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RESEARCH ARTICLE

NON-EXPANDED RICE BASED SNACK: EFFECT OF PROCESSING VARIABLES ON CHARACTERISTICS AND OPTIMIZATION OF EXTRUSION PROCESS USING GENETIC ALGORITHM (GA)

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ABSTRACT

The effect of extrusion conditions, including feed moisture (40–45%), screw speed (300–400 rpm) and barrel temperature (65–75°C) on the extrusion behaviour and extrudate properties of non-expanded rice snack was investigated and optimization of process variables was carried out using response surface and genetic algorithm. Polynomial equations were developed for the extrudate properties such as water solubility index (WSI), water absorption index (WAI), specific mechanical energy (SME), power consumption and throughput in terms of the independent variables. These equations were used as the objective function to find the optimum process conditions for extrudate. The developed equations of WAI, WSI and throughput were maximized whereas power consumption and SME were minimized for optimum process conditions. Common optimum process conditions required a low screw speed of 323rpm, high moisture content of 44.59% (db) and low barrel temperature 65.82°C. The experimental extrudate properties matched the values predicted for common optimum conditions more closely than those for individual optimum conditions and percentage errors were higher in case of individually optimized conditions.

INTRODUCTION

Extrusion cooking is a most popular method for preparing snacks. In the non-expanded or pellet snacks market, extrusion cooking has become the preferred processing technology. Extrusion cooking is a single process step where with the helps of various ingredients a wide variety of shapes and textures can be produced. The application of single screw extrusion cooking in processing of rice flour appears to be a simple process, but the control of the finished product characteristics is rather complicated (Brent *et al*., 1997). Response surface methodology (RSM) is very widely used to study the effect of process variables on product properties as well as for process optimization. Response surface methodology is consisted of some group of mathematical and statistical techniques used for development of relationship between dependent and independent parameter (Khuri and Cornell, 1987). It is particularly useful in areas where all the independent variables and their levels and responses are not clearly known (Harper, 1981). There is an abundant literature on the use of RSM for process development and optimization (Bhattacharya and Prakash, 1994, Khuri and Cornell, 1987, Sacchetti *et al*., 2004, Shankar and Bandyopadhyay, 2004, Shankar and Bandyopadhyay, 2005). Although RSM is intuitively a simple method, interpretation of the RSM results become tedious when optimizing a function with more than three independent variables at wider experimental range. Further, solving the RSM equations using canonical analysis involves orthogonal rotation of canonical varieties and the interpretation is widely believed to be very difficult (Das, 2005). In recent years, other optimization techniques for multiple process parameters have been used. Genetic algorithms (GAs) are one of them that have gained popularity in process engineering design. Genetic algorithms have found extensive application where process is highly complex and nonlinear (Goldberg, 2001). Food extrusion mechanisms are highly non-linear because of the complexity and variability of the extruder feed ingredients (Harper, 1981). For optimization of such type non-linear problems, genetic algorithms (GA) are one of the most promising techniques (Holland, 1992). However, literature regarding the application of genetic algorithms for optimization of process variables in extrusion cooking is uncommon. The present work has been undertaken to optimize the process variables for production of non-expandade rice snacks using single screw extruder. The specific objective of the present investigation was to find the optimum process conditions separately for each (individual) and commonly for all (common) extrudate properties.

MATERIALS AND METHODS

Raw Material

Rice flour from broken rice of Lal Sawarna was used in this study. Broken rice was produced during the milling of rice.

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For conducting experiment broken rice was collected from the local rice mill in Kharagpur.

Feed preparation

Each experiment was conducted with 500 g of broken rice flour. The ingredients were mixed with rice flour and then measured amount of water (to maintain 40, 42.5 and 45 % db moisture content) was added slowly and mixing was carried out using a mixer. After mixing, feed sample put in polyethylene package at room temperature to equilibrate the moisture.

Extrusion

Each test was based on 500 g rice flour which was well mixed, adjusted to the desired moisture content (40, 42.5 and 45 % db) by adding water. For conducting the experiment a single screw cooking extruder was developed and fabricated at the workshop of the Indian Institute of Technology, Kharagpur. During extrusion, only the steady-state output was taken for analysis. Feeds were fed manual through the hopper.

Determination of dependent parameter

Evaluation for water absorption index (WAI) and water solubility index (WSI) of extrudates

WAI and WSI were determined according to the method developed for cereals (Stojceska *et al*., 2008). The ground extrudates were suspended in water at room temperature for 30 min, gently stirred during this period and then centrifuged at 3000 g for 15 min. The supernatants were decanted into an evaporating dish of known weight. The WAI was the weight of gel obtained after removal of the supernatant per unit weight of original dry solids. The WSI was the weight of dry solids in the supernatant expressed as percentage of the original weight of sample.

$$WAI = \frac{Weight\ gain\ by\ gel}{Dry\ weight\ of\ extrudate}$$

$$WSI = \frac{Weight\ of\ Dry\ Solid\ in\ Supernatant}{Dry\ Weight\ of\ Extrudate} \times 100$$

Power consumption

Power consumption was measured using standard energy meter during experiment.

