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A study on evaluation and characterization of extruded product by using various by-products

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Broken rice flour was added in proportions (75%) to equal amount of dehydrated pineapple waste pulp powder and red gram powder (12.5%) were extruded in a twin-screw extruder. The formulation was extruded at different moisture content (17-21%), screw speed (260-340 rpm) and die temperature (120-140°C). The lateral expansion, bulk density, water absorption index, water solubility index, hardness and sensory characteristics were measured as responses. In the experiments, increase in barrel temperature resulted in extrudate with higher expansion, higher hardness, lower bulk density, lower WSI and higher WAI. Increasing in screw speed resulted in higher expansion, lower bulk density, higher overall acceptability and lower hardness; whereas, increasing level of moisture resulted in lower hardness, lower expansion and minimum bulk density and higher overall acceptability. In the experiment, optimization studies resulted in 132.27°C of barrel temperature, 315 rpm of screw speed and 18.48% of feed moisture.

Key words: Twin screw extrusion, pineapple waste pulp, response surface methodology (RSM), broken rice flour, red gram powder.

INTRODUCTION

Fruit and vegetable wastes are inexpensive, available in large quantities, characterized by a high dietary fibre content resulting to high water binding capacity and relatively low enzyme digestible organic matter (Serena and Knudsen, 2007). A number of researchers have used fruits and vegetable by-products such as apple, pear, orange, peach, blackcurrant, cherry, artichoke, asparagus, onion, carrot pomace and pineapple waste pulp (Grigelmo-Miguel and Martin-Belloso, 1999; Ng et al., 1999; Nawirska and Kwasnievska, 2005) as sources of dietary fibre supplements in refined food. Cereal grains are generally used as major raw material for development of extruded snack foods due to their good expansion characteristics because of high starch content. The broken rice is a by-product 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 (Zhoul et al., 2002).

Rice flour has become an attractive ingredient in the extrusion industry due to its bland taste, attractive white colour, hypoallergenicity and ease of digestion (Kadan et al., 2003). Cereal grains tend to be low in protein have a poor biological value due to their limited essential amino

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acid content and are usually fortified with lysine or pulse protein to produce nutritious snack foods. Among food legumes, pigeon pea is a valuable source of protein, minerals and vitamins and occupies a very important place in human nutrition in many developing countries (Singh, 1988). The method of dehulling of legumes significantly affects the formation of broken and powdered particles and in the case of pigeon pea it varies between 9 - 24.6% for broken and 5.5 - 6.1% for powder (Singh et al., 1992). Red gram powder is a by-product of milling process which has a high protein content (22%) similar to dhal and easily available at relatively lower cost as compared to whole pigeon pea dhal. Pineapple (*Ananas comoscus*) is sometimes called the ‘King of Fruit,’ one of the most popular of the non citrus tropical and subtropical fruit, though it is mainly processed into canned products and also processed into various food products such as jam, jelly, beverage and concentrate, which produce a large amount of solid waste such as skin, core. The production of canned pineapple was estimated at about 48 million standard cases as against 41 million standard case tones in 1996, an increase of almost 16% in the year 2008-2011.

Major world producers of canned pineapple are Thailand (40%), Philippines (25%), Indonesia (14%) and Kenya (9%) which altogether contribute to more than 80% of total world canned pineapple production in 2008-11. Malaysia’s production amounting to 1,563,291 standard cases would be equivalent to 3.3% of total world production. In India, north east India, cover Tripura, Manipur, Nagaland, Meghalaya and Assam. There is a lot of solid pineapple waste by the canned industries every year; it includes cellulose, hemicelluloses and other carbohydrates. This waste cannot be used for further process and also causes lot of environmental problems and pollution problems. That is why we planned to recycle the pineapple pulp waste in the form of incorporation extruded product (Abdullah and Hanif, 2008).This particular study aims at utilization of various by-products (pineapple waste pulp, broken rice flour and red gram powder).

MATERIALS AND METHODS

Experimental design

Response surface methodology (RSM) was adopted in the design of experimental combinations (Altan et al., 2008a; Yagci and Gogus, 2008; Ding et al., 2005; Montgomery, 2001). The main advantage of RSM is the reduced number of experimental runs needed to provide sufficient information for statistically acceptable results. A three-variable (five levels of each variable) central composite rotatable experimental design was employed (Montgomery, 2001; Yagci and Gogus, 2008). The parameters and their levels were chosen based on the literature available on rice based extrudates (Yagci and Gogus, 2008; Ibanoglu et al., 2006; Ding et al., 2005; Upadhyay et al., 2008). The ingredients used for the preparation of ready-to-eat snack products were: pineapple waste pulp, broken rice flour, red gram powder (pigeon pea). The independent variables including the proportion of CPPP in rice flour (equal amount of pineapple waste pulp and red gram powder (75: 12.5+12.5%) : are maintained constant throughout the experiment, and moisture content (16-21%), screw speed (260 - 340 rpm) and die temperature (120-140°C) are variables. Response variables were expansion index, bulk density, water absorption and solubility index, hardness and sensory characteristics. The five levels of the process variables were coded as -1.68, -1, 0, +1, +1.68 (Montgomery, 2001) and design in coded (*x*) form and at the actual levels A, B, C, and D are given in Table 1.

Dry pineapple waste pulp powder preparation

Commercial variety (KEW) was procured from local market, Longowal, District. Sangrur, India. These were washed in running tap water two times and leafy top were removed by twisting off with hands. Then it was set aside, using a plane stainless steel knife, eyes were removed then the fruit and trimmed to remove extra hard material. The juice was extracted using a Juice Mixer Grinder cum Food Processor (Make: Supremo DLX, Maharaja appliance limited, New Delhi, India) to extract carrot juice (Goyal, 2004). The pineapple waste pulp was collected for further studies. A hot air oven (Make: Osaw Industrial Products Pvt. Ltd., Haryana, India) was used for drying pineapple waste pulp, which could regulate drying air temperature up to 250°C with ± 2°C accuracy.

The dryer consisted of a preheating and heating chamber with thermostat based control unit, an electrical fan, and measurement sensors. The samples were spread over the trays and the temperature of the dryer was set at 60°C. The drying procedure continued till the moisture content of the sample was reduced to about 5±1% (wet basis). The grinding was performed using the same food processor (Make: Supreme DLX, Maharaja appliance limited, New Delhi, India) with grinder attachment. The material was ground to pass through the sieve of 2 mm size. The pomace was stored in sealed polythene bag for further use.

