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Evaluation of extrudate from sweetpotato flour and tomato pomace blend by extrusion processing

Pramesh Kr. Dhungana, Arti Chauhan and Sukhcharn Singh*

Department of Food Engineering and Technology, Sant Longowal Institute of Engineering and Technology, Longowal, Sangrur-148106, Punjab, India.

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Sweet potato flour and tomato pomace blend were used for the development of extruded products. The response surface methodology was adopted in the experimental design to investigate the effect of feed proportion (5-25% tomato waste powder), moisture content (13-17%), screw speed (275-325 rpm) and barrel temperature (120-140°C) on the quality of the extruded products. Regression equation describing the effect of each variable on the system parameters and product responses were obtained. In all the experiments, the responses were almost equally affected by changes in tomato pomace level, feed moisture, extrusion temperature and screw speed. Increase in barrel temperature results in maximum expansion, minimum hardness and maximum water absorption index (WAI). Higher tomato pomace proportion in feed composition showed minimum expansion, maximum bulk density, minimum WAI and maximum water solubility index (WSI). The compromised optimum condition obtained by numerical optimization were: barrel temperature, 137.01°C, screw speed 343.48 rpm, feed moisture 13.86% and tomato pomace 21.31%. The findings of this study demonstrate the feasibility in development of value added extruded products from tomato pomace and sweet potato flour.

Key words: Twin screw extrusion, sweetpotato flour, tomato pomace, response surface methodology.

INTRODUCTION

Sweetpotato (*Ipomea batatas*) also known as Shakharkhand, is a very important crop in the developing world. This tuber is an efficient producer of calories which make significant nutritional contributions to the diet. Apart from being a staple crop for some parts of the world (Papua New Guinea, some parts of the Philippines, Tonga and Solomon Islands), sweetpotato plays a multitude of varied roles in the human diets, being either supplemental or a luxury food. Sweetpotato is one of the seven crops in the world which produce over 135 hundred million metric tons of edible food products in the world annually. China alone produces 80-85% of the total world production (FAO, 1984). The remaining countries in Asia have the next highest production and then followed by Africa and Latin America (Wanda, 1987). The nutritional qualities of sweetpotato which are important in meeting human nutritional needs include carbohydrates, vitamins, high quality protein, fiber and minerals like

*Corresponding author. E-mail: sukhcharns@yahoo.com. Tel 01672-253705.

potassium and iron. Sweet potato contains as much as 44% dry matter (Moorthy, 2002; Hoover, 2001). However, most commercial cultivars, especially in the US, contains 20-30% dry matter. The major components of dry matter are carbohydrates which make up 90% of dry matter in most cultivars. In sweetpotato, the protein content is generally low, ranging from 1.0 to 14.2% dry weight basis (dwb) (Bradbury and Howard, 1989). Sweetpotato protein is good quality and contains excess amounts of essential amino acids except tryptophan and total sulfur amino acids (Wanda, 1987). The possibility of utilization of sweet potato and cassava flour in bread has been investigated by several researcher. The good quality bread can be produce by replacing 10-15% wheat flour with sweetpotato flour (Greene and Bovell-Benjamin, 2004).

Tomato (*lycopersicon esculentum*) is a nutritious fruit and an important part of human diet worldwide. A waste (tomato pomace) at the rate of 4-7% is produced from the tomato processing industries. Tomato pomace consists of dried and crushed skins and seeds of the fruits. The dried pomace contains 44% seed and 56% pulp and skin (Sogi et al., 1998). Tomato pomace is a rich source of bioactive compounds such as high-valuable oils, dietary fibre, vitamins and secondary plant metabolites (Bildstein et al., 2009). The skin (an important component of pomace) is a good source of lycopene. It has attracted attention due to its biological and physiochemical properties, especially related to its effects as a natural antioxidant. Although it has no pro vitamin A activity, it does exhibit the singlet oxygen quenching capacity twice higher than of beta-carotene. This makes its presence in the diet of considerable interest. Increasing clinical evidence supports the role of lycopene as a micronutrient with important health benefits, because it appears to provide protection against a broad range of epithelial cancers. The use of pomace could provide valuable substance and at the same time reduce the waste disposal problems.

Extrusion technology is very useful because nutrient losses are lower than other thermal processing methods (Moscicki et al., 2003). In the extruder, food mix is thermo-mechanically cooked at high temperature, pressure and shear stress which is generated in the screw-barrel assembly. The cooked melt is then texturized and shaped in the die (Arhaliass et al., 2003). It offers several advantages over other types of cooking processes, such as faster processing time and significant reduction in energy consumed; which consequently results in a lower price for the final product. Extrusion cooking technology is used increasingly in the food industries for the development of new products (Sebio and Chang, 2000). Extrusion cooking of food ingredients brings gelatinization of starch, denaturation of protein, modification of lipid and inactivation of enzymes, microbes and many anti nutritional factors (Bhattacharya and Prakash, 1994). Some attempts have been made to produce extruded product either by partial substitution or using sweetpotato flour alone. Extrusion processing is a very viable method used for preparation of valuable products from fruits and vegetables waste due to its versatility, relative low cost and high productivity. Therefore, the objective of this research was to investigate the possibility of utilization of tomato pomace with sweetpotato flour to produce the nutritionally rich extruded product. Response surface methodology was used to study the effect of various process variables on the various properties of extrudates.

MATERIALS AND METHODS

Fully matured sweetpotato was purchased from a local market. Hand peeling was done with knife. The peeled sweetpotato was dipped into 2% salt solution in order to prevent initial browning. Sweetpotato slices of 2-3 mm thickness were dipped in a solution containing 0.5% potassium metabisulphite (KMS) and 0.5% citric acid for 30 min. Thus, treated slices were dried in cabinet dryer at 55°C. Slices were ground and flour was passed through 2 mm sieve to get uniform particle size. Flour was then packed in HDPE bag and sealed tightly. Tomato pomace was taken from Nigger Agro Pvt. Ltd. The pomace was dried to moisture content of about 3.5±.5% (wet basis) in cabinet dryer at 55°C. Dried pomace was ground and stored at refrigeration temperature for future use.

Sample preparation

Samples were conditioned by sprinkling the calculated amount of distilled water in all the dry ingredients. The ingredients were weighed and then mixed in the Food Processor (Make: Maharaja Whiteline, Asiatic Engineers Pvt. Ltd., New Delhi 600W) with mixer attachment for 20 min. This mixture was then passed through a 2 mm sieve to reduce the 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 was estimated using the hot air oven method (Ranganna, 2003). All the samples were kept in high precision (±0.1°C) incubator (Macro Scientific works, New Delhi) at 60°C for 12 h duration for the stabilization of moisture.

