been widely used in formation of various types of product. However, the incorporation of fruit and vegetable wastes and pulses in rice based extruded products to make a healthy nutritious snack is still not fully explored.

The broken rice is a byproduct of modern rice milling process. The rice portion can have varying percentages (5-7%) of broken kernels which contain nutritive value similar to whole rice and are available readily at relatively lower cost. Rice contains approximately 7.3% protein, 2.2% fat, 64.3% available carbohydrate, 0.8% fiber and 1.4% ash content (Zhou *et al.*, [39]). Rice flour has become an attractive ingredient in the extrusion industry due to its bland taste, attractive white color, hypo-allergenicity and ease of digestion (Kadan *et al.*, [25]).

The extruded products which are high in fiber content could be improved in its overall nutritional content and taste by incorporation of protein rich ingredients. Among other materials, incorporation of legume flour has positive impact on levels of proteins and dietary fiber of extruded snacks (Berrios, [8]). The pulses in the extruded product can pave the way for a snack which is rich in both fiber and protein contents. The lentil (also known as red dhal, massar, masuri, till seed and split pea) is an important legume crop in developing countries, grown annually in semi-arid regions of the world and exclusively used in human food and is mainly produced in Asia and the Middle East. Lentils contain dietary fiber, folate, vitamin B1, calcium, phosphorus and potassium, along with oleic, linoleic and palmitic acid (Adsule, [2]). The nutritional characteristics of lentil have been associated with cholesterol and lipid lowering effects in humans, along with reducing the incidence of colon cancer and type-2 diabetes (Agriculture and Agri-Food Canada, [3]).

Extruded products based on wheat flour, rice flour, maize grits, barley flour and their combinations have been widely developed by the extrusion industry but the incorporation of by-products (waste) from different fruit and vegetable processing industries has opened a new hope for their utilization as well as development of nutritionally sound extruded products. Altan *et al.*, [5] processed the blends of barley flour and tomato pomace; barley flour and grape pomace and corn flour and tomato pomace in a co-rotating twin-screw extruder. Some work on change in physical and functional properties of extrudates with change in extrusion process variables have been reported (Ali *et al.*, [1]; Carvalho and Mitchell, [11]; Ding *et al.*, [15]; Yagci and Gogus, [38]; Altan *et al.*, [5]). Such studies are lacking for carrot pomace and red lentil incorporated extruded product. Thus, the present investigation was undertaken with the objectives to study the effect of extrusion process parameters on quality of red lentil-carrot pomace incorporated ready-to-eat expanded product and to model and optimize the extrusion process for the developed extrudates using response surface methodology.

## 2. Materials and Methods

### 2.1. Experimental Design

A four factor three level Box-Behnken experimental

design of Response surface methodology (RSM) was used for the study (Ding *et al.*, [16]; Montgomery, [29]; Altan *et al.*, [5]; Yagci and Gogus, [38]). The parameters and their levels were chosen based on the literature available on rice based extrudates (Ding *et al.*, [16]; Upadhyay, [35]; Yagci and Gogus, [38]; Ibanoglu *et al.*, [22]). For development of ready-to-eat snack, the ingredients used were: Rice flour; pulse flour (Red lentil), carrot pomace flour and salt. The independent variables were the proportion of pulse flour in rice flour (10-30%), feed moisture content (14-20%), screw speed (300-500 rpm) and die temperature (120-180°C). Response variables were expansion ratio, bulk density, water absorption index, water solubility index, specific mechanical energy, hardness and overall acceptability.

### 2.2. Sample Preparation

For development of red lentil-carrot pomace based ready-to-eat snack, the ingredients were: Rice flour; pulse flour (Red lentil), carrot pomace flour and salt. The carrot pomace left after juice extraction was pretreated with 1% w/v citric acid prior to drying. The pretreated pomace was dried at 65°C in a tray dryer upto desired moisture content of 6.0% d.b. The dried pomace was grinded to flour using grinder (Make: Sujata 750 W). The pomace flour was stored in sealed laminated aluminum films for further use.

The rice and pulse samples were procured from local market in Ludhiana, Punjab, and were grinded to form flour. The raw samples obtained for each extrusion experiment were prepared as per the experimental combinations (Table 1). In order to enhance the nutritional quality and taste, 10% carrot pomace flour and 2 % salt was added to each experimental sample. The moisture was adjusted by sprinkling distilled water in dry ingredients. After mixing, samples were packed in polyethylene bags at room temperature for 24 h (Stojceska *et al.*, [34]). The moisture content of all the samples were determined by halogen moisture analyzer prior to extrusion experiments.

### 2.3. Extrudates Preparation

A laboratory scale co-rotating twin-screw extruder with intermeshing (Model BC2; Cletral, Firminy Cedex, France) was used for extrusion study. The barrel diameter and its length-to diameter (L/D) were 2.5 mm and 16:1, respectively. The extruder had 4 barrel zones. Temperature of the first, second and third zone were maintained at 40, 70 and 100°C respectively throughout the experiments, while the temperature at last zone (compression and die section) was varied according to the experimental design. The diameter of die opening was 6 mm. The extruder was equipped with a torque indicator, which showed present of torque in proportion to the current drawn by the drive motor. 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. A variable speed die

face cutter with four bladed knives was used to cut the extrudates. The twin screw extruder was kept to stabilize the set temperatures and samples were then poured into feed hopper and the feed rate was adjusted according to study. The product was collected at the die end and kept at  $60 \pm 0.5^\circ\text{C}$  in hot air oven for 1 h duration to remove extra moisture from the product. The samples were packed in polythene bags for further analysis.

## 2.4. Product Quality Responses

### 2.4.1. Bulk Density of Extrudates

Bulk density (BD, g/cm<sup>3</sup>) of extrudates was determined by using average diameter and an average length of 25 extrudate samples and calculated using following expression (Stojceska *et al.*, [34])

$$BD = 4m / \pi d^2 L$$

Where, m is mass in g; L is length in cm and d is diameter in cm of extrudates.