Sample preparation

Ingredient formulations for extrusion products are: The rice flour : pineapple waste pulp powder and red gram powder were mixed in equal proportion in a food processor with mixer attachment. The moisture content of the formulation was estimated by hot air oven method (Ranganna, 1995). The moisture was adjusted by sprinkling distilled water in dry ingredients. All the ingredients were weighed and then mixed in the Supremo DLX food processor for 10 min based on preliminary study. The mixture was then passed through a 2 mm sieve to reduce the number of lumps formed due to addition of moisture. After mixing, samples were stored in polyethylene bags at room temperature for 24 h (Stojceska et al., 2008). The moisture content of all the samples were again determined by hot air oven method (Ranganna, 1995) prior to extrusion experiments.

Extrudates preparation

Extrusion of samples was performed using a co-rotating twin-screw extruder (Basic Technology Pvt. Ltd., Kolkata, India). The length-to-diameter (L/D) ratio of the extruder was 8:1. The main drive of extruder was provided with a 7.5 HP motor (400 V, 3 ph, 50 cycles). The output shaft of worm reduction gear was provided with a torque limiter coupling. The barrel of the extruder received the feed from a co-rotating variable speed feeder. The barrel was provided with two electric band heaters and two water cooling jackets. A temperature sensor was fitted on the front die plate, which was connected to temperature control unit placed on the control panel. The die was required to be fixed on the face of barrel by a screw nut tightened

Table 1. The central composite rotatable experimental design (in coded and uncoded levels of three variables and five levels) employed for development of pineapple waste pulp, broken rice flour and red gram powder based extrudates and the responses of developed extrudates.

S/N	Independent variables						dependent variables					
	Moisture content		Screw speed		temperature		LE (%)	BD g/cc	WAI (g/g)	WSI (%)	Force	Sensory
	Coded	Uncoded	Coded	Uncoded	Code	uncoded	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6
1	-1	16	-1	120	-1	260	119.6	0.3202	4.115	16.2	11.50	5.21
2	1	21	-1	120	-1	260	112.2	0.3088	4.148	17.2	15.03	5.79
3	-1	16	1	140	-1	260	162.5	0.3503	4.001	18.8	7.803	6.15
4	1	21	1	140	-1	260	132.5	0.3125	4.132	16.2	14.17	5.89
5	-1	16	-1	120	1	340	95.2	0.2459	4.191	15.6	14.95	5.51
6	1	21	-1	120	1	340	140	0.2957	3.918	17.2	13.45	5.98
7	-1	16	1	140	1	340	165	0.3215	4.242	20.8	11.92	6.45
8	1	21	1	140	1	340	137.5	0.3483	4.484	14	13.40	5.89
9	-1.68	14.3	0	130	0	300	130	0.2087	4.801	16.4	11.12	5.22
10	1.68	22.7	0	130	0	300	122.5	0.2528	4.712	14.8	12.08	6.14
11	0	18.5	-1.68	113.8	0	300	140	0.2614	5.304	11.2	9.19	5.44
12	0	18.5	1.68	146.82	0	300	170.2	0.2521	5.128	14	10.89	6.2
13	0	18.5	0	130	-1.68	232.73	147.5	0.3138	4.046	18	12.08	6.85
14	0	18.5	0	130	1.68	367.27	160	0.1654	4.622	20.8	9.19	8.19
15	0	18.5	0	130	0	300	180	0.0202	5.997	11.2	10.96	6.67
16	0	18.5	0	130	0	300	180	0.0202	5.997	11.2	10.9	7.67
17	0	18.5	0	130	0	300	180	0.0202	5.997	11.2	10.9	7.67
18	0	18.5	0	130	0	300	180	0.0202	5.997	11.2	10.9	7.67
19	0	18.5	0	130	0	300	180	0.0202	5.997	11.2	10.9	7.67
20	0	18.5	0	130	0	300	180	0.0202	5.997	11.2	10.9	7.67

LE = Lateral expansion, BD = bulkdensity, WAI = water absorption index, WSI = water solubility index.

by a special wrench provided. The twin screw extruder was kept on for 30 min to stabilize the set temperatures and samples were then poured in to feed hopper and the feed rate was adjusted to 4 kg/h for easy and non-choking operation. The die diameter was selected at 4 mm as recommended by the manufacturer for such product and recommended by Stojceska et al. (2008). The product was collected at the die end and kept at 60 ± 0.5°C in an incubator (Orbital Incubator, Macro Scientific Works, New Delhi) for 12 h duration to remove extra moisture from the product. The samples were packed in polythene bags for further analysis.

Evaluation for lateral expansion of extrudates

The ratio of diameter of extrudates and the diameter of die was used to express the expansion of extrudates (Fan, 1996; Ibanoglu et al., 2006). Six lengths of extrudates (approximately 120 mm) were selected at random during collection of each of the extruded samples. The diameter of the extrudates was then measured at 10 different positions along the length of each of the six samples, using a vernier caliper. Lateral expansion (LE, %) was then calculated using the mean of the measured diameters:

$$LE = \frac{(\text{diameter of product} - \text{diameter of hole})}{\text{diameter of hole}} \; X \; 100 \tag{1}$$

Evaluation of bulk density of extrudates

Bulk density (BD, g/cm^3) was calculated using the following expression (Stojceska et al., 2008):

$$BD = \frac{4\,m}{\pi\, d^2\, L} \tag{2}$$

Where m is mass (g) of length L (cm) of extrudate with diameter d (cm).

Evaluation of 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 extrudate was suspended in water at room temperature for 30 min, gently stirred during this period, and then centrifuged at 3000 g for 15 min. The supernatant was 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 a percentage of the original weight of sample.

$$WAI\ (g/g) = \frac{\text{Weight gain by gel}}{\text{Dry weight of extrudate}} \tag{3}$$

$$WSI\ (\%) = \frac{\text{Weight of dry solid in supernatent}}{\text{Dry weight of extrudate}} \; X \; 100 \tag{4}$$

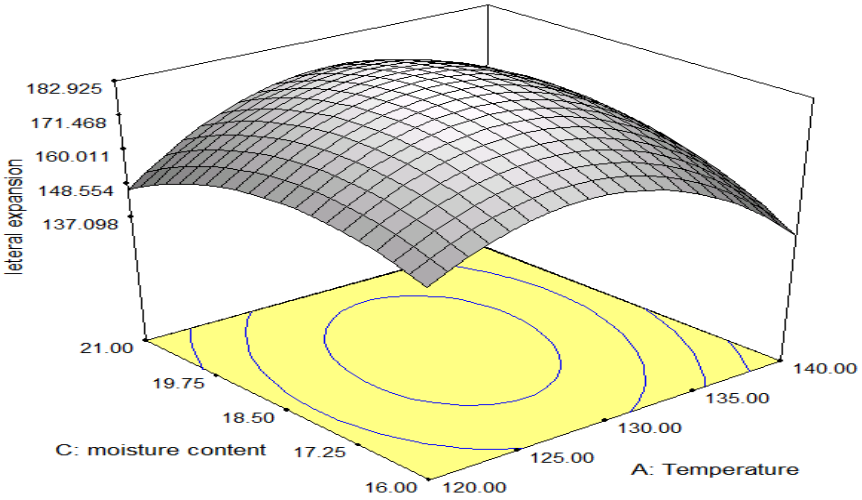

Figure 1A. Response surface plot for the lateral expansion of extrudate as a function of temperature and moisture content.