Extrusion experiments

Extrusion trials were performed using a co-rotating twin-screw extruder (Basic Technology Pvt. Ltd. Kolkata, India). The main drive is provided with 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 twin screw extruder was kept running for 30 min to stabilize the set temperatures. The samples were then poured into feed hopper and the feed rate was adjusted to 4 kg/h for easy and non choking operation with 4 mm die. The product (approximately 30-35 mm long cylindrical shape) was collected at the die end and kept at 55± 0.5°C in an incubator (Macro Scientific Works, New Delhi) for 12 h duration to remove extra moisture from the product. The product was then packed in already numbered zipped lock packs and kept in proper storage.

Experimental design

Response surface methodology (RSM) was adopted in the

Table 1. Values of independent process variables at five levels of the central composite design arrangement.

Independent variables	Code	± Increment	Levels in coded form				
			-2	-1	0	+1	+2
Tomato pomace (%)	X_1	5	5	10	15	20	25
Feed moisture (%)	X_2	01	13	14	15	16	17
Screw speed (rpm)	X_3	05	120	125	130	135	140
Die temperature (°C)	X_4	25	275	300	325	350	375

Table 2. CCRD (coded and actual levels) employed for development of sweet potato flour and tomato pomace flour based extruded snacks.

S/N	Coded variables				Actual variables			
	X1	X2	X3	X4	X1 TomatoPomace (%)	X2 Moisture content (%)	X3 Screw speed (rpm)	X4 Temperature (°C)
1	-1	-1	-1	-1	10	14	300	125
2	1	-1	-1	-1	20	14	300	125
3	-1	1	-1	-1	10	16	300	125
4	1	1	-1	-1	20	16	300	125
5	-1	-1	1	-1	10	14	300	140
6	1	-1	1	-1	20	14	300	140
7	-1	1	1	-1	10	16	300	140
8	1	1	1	-1	20	16	300	140
9	-1	-1	-1	1	10	14	350	125
10	1	-1	-1	1	20	14	350	125
11	-1	1	-1	1	10	16	350	125
12	1	1	-1	1	20	16	350	125
13	-1	-1	1	1	10	14	350	135
14	1	-1	1	1	20	14	350	135
15	-1	1	1	1	10	16	350	135
16	1	1	1	1	20	16	350	135
17	-2	0	0	0	5	13	325	130
18	2	0	0	0	25	15	325	130
19	0	-2	0	0	15	13	325	130
20	0	2	0	0	15	17	325	130
21	0	0	-2	0	15	15	325	120
22	0	0	2	0	15	15	325	140
23	0	0	0	-2	15	15	275	130
24	0	0	0	2	15	15	375	130
25	0	0	0	0	15	15	325	130
26	0	0	0	0	15	15	325	130
27	0	0	0	0	15	15	325	130
28	0	0	0	0	15	15	325	130
29	0	0	0	0	15	15	325	130
30	0	0	0	0	15	15	325	130

experimental design as it emphasizes the modeling and analysis of the problem in which response of interest is influenced by several variables (Montgomery, 2001). The independent variables selected for the experiments were: Tomato pomace (x_1), moisture content (x_2), screw speed (x_3,), and barrel temperature (x_4). The five levels of the process variables were coded as −2, −1, 0, +1 and +2 (Montgomery, 2001) and design in coded and at the actual levels (X) is given in Table 1. The experimental design with coded and actual level is shown in Table 2. The levels were also selected based on the conclusion of previous experiments. The dependent variables were lateral expansion, bulk density (BD, g/cm^3), color (L*, a*, b*), water absorption index (WAI), water solubility index

(WSI), texture, lycopene content, reducing sugar content and sensory characteristics as product responses.

Product analysis

Lateral expansion

The ratio of the diameter of extrudate and the diameter of the die end was used to express the expansion of extrudate (Ainsworth et al., 2006). Lateral expansion (LE, %) was calculated using the mean of the measured diameters. The values were calculated as the average of three replicate.

LE = (diameter of product - diameter of die hole) / diameter of die hole × 100 (1)

Bulk density

The individual cylindrical extruded rod was weighed individually, the diameter and length were measured by using a digital vernier caliper. Density of extrudate was calculated according to the method of (Stojceska et al., 2008).

$$\text{Density } (g\ cm^3) = 4m/\pi\ d^2\ L \quad (2)$$

Where m is the mass (g) of a length L (cm) of extrudate with diameter d (cm). The values were calculated as the average of three replicate.

Water absorption index (WAI) and water solubility index (WSI)

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.

$$\text{WAI (g/g)} = \frac{\text{Weight gain by gel}}{\text{Dry weight of extrudate}} \quad (2)$$

$$\text{WSI (\%)} = \frac{\text{Weight of dry solid in supernatent}}{\text{Dry weight of extrudate}} \text{X } 100 \quad (3)$$

Texture characteristics

Texture characteristics of the extrudates were measured by using a TA – XT2 Texture analyzer (Stable Micro Systems Ltd., Godalming, UK) equipped with a 500 kg load cell. An extrudate 35 mm long was compressed with a probe SMS – P/75 – 75mm diameter at a crosshead speed 5 mm/s to 3 mm of 90% of the diameter of the extrudate. The compression generates 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., 2008). Five randomly collected samples of each replicate were selected for texture measurement and the values are reported in an average.

Lycopene content

The lycopene content was estimated by spectrophotometric method (Ranganna, 2003).

Reducing sugar (Maltose) content

Reducing sugar was estimated by Di-nitrosalicylic Acid (DNS) method (Caraban et al., 2005). DNS reagent was prepared by dissolving DNS- 10 g, sodium sulfite- 0.5 g, and sodium hydroxide- 10 g in one liter distilled water. The DNS reagent (3 ml) was mixed with 3 ml of maltose solution. The mixture was heated at 90°C for 10 min to develop the red-brown color. Then 1 ml of 40% potassium sodium tartrate (Rochelle Salt) solution was added to the above mixture to stabilize the color. After cooling to room temperature in a cold water bath, absorbance was recorded at 546 nm. A standard curve of Malthus was prepared using the same procedure as above, taking known amount of maltose instead of samples.

Sensory characteristics of extrudates

Sensory analysis was conducted on five samples with tomato pomace levels of 5, 10, 15, 20 and 25%. Fifteen panelists were asked to assess the expanded snacks for flavor acceptability, and to mark on a Hedonic Rating Test (1– Dislike extremely, 5– Neither like nor dislike and 9– Like extremely) in accordance with their opinion of taste, texture, color and overall acceptability.