**Table 1.** Experimental data of extruded product for response surface analysis

S.NO.		Independent variables							Responses						
Proportion (Rice: PF: CPF)		SS (rpm)		DT ( $^\circ\text{C}$ )		FMC (%)		BD (Kg/cm <sup>3</sup> )	ER	SME (Wh/kg)	OA (%)	WAI	WSI (%)	Hardness (Kg)	
Coded	Actual	Coded	Actual	Coded	Actual	Coded	Actual	Y <sub>1</sub>	Y <sub>2</sub>	Y <sub>3</sub>	Y <sub>4</sub>	Y <sub>5</sub>	Y <sub>6</sub>	Y <sub>7</sub>	
1	0	70:20:10	0	400	0	150	0	17	0.428	2.140	14.17	61.11	4.19	7.10	149.407
2	0	70:20:10	0	400	-1	120	-1	14	0.282	2.674	11.72	83.33	4.63	8.80	110.081
3	-1	60:30:10	-1	300	0	150	0	17	0.443	2.194	12.78	59.26	3.68	7.20	173.21
4	0	70:20:10	0	400	0	150	0	17	0.388	2.259	13.17	68.52	4.05	8.60	194.31
5	0	70:20:10	-1	300	-1	120	0	17	0.399	2.330	9.02	48.15	3.84	6.40	107.556
6	-1	60:30:10	0	400	0	150	-1	14	0.310	2.505	15.00	72.22	4.19	8.80	179.442
7	0	70:20:10	0	400	0	150	0	17	0.366	2.320	14.17	68.52	4.06	8.60	170.022
8	0	70:20:10	-1	300	0	150	1	20	0.431	2.185	11.67	66.67	3.76	7.20	125.803
9	-1	60:30:10	1	500	0	150	0	17	0.301	2.540	15.28	79.63	4.26	8.90	177.925
10	1	80:10:10	0	400	-1	120	0	17	0.242	2.240	10.28	57.41	3.82	6.00	128.304
11	1	80:10:10	-1	300	0	150	0	17	0.442	2.176	12.50	55.56	4.78	4.80	130.811
12	0	70:20:10	0	400	1	180	1	20	0.381	2.131	11.39	77.78	4.12	8.80	149.212
13	-1	60:30:10	0	400	0	150	1	20	0.417	2.230	12.61	64.81	3.65	6.40	112.508
14	0	70:20:10	0	400	-1	120	1	20	0.430	2.292	13.89	61.11	3.65	5.90	59.897
15	0	70:20:10	-1	300	1	180	0	17	0.420	2.004	11.28	61.11	4.19	8.60	144.449
16	1	80:10:10	0	400	0	150	-1	14	0.363	2.389	16.24	74.07	4.50	7.80	185.323
17	-1	60:30:10	0	400	-1	120	0	17	0.401	2.446	16.56	64.81	3.72	10.60	115.324
18	0	70:20:10	1	500	1	180	0	17	0.262	2.473	14.17	88.89	4.41	8.60	175.957
19	0	70:20:10	1	500	-1	120	0	17	0.387	2.468	15.95	64.81	4.07	9.20	138.432
20	1	80:10:10	0	400	0	150	1	20	0.483	2.036	12.78	68.52	4.17	7.00	164.694
21	1	80:10:10	0	400	1	180	0	17	0.353	2.305	13.89	77.78	4.49	6.80	192.223
22	0	70:20:10	0	400	1	180	-1	14	0.253	2.453	13.61	90.74	4.68	8.00	171.056
23	1	80:10:10	1	500	0	150	0	17	0.233	2.420	14.44	85.19	4.50	9.00	179.869
24	0	70:20:10	1	500	0	150	1	20	0.422	2.168	12.11	70.37	4.54	4.80	151.078
25	0	70:20:10	1	500	0	150	-1	14	0.307	2.512	16.67	92.59	4.65	10.60	161.156
26	-1	60:30:10	0	400	1	180	0	17	0.307	2.434	13.61	79.63	4.09	10.80	186.402
27	0	70:20:10	-1	300	0	150	-1	14	0.325	2.418	14.17	68.52	4.56	6.60	154.828

#### 2.4.2. Water Absorption Index (WAI) and Water Solubility Index (WSI) of Extrudates

Water Absorption Index (WAI) was determined according to the method suggested by Kaur & Singh, [26]. A  $2.0 \text{ g} \pm 0.005 \text{ g}$  sample was placed in a tare centrifuge tube and 20 ml distilled water added. After keeping for 15 min (with intermittent shaking every 5 min), the sample was centrifuged at 4000 rpm for 15 min. The supernatant was decanted into a tare aluminum pan and weight gain in the gel was noted. Water absorption index (WAI) was calculated as the increase in weight of sediment obtained after decanting the supernatant as:

$$\text{WAI} = \frac{\text{Weight of wet sediment (g)}}{\text{Weight of dried sediment (g)}}$$

The supernatant was evaporated to dryness at  $105^\circ\text{C}$  until constant weight. Water solubility index (WSI) was determined as (Anderson, *et al.* [7])

$$\text{WSI (\%)} = \frac{\text{Weight of dried supernatant (g)} \times 100}{\text{Weight of dried sample (g)}}$$

#### 2.4.3. Specific Mechanical Energy

Specific mechanical energy, the mechanical energy input per unit mass of the extrudate, was calculated by dividing the net power input to the screw by the extrudate flow rate. SME input was calculated by the following equation.

$$\text{SME (Wh/kg)} = \frac{\text{Screw speed} \times \text{torque}}{\text{mass flow rate}}$$

Torque was recorded every 6 s for at least 12 min and SME was calculated and averaged for each processing condition.

#### 2.4.4. Expansion Ratio

The ratio of diameter of extrudate and the diameter of die was used to express the expansion of extrudate (Fan *et al.*, [18]). The diameter of extrudate was determined as the mean of 10 random measurements made with a Vernier caliper. The extrudate expansion ratio was calculated using the expression as given below

$$\text{Expansion Ratio} = \frac{\text{Extrudate Diameter}}{\text{Die Diameter}}$$

#### 2.4.5. Hardness

Mechanical properties of the extrudates were determined by crushing method using a TA-XT2i (Stable Micro-Systems, Surrey, England) with a compression plate p75. The tests were conducted at pre-test speed of 1.0 mm/sec, test speed of 5 mm/sec, post-test speed of 5 mm/s, strain- 25%, and trigger force of 0.4903 N and load cell of 50kg.

An extrudate was compressed with a probe SMS-P/75-75 mm diameter at a crosshead speed 5 mm/s to 3 mm of 90% of diameter of the extrudate. The compression generated a curve with the force over distance. The highest first peak value was recorded as this value indicated the first rupture of

snack at one point and this value of force was taken as a measurement for hardness (Stojceska *et al.*, [34]).

#### 2.4.6. Sensory Evaluation

Sensory quality of extrudates sample was determined with the help of 10 semi trained consumer panelist using a 9-point Hedonic scale (9-liked extremely to 1-disliked extremely) method described by Amerine *et al.*, [6]. The aspects considered were color, appearance, taste, flavor and overall acceptability (OA). OA was evaluated as an average of color, appearance, taste and flavor. The average scores of all the 10 panelists were computed for different characteristics.

### 2.5. Optimization of Process Parameters

Response surface methodology was applied to the experimental data using a commercial statistical package, Design-Expert version 8.0.7.1 (Statease Inc, Minneapolis, USA, Trial version). The same software was used for the generation of response surface plots, superimposition of contour plots and optimization of process variables. The response surface and contour plots were generated for different interaction for any two independent variables, while holding the value of other two variables as constant (at the central value). Such three-dimensional surfaces could give accurate geometrical representation and provide useful information about the behavior of the system within the experimental design (Cox *et al.*, [14]). The optimization of the extrusion process aimed at finding the levels of independent variables viz. Moisture content, Screw speed, Die temperature, and rice flour, which could give maximum expansion ratio, water absorption index and overall acceptability; and minimum bulk density, water solubility index, specific mechanical energy and in range hardness. Desirability, a mathematical method was used for selecting the optimum process values. For several responses and factors, all goals get combined into one desirability function. The numerical optimization finds a point that maximizes the desirability function.

## 3. Results and Discussion

The value of various responses at different experimental combinations for coded variables is given in Table 1. A wide variation in all the responses was observed for different experimental combinations i.e. 0.233 to  $0.483 \text{ kg/cm}^3$  for BD, 2.004 to 2.673% for ER, 9.02 to 16.67Wh/kg for SME, 3.65 to 4.78 for WAI, 4.8 to 10.8 for WSI 59.896 to 194.31N for hardness, and 48.15 to 92.59 for OA. Maximum consumer acceptance was recorded for the sample developed at experimental condition of 14% FMC, 70% Rice flour, and  $150^\circ\text{C}$  DT at maximum SS (500 rpm).