Evaluation for hardness of extrudates

Mechanical properties of the extrudates were determined by crushing method using a TA-XT2 texture analyzer (Stable Micro Systems Ltd., Godalming, UK) equipped with a 500 kg load cell. An extrudate of about 40 mm long, was compressed with a probe SMS P/75 - 75 mm diameter at a crosshead speed of 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., 2008).

Evaluation of sensory characteristics of extrudates

Sensory analysis was conducted for all the samples. Twelve panellists were asked to assess the expanded snacks and mark on a Hedonic Rating Test (1 - dislike extremely, 5 - neither like nor dislike and 9 - like extremely) in accordance with their opinion for taste, texture, color and overall acceptability.

Statistical analysis of responses

The responses (lateral expansion, bulk density, water absorption index, water solubility index, hardness and sensory evaluation of the extrudates) for different experimental conditions were related to coded variables (xi, I = 1, 2 and 3) by a second degree polynomial equation as given below:

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_{12}x_1x_2 + b_{13}\ x_1x_3 + b_{14}\ x_1x_4 + b_{23}\ x_2x_3 + b_{24}\ x_2x_4 + b_{34}x_3x_4 + b_{11}\ x_1^2 + b_{22}\ x_2^2 + b_{33}\ x_3^2 + b_{44}\ x_4^2 + \varepsilon \quad (5)$$

Where, x_1, x_2 and x_3 are the coded values of temperature (°C), screw speed (rpm) and moisture content (%), respectively. The coefficients of the polynomial were represented by β_0 (constant); β_1, β_2, β_3 (linear effects); β_{12}, β_{13} $\beta_{,23}$, (interaction effects); β_{11} $\beta_{,22}$, β_{33} (quadratic effects); and ε (random errors). Data were modelled by multiple regression analysis and statistical significance of the terms was examined by analysis of variance for each response. The statistical analysis of the data of three dimensional plotting was performed using Design Expert Software (Statease 6.0). The adequacy of the regression model was checked by R^2 Adjusted R^2 Adequate precision and Ficher's F-test (Montgomery, 2001). The regression coefficients were then used to make statistical calculation to generate three dimensional plots for the regression model.

RESULTS AND DISCUSSION

Variation of responses (lateral expansion, bulk density, water absorption index, water solubility index, hardness and sensory evaluation) of extrudates with independent variables (feed proportion, moisture content, screw speed and temperature) are shown in Table 1. A complete second order model (Equation 5) was tested for its adequacy to decide the variation of responses with independent variables. To aid visualization of variation in responses with respect to processing variables, series of three dimensional response surfaces (Figures 1 to 6) were drawn using design expert software (Statease 6.0).

Lateral expansion

Lateral expansion of extrudates ranged from 95.25 and 190% with an average value of 110.76%. The coefficients of the model and other statistics are given in Table 2A. The model F value of 15.16 implies that the model is significant ($P<0.0001$). R^2 and Adjusted R^2 values of the model are 0.9379 and 0.7514, respectively. The Adequate precision value of 10.447 indicates that the model can be used to navigate the design space as it is greater than 4.0 (Montgomery, 2001). Considering these criteria, the following response model was selected for representing the variation of lateral expansion for further

Table 2A. Regression coefficients of second order polynomial and their significance for lateral expansion, bulk density and water absorption index.

Coefficient	Lateral expansion (%)			Bulk density (g/cc)			WAI (g/g)		
	Coefficient value	F	P	Coefficient value	F	P	Coefficient value	F	P
x_1	-2.40^{ns}	.79	0.3953	7.437E- 003^{ns}	0.20	0.6662	-1.22E-003^{ns}	1.538E-004	0.9903
x_2	13.27***	24.22	0.0006	0.001^{ns}	0.41	0.5363	0.014^{ns}	0.020	0.8899
x_3	2.34^{ns}	.75	0.4065	-0.024^{ns}	2.80	0.1794	0.10^{ns}	1.10	0.3199
x_1^2	-21.93***	69.79	0.0001	0.077***	22.57	0.0008	-0.51***	27.75	0.0004
x_2^2	-11.73**	19.97	0.0012	0.087***	28.25	0.0003	-0.34**	12.77	0.0051
x_3^2	-12.2***	21.63	0.0009	-0.081***	24.43	0.0006	-0.65***	46.60	0.0001
$x_1.x_2$	-11.86**	11.33	0.0072	-6.17E-003^{ns}	0.080	0.7834	0.077^{ns}	0.35	0.5647
$x_1.x_3$	6.84*	3.76	0.0810	0.016^{ns}	0.52	0.4855	-0.024^{ns}	0.036	0.8535
$x_2.x_3$	.51^{ns}	0.021	0.8873	0.012^{ns}	0.29	0.6012	0.093^{ns}	0.53	0.4847
R^2	0.9379			0. 8691			0.8840		
Adjusted R^2	0.8703			0.7514			0.7995		
Adequate precision	10.447			6.450			7.866		
Lack of fit	2.84			0.75			4.37		
F-value	9.44			7.38			8.46		

Significant at 10% (*), 5% (**), 1% (***), ns- non significant, E = 10^{-3}.

analysis.

$$LE = 182.81 - 2.40x_1 + 13.27x_2 + 2.34x_3 - 21.93x_1^2 - 11.73x_2^2 - 12.21x_3^2 - 11.86x_1x_2 + 6.84x_1x_3 + .51x_2x_3 \quad (6)$$

Where, x_1, x_2 and x_3 are the coded values of temperature (°C), screw speed (rpm) and moisture content (%), respectively. The following observations can be made from Equation 6 .The coefficients of x_1 are negative, but those of x_2 and x_3 are positive. Whereas, the coefficient of x_1^2, x_2^2 and x_3^2 is negative, F-values for square term of temperature, moisture content and screw speed (x_1^2, x_2^2 and x_3^2) were 69.79, 19.79 and 21.63 and p value was <0.0001, 0.0012 and 0.0009 ($P< 0.05$) respectively, validating that these terms are significant. From Table 2A, the coefficients of x_1^2 x_2^2 and x_3^2 are negative therefore they will show negative quadratic effect on lateral expansion ratio, among them, x_1^2 is more negative. A maximum expansion will occur in the range of temperature considered in the study.