Statistical analysis of responses

The responses for different experimental combinations were related to the coded variables (x_i, i = 1, 2, 3 and 4) by a second degree polynomial equation:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{44} x_4^2 + \beta_{12} x_1.x_2 + \beta_{13} x_1.x_3 + \beta_{14} x_1.x_4 + \beta_{23} x_2.x_3 + \beta_{24} x_2.x_4 + \beta_{34} x_3.x_4 + \varepsilon \quad (5)$$

The coefficients of the polynomial were represented by β_0 (constant), β_1, β_2, β_3, β_4 (linear effects); β_{12}, β_{13}, β_{14} β_{23}, β_{24}, β_{34} (interaction effects); β_{11}, β_{22}, β_{33}, β_{44} (quadratic effects); and ε (random error). Data were modeled by multiple regression analysis and the statistical significance of the terms was examined by analysis of variance for each response.

Analysis of data

A complete second order quadratic model employed to fit the data and adequacy of the model was tested considering R^2 (the coefficient of multiple determination, a measure of the amount of variation around the mean explained by the model), Adj R^2 (a measure of the amount of variation around the mean explained by the model, adjusted for the number of terms in the model), predicted R^2 (a measure of how good the model predicts a response value) and Fischer's F-test. Coefficient of determination R^2 is defined as the ratio of the explained variation to the total variation and is a measure of the degree of fit. It is also the proportion of the variability in the response variables, which account for the regression analysis. When R^2 approaches unity, the better the empirical model fits the actual data. The smaller the value of R^2, the less relevance the dependent variables in the model have in explaining the behavior variation. The models were then used to interpret the effect of various predictors (terms) on the response. The analysis of variance (ANOVA) tables was generated and the effect and regression coefficients of individual linear, quadratic and interaction terms were determined. The significances of all terms in the polynomial were judged statistically by computing the F-value at probability (p) of 0.01 or 0.05. The regression coefficients were then used to make statistical calculations to generate contour maps from the regression models. Optimization of process parameters was

Table 3. Central composite design arrangement and experimental results for each test run.

Std. No	Independent variables				Responses							
	X1	X2	X3	X4	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8
1	-1	-1	-1	-1	128.28	0.41	12.55	5.65	26.49	11.83	1.29	6.97
2	1	-1	-1	-1	118.28	0.35	19.75	5.61	36.97	8.53	2.31	6.72
3	-1	1	-1	-1	111.95	0.47	18.20	5.95	31.23	6.37	1.90	6.55
4	1	1	-1	-1	105.00	0.48	17.91	5.79	39.33	5.20	2.65	6.45
5	-1	-1	1	-1	82.81	0.48	16.24	5.15	27.01	7.12	2.05	6.57
6	1	-1	1	-1	83.88	0.43	25.36	4.81	35.98	5.16	3.54	6.35
7	-1	1	1	-1	93.59	0.48	17.56	5.91	34.95	12.29	1.90	6.25
8	1	1	1	-1	87.58	0.45	19.64	5.13	41.53	9.72	3.36	6.33
9	-1	-1	-1	1	127.66	0.40	15.28	5.65	30.40	16.60	1.70	7.12
10	1	-1	-1	1	118.83	0.33	17.66	5.33	34.56	7.04	2.25	6.91
11	-1	1	-1	1	104.84	0.50	18.36	5.86	33.12	21.58	1.50	6.61
12	1	1	-1	1	94.06	0.48	8.21	5.46	35.82	11.43	2.46	6.51
13	-1	-1	1	1	115.16	0.46	18.48	5.31	29.57	16.55	2.00	6.55
14	1	-1	1	1	121.80	0.39	20.12	4.54	29.64	10.66	3.04	7.05
15	-1	1	1	1	107.66	0.45	17.64	5.48	35.59	18.02	1.58	6.25
16	1	1	1	1	99.95	0.46	9.09	4.74	35.94	14.75	2.73	6.42
17	-2	0	0	0	113.75	0.46	13.55	6.27	27.09	16.49	0.91	6.77
18	2	0	0	0	112.81	0.41	18.25	5.80	35.53	3.55	3.57	6.53
19	0	-2	0	0	127.50	0.37	20.80	5.22	34.42	14.49	2.27	7.12
20	0	2	0	0	105.47	0.49	18.55	5.98	39.90	13.00	2.71	6.35
21	0	0	-2	0	105.63	0.51	14.48	6.22	27.49	11.52	1.34	6.95
22	0	0	2	0	80.63	0.56	19.36	4.96	29.49	10.06	2.71	6.12
23	0	0	0	-2	105.64	0.43	16.28	5.25	38.30	8.60	2.78	6.77
24	0	0	0	2	124.00	0.33	8.99	4.45	30.25	16.80	1.75	7.25
25	0	0	0	0	110.78	0.47	16.20	5.34	34.92	6.97	2.55	7.00
26	0	0	0	0	114.82	0.43	16.16	5.30	35.72	8.35	2.46	7.24
27	0	0	0	0	108.53	0.50	16.80	5.89	35.35	4.46	2.39	7.19
28	0	0	0	0	112.50	0.45	18.64	5.14	33.02	8.16	2.46	7.12
29	0	0	0	0	111.09	0.46	16.35	5.35	33.44	6.88	2.73	7.20
30	0	0	0	0	112.03	0.47	16.54	5.30	35.02	6.51	2.64	7.10

Y1, Lateral expansion; Y2, Bulk density; Y3, Water solubility index; Y4, Water adsorption index; Y5, Texture hardness; Y6, Maltose; Y7, Lycopene; Y8, Overall Acceptability.

done by partially differentiating the model with respect to each parameter, equating to zero and simultaneously solving the resulting functions. Design Expert 6.0 was used for this purpose and contour plots were developed for selected parameters. Design Expert (Statease Inc, version 6.01, 2001, Minneapolis, MN, USA) was used for the analysis of the data.

RESULTS AND DISCUSSION

Proximate analysis of raw materials

Proximate analysis of sweet potato flour shows that the tomato pomace powder was very high in protein (18.1%) and fat (13.5%). The experiment arrangements and variation of responses of extruded products are shown in Table 3.

Effect of process variables on product lateral expansion ratio

Lateral expansion is the most important physical property of the snack food. Starch, the main component of cereal plays major role in the expansion process (Kokini et al., 1992). The measured expansion ratio of the extrudate varied from 80.625 to 128.28%. The following regression equation was selected to represent the variation of expansion ratio with independent variables:

Table 4. Analysis of variance results for fitted models.