Specific Mechanical Energy (SME)

After the consideration of motor load and its efficiency, the SME values were calculated according to the method described by Bhattacharya and Choudhury, (1994).

$$SME(\frac{kWH}{kg}) = \frac{Screw\ Speed \times Power \times Torque}{Maximum\ Screw\ Speed \times Throughput \times 100}$$

Throughput of Extrudates

Throughput was determined by using the method described by Chevanan *et al*. (2008). The extrudate produced over a period of time collecting and weighing in an open pan. The experiment was carried out for five replicates for each run and for each sample products collection after 10 minutes of regular production. The throughput of the extruder at different conditions was determined for each sample.

Experiment at Design

Experiments were conducted according to 3-level Factorial Design. The coded values of the independent variables and their real values are shown in Table.1. Based on the experimental design, trials were conducted and the statistical analysis was carried out by using Design Expert 7.0.0 (Stat-Ease) software and genetic algorithm to obtain the optimized solution. Solution with highest desirability was chosen as the optimal solution.

Table 1. Real and coded value

Name	Units	Low Actual	Low Coded	High Actual	High Coded
Screw Speed	rpm	300	-1	400	1
Moisture Content	% (db)	40	-1	45	1
Temperature	°C	65	-1	75	1

Optimization of independent variables

Optimization of processing variables for developed single screw extruder was carried out by Response Surface Methodology and Genetic Algorithm. For this purpose, the experiments were conducted by using 3-level factorial design. Total number of experiments was 32 with 3 independent variables (screw speed, moisture content and barrel temperature) and 5 responses (power consumption, flow rate, specific mechanical energy, water absorption index and water solubility index) where the centre point was replicated five times. The function was assumed to be approximated by a second-degree polynomial equation:

$$y = b_0 + \sum_{i=1}^{3} b_i x_i + \sum_{i=1}^{3} b_{ii} x_i^2 + \sum_{i=1}^{3} b_{ij} x_i x_j \qquad (1)$$

Where y is the dependent variable, x_i and x_j are the coded independent variables, b_0, b_i, b_{ij} are regression coefficients. Experiments were conducted as per experimental design. Results obtained during experiments are presented in Table 2.

Statistical Analysis

Analysis of data

The regression analysis was conducted using the "stepwise variable selection backward elimination" procedure for fitting the model represented by the equation to the experimental data. Maximization and minimization of the polynomial thus fitted was performed by numerical techniques and mapping of the fitted responses was achieved using Stat-Ease software (Design Expert 7.0.0. Stat-Ease, MN, USA). The regression equations developed for the extrudate properties (WSI, WAI, Power Consumption, SME, Flow rate) were subsequently used as the objective functions in the genetic algorithm.

Process Optimization Using Genetic Algorithm

A genetic algorithm (GA) is a procedure used to find approximate solutions to search problems through application of the principles of evolutionary biology. Genetic algorithms used biologically inspired techniques such as genetic inheritance, natural selection, mutation and sexual reproduction (recombination, or crossover). Genetic algorithms are typically implemented using computer simulations in which an optimization problem is specified. For this problem, members of a space of candidate solutions, called individuals, are represented using abstract representations called chromosomes. The GA consists of an iterative process that evolves a working set of individuals called a population toward an objective function, or fitness function (Goldberg, 1989). Traditionally, solutions are represented using fixed length strings, especially binary strings, but alternative encodings have also been developed. In genetic algorithm independent variable as a group are expressed by binary numbers 0 and 1. The evolutionary process of a GA is a highly simplified and stylized simulation of the biological version. It starts from a population of individuals, randomly generated according to some probability distribution, usually uniform and updates this population in steps called generations. Each generation, multiple individuals are randomly selected from the current population based upon some application of fitness, bred using crossover and modified through mutation to form a new population.

The goodness of the chromosome in the population is evaluated over a fitness function, which is the objective function of the optimization problem. In genetic algorithm, fitness is used to allocate reproductive traits to the individuals in the population and thus act as some measure of goodness to be maximized. This means that individuals with higher fitness value will have higher probability of being selected as candidates for further examination. Certain genetic operators require that the fitness function be non-negative, although certain operators need not have this requirement. For maximization problems, the fitness function can be considered to be the same as the objective function. For minimization problems, to generate non-negative values in all the cases and to reflect the relative fitness of individual string, it is necessary to map the underlying natural objective function to fitness function form. A number of such transformations are possible.

Iteration

At each step a new population is generated after crossover and mutation operations. The chromosomes are decoded and the new fitness values are computed. The crossover and mutation operations and fitness evaluation are repeated until the fitness values do not change after a certain number of iterations (stopping criteria). The stopping criterion is usually dependent on the best fitness, which does not change after certain number of iterations or time. The representation of decision variables, initial population size, crossover rate, mutation rate and stopping criteria all affect the performance of the genetic algorithm (Shankar and Bandyopadhyay, 2004).

RESULTS AND DISCUSSIONS

Effects of process parameters on dependent variables

Water Solubility Index (WSI)

WSI, often used as an indicator of degradation of molecular components (Kirby *et al.* 1988), measures the degree of starch conversion during extrusion which is the amount of soluble polysaccharide released from the starch component after extrusion. The effects of extrusion conditions on water solubility index of extrudate are shown in Figs. 1(a) 1(b) and 1(c). It was observed that water solubility index of rice extrudate product varied between 1.23 and 2.97.