It may be seen from Figure 1A that, there was slight expansion with the increase in moisture content, which may be due to gelatinization of starch, whereas further decrease in expansion with increase in moisture content may be attributed to the reduction of elasticity of dough through plasticization of melt as observed by Ding et al. (2005, 2006). The lateral expansion rapidly increased with increase in the die temperature which may be due to expandability of pulse powder at higher temperature, and further decrease in expansion with increase in the die temperature due to higher degree of superheating of water in the extruder encoun-tering the bubble formation (Ding et al., 2006). It may be observed from Figure 1B that the expan-sion increased with the increase in screw speed, which may be due to high mechanical shear resulting in higher expansion. Similar results have been reported by Ding et al. (2006).

Bulk density

Bulk density is a major physical property of the extrudate products. The bulk density, which

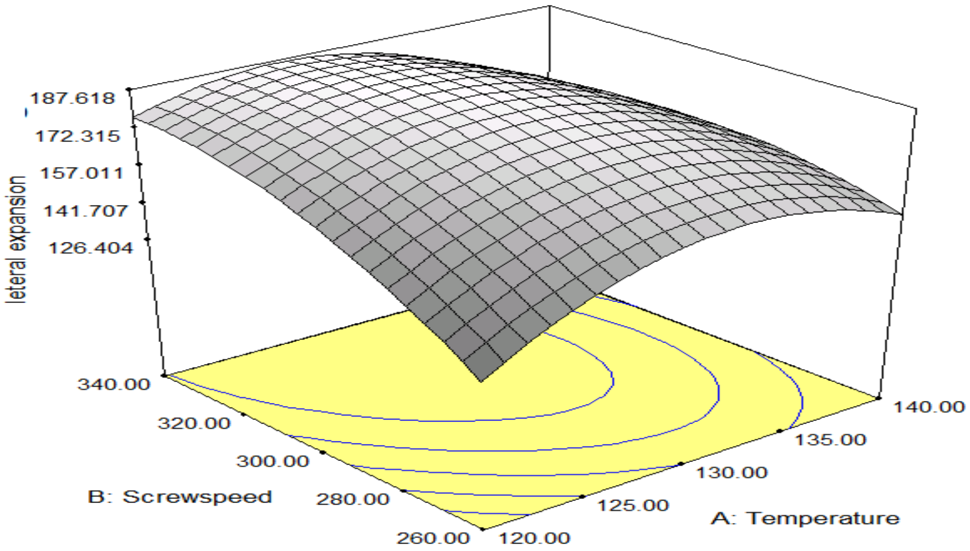

Figure 1B. Response surface plot for the lateral expansion of extrudate as a function of temperature and screw speed.

considers expansion in all direction, ranged from 0202 to 3503 g/cc for the rice flour and pulse powder, pineapple waste pulp powder extrudates. The coefficients of the model and other statistics are given in Table 2A. The Model F-value of 7.38 indicates that the model is significant ($P < 0.05$). R^2 (0.8691) and adjusted R^2 (0.7514) values are similar. The Adequate Precision (6.450) indicates that model can be used for prediction purposes. Considering these criteria, the following response model was selected for representing the variation bulk density for further analysis.

$$BD = 0.045 + 7.437E\text{-}003.x_1 + 0.011x_2 - 0.024x_3 + 0.077x_1^2 + 0.087x_2^2 + 0.081x_3 - 6.175E\text{-}003x_1x_2 + 0.016x_1x_3 + 0.012x_2x_3 \quad (7)$$

It is evident from Equation 7 that coefficients of x_1, x_2 are is positive, but that of x_3 is negative. Therefore, increase in temperature and screw speed may increase the bulk density, whereas increase in moisture content may reduce the bulk density of the product. Since coefficient of x_2^2 is higher than any other positive coefficients terms indicating that it is more significant than others, a minimum bulk density will occur in the range of screw speed selected for the study, x_1x_2 is negative, a maximum bulk density will be in the range of temperature considered in the study reported by Ding et al. (2006).

It is observed from Table 2A and Equation 7 that F values for x_1^2 x_2^2 and x_3^2 were 22.57, 28.25 and 24.43 and p value was 0.0008, 0.0003 and 0.0006, respectively, validating that these terms are significant, among x_2^2 high significance was observed in Table 2A.

It is perceived from Figure 2A that bulk density initially decreased with moisture content, which may be due to proper gelatinization and higher expansion, whereas further increase in bulk density may be because of reduction in elasticity of dough and lower expansion as reported by Ding et al. (2005, 2006). However, it decreased bulk density initially with screw speed , which may be attributed to lighter mass of the fiberous pomace in comparison to other constituents, whereas further increase in bulk density with screw speed may be because of more water binding property of non starch polysaccharides than protein and starch (Yagci and Gogus, 2008; Pansawat et al., 2008). The contour plot in Figure 2B demonstrate the initial increase in bulk density with the increase in temperature, which may be due to the presence of pineapple pulp in the feed formulations, whereas further decrease in bulk density with the increase in temperature may be attributed to higher expansion (Ding et al., 2006).