Response	Source	Sum of squares	df	Mean squares	F-value	P-value
LE	Regression	4758.953	14	339.9252	25.93626	< 0.0001*
	Lack of fit	174.8758	10	17.48758	4.026263	0.0688
	Pure error	21.71689	5	4.343378		
	Residual	196.5927	15	13.10618		
	Total	4955.546	29			
BD	Regression	0.075189	14	0.005371	12.64846	< 0.0001*
	Lack of fit	0.003796	10	0.00038	0.737647	0.6818
	Pure error	0.002573	5	0.000515		
	Residual	0.006369	15	0.000425		
	Total	0.081558	29			
WSI	Regression	353.363	14	25.24021	17.68127	< 0.0001*
	Lack of fit	16.98939	10	1.698939	1.92045	0.2442
	Pure error	4.423283	5	0.884657		
	Residual	21.41268	15	1.427512		
	Total	374.7757	29			
WAI	Regression	5.556187856	14	0.396871	9.823989	< 0.0001*
	Lack of fit	0.266685953	10	0.026669	0.393011	0.9021
	Pure error	0.339285633	5	0.067857		
	Residual	0.605971586	15	0.040398		
	Total	6.16	29			
Hardnes (H)	Regression	428.0071	14	30.57193	15.5089	< 0.0001*
	Lack of fit	23.63475	10	2.363475	1.991461	0.2314
	Pure error	5.934021	5	1.186804		
	Residual	29.56877	15	1.971251		
	Total	457.5758	29			

* significant at P < 0.05, df: degrees of freedom.

$$LE = 111.63 - 1.85x_1 - 5.67x_2 - 6.94x_3 + 4.80x_4 - 5.14x_3^2 + 1.91x_1x_3 + 3.90x_2x_3 - 3.86x_2x_4 + 7.18x_3x_4 \quad (6)$$

It was observed that tomato pomace (x_1), moisture (x_2) and screw speed (x_3) had highly significant negative linear effect ($P < 0.001$) and the temperature had highly positive significant effect on expansion followed by a negative quadratic effect of screw speed (Table 4). The interaction of moisture and screw speed ($x_2 x_3$) and screw speed and temperature ($x_3 x_4$) had strong significant positive effect ($P < 0.001$) on expansion of extrudates (Equation 6).The expansion of extrudates decreased with increase in the level of tomato pomace. This may be attributed to the dilution effect of pomace on starch and results are in agreement with the work of Anton (2008). It appears that expansion increased with increasing barrel temperature. The increase in temperature will increase the degree of superheating of the water in the extruder and would increase at higher temperature, leading to the slightly greater expansion. Similar finding has been reported by several workers (Ding et al., 2005; Camire and King, 1991; Lerrea et al., 2005). The increase in die temperature will decrease the melt viscosity. The reduced viscosity effect would favor the bubble growth during extrusion which leads to increased expansion of extrudates (Mercier and Feillet, 1975). However, increased feed moisture leads to a decrease in expansion. Increased feed moisture content during extrusion would change the amylopectin molecular structure of the material reducing the melt density thus decreasing the expansion of the extrudate. Foods with lower moisture tend to be more viscous than those with higher moisture and, therefore, the pressure difference would be smaller for higher moisture foods, leading to a less expanded product. These observations are in agreement with the work reported by Ding et al. (2005), Baik et al. (2004), Gujral et al. (2001) and Singh et al. (2007). Response surface plot showed that lateral expansion decreased with increasing moisture content whereas increased with a decrease in screw speed as shown in Figure 1.

Effect of process variables on product bulk density

The bulk density, which considers expansion in all

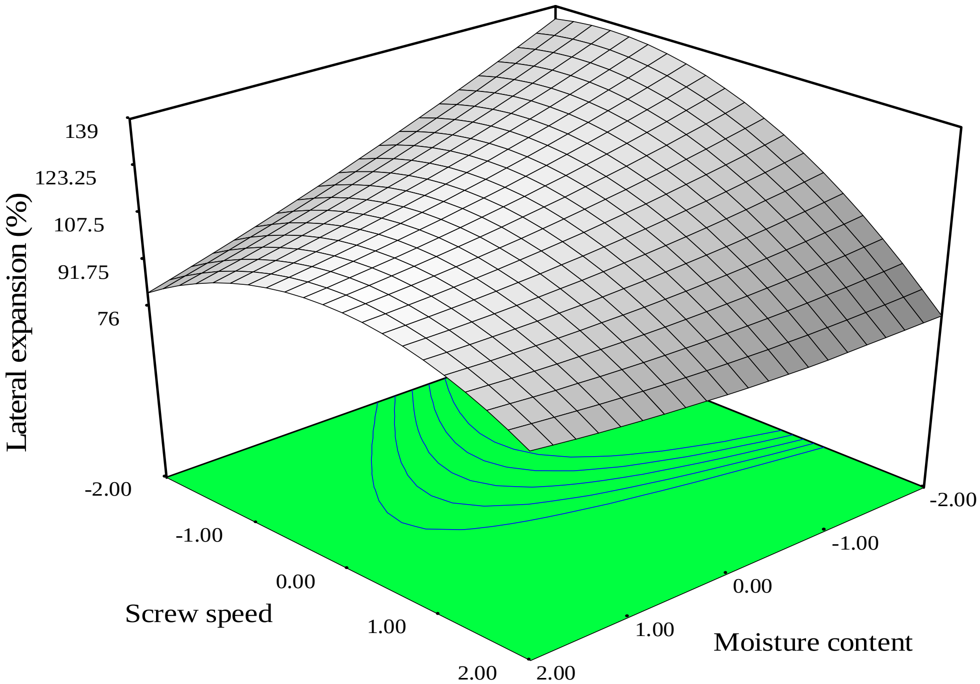

Figure 1. Response surface plot for lateral expansion ratio as a function of feed moisture and screw speed.

direction, ranged from 0.33 to 0.56 g/cm^3 for the extrudate. The following regression equation was selected to represent the variation of bulk density (BD) (g/cm^3) with independent variables:

$$\text{Bulk density} = 0.46 - 0.016.x_1 + 0.031.x_2 + 0.011.x_3 - 0.012.x_4 - 0.00989.x_2^2 + 0.017.x_3^2 - 0.021.x_4^2 + 0.013.x_1.x_2 - 0.022.x_2.x_3 \quad (7)$$

It was observed that tomato pomace (x_1) and temperature (x_4) had highly significant negative linear effect ($P < 0.05$) whereas moisture content and screw speed had highly positive significant ($P < 0.001$) effect on bulk density.

The quadratic term of feed moisture (x_2^2) and barrel temperature(x_4^2) had highly negatively significant ($P<0.001$) effect on product bulk density. The other quadratic terms of and screw speed (X_3^2) had significant positive effect on product bulk density at 95% confidence level. The interaction term of tomato pomace and moisture content (x_1x_2) had a significant effect at 95% confidence level. ANOVA for bulk density of quadratic models (Equation 7) is given in Table 4. The regression model fitted to experimental results of bulk density showed a good coefficient (R^2= 0.9219), whereas lack of fit was not significant.