**Table 2.** Analysis of variance of linear, quadratic and interactive terms of extrusion process variables on responses

Term	Sum of squares						
	BD (Kg/cm <sup>3</sup> )	ER	SME (Wh/kg)	WAI	WSI	Hardness (kg)	OA (%)
Model	9.815 × 10 <sup>-2</sup> *	0.595 × 10 <sup>-5</sup> *	70.218*	2.808*	53.064*	23156.59*	2930.379*
FMC	4.379 × 10 <sup>-2</sup> *	0.303*	13.996*	0.918*	9.187*	3289.923*	434.523*
SS	2.492 × 10 <sup>-2</sup> *	0.134*	24.653*	0.218*	8.840*	1819.414*	1244.607*
DT	2.291 × 10 <sup>-3</sup>	3.506 × 10 <sup>-2</sup> **	2.340 × 10 <sup>-2</sup>	0.421*	1.840	10782.29*	772.968*
Rice flour	3.305 × 10 <sup>-4</sup>	5.125 × 10 <sup>-2</sup> *	2.717	0.594*	10.64*	110.4888	0.279
FMC * SS	2.250 × 10 <sup>-5</sup>	3.033 × 10 <sup>-3</sup>	1.060	0.119**	10.24*	89.75632	103.734**
FMC * DT	9.220 × 10 <sup>-5</sup>	9.024 × 10 <sup>-4</sup>	4.818	4.410 × 10 <sup>-2</sup>	3.422	200.7903	21.436
FMC * Rice flour	4.573 × 10 <sup>-5</sup>	1.527 × 10 <sup>-3</sup>	0.286	1.102 × 10 <sup>-2</sup>	0.64	536.0241	0.864
SS* DT	5.346 × 10 <sup>-3</sup>	2.737 × 10 <sup>-2</sup>	4.080	2.500 × 10 <sup>-5</sup>	1.96	0.10015	30.913
SS* Rice flour	1.125 × 10 <sup>-3</sup>	2.556 × 10 <sup>-3</sup>	7.840 × 10 <sup>-2</sup>	0.184*	1.562	491.5732	21.436
DT * Rice flour	1.060 × 10 <sup>-2</sup> **	1.444 × 10 <sup>-3</sup>	10.758*	2.250 × 10 <sup>-2</sup>	0.09	12.81358	7.700
FMC * FMC	1.106 × 10 <sup>-4</sup>	1.078 × 10 <sup>-2</sup>	4.005 × 10 <sup>-2</sup>	9.187 × 10 <sup>-2</sup>	1.493	1919.127*	257.088*
SS*SS	3.798 × 10 <sup>-4</sup>	5.418 × 10 <sup>-3</sup>	0.526	0.118	0.766	259.0742	2.579
DT * DT	8.655 × 10 <sup>-3</sup> **	3.161 × 10 <sup>-2</sup> **	4.300	9.633 × 10 <sup>-3</sup>	1.060	3264.994*	34.555
Rice flour * Rice flour	1.788 × 10 <sup>-3</sup>	6.575 × 10 <sup>-3</sup>	0.972	3.333 × 10 <sup>-3</sup>	0.057	201.752	1.142
Residual	3.127 × 10 <sup>-2</sup>	0.110	22.266	0.353	14.823	3777.257	384.537
Lack of fit	2.929 × 10 <sup>-2</sup>	9.349 × 10 <sup>-2</sup>	21.600	0.341	13.323	2766.862	347.931
Pure error	1.978 × 10 <sup>-3</sup>	1.694 × 10 <sup>-2</sup>	0.666	1.220 × 10 <sup>-2</sup>	1.5	1010.396	36.605
C.V. %	14.10	4.13	10.13	4.09	14.16	11.71	8.0
R <sup>2</sup>	0.758	0.8436	0.759	0.888	0.781	0.859	0.884

\*significant:(p≤0.05),\*\*significant(p≤0.1)

The data was analyzed using multiple regression technique. A linear model and a second order model with and without interaction terms for each responses were tested for their adequacies and R<sup>2</sup> values were calculated. A second order polynomial equation was fitted to the data for all the responses and the results are given in Table 2.

$$Y_k = \beta_0 + \sum_{i=1}^n \beta_i x_i + \sum_{i=1}^n \beta_{ii} x_i^2 + \sum_{i=1}^{n-1} \sum_{j=i+1}^n \beta_{ij} x_i x_j$$

Where,  $\hat{\alpha}_i$ ,  $\hat{\alpha}_{ii}$ ,  $\hat{\alpha}_{ij}$  are constant coefficient and  $x_i$ ,  $x_j$  are coded independent variables.

All models were tested for their adequacy using ANOVA technique. F-values for the lack of fit were found non-significant (p≤0.05) for each responses thereby confirming the validity of the models. Analysis of experimental values for responses revealed that BD, ER, SME, WAI, WSI, hardness, and OA witnessed 0.758, 0.843,

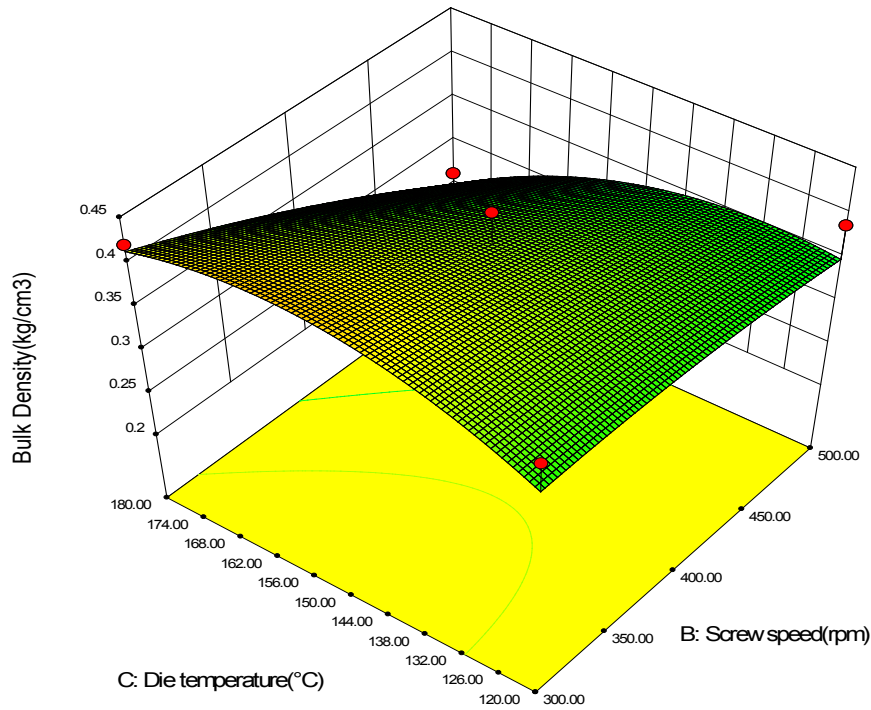
0.759, 0.888, 0.781, 0.859, and 0.884 coefficient of regression, respectively. Table 2 shows that the linear, quadratic as well as interaction model term significantly (p≤0.05) affected all the responses.