Water absorption index

Water absorption measures the amount of water absorbed by starch that can be used as an index of gelatinization (Anderson et al., 1969) and it is generally agreed that barrel temperature exert greatest effect on the extrudate by promoting gelatinization (Ding et al., 2005). The water absorption index of extrudates varied in the range of 3.91 to 5.99 g/g. The coefficients of the model and other statistics are given in Table 2A. The Model F-value of 8.46 signifies that the model is significant ($P < 0.05$). R^2 (0.8840) and Adjusted R^2 (0.7995) are in reasonable agreement. The Adequate Precision value of 7.866 implies that the model can be used for prediction purposes. Considering these criteria,

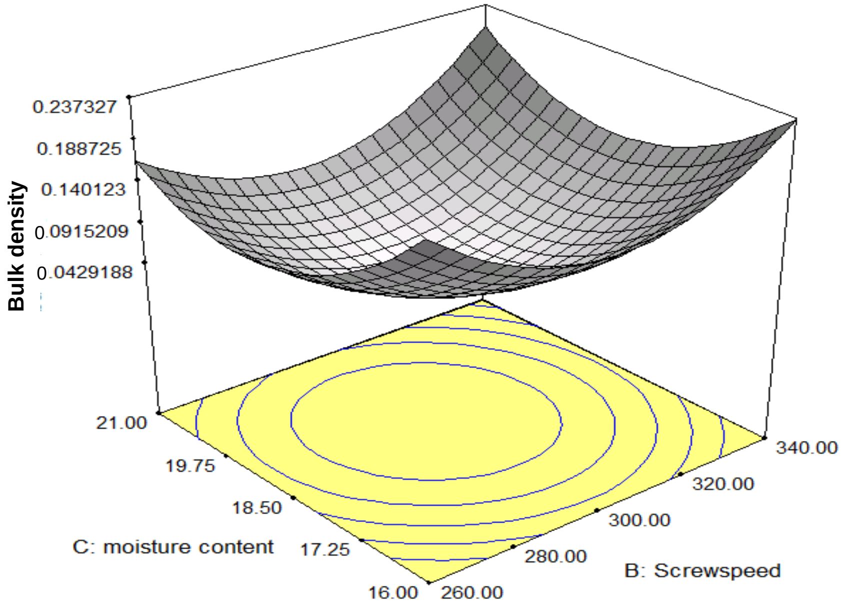

Figure 2A. Response surface plot for the bulk density of extrudate as a function of moisture content and screw speed.

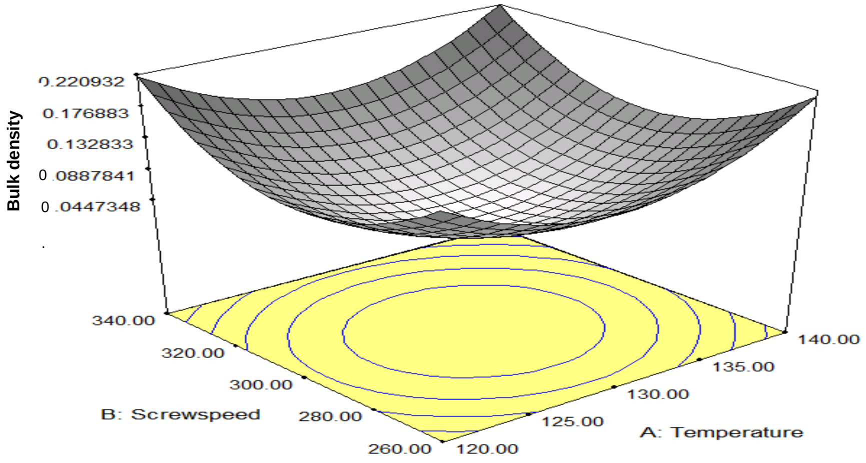

Figure 2B. Response surface plot for the bulk density of extrudate as a function of screw speed and temperature.

the following response model was selected for representing the variation water absorption of for further analysis:

$$WAI = 5.881\text{-}226E\text{-}003x_1 + 0.014x_2 + 0.10x_3 0.51x_1^2 - 0.34x_2^2 + 0.65x_3^2 + 0.077 + x_1x_2 - 0.024x_1x_3 . 0.093x_2x_3 \quad (8)$$

It can be seen from Equation 8 that the coefficients of x_2, x_3 are positive, but that of x_1 is negative; therefore increase in screw speed and moisture content may increase the water absorption index, whereas increase in temperature may reduce the water absorption index of the product. F-values for square term of temperature, screw speed and moisture content (x_1^2 x_2^2 and x_3^2) were 22.57, 28.25 and 24.43 and p value are (0.0008,0.0003and0.0006), respectively, validating that these terms are significant, among these x_2^2 highly significant was observed (Table 2A).

It was observed from Figure 3A that increase in feed moisture content resulted in quadratic decrease in water absorption index. Altan et al. (2008b) also reported the similar behaviour due to competition of absorption of water between pineapple pulp and available starch. It was observed from Figure 3B that increase in temperature

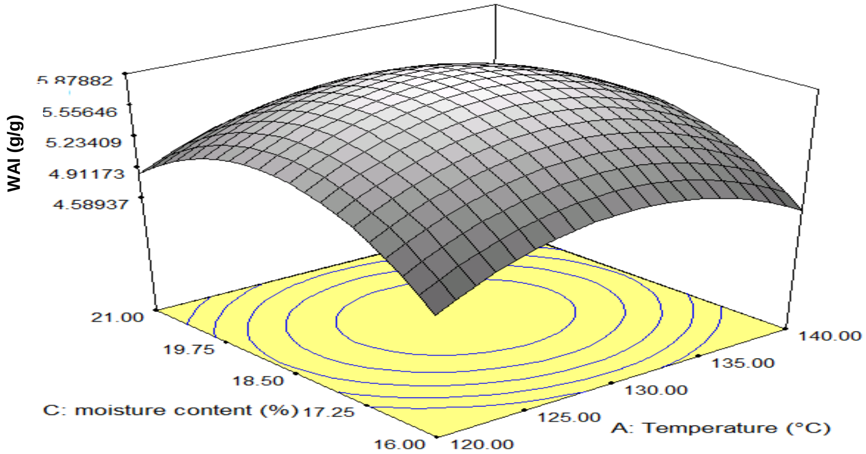

Figure 3a. Response surface plot for the variation of WAI of extrudate as a function of moisture content and temperature.