The dependence of bulk density and expansion on feed moisture would reflect its influence on elasticity characteristics of the starch based material. Increased feed moisture content during extrusion would change the amylopectin molecular structure of the material reducing the melt elasticity thus decreasing the expansion, but increasing the density of extrudate (Faubion and Hoseney, 1982; Fletcher et al., 1985; Ilo et al.,1999; Launay and Lisch, 1983). The coefficient of tomato pomace (x_1) was negative. It reveals that the increase in tomato pomace level decreases product bulk density (Figure 2). This may be due to the large difference between densities of sweet potato flour and tomato pomace. Increase in temperature decreased bulk density as in agreement with Ilo et al. (1999) and Singh et al. (2007). Higher temperature provides higher potential energy for flash-off of super-heated water from extrudates as they leave the die. With higher barrel temperatures, the extrudates exiting the die lose more moisture and become lighter in weight (Koksel et al., 2004). This result is consistent with our result on the effect of temperature on lateral expansion. Quadratic terms of feed moisture (x_2^2) and barrel temperature (x_4^2) had a negative coefficient showing convex shaped variation in bulk density with these variables. Quadratic terms of screw speed (x_3^2) had a positive coefficient showing concave shaped effect on bulk density. The sign of all the significant square terms is opposite to the expansion terms as expected. In this study, interaction term of tomato pomace and moisture (x_1x_2) was found to be positively significant ($P < 0.05$). Therefore, we can assume that bulk density will show convex shape variation with the change in value of variables. It reveals that higher product bulk density will obtain increase tomato pomace and feed moisture. Other significant ($P<0.05$) interaction term of feed moisture and screw speed had negative coefficient. This indicates a concave

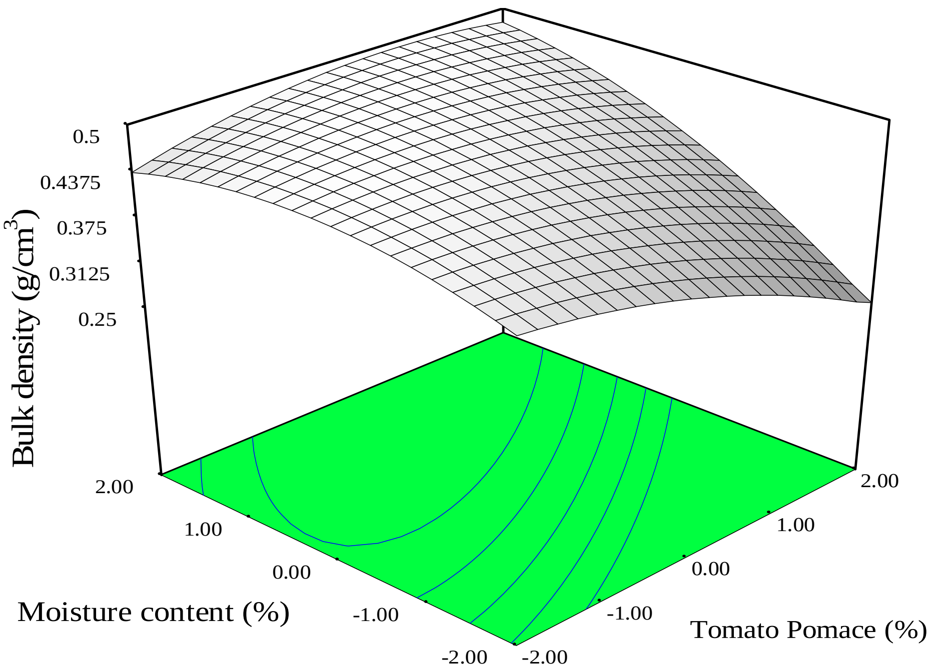

Figure 2. Response surface plots for the variation of bulk density as function of feed moisture and tomato pomace.

shaped variation in bulk density. So there will be low product bulk density with decrease in both screw speed and feed moisture.

Effect of process variables on product water solubility index (WSI)

The WSI values ranged from 8.21 to 25.36% for the sweet potato flour and tomato pomace extrudates. A multiple regression equation was generated relating to water solubility index (WSI) to coded levels of variability.

$$WSI = 16.78 + 0.53x_1 - 0.97x_2 + 1.08x_3 - 1.54x_4 + 0.84x_2^2 - 0.92x_4^2 - 2.33x_1x_2 - 2.05x_1x_4 - 0.86x_2x_3 - 1.10x_2x_4 \quad (8)$$

The negative coefficient of moisture content (x_2) of WSI model supports that the value will decrease significantly ($P < 0.05$) with increasing feed moisture content. The result is consistent with previous studies on extrudate from rice (Ding et al., 2005) and from maize and finger millet (Onyango et al., 2004). It suggested that increasing WSI is caused by greater shear degradation of starch during extrusion at low moisture conditions. The WSI increased significantly ($P < 0.05$) with increasing screw speed (Figure 3). The increase in WSI with increasing screw speed was consistent with the results reported for corn meal and corn and wheat extrudates (Jin et al.,1995; Mezreb et al., 2003). Mezreb et al. (2003) reported that the increase of screw speed induced a sharp increase of specific mechanical energy, the high mechanical shear degraded macromolecules, and so the molecular weight of starch granules decreased and hence increased WSI (Equation 8).

WSI decreased significantly ($P < 0.05$) with increasing sweet potato flour proportion in the extrudate. WSI is a parameter that reflects the degradation suffered by the components of the fiber Larrea et al. (2005). Tomato pomace is high in fiber content which disrupts the continuous structure of the melt in the extruder, impeding elastic deformation during extrusion (Moraru and Kokini, 2003). So, the highest WSI values may be due to the disintegration of starch granules and low molecular compounds from extrudate melt during extrusion. This may cause an increase in soluble material. WSI determines the amount of free polysaccharide or polysaccharides released from the granule after addition of excess water (Sriburi and Hill, 2000; Aylin et al., (2008). Increase in feed moisture content significantly ($P < 0.050$) decreases WSI. Increase in feed moisture increases the plasticity of feed thus minimizes the chance of the formation of small fraction polymer. WSI increased significantly ($P < 0.05$) with an increase in screw speed (x_3). In this experiment, the WSI decreased significantly with increasing barrel temperature (Figure 3). In this study coefficient of the interaction term of x_1x_2, x_1x_4, x_2x_3 and x_2x_4 were found to be negatively significant therefore; they will show convex shape variation with the change in value of variables.