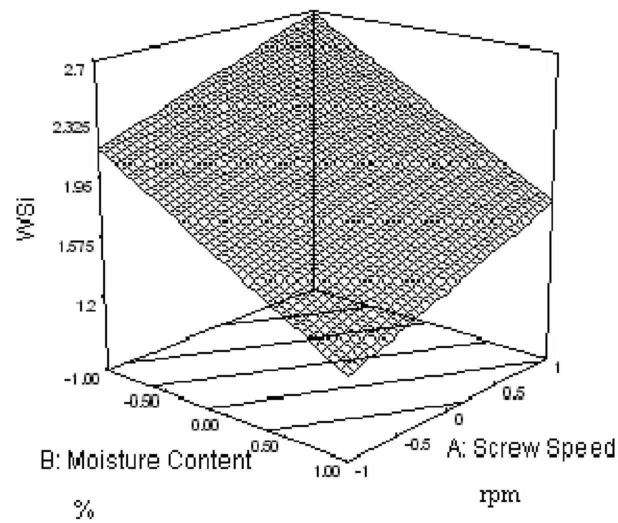

Figure 1(a). Effect of screw speed, moisture content at temperature of 70°C on water soluble index

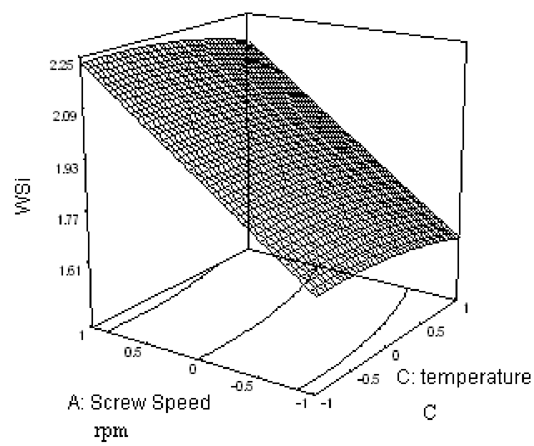

Figure 1(b). effect of screw speed, temperature at moisture content of 42.5 % (db) on water soluble index

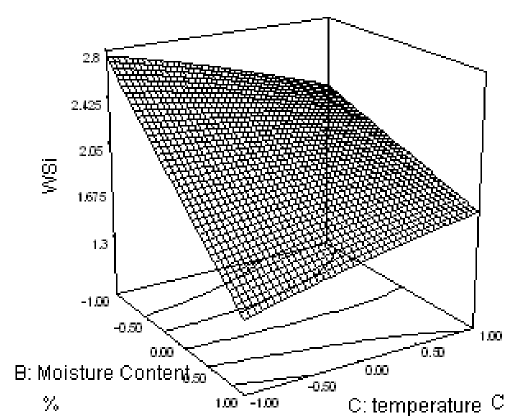

Figure 1(c). Effect of temperature, moisture content at screw speed of 350rpm on water soluble index

From ANOVA (Table 3) data set, high model F-value and R^2 indicated that the quadratic model can be successfully fitted to the experimental data (p<.001). It was observed from the graphs that increasing screw speed and barrel temperature significantly increased the WSI of extrudate, consistent with the results reported for extrudate wheat products (Singh and Smith, 1997), where as increased feed moisture was observed to result in a significant decrease in the WSI of extrudate, similar effects have been reported earlier for starch, maize grits, wheat and pea flour (Kirby *et al*. 1988). The WSI depends on quantity of soluble which increases due to the degradation of starch. Wen, *et al*. (1990) indicated that screw speed had a direct effect on polysaccharide size distribution. A higher screw speed resulted in more fragmentation than a lower screw speed. A degradation of amylose and amylopectin molecules of maniac starch through chain splitting has been reported by Guha *et al*. (1997). It could be, therefore, inferred that the combined effect of high temperature and high screw speed enhanced the amount of soluble materials in the extrudate. Whereas for the increase of feed moisture resulted in less fragmentation of starch which decreases the quantity of soluble in extrudate, as a result lower WSI for increase of feed moisture content.

Water Absorption Index

The WAI measures the volume occupied by the starch after swelling in excess water, which maintains the integrity of starch in aqueous dispersion. In the present study, it was observed that water absorption index of extrudate product varied between 1.84 and 4.081 (Table 2). From ANOVA (Table 3) data set, high model F-value and R^2 indicated that the quadratic model can be successfully fitted to the experimental data (p<.001). It was observed from the graphs (Fig. 2(a), 2(b) and 2(c)) that for the increase of screw speed and temperature, water absorption index of extrudate gradually decrease probably due to increase in starch degradation, Hagenimana *et al*. (2006) observed similar type of result for wheat based expanded extrudate snacks product. Whereas, opposite effect observed in case of moisture content. Water absorption has been generally attributed to the dispersion of