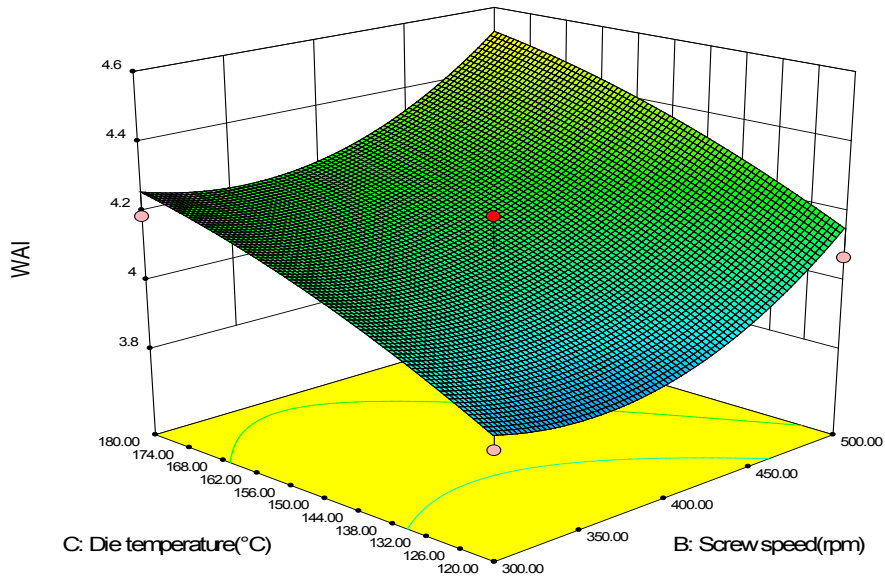
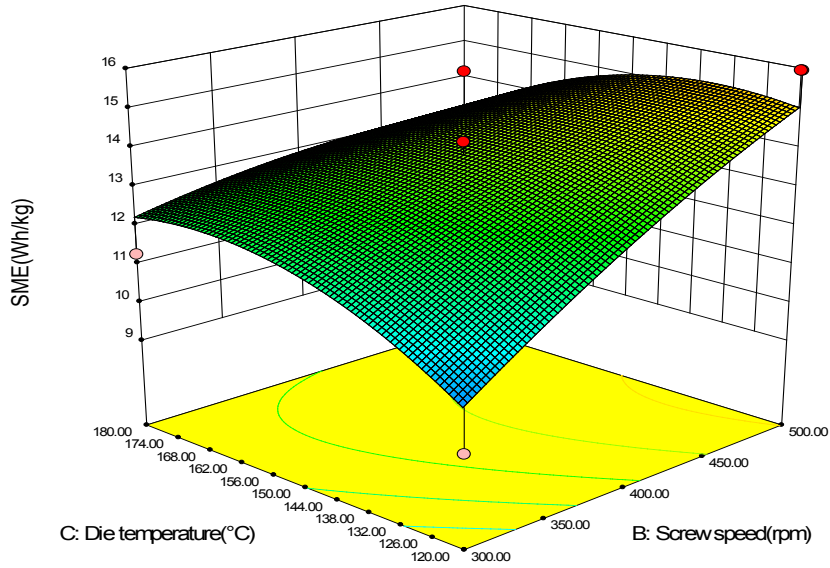
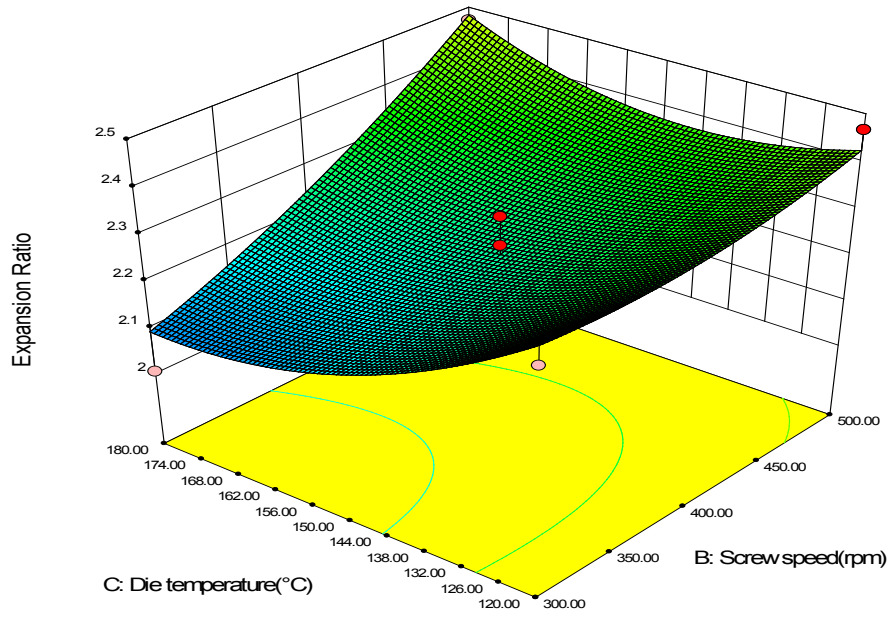
The results revealed the higher influence of FMC, SS and DT in comparison to Rice flour proportion, irrespective of the responses.

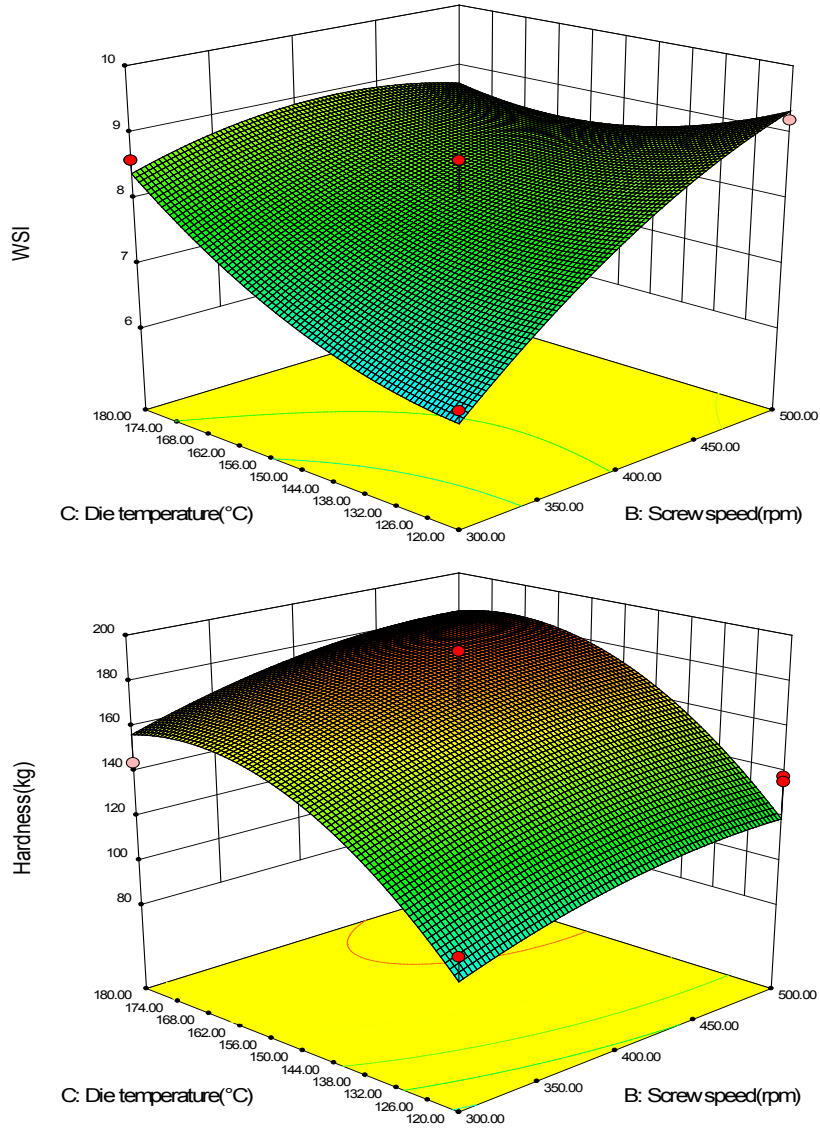
Second order model was fitted to the experimental data and regression coefficients were computed and are presented in Table 3. The sign and magnitude of coefficients indicate the effect of process variable on the response. Negative sign of the coefficient shows decrease while positive sign indicates increase in the response with the increase in variable level. Significant interaction suggests that the level of one of the interactive variable can be increased while the other decreased for constant value of the response (Montgomery [30]). Effect of variables on the selected quality parameters of extrudates are presented in Fig. 1&2.