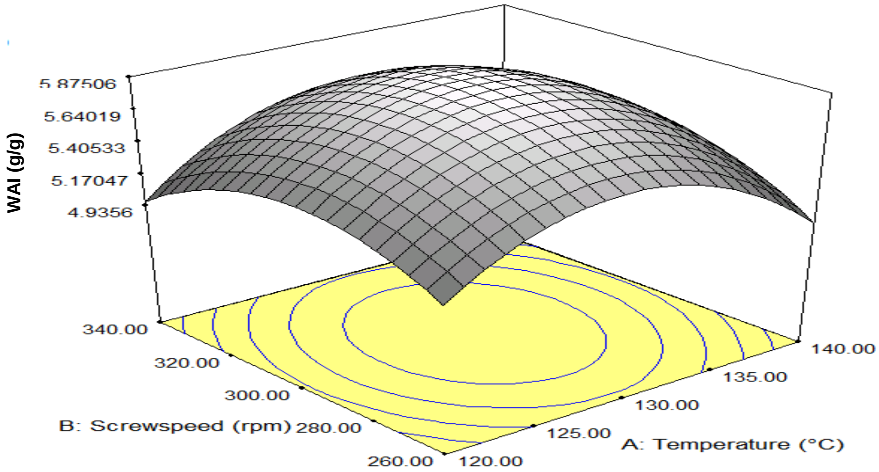

Figure 3b. Response surface plot for the variation of WAI of extrudate as a function of screw speed and temperature.

content resulted in quadratic decrease in water absorption index. Whereas, further increase water absorption index may be because dextrinization at higher temperature, similar observations were reported by Mercier and Feillet (1975). Water absorption index increased with increase in screw speed, may be attributed to high mechanical shear and higher expansion due to gelatinization. Whereas further decrease water absorption index may be because of plasticization of melt at higher moisture content (Ding et al., 2006).

Water solubility index

Water solubility index was used as an indicator of degradation of molecular components. It measures the amount of soluble polysaccharide released from the starch component after extrusion (Ding et al., 2005). Water solubility index of extrudates ranged from 11.2 to 20.2%. The coefficients of the model and other statistics are given in Table 2B. The Model F-value of 19.47 indicates that the model is significant ($P < 0.05$). R^2 (0.9460) and Adjusted R^2 (0.8974) are in reasonable agreement. Moreover, the adequate precision (12.217) is greater than 4, indicating a good fit of experimental data and the acceptability of the model for prediction purposes. Considering these criteria, the following response model was selected for representing the variation of lateral expansion for further analysis:

$$WSI = 11.59 - 0.065x_1 + 0.65x_2 + 0.33x_3 + 1.61x_1^2 + 0.54x_2^2 + 2.95x_3^2 - 1.59x_1x_2 - 0.53x_1x_3 - 0.025x_2x_3 \quad (9)$$

It was observed from Equation 9 that the coefficient of x_1

Table 2B. Regression coefficients of second order polynomial and their significance for water solubility index, hardness and sensory characteristics.

S/N	Coefficient	Hardness (%)			WSI (N)			Sensory characteristics		
		Coeff. value	F	P	Coeff. value	F	P	Coeff. value	F	P
1	x_1	0.84*	7.96	0.0181	-0.65*	5.46	0.0416	0.13^{ns}	1.27	0.2865
2	x_2	-1.11**	13.76	0.0040	0.65*	5.48	0.0413	0.23*	4.03	0.0726
3	x_3	0.17^{ns}	0.33	0.5764	0.33^{ns}	1.40	0.2635	0.22**	3.72	0.082
4	x_1^2	0.58*	4.00	0.0733	1.61***	35.03	0.0001	-0.72***	40.93	0.0001
5	x_2^2	1.53***	27.95	0.0004	0.54*	4.04	0.0723	-0.67***	35.50	0.0001
6	x_3^2	0.023^{ns}	9.19-E003	0.9255	2.95***	118.18	0.0001	-0.069^{ns}	0.38	0.5511
7	$x_1.x_2$	0.73*	3.49	0.0914	-1.59**	18.71	0.0015	-0.23^{ns}	2.40	0.1527
8	$x_1.x_3$	-1.24**	10.41	0.0098	$-.53^{ns}$	2.08	0.1799	-0.051^{ns}	0.12	0.7414
9	$x_2.x_3$	0.18^{ns}	0.22	0.6467	-0.025^{ns}	4.714E-003	0.9466	-0.024^{ns}	0.025	0.8782
10	R^2	0.8691			0. 9460			0.8905		
11	Adjusted R^2	0.7512			0. 8974			0.7920		
12	Adequate precision	10.689			12.217			8.382		
13	Lack of fit	3.48			2.18			1.43		
14	F-value	7.37			19.47			9.04		

Significant at 10% (*), 5% (**), 1% (***), ns - non significant, E = 10^{-3}.

is negative, but that of x_2 and x_3 are positive. Therefore, increase in temperature content may reduce the water solubility index, whereas increase in screw speed and moisture content may increase the water solubility index of the product. The coefficient of x_3^2 is the highest followed by the x_1^2 and x_2^2 in the positive direction, a minimum water solubility index will be in the range of moisture content and followed by screw speed. Among these x_2^2 had more significant maximum water solubility index which lie in the range of temperature considered in the study.

Analysis of variance of Equation 9 (Table 2B) show that F values for x_1 ,x_2 and x_3 were within 5.48 and p value more than 0.0413 ($P < 0.05$), indicating no direct significance on water solubility index. The F values of parameters x_1^2 x_2^2 and x_3^2 were below 118.08 and p values less than 0.0001 ($P < 0.05$), show the significant quadratic contribution.

It is evident from Figure 4A that water solubility index decreased initially and increased further with increase in temperature, which may be attributed to increased dextrinization at higher temperature and it causes more solubility due to change in the starch granule structure (Mercier and Feillet, 1975). Water solubility index increases with increase screw speed due to high mechanical shear exerted on extrudates. Similar observations were reported by Ding et al. (2005). It was observed from Figure 4B that water solubility index decreased initially with the increase in moisture content, which may be due to proper gelatinization and lateral expansion of the starch, whereas further increase with the increase in moisture content may be attributed to reduction in lateral expansion due to plasticization of melt as observed by Ding et al. (2005).

Hardness

The textural property of extrudate was determined by measuring the force required to break the extrudate (Singh et al., 1994). The higher the value of maximum peak force required in Newton, which means the more force required to breakdown

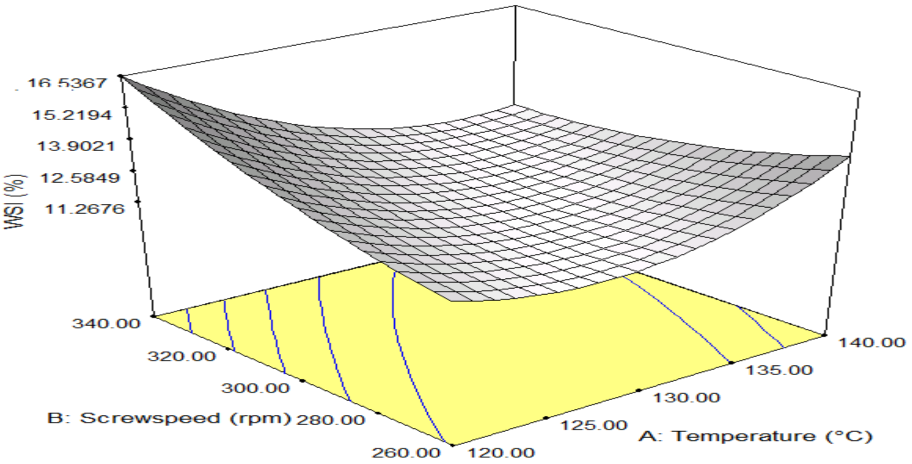

Figure 4A. Response surface plot for the variation of WSI of extrudate as a function of screw speed and temperature.