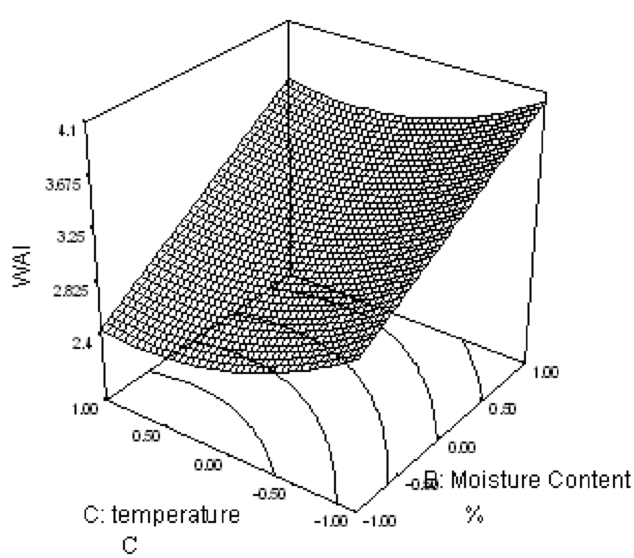

Figure 2(a). Effect of temperature, moisture content at screw speed 350rpm on water absorption index

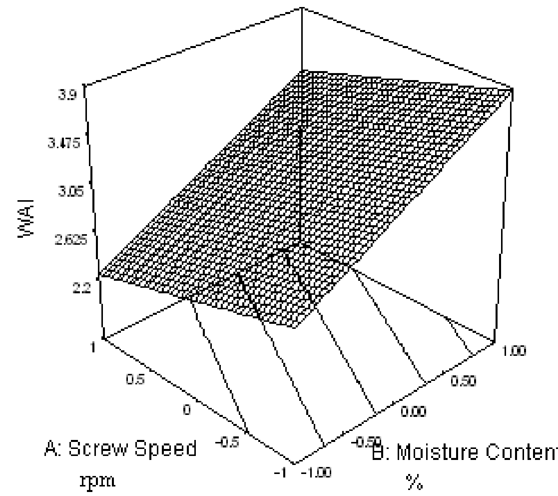

Figure 2(b). Effect of moisture content, screw speed at temperature 70°C on water absorption index

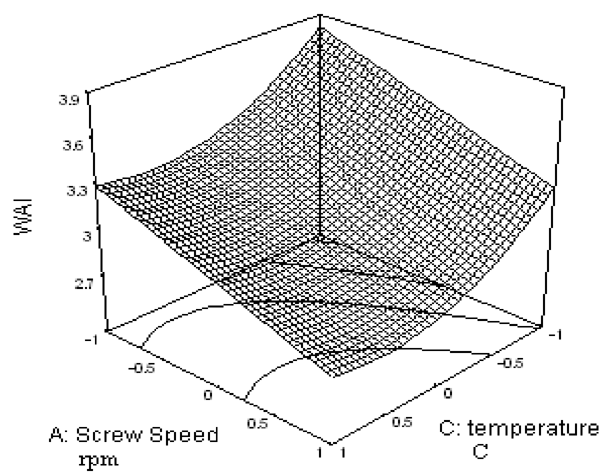

Figure 2(c). Effect of screw speed, temperature at moisture contain of 42.5 % (db) on water absorption index

starch in excess water and the dispersion is increased by the degree of starch damage due to gelatinization and extrusion-induced fragmentation, that is, molecular weight reduction of amylose and amylopectin molecules (Rayas-Duarte *et al*. 1998).

Power Consumption

Power consumption during extrusion cooking of broken rice flour varied from 307 to 468W (Table.2). The highest value for power consumption 468W was obtained at extrusion condition of 75°C, 400 rpm and 40% for barrel temperature, screw speed and feed moisture content respectively, while 70°C barrel temperature, 350 rpm screw speed and 45% (db) feed moisture content produced the least power consumption of 307W. The Model F-value of 21.53 implies the model is significant. It was observed (Fig 3(a)) that for the increase in feed mositure content power comsumption gradually decrease, observations are consistent with previous studies (Akdogan, 1996), probably due to increase of feed moisture content, and hence lowering the viscosity, resulted in a lower power consumtion. In case of screw speed it seems logical to mention that the increase in screw speed increases the power consumtion of extrusion process (Fig. 3(b) and 3(c)).