**Table 3.** Regression coefficients (un-coded variables) of selected quadratic model and their significance

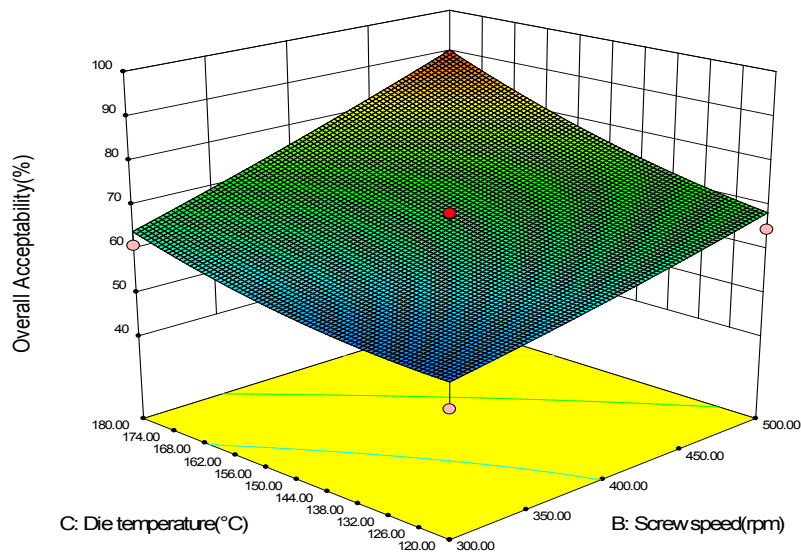
Term	Regression Coefficient	BD (kg/cm <sup>3</sup> )	ER	SME (Wh/kg)	WAI	WSI (%)	Hardness (kg)	OA (%)
Constant	β <sub>0</sub>	0.393	2.239	13.836	4.1	8.1	171.246	66.05
FMC	β <sub>1</sub>	6.041 × 10 <sup>-2</sup>	-0.159	-1.08	-0.276	-0.875	-16.557	-6.017
SS	β <sub>2</sub>	-4.557 × 10 <sup>-2</sup>	0.106	1.433	0.135	0.858	12.313	10.184
DT	β <sub>3</sub>	-1.381 × 10 <sup>-2</sup>	-5.406 × 10 <sup>-2</sup>	4.416 × 10 <sup>-2</sup>	0.1875	0.391	29.975	8.025
Rice flour	β <sub>4</sub>	-5.248 × 10 <sup>-3</sup>	-6.535 × 10 <sup>-2</sup>	-0.475	0.2225	-0.941	3.034	-0.152
FMC * SS	β <sub>12</sub>	2.372 × 10 <sup>-3</sup>	-2.754 × 10 <sup>-2</sup>	-0.515	0.1725	-1.6	4.736	-5.092
FMC * DT	β <sub>13</sub>	-4.801 × 10 <sup>-3</sup>	1.502 × 10 <sup>-2</sup>	-1.0975	0.105	0.925	7.085	2.315
FMC * Rice flour	β <sub>14</sub>	3.381 × 10 <sup>-3</sup>	-1.954 × 10 <sup>-2</sup>	-0.2675	5.25 × 10 <sup>-2</sup>	0.4	11.576	0.465
SS * DT	β <sub>23</sub>	-3.655 × 10 <sup>-2</sup>	8.272 × 10 <sup>-2</sup>	-1.01	-2.500 × 10 <sup>-3</sup>	-0.7	0.158	2.78
SS * Rice flour	β <sub>24</sub>	-1.677 × 10 <sup>-2</sup>	-2.528 × 10 <sup>-2</sup>	-0.14	-0.215	0.625	11.085	2.315
DT * Rice flour	β <sub>34</sub>	5.150 × 10 <sup>-2</sup>	1.9 × 10 <sup>-2</sup>	1.64	7.500 × 10 <sup>-2</sup>	0.15	-1.789	1.3875
FMC * FMC	β <sub>11</sub>	-4.554 × 10 <sup>-3</sup>	4.497 × 10 <sup>-2</sup>	-8.666 × 10 <sup>-2</sup>	0.131	-0.529	-18.969	6.942
SS * SS	β <sub>22</sub>	-8.439 × 10 <sup>-3</sup>	3.187 × 10 <sup>-2</sup>	-0.314	0.1487	-0.379	-6.969	0.695
DT * DT	β <sub>33</sub>	-4.028 × 10 <sup>-2</sup>	7.699 × 10 <sup>-2</sup>	-0.897	-4.25 × 10 <sup>-2</sup>	0.445	-24.742	2.545
Rice flour * Rice flour	β <sub>44</sub>	-1.831 × 10 <sup>-2</sup>	3.511 × 10 <sup>-2</sup>	0.427	-2.500 × 10 <sup>-2</sup>	-0.104	6.150	0.462







**Figure 1.** Effect of screw speed and die temperature on bulk density, expansion ratio, specific mechanical energy, water absorption index, water solubility index and hardness.



**Figure 2.** Effect of screw speed and die temperature on overall acceptability.



### 3.1. Effect of Extrusion Variables on Bulk Density

The regression analysis revealed that the regression model for bulk density was significant ( $P \leq 0.05$ ). The coefficient of regression being high ( $R^2 = 0.758$ ) and 'F-values' for the lack of fit being non-significant, thereby confirm the validity of the fitted model to the experimental data. Bulk density values for the extrudates were between  $0.233 \text{ kg/cm}^3$  and  $0.483 \text{ kg/cm}^3$ . The lowest BD value was obtained for the samples developed at SS (500 rpm), rice flour (80%) and DT ( $150^\circ\text{C}$ ) with 17% FMC whereas the highest BD value was obtained for the samples with maximum level of rice flour and FMC and  $150^\circ\text{C}$  DT at 400 rpm SS. Fig.1 shows the influence of DT and SS on BD. The BD decreased with the increase of SS and increased with the increase in DT at a certain level and then decrease slightly. However, BD increased with the increase in FMC and rice flour proportion. At a given DT ( $150^\circ\text{C}$ ), the BD was  $0.431 \text{ kg/cm}^3$  at 300 rpm,  $0.393 \text{ kg/cm}^3$  at 400 rpm and  $0.339 \text{ kg/cm}^3$  at 500 rpm SS. At 400 rpm SS, the BD first increased from  $0.367 \text{ kg/cm}^3$  at  $120^\circ\text{C}$  DT to  $0.393 \text{ kg/cm}^3$  at  $150^\circ\text{C}$  DT and then slightly decreased to  $0.339 \text{ kg/cm}^3$  at  $180^\circ\text{C}$  DT. The bulk density values decreased when the extrusion temperature and screw speed increased probably due to starch gelatinization. According to Case *et al.*, [12] and Mercier & Feillet [28], with advance in gelatinization, the volume of extruded product increases resulting in decrease in bulk density which is in agreement with our observations.