Effect of process variables on product WAI

The WAI ranged from 4.45 to 6.27 g/g for sweetpotato

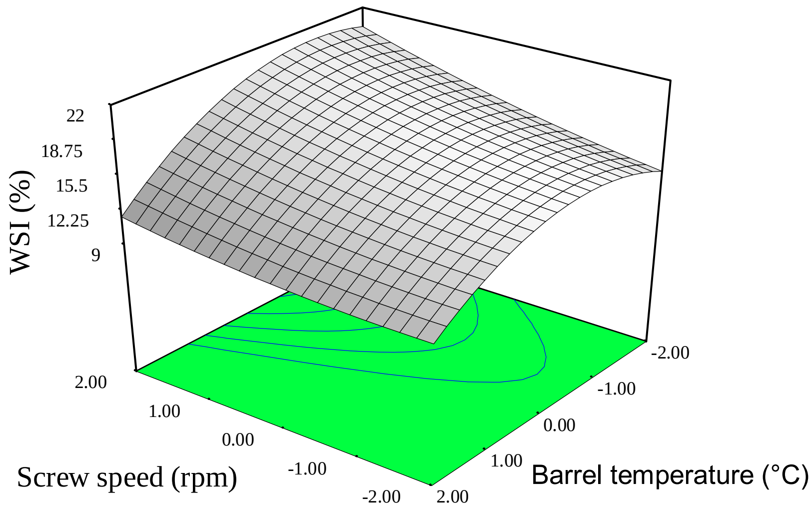

Figure 3. Response surface plot for water solubility index as a function of screw speed and temperature.

flour and tomato pomace extrudate. WAI measures the amount of water absorbed by starch that can be used as an index of gelatinization. A multiple regression equation between water absorption index (g/g) of extrudate and coded levels of independent variables was as follows:

$$WAI = 5.39 - 0.19x_1 + 0.16x_2 - 0.28x_3 - 0.14x_4 + 0.144x_1^2 - 0.15x_4^2 - 0.11x_1x_3 \quad (9)$$

The negative coefficient of linear terms of feed moisture (x_1), screw speed (x_3) and temperature (x_4) indicated that the content of WAI decreased with the increase of these variables. A decrease in WAI with increasing temperature was probably due to decomposition or degradation of starch (Pelembe et al., 2002). Ding et al. (2005) also stated that the WAI decreases with increasing temperature if dextrinization or starch melting prevails over the gelatinization phenomenon. Similar findings were reported in extrusion of corn fiber and corn starch blend (Artz et al., 1990). Singh et al. (2007) observed decrease in WAI with the addition of pea grits in extrusion of rice. Screw speed had a significant negative effect on WAI which shows that increase in screw speed will decrease WAI (Equation 9). The coefficient for interaction term of feed composition and screw speed (x_1x_3) is significant and negative thereby it will show the concave shape (Figure 4) variation with the change in value of variables. ANOVA for WAI in Table 4 showed that the model was significant ($P < 0.05$), however the lack of fit was not significant. Figures also shows that there will be higher value of WAI at low level of tomato pomace irrespective of screw speed level. In our study, sweetpotato flour is only one source of starch, so there is higher amount of starch for gelatinization. In Figure 4, an increase in feed composition (tomato pomace) decrease WAI and increase in feed moisture increases WAI. The figures shows that higher values of WAI will be obtained at a higher level of moisture and lower level of tomato pomace.

Effect of process variables on texture of extrudate (H)

Hardness of the extrudate varied between 26.50 and 41.53 N. The quadratic model for hardness (H) in terms of coded levels of variables was developed as follows:

$$H = 34.58 + 2.43x_1 + 1.99x_2 - 1.04x_4 - 0.68x_1^2 + 0.78x_2^2 - 1.38x_3^2 - 1.68x_1x_4 + 0.92x_2x_3 \quad (10)$$

Hardness of extrudates was found to increase with increased feed composition. The positive effect of feed composition indicates that the higher tomato pomace content causes less crispy extrudate. This might be the result of the effect of fiber in the tomato pomace. Fiber reduces the cell size, probably by causing premature rupture of gas cells, which reduces the overall expansion and results in a less porous structure (Lue et al., 2000). Concave shaped variation resulted in hardness due to increase in moisture as a quadratic term of moisture was significant, indicating that hardness increases more sharply at higher moisture level than at lower level. It might be due to the reduced expansion caused by the increased moisture content (Ding et al., 2005). Increase in temperature resulted in a decrease in product hardness. Therefore, a crispy texture was obtained by increasing temperature due to decrease in hardness.

This result is in agreement with Bhattacharya and Prakash (1994), Ryu and Walker (1995) and Duizer and Winger (2006).

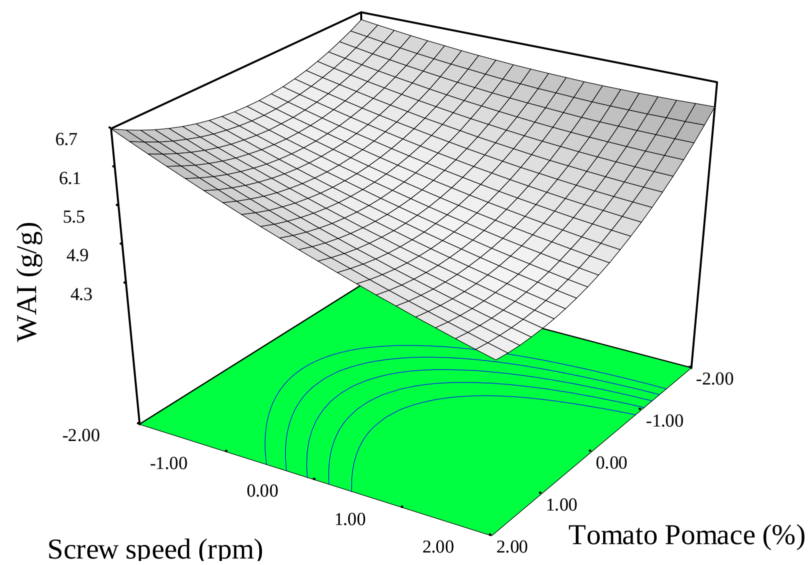

Figure 4. Response surface plot for water absorption index as a function of tomato pomace and screw speed.