Table 2. 3-Level factorial design arrangement and responses

	Factor			Response				
Run	Screw Speed rpm	Moisture Contain %	Temperature °C	WSI	WAI	Power Consumption w	SME kWh/kg	Flow Rate gm/min
1	-1	-1	-1	2.56	3.19	437	0.14	27.9
2	0	0	0	1.91	2.98	342	0.1471	23.13
3	-1	0	1	1.78	3.1	350	0.1357	34.124
4	-1	1	0	1.56	4.038	310	0.1099	17.02
5	0	-1	1	2.34	2.791	460	0.1688	35.23
6	0	0	0	1.89	2.98	340	0.1479	23.13
7	0	0	0	1.99	2.88	340	0.1579	21.13
8	1	0	-1	1.98	3.291	460	0.1499	31.646
9	-1	1	-1	1.14	4.081	360	0.1349	25.705
10	0	1	1	1.23	3.513	431	0.1492	33.122
11	0	-1	0	1.802	2.97	420	0.1632	29.482
12	1	0	1	2.31	2.78	430	0.1584	34.854
13	0	0	0	1.89	2.98	340	0.1479	23.13
14	-1	-1	1	1.85	2.825	451	0.1602	34.896
15	-1	-1	0	1.75	2.972	320	0.1574	31.074
16	1	-1	0	2.97	1.87	432	0.1643	39.299
17	1	1	1	1.34	3.32	441	0.1532	33.874
18	-1	1	1	1.69	4.078	422	0.1124	32.456
19	1	1	-1	1.37	3.876	372	0.1566	23.508
20	1	-1	1	2.48	1.84	468	0.1824	36.012
21	0	0	0	1.89	2.98	340	0.1479	23.13
22	1	1	0	2.09	3.345	335	0.1424	20.519
23	-1	0	0	1.64	3.27	330	0.1386	22.31
24	-1	0	-1	1.197	3.687	452	0.1405	30.306
25	0	1	0	1.94	3.79	307	0.1267	17.612
26	0	0	-1	1.69	3.628	450	0.1453	37.324
27	0	1	-1	1.34	4.058	345	0.1356	23.625
28	0	-1	-1	2.98	3.0121	467	0.1502	38.4
29	0	0	0	1.89	2.98	340	0.1479	23.13
30	0	0	1	1.93	3.028	380	0.149	35.234
31	1	-1	-1	3.4	3.007	468	0.1582	34.68
32	1	0	0	2.1	2.89	354	0.1528	23.961

Table 3. Analysis of variance for different models

Response	Sources	Sum of squares	df	Mean square	F	R-Squared
y_1	Regression	5.9017	5	1.1803	11.8173	0.894
	Lack Of Fit	2.5889	21	0.1232	4.7051	
	Pure Error	0.008	5	0.0016		
	Cor Total	8.4986	31			
y_2	Regression	8.1050	5	1.6210	41.7883	0.889
	Lack Of Fit	1.0002	21	0.0476	2.8578	
	Pure Error	0.0083	5	0.0016		
	Cor Total	9.1136	31			
y_3	Regression	77883.2	5	15576.6	21.5253	0.885
	Lack Of Fit	18811.3	21	895.777	3.4367	
	Pure Error	3.3333	5	0.6666		
	Cor Total	96697.9	31			
y_4	Regression	0.0054	5	0.00109	23.0966	0.816
	Lack Of Fit	0.0011	21	5.4E-05	3.1456	
	Pure Error	8.7E-05	5	1.7E-05		
	Cor Total	0.0066	31			
y_5	Regression	1027.11	5	205.422	19.3509	0.788
	Lack Of Fit	272.672	21	12.9844	1.9476	
	Pure Error	3.3333	5	0.6666		
	Cor Total	1303.11	31			

Specific Mechanical Energy

The total SME, defined as the total mechanical energy input to obtain 1 kg of extrudate, varied between 0.1099 and 0.1824 kWH/kg (Table 2). The lowest value 0.1124 kWH/kg of SME was obtained at high temperature (75°C), low screw speed (300 rpm) and high feed moisture (45% db). The quadratic model could be fitted to the experimental data and statistical significance (Table 3). The model had moderate F value and R^2 value (0.81) fitted well (p<.001) in relating Specific mechanical energy (SME) with independent variables. The Model F-value of 23.0967 implies the model is significant. Any variable which affects viscosity would correspondingly affect SME. It was observed that increase in screw speed increases the SME values as directly proportional to screw speed (Fig .4(a)). These observations are consistent with previous studies (Guha *et al*. 1997). SME also decreased with increasing feed moisture (Fig. 4(b)). Ilo *et al*. (1999) observed same pattern of result in rice flour and amaranth blends extrudate product. These results could be explained by the dependence of melt viscosity on temperature, moisture and fat content. In the present study, it was observed that an increase in the temperature increased the SME. This result is in agreement with the findings of Bhattacharya and Choudhury, (1994) during extrusion of rice flour. The decreases in SME with increasing feed moisture could be attributed to the changes in melt viscosity. In general increasing barrel temperature and screw speed would both cause a decline in the melt viscosity and consequently, a decrease in SME. The torque required to turn the extruder screw is also related to degree of fill in the extruder barrel (Akdogan, 1996). At a constant feed rate, an increase in screw speed decreased the length of filled flights.