### 3.2. Effect of Extrusion Variables on Expansion Ratio

Table 2 clearly shows significant ( $P \leq 0.05$ ) regression model for expansion ratio witnessing higher ( $R^2 = 0.843$ ) coefficient of regression and non-significant lack of fit based on 'F-values' confirming the validity of the model. Fig.1 clearly shows the influence of DT and SS on ER. The values of ER had positive correlation with screw speed. At a constant die temperature of  $150^\circ\text{C}$  the ER at 300, 400 and 500 rpm screw speed were, 2.165, 2.239 and 2.377 respectively. While minor decreasing trend was observed with increasing die temperature at constant 400 rpm screw speed, the ER ranges from 2.370 at  $120^\circ\text{C}$  to 2.262 at  $180^\circ\text{C}$  (Fig.1). Similar trends were also noticed by others (Ilo *et al.*, [23]; Dogan & Karwe, [17]) suggesting the existence of temperature plateau for expansion, between  $150^\circ\text{C}$  and  $170^\circ\text{C}$ , depending on the type of food material. This phenomenon may be caused by excessive structure breakdown and starch degradation under high temperature, which weakened the extrudate structure resulting to its collapse. The linear as well as quadratic term of DT showed significant effect on ER and the values of ER were decreased with decrease FMC and Rice flour (Table 2).

### 3.3. Effect of Extrusion Variables on Specific Mechanical Energy

The regression model for SME was found to be significant

( $P \leq 0.05$ ). The coefficient of regression was moderately high ( $R^2 = 0.759$ ) and 'F-values' for the lack of fit were non-significant showing the adequacy of model to the experimental data. The SME of extrudates varied in the range of 9.02 Wh/kg to 16.67 Wh/kg with an average value of 13.449 Wh/kg. The maximum SME (16.67 Wh/kg) was found at 300 rpm SS,  $120^\circ\text{C}$  DT, 70 % rice flour with 17 % FMC while minimum SME (9.02 Wh/kg) was found at maximum 500 rpm SS,  $120^\circ\text{C}$  DT, 70 % rice flour with minimum FMC (14%). Fig.1 shows the effect of SS and DT on SME. SME increased with increase SS but decreased with increase FMC and rice flour composition and SME first increased and then slightly decrease with increase DT. At a constant  $120^\circ\text{C}$  DT, the SME were 10.137 Wh/kg at 300 rpm, 12.901 Wh/kg at 400 rpm and 15.023 Wh/kg at 500 rpm SS. At a given SS (400 rpm), the SME increased from 12.901 Wh/kg at  $120^\circ\text{C}$  DT to 13.836 Wh/kg at  $150^\circ\text{C}$  DT and then slightly decreased to 12.988 Wh/kg at  $180^\circ\text{C}$  DT. Similar result was found by (Meng *et al.*, [27]), that SME increased proportional to the screw speed, although a decrease in SME was also expected because melt viscosity would decrease with increase in SS. This result indicated that the effect of SS dominated the effect of melt viscosity thus witnessing decrease in SME (Jin *et al.*, [24]; Akdogan, [4]; Bhattacharya, [9]).

### 3.4. Effect of Extrusion Variables on Water Absorption Index

Table 2 shows the significance of regression model for WAI at  $p \leq 0.05$  witnessing 0.888 coefficient of regression ( $R^2$ ) and non-significant 'Lack of fit', indicating that the experimental values were in good agreement with the predicted values. The WAI of extrudates varied in the range of 3.65 and 4.78 with an average value of 4.19. WAI of the product increased with the increase in rice flour proportion whereas decreased with increase in FMC. Fig.1 shows the effect of SS and DT on WAI. The WAI slightly decreased with increase in SS at a certain level and then increased, while increasing trend was found with the increase in DT. At a given DT ( $120^\circ\text{C}$ ), the WAI slightly decreased from 3.88 at 300 rpm SS to 3.87 at 400 rpm SS and then increased to 4.16 at 500 rpm SS. At a constant SS (400 rpm), the WAI increased from 3.87 at  $120^\circ\text{C}$  DT to 4.245 at  $180^\circ\text{C}$  DT. Increasing trend may be due to the more heat generation and reduced particle size of rice flour which favors the starch gelatinization. Similar results have been reported by Valentina *et al.* [36]).

### 3.5. Effect of Extrusion Variables on Water Solubility Index

The results revealed that the regression model for WSI was significant at ( $P \leq 0.05$ ) witnessing moderately high ( $R^2 = 0.781$ ) coefficient of regression and non-significant 'lack of fit' (Table 2). The WSI of extrudates varied in the range of 4.1 to 10.8 with an average value of 7.85. Maximum

WAI (10.8) was found at 400 rpm SS, 17% FMC, 60% rice flour and 180°C DT, while minimum (3.65) was at 500 rpm SS, 20% FMC, 70% rice flour and 150°C DT. Fig.1 shows that WSI increased with increase SS and DT but decreased with increase FMC and rice flour. At a given DT (150°C), the WSI were 6.867 at 300 rpm SS, 8.1 at 400 rpm SS and 8.573 at 500 rpm SS. At a constant SS (400 rpm), the WAI increased from 8.1 at 150°C DT to 8.937 at 180°C DT. Similarly reported by Stojceska *et al.*, [34], WSI increased in apple with increase of barrel temperature and increased in carrot with increase screw speed. At a given rice flour (60%), the WAI decreased from 9.683 at 14% FMC to 7.133 at 20% FMC. At a constant FMC (17%), the WSI decreased from 8.935 at 60 % to 7.056 at 80% rice flour. Minimum WSI is favor property of ready- to-eat extrudates. Ilo *et al.*, [23] reported that the degree of gelatinization of extruded maize grits decreased with increasing feed moisture, and increased with increasing feed rate and product temperature.

### 3.6. Effect of Variables on Hardness

The regression model for hardness was significant at  $p \leq 0.05$  (table 2) recording coefficient of regression ( $R^2$ ) of 0.859. The hardness of extrudates varied in the range of 59.89 kg to 194.31 kg with an average value of 151.45. The die temperature significantly affected the hardness ( $p \leq 0.05$ ). The maximum hardness (194.31 kg) was noticed for the extrude developed at 400 rpm SS, 150°C DT, 70 % rice flour with 17 % FMC while minimum hardness (59.896kg) was observed for extrudate developed at 20% FMC, 400 rpm SS, 120°C DT and 70 % rice flour. The lower values of hardness which is favor property of extrudates. Fig.1 shows that with the increase in SS and DT, the hardness of the extrudate increases. At a given DT (120°C), hardness was 97.404 kg at 300 rpm, 116.876 kg at 400 rpm and 121.714 kg at 500 rpm of SS. At constant SS of 400 rpm, the hardness increased from 116.876 kg at 120°C to 176.57 kg at 180°C. Hardness slightly decreased first and then drastically increased with an increase in rice flour proportion and decreased with an increase in FMC. At a constant SS (400rpm) the hardness increased from 169.86kg at 14% FMC to 171.246 at 17% FMC and then decreased. Moreover, an increase in feed moisture content corresponds to an increase followed by decrease in hardness.