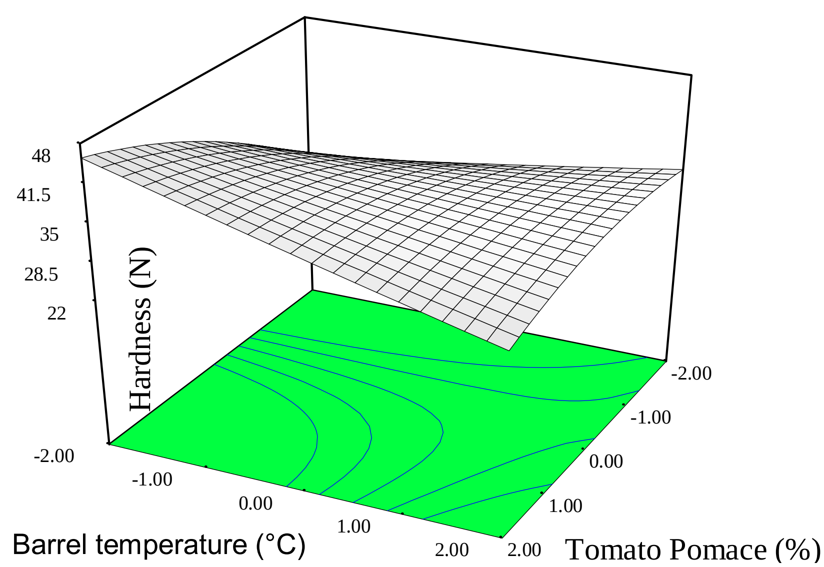

Figure 5. Response surface plot for hardness as a function of tomato pomace and barrel temperature.

F-value for interaction term of feed composition and barrel temperature (x_1x_4) is 22.87 and p value 0.0002 predicting the term is significant which is in agreement with the finding of Aylin et al. (2008). Since the coefficient of a term is negative, it will show convex shape variation with the change in value of variables. Response surface plot (Figure 5), predicted that hardness increased with increasing feed composition and barrel temperature (equation 10).

The interaction term of feed moisture and screw speed (x_2x_3) was significant at 95% confidence level (F-value 6.88 and P-value 0.0192). Coefficient of x_2x_3 was positive so causes concave shaped variation in product hardness. Response surface plot (Figure 5) show variation in hardness with an increase in feed moisture and screw speed.

Effect of process variables on product maltose content (MC)

Extrusion cooking is one processing method that has

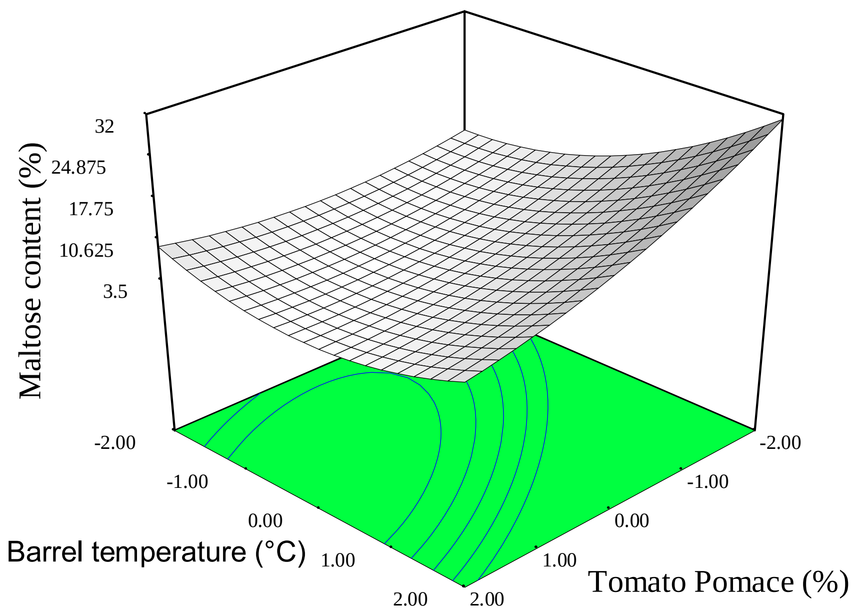

Figure 6. Response surface plot for maltose content as a function of tomato pomace and barrel temperature.

been used to modify the digestible characteristics of starchy materials. Maltose content (MC) of extrudate varied from 5.16 to 21.57. The quadratic model for maltose content (MC) in terms of coded levels of variables was developed as follows:

$$MC = 6.89 - 2.66x_1 + 2.78x_4 + 1.65x_2^2 + 0.91x_3^2 + 1.39x_4^2 - 1.24x_1x_4 \quad \text{....(11)}$$

The maltose content of extrudates was found to decrease with increase in tomato pomace. Increase in tomato pomace limits the availability of starch. Maltose content is directly related to the amount of starch present in the raw material. The negative effect of feed composition indicates that the highest tomato content causes the less gelatinized extrudate (Equation 11). This result is supported by trends in the expansion ration with respect to feed composition. Increase in tomato pomace caused a decrease in expansion ratio. The expansion ratio is also a degree of gelatinization dependent factor. This might be the result of the effect of fiber in the tomato pomace. Fiber reduces the cell size, probably by causing premature rupture of gas cells, which reduces the overall expansion and results in a less porous structure (Lue et al., 2000; Aylin et al., 2008). The study showed that starch digestion (maltose content) increases with increase in temperature. Among the significant terms, barrel temperature had the highest F-value, 38.07 indicating the most influencing factor for starch digestion. The quadratic term of barrel temperature was also significant at 95% confidence level. It indicates that as extrusion temperature increases, extent of starch conversion will be higher. Higher temperature might have favored hydrolytic breakage of starch chains along with the formation of shorter chain during gelatinization.

Study of analysis of variance of the data showed that maltose content had a significant effect of quadratic terms of feed moisture and screw speed. Positive coefficient of both quadratic terms indicated that there will be concave shaped variation in maltose content with increase in values of feed moisture and screw speed. Higher expansion was obtained at lower feed moisture and screw speed. Figure 6 shows that increasing feed moisture up to middle value decreases maltose content. There may be dominant effect of water as plasticizer for that range of moisture. However, further increase in feed moisture to positive extreme value caused increased maltose content. In this situation, there may be significant hydrolytic cleavage of the starch at elevated temperature (120 to 140°C).

The interaction terms, x_1x_4 was found to be negatively significant. It indicates that lower amounts of maltose will be obtained at higher tomato pomace level depending upon range temperature. Figure 6 shows the variation in maltose content as a function of feed composition and barrel temperature.

Effect of process variables on product lycopene content

The lycopene content of the extrudate ranged from 0.91 to 3.56 mg/100g (db). The model represents the variation of lycopene content and for further analysis.

Table 5. Analysis of variance results for fitted models.