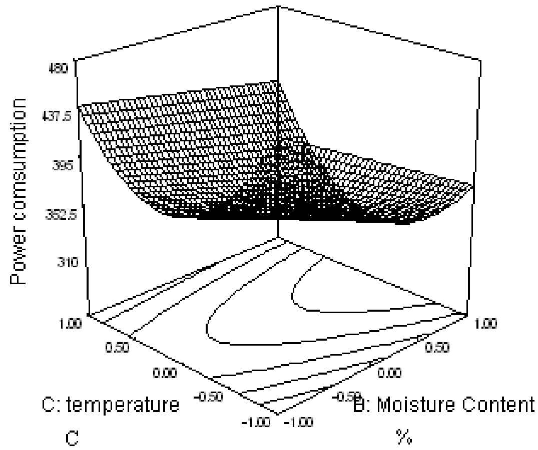

Figure 3(a). Effect of temperature, moisture at a screw speed of 350rpm on power consumption

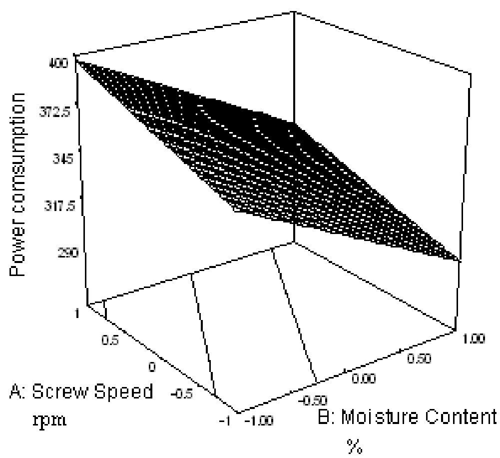

Figure 3(b). Effect of screw speed, moisture content at temperature of 70 °C on power consumption

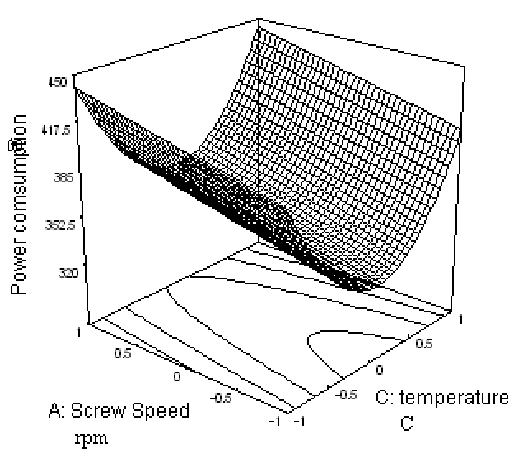

Figure 3(c). Effect of screw speed, temperature at moisture content of 42.5 % (db) on power consumption

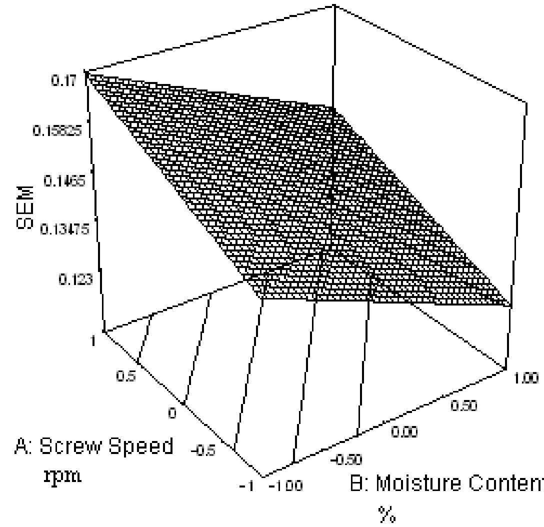

Figure 4(a). Effect of moisture content, screw speed at temperature of 70 °C on specific mechanical energy

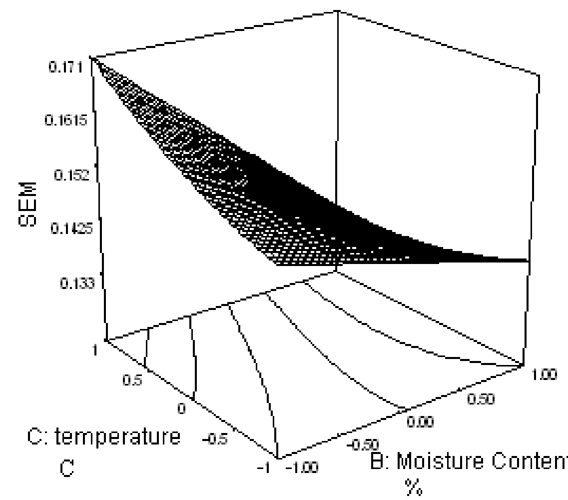

Figure 4(b). Effect of temperature, moisture content at screw speed of 350rpm on specific mechanical energy

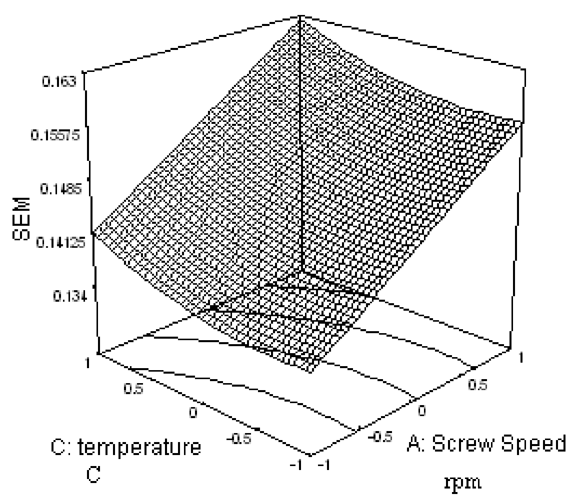

Figure 4(c). Effect of temperature, screw speed at moisture content of 42.5 % (db) on specific mechanical energy

This resulted in a decrease in the load on the screw shaft motor. Thus, the extruder torque was reduced. However, as shown in the surface plot (Fig. 5), SME increased proportional to the screw speed, This result indicated that the effect of screw speed dominated the effect of melt viscosity, as reported in other studies (Akdogan, 1996). On the contrary, increasing feed moisture content, lowering the melt viscosity did not result in a lower SME. This could be due to the relatively narrow feed moisture range used in the study.