### 3.7. Effect of Variables on Overall Acceptability

Table 2 shows the regression model for OA was significant ( $p \leq 0.05$ ) with reasonably high coefficient of regression ( $R^2=0.884$ ) and non-significant lack of fit showing agreement with the experimental data. The OA of extrudates varied in the range of 48.15 to 92.59% with an average value of 70.78%. The maximum value was recorded

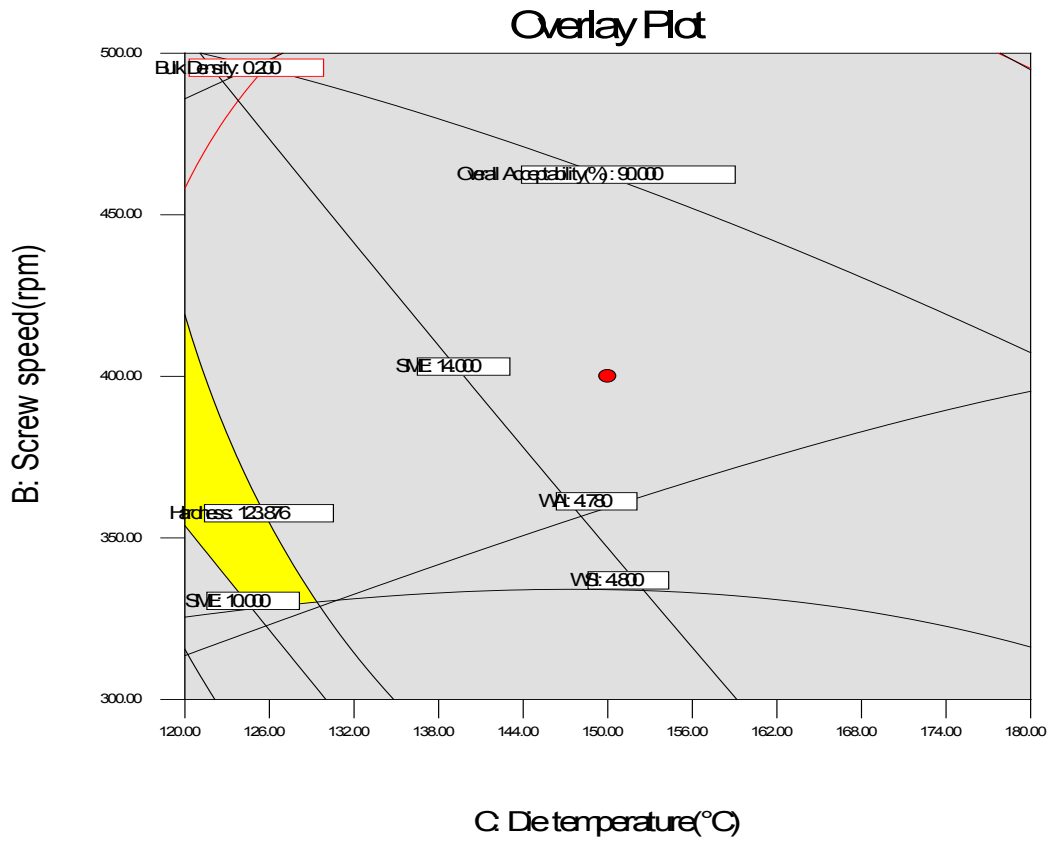
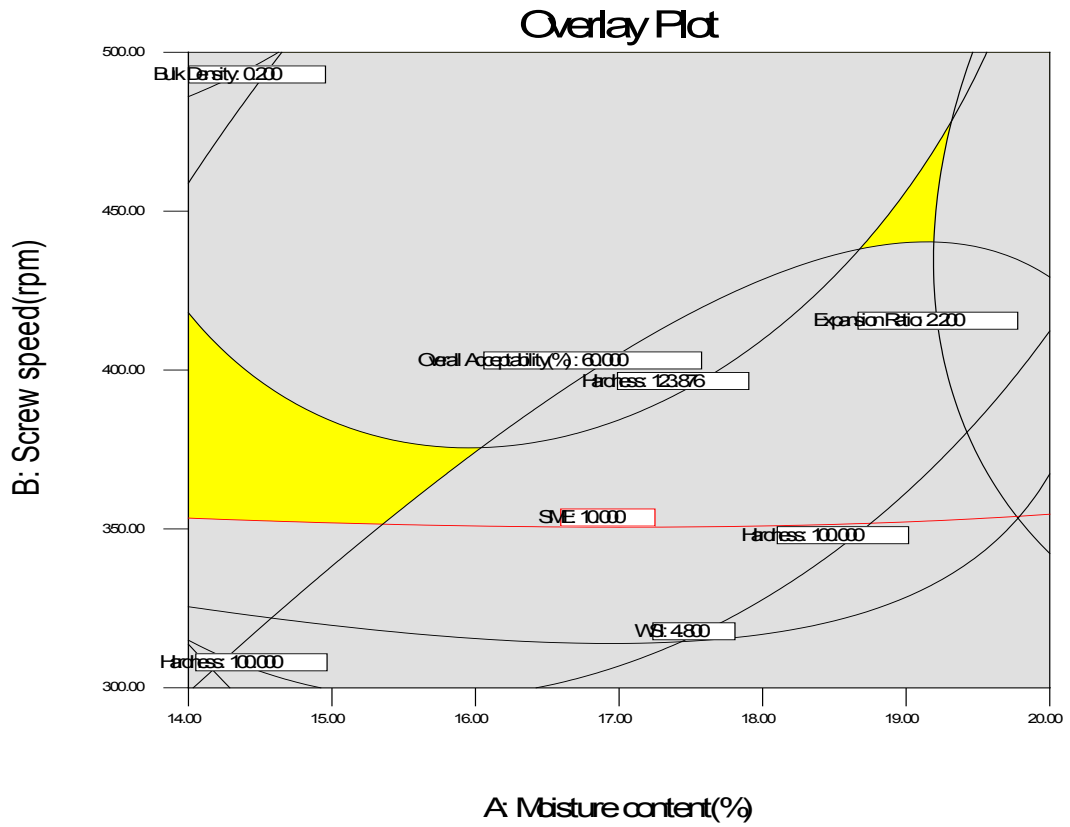
for experimental condition of 14% FMC, 70% Rice flour, and 150°C DT with maximum SS (500 rpm).