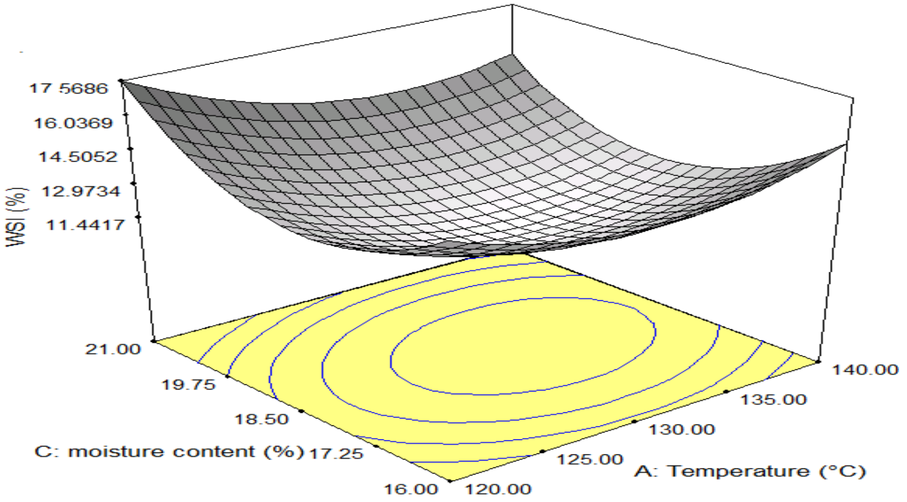

Figure 4B. Response surface plot for the variation of WSI of extrudate as a function of moisture content and temperature.

the sample, the higher the hardness of the sample to fracture (Li et al., 2005). Hardness of rice flour and pulse powder, pineapple pomace extrudate varied between 8.94 and 16.52 N. Table 2B shows the coefficient of the model and other statistical attributes of hardness. The Model F-value of 7.37 implies the model is significant. In this case x_1, x_2, x_2^2, $x_1.x_3$ are significant model terms at $P<0.05$. R^2 and Adjusted R^2 values of the model are 0.8691and 0.7512, respectively. Considering these criteria, the following response model was selected to represent the variation of lateral expansion for further analysis:

$$H = 10.36 + 0.84x_1 -1.11 x_2+0.17x_3 -0.58x_1^2 -1.53x_2^2 +0.0286x_3^2 + 0.73x_1x_2 -1.24x_1x_3 +0.18x_2x_3 \quad (10)$$

The following observations can be made from Equation 10. The coefficient of x_1, x_3 is positive, but those of x_2 are negative. Therefore, increase in temperature and moisture content may increase the hardness whereas, increase in screw speed may reduce the hardness of the product. Since coefficient of x_2^2 is maximum, positive, minimum hardness will be in the range of screw speed considered in the study.

It is evident from Figure 5A that the hardness increase with the increase in moisture content, which may be due to increase expansion with the increase in moisture content. The increase in hardness with increase in temperature may be due to higher expansion at elevated temperatures and would decrease melt viscosity, but it also increases the vapor pressure of water. This favors

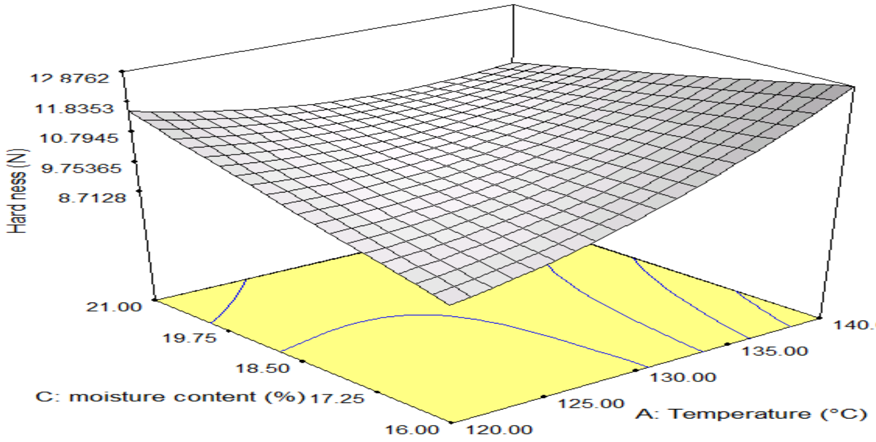

Figure 5A. Response surface plot for the variation of hardness of extrudate as a function of moisture content and temperature.

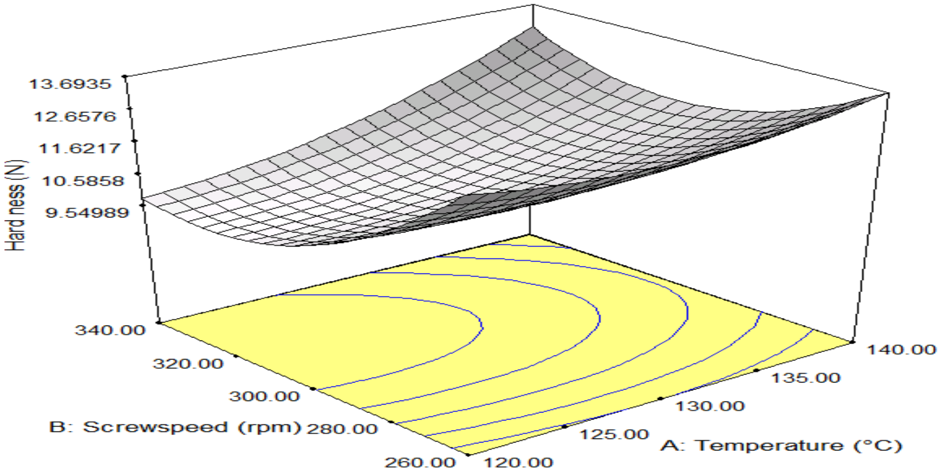

Figure 5B. Response surface plot for the variation of hardness of extrudate as a function of screw speed and temperature.

the bubble growth which is the driving force for expansion that produces low density products and thus increases hardness of extrudate. Similar findings have been reported by Altan et al. (2008b). It may be observed from Figure 5B that hardness decreased with the increase in screw speed. Similar decrease in hardness with increased screw speed due to lower melt density was observed by Ding et al. (2006).