Throughput of Extrudate

Throughput is a parameter that determines production efficiency in terms of production output per unit time. In the present study the extrusion cooking of broken rice flour varied between 17.02 and 39.299 gm/min (Table 2). The highest value for throughput 39.299 gm/min was obtained at extrusion condition of 70°C, 400 rpm and 40% for barrel temperature, screw speed and feed moisture content respectively, while 70°C barrel temperature, 300 rpm screw speed and 45% feed moisture content produced the least through- put of 17.02 gm/min. Throughput was observed to be positively correlated with barrel temperature and screw speed of extruder. Response surface plots of interactions amongst the process variables as they affected throughput in this study are shown in Figures 5(a), 5(b) and 5(c).

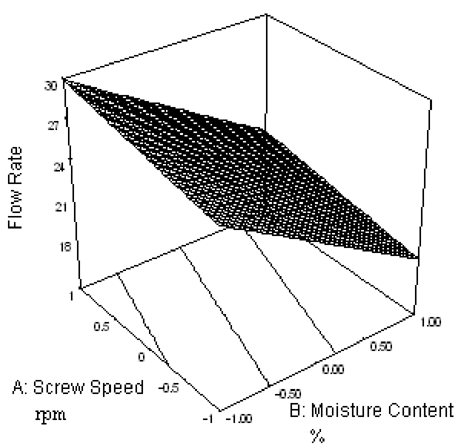

Figure 5(a). Effect of moisture content, screw speed at temperature of 70°C on flow rate

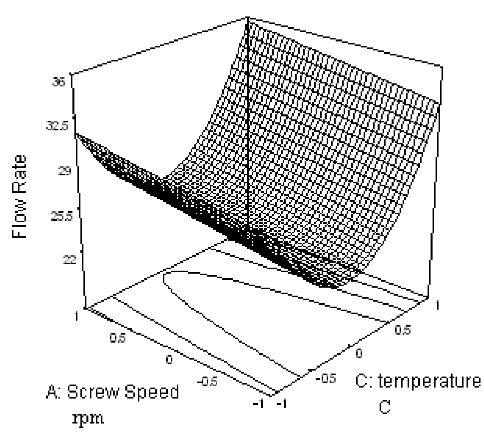

Figure 5(b). Effect of temperature, screw speed at moisture content of 42.5 % (db) on flow rate

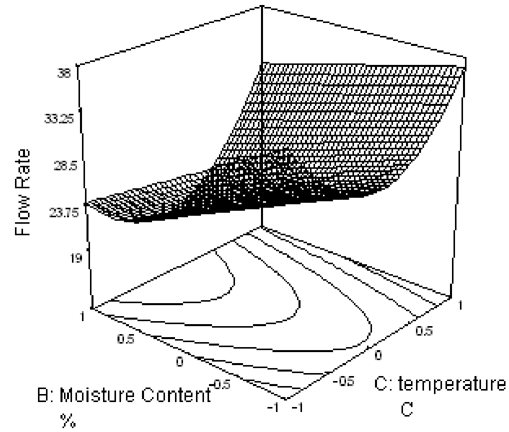

Figure 5(c). Effect of temperatures, moisture content at screw speed of 350rpm on flow rate

Table 4. Individual and common optimized solution for maximum WSI, maximum WAI, maximum flow rate, minimum power consumption and minimum specific energy

Dependent variable	Independent variable		
	Screw Speed (rpm)	Moisture (% db)	Temperature (°C)
WSI	394	44.94	74.85
WAI	381	40	65
Power consumption (W)	300	40	65
SME (kWh/kg)	300	45	65
Flow rate (g/min)	378	45	75
common	323	44.59	65.82

Throughput gradually and rapidly increased with increase in screw speed but marginally increased with increase in barrel temperature. Both feed moisture content and barrel temperature had marginal effect on throughput over other process variables used in this study.

Diagnostic checking of the fitted model

After model reduction, the regression coefficients were obtained for all the models. Regression analyses for different models indicated that the fitted quadratic models accounted for more than 80 % of the variations in the experimental data, which were found to be highly significant. Multiple regression equations were generated relating to water solubility index (y_1), water absorption index (y_2), power consumption (y_3), specific mechanical energy (y_4), flow rate (y_5) to coded levels of the variables; screw speed (x_1), feed moisture content (x_2), barrel temperature (x_3).