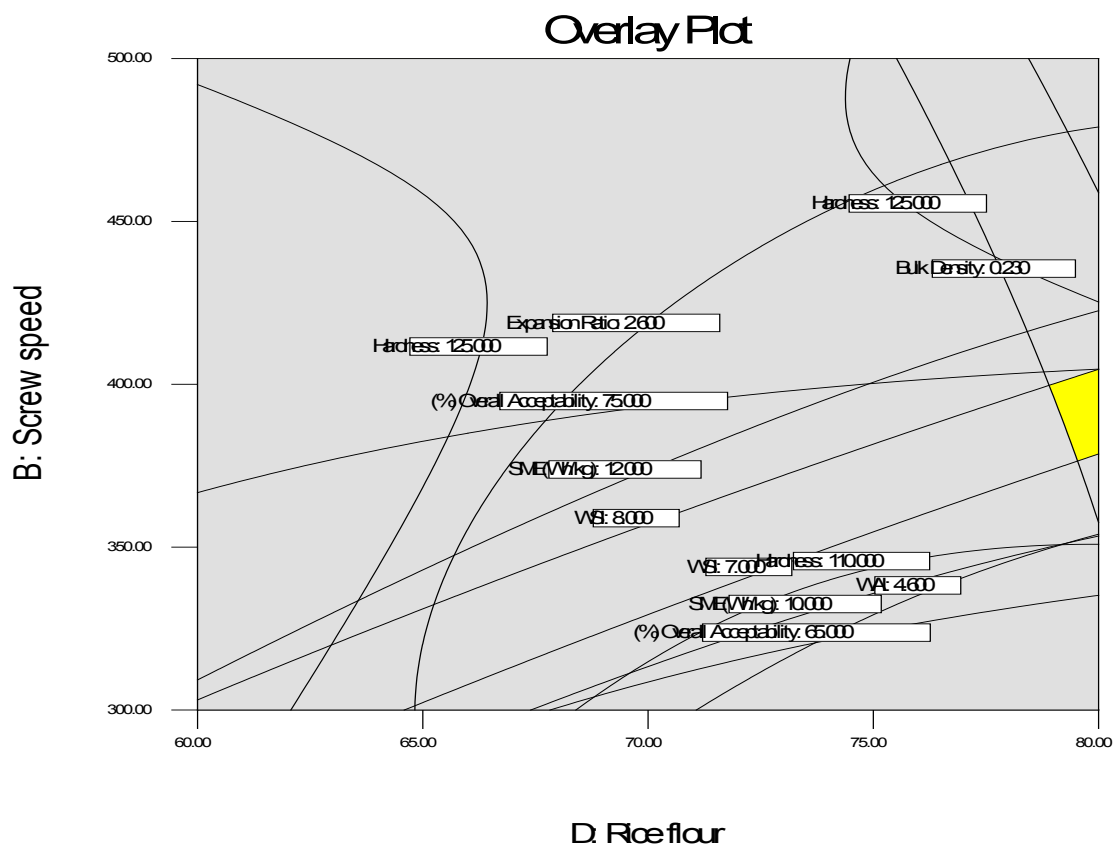
Fig.2 shows that, the significant effect of SS and DT on OA (table2); showing increase in OA with the increase in both the parameters. At a given DT (120°C), the OA increase from 53.86% at 300 rpm to 68.669% at 500 rpm SS. At a constant SS (400 rpm), the OA were 60.576% at 120°C DT, 66.05% at 150°C DT and 76.63 at 180°C DT. Higher value of OA at a higher SS indicates the proper homogenization and gelatinization of dough at higher SS resulting in higher consumer acceptability. The shearing forces inside the extruder increases with the increase in mechanical and thermal energy (when screw speed and barrel temperature are increased) inputs, thus leading to lowering of product density due to enhancement of gelatinization (Guha [21]), that's favor the better product acceptability. From table 2, the interaction term of FMC and SS and quadratic term of FMC had significantly higher effect on OA.

### 3.8. Optimization of Extrusion Process Parameters for Ready-to-eat Extruded Product

Graphical multi-response optimization technique was adopted to determine the workable optimum conditions for the development of extruded product using design expert software (Statease, DE 8.0.6.1). The contour plots for all the responses were superimposed and regions that best satisfied all the constraints were selected as optimum conditions. The main criteria for constraints optimization were maximum possible ER, WAI, sensory OA, and lower BD, SME, WAI, with hardness is in range. These constraints resulted in "feasible zone" of optimum conditions (shaded area in the superimposed contour plots). Superimposed contour plots having common superimposed area of all the responses for extrusion processes are presented in Fig.3 The optimum ranges of process parameters obtained for development of extrudates were: 14 to 17 % of FMC, 120 to 130°C DT, 353 to 417 rpm SS and 66 to 80 % of rice flour with 10% carrot pomace.

In order to optimize the process conditions for extrusion process by numerical optimization, which finds a point that maximizes the desirability function; equal importance of '3' was given to all the 4 process parameters. However, based on their relative contribution to quality of final product, the importance given to different responses was 3 for SME, WAI, WSI, hardness and 5 for BD, ER and OA, respectively. The optimum operating conditions for SS, DT, FMC and Rice flour was 394 rpm, 120°C, 14% and 80%, respectively. Corresponding to these values of process variables, the value of BD obtained were 0.221 kg/cm<sup>3</sup>, ER 2.558, SME 11.215 Wh/kg, WAI 4.416, WSI 7.604, hardness 119.67 kg and OA 73.467 % (Table 4). The overall desirability, which ranges from zero outside of the limits to one at the goal, was 0.728.





**Figure 3.** Overlaid contours of different responses for optimization of extrusion process parameters.

**Table 4.** Optimum values of process parameters and responses

	Target	Experimental Range		Importance	Optimum value	Desirability
		Min	Max			
Feed Moisture content (%)	range	14.00	20.00	3	14.00	
Screw speed (rpm)	range	300.00	500.00	3	394.17	
Die temperature (°C)	range	120.00	180.00	3	120.07	
Rice flour (%)	range	60.00	80.00	3	80.00	
Pulse flour (%)	range	10.00	30.00	3	10.00	
Carrot pomace flour (%)	range	10.00	10.00	3	10.00	
<b>Responses</b>					<b>Predicted values</b>	
Bulk Density(kg/cm <sup>3</sup> )	minimize	0.23	0.48	5	0.22	<b>0.728</b>
Expansion Ratio	maximize	2.00	2.67	5	2.55	
SME(Wh/kg)	minimize	9.02	16.67	3	11.21	
WAI	maximize	3.65	4.78	3	4.46	
WSI (%)	minimize	4.80	10.80	3	7.60	
Hardness (kg)	in range	59.90	194.31	3	119.66	
Overall Acceptability (%)	maximize	48.15	92.59	5	73.44	

## 4. Conclusions

The response surface methodology was effective in optimizing extrusion process parameters for red lentil-carrot pomace incorporated ready-to-eat rice based expanded product with feed moisture in the range of 14 to 20%, die temperature 120-180°C, screw speed 300-500 rpm and

ingredient formulation (rice flour: pulse flour; 60-80%: 10-30%) with 10% carrot pomace flour. The regression equations obtained can be used for optimum conditions for desired responses within the range of conditions applied in this study. Graphical techniques, in connection with RSM, aided in locating optimum operating conditions, which were experimentally verified and proven to be adequately

reproducible. Significant quadratic regression model were established with the coefficient of determination,  $R^2$  greater than 0.758 for all responses. The optimum process parameters obtained for development of extrudates were 14% feed moisture, 394 rpm screw speed, 120°C die temperature and formulation of 80:10:10; rice flour: pulse flour: carrot pomace flour; for developing extruded product with maximum possible expansion ratio, water absorption index and overall acceptability and minimum water solubility index, bulk density and specific mechanical energy with hardness within the experimental range.

### Nomenclature

PF= Pulse Flour

CPF= Carrot Pomace Flour

SS= Screw Speed

DT= Die Temperature

FMC= Feed Moisture Content

BD= Bulk Density

ER= Expansion Ratio

SME= Specific Mechanical Energy

OA= Overall Acceptability

WAI= Water Absorption Index

WSI= Water Solubility Index

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