Sensory characteristics

Sensory evaluation indicates the acceptability of the product. Hedonic scale is used to find the different aspect of sensory evaluation. The overall acceptability of the product ranges from 5.2 to 7.5 in the extrudates prepared from rice flour, red gram powder and pineapple waste pulp powder. The coefficients of the model and other statistics are given in Table 2B. The Model F-value of 9.04 indicates that the model is significant ($P < 0.0005$). R^2 (0.8509) and Adjusted R^2 (0.7920) values and Adequate Precision (8.352) indicates that the model can be used for prediction purposes. Considering these criteria, following response model was selected for representing the variation of lateral expansion for further analysis:

$$\text{Sensory evaluation} = 7.48 + 0.13x_1 + 0.23\,x_2 + 0.22x_3 - 0.72x_1^2 -.0.67x_2^2 - 0.069x_3^2 - 0.23x_1x_2 - 0.051x_1x_3 + 0.024\,x_2x_3 \quad (11)$$

It was observed from Equation 11 that coefficient of x_1, x_1

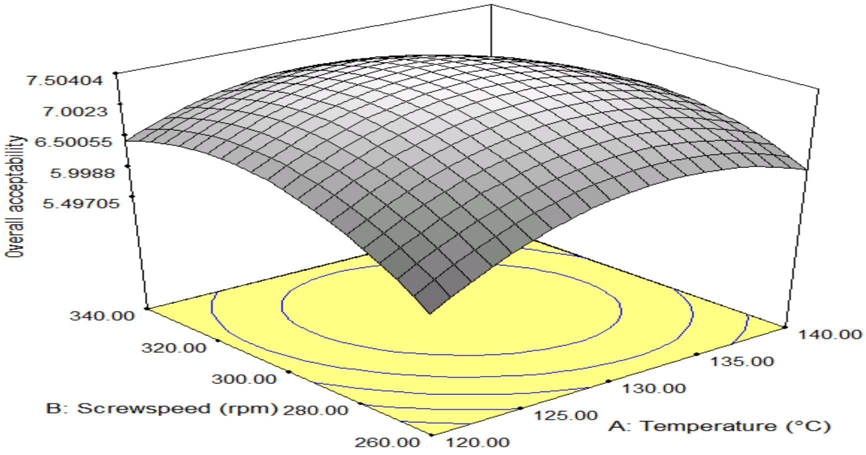

Figure 6A. Response surface plot for the variation of OA value of extrudate as a function of screw speed and temperature.

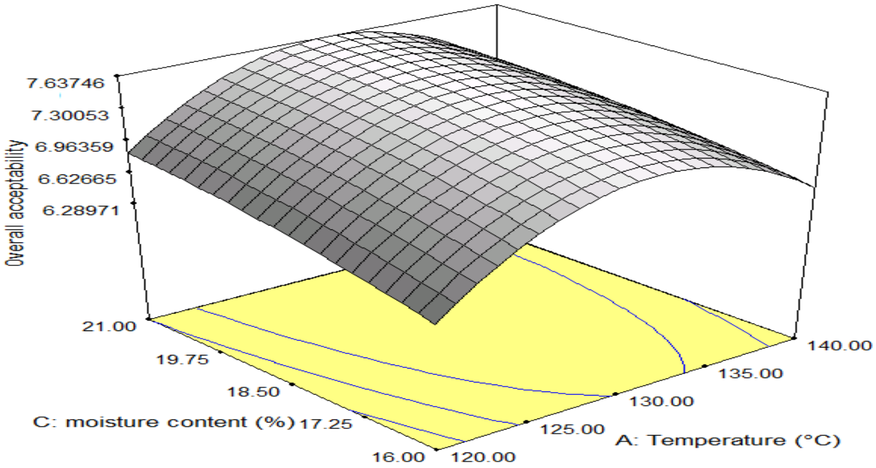

Figure 6B. Response surface plot for the variation of OA value of extrudate as a function of moisture content and temperature.

and x_3 are positive indicating that increases in temperature, screw speed and moisture content will increases the overall acceptability. All linear and interaction terms were not significant ($P > 0.05$). In this case only square terms x_1^2 and x_2^2 were significant model terms.

Analysis of variance of Equation 11 (Table 2B) show that F-values and p values for square term of temperature and screw speed were *40.93*, 0.0026 and 0.0001, 0.0001, respectively ($P < 0.0005$). Indicating that temperature and screw speed is significant for the overall acceptability of the product. Since coefficient of x_1^2, x_2^2 are negative; they will show negative effect on graph variation with the change in value of variables.

It is evident from Figure 6A that the overall acceptability value increased quadratically with increase in screw speed and temperature, and later decreased linearly with decreased screw speed and temperature, which may be attributed to the significant square terms of (x_1^2 *and* x_2^2). These coefficients of $x_1^2$and x_2^2 are negative therefore they will show negative quadratic effect on the overall acceptability value. It was also perceived from Figure 6B that the overall acceptability value increase with increase in moisture content. This may be due to effect of pineapple pomace. Similar results were reported by Upadhayay et al. (2008).

Compromised optimum condition

The compromised optimum condition for the development ready-to-eat extrudates was then determined using design expert software (Statease, DE 6). The final product would be considered optimum, if the sensory score, lateral expansion, water absorption index are as high as possible, whereas bulk density should be as low as possible. Therefore, compromised optimum condition criteria applied for numerical technique optimization were as follows: (1) maximum sensory score for product acceptability; (2) maximum lateral expansion for proper fluffiness; (3) maximum water absorption index for good digestibility and (4) minimum bulk density. The compromised optimum conditions obtained for the development of extrudates were: The product temperature, 132.27°C; moisture content, 18.48% and screw speed, 315 rpm.

Conclusion

From the present study, it was concluded that:

1. In this experiment, the product responses like lateral expansion bulk density were mostly affected by changes in temperature and moisture content.
2. Increasing in barrel temperature and moisture content resulted in maximum expansion, minimum bulk density was observed. WAI and WSI are mostly affected by changes in temperature and screw speed.
3. Increased barrel temperature and screw speed resulted in maximum WAI and minimum WSI was observed. The responses of hardness are mostly affected by changing temperature and moisture content.

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