WSI (y_1) $=1.95+0.27*x_1-0.47*x_2-0.039*x_3+0.22*x_2*x_3-0.028*x_3^2$ 5.1
WAI (y_2) $=3.07-0.28*x_1+0.53*x_2-0.25*x_3+0.054*x_2*x_3+0.22*x_3^2$ 5.2
Power Consumption (y_3) $=346.43+18.22*x_1-33.33*x_2+1.22*x_3+17.50*x_2*x_3+78.24*x_3^2$ 5.3
SEM (y_4) $=0.15+0.010*x_1-0.012*x_2+3.228e{-}003*x_3-6.275e{-}003*x_2*x_3+2.352e{-}03*x_3^2$ 5.4
Flow Rate (y_5) $=24.15+1.25*x_1-4.42*x_2+2.04*x_3+1.79*x_2*x_3+8.24*x_3^2$ 5.5

The linear, quadratic and interaction were calculated for each model. The correlation coefficients for all the responses are quite high for response surfaces. The screw speed (x_1) has positive linear effects for all responses, whereas, it has no quadratic effect on responses. The feed moisture content (x_2) has a positive linear effect for all the responses except water

Table 5. Experimental and predicted values of maximum WSI, maximum WAI maximum flow rate, minimum power consumption and minimum specific energy for optimized process condition

Dependent variable	Individual			Common		
	Predicted	Experimental	Percentage error	Predicted	Experimental	Percentage error
WSI	2.915	3.042	4.17	2.972	2.853	4.17
WAI	2.152	2.542	15.34	2.936	3.021	2.81
Power consumption	293.814	300.23	2.13	314.611	309.12	1.77
SME	0.127	0.154	17.53	0.146	0.164	10.97
Flow rate	38.296	36.421	5.61	37.563	38.632	2.76

absorption index (y_2), whereas, the quadratic effect with combination with barrel temperature (x_3) has negative for specific mechanical energy (y_4) and positive for all other responses. Barrel temperature has all types of relationship with responses. It has negative linear relationship with WAI, WSI and SME and other have positive linear relationship. Combination with feed moisture contains, barrel temperature has negative effect only on specific mechanical energy and other has positive effect. In case of quadratic relationship except WSI, all other have positive relationship with barrel temperature. An analysis of variance for all the responses is presented in Table 3. The F values for water solubility index, water absorption index, power consumption, specific mechanical energy, flow rate were 11.81, 41.78, 21.52, 23.09 and 19.35 respectively. The values of the lack of fit for all the models were not significant relative to the pure error. On these bases, it can be concluded that the selected models adequately represent the data for all the responses.

Optimization of Individual and common process condition

To find out the optimal solution, of the independent processing parameters, statistical optimization was done, with the help of genetic algorithm. The program developed for optimization using genetic algorithm was used in the present study. The program was developed in Mat Lab R2008a language to make it user-friendly. The development program included writing procedures to create an initial population, to calculate the probability of selection, to identify individuals for crossover and elements for mutation, for reproduction and calculation of fitness value. The objective function used was the regression equation (Eq.1). The objective function used to evaluate the fitness values of each individual extrudate property as the second-order polynomial regression equations obtained using RSM. Random populations of 100 chromosomes were generated. Selection of good chromosomes was based on fitness values at a crossover rate of 0.75, mutation probability 0.05 and degree of precision are 0.01, 0.001 and 0.001. The search was stopped after 50 generation and the corresponding results were displayed. The objective of the optimization was to determine the combination of values of process variables like screw speed (rpm), barrel, temperature (°C), feed moisture content (%) which will be in the range and maximize the flow rate, WSI and WAI value as well as minimize power consumption and specific mechanical energy during extrusion. Common and individual optimum values of process parameter are given in Table 5 the common optimum condition were screw speed 323 rpm, feed moisture content 44.59 % (db), barrel temperature 65.82°C. The product obtained in the common optimum condition, values of experimental independent variables were water Solubility index 2.853 and water absorption index 3.021, power consumption 309.12 W, specific mechanical energy 0.164 kWh/kg and flow rate 38.632 g/min.

Table 5 shows the extrudate properties obtained at the individual and common optimum process conditions. The values show that all the values of experimental extrudate properties matched the predicted values more closely in the case of common optimum conditions than in the case of individually optimized conditions. The percentage errors of extrudate properties were higher in case of individually optimized conditions than common optimized condition.

Conclusion

Change of extrusion conditions, feed moisture content, screw speed and barrel temperature, affected the extruder system parameters and physical properties of the rice based snack. High water solubility index and low water absorption index observed at high screw speed and high barrel temperature, whereas, opposite effect were observed in the case of moisture content. It was observed that increase in screw speed increases the SME, throughput and power consumption rapidly. Both feed moisture content and barrel temperature had marginal effect on throughput. Optimum process conditions for rice snack by single-screw extrusion, established using response surface methodology and genetic algorithm. The individual and common optimum process conditions obtained using RSM and GA, was precisely pinpointed and varied within the experimental limits. The common optimum value of parameters were 323 rpm, 44.59 % (db) and 65.82°C for screw speed, moisture content and barrel temperature respectively. The values show that all the values of experimental extrudate properties matched the predicted values more closely in the case of common optimum conditions than in the case of individually optimized conditions. The percentage errors of extrudate properties were higher in case of individually optimized conditions than common optimized condition.

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