Response	Source	Sum of squares	df	Mean squares	F-value	P-value
Maltose Content	Regression	542.8975	14	38.7784	7.838053	0.0001*
	Lack of fit	64.39502	10	6.439502	3.27985	0.1010
	Pure error	9.816763	5	1.963353		
	Residual	74.21179	15	4.947452		
	Total	617.1093	29			
Lycopene Content	Regression	11.79661	14	0.842615	25.09101	< 0.0001
	Lack of fit	0.421448	10	0.042145	2.560826	0.1555
	Pure error	0.082288	5	0.016458	0.082288	
	Residual	0.503735	15	0.033582	0.503735	
	Total	12.30035	29			
Overall acceptability (OA)	Regression	3.228657	14	0.230618	11.98093	< 0.0001
	Lack of fit	0.251175	10	0.025118	3.343932	0.0975
	Pure error	0.037557	5	0.007511		
	Residual	0.503735	15	0.033582		
	Total	3.517389	29			

* significant at P < 0.05, df: degrees of freedom.

Lycopene content = $2.54+0.57x_1+0.29x_3-0.16x_4-0.073x_1^2-0.13x_3^2-0.067x_4^2+0.12x_1x_3-0.13x_2x_3-0.085x_2x_4$ ....(12)

Feed composition was found to be the main factor affecting product lycopene content (Table 5). It is obvious that the tomato pomace is the only source of lycopene in the extrudate. The lycopene content of the sweet potato flour and tomato pomace extrudate increased with increase in screw speed. This may be due to lower residence time for lycopene degradation. However, significant negative effect of a quadratic term of screw speed (x_3^2) indicate a convex shaped variation in lycopene content to increase in screw speed. It means the lycopene content of the extrudate increases initially and again decreases with increase in screw speed. Decrease in lycopene content at higher screw speed might be due to input of higher amount of mechanical energy. Increase in screw speed might cause even mixing and disruption of tomato pomace exposing more lycopene to heat. Study of the data reveals that the increase in barrel temperature caused a decrease in the lycopene content of the extrudate. Although the quadratic term of barrel temperature (x_4^2) was significant only at the 90% confidence level, however, it could be said that as temperature increases the rate of lycopene destruction increases showing a convex shaped variation in lycopene content (Equation 12).

The interaction term of feed composition and screw speed (x_1x_3) had a significant positive effect on lycopene content. A positive coefficient indicates that higher lycopene content will result to an increase in tomato pomace level and screw speed. Figure 7 shows the change in lycopene content as a function of feed composition and screw speed. Coefficient of the interaction term of feed moisture and screw speed (x_2x_3) was negative indicating that the lower lycopene content will result to lower feed moisture depending up on screw speed. Figure 7 shows the change in lycopene content as a function of feed moisture and screw speed.

Effect of process variables on product overall acceptability (OA)

The overall acceptability of the product ranges from 6.12 to 7.25 in the extrudates prepared from sweet potato flour and tomato pomace powder (Table 3). The coefficient of the model and other statistical attributes of overall acceptability are shown in Table 5. The Model F-value of 11.98 implies the model is significant. In this case x_2, x_3, x_4, x_1^2, x_2^2, x_3^2, x_4^2, and x_1x_3 are significant model terms at P<0.05. Considering all the above criteria, the following model was selected for further analysis.

OA = $7.14 -0.18.x_2 -0.16.x_3 +0.92.x_4 -0.15.x_1^2-0.13.x_2^2-0.17.x_3^2 -0.06.x_4^2 +0.07.x_1.x_3$ …(13)

The coefficients of the linear terms x_2 and x_3 *are* negative which indicates that increase in feed moisture and screw speed will decrease the overall acceptability. The term x_4 positive indicate that increase in temperature will increase the overall acceptability. All the quadratic terms are significant at 95% confidence level. Of the

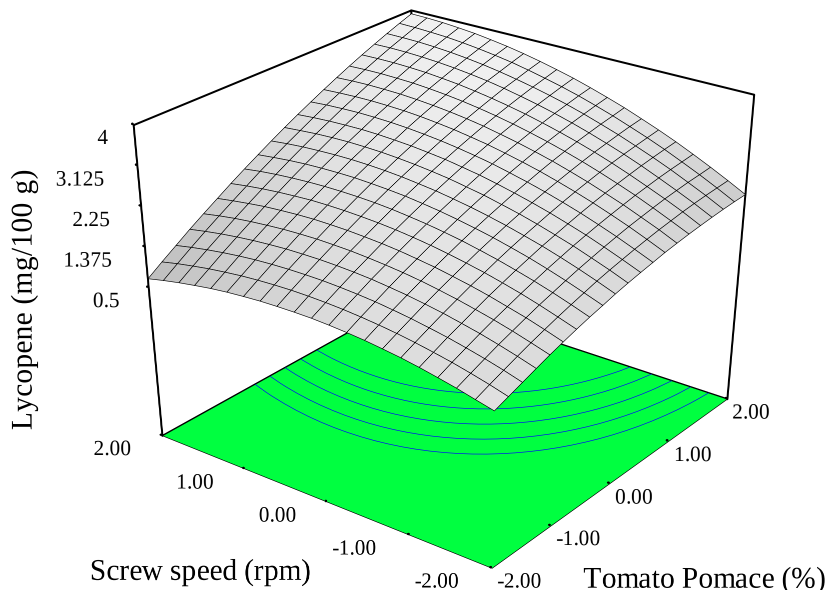

Figure 7. Response surface plot for lycopene content as a function of tomato pomace and screw speed.

quadratic terms x_1^2, x_2^2, x_3^2 and x_4^2 have a negative coefficient.The interaction term of tomato pomace and and screw speed (x_1x_3) had a significant positive effect at 95% confidence level. Increase in feed moisture caused a decrease in the overall acceptability of the extrudate. As the quadratic term of x_3^2 is also significant with negative coefficient, it indicates that product OA will be very low with further increase in screw speed. The temperature had significant positive linear effect on product OA. It indicates that increase in barrel temperature increases product OA. This may be due to higher expansion of the extrudate. However, further increase in temperature caused slight decrease in product OA. Although there is no decrease in the expansion ratio at higher temperature, decrease in OA may be due to degradation of color pigment (lycopene). Feed composition had a significant effect only at quadratic level showing convex shaped variations on product OA. Initially, increase in overall acceptability may be due to increase in redness of product due to increase in tomato pomace level. But a further increase in tomato pomace level decreased product OA. This may be due to low expansion and increased hardness at higher pomace level (Table 5).

Optimization

A numerical multi-response optimization technique was applied to determine the optimum combination of sweet potato flour and tomato pomace in feed composition, feed moisture, screw speed and barrel temperature for the production of extrudate containing sweet potato flour and tomato pomace. The assumptions were to develop a product which would have maximum score in sensory acceptability so as to get market acceptability, maximum expansion, minimum bulk density, and minimum hardness. Lycopene content was set as target. This is done to get 6.5 mg lycopene from 200 g extrudate. According to American Dietetic Association, incorporation of 6.5 mg lycopene per day has a protective effect over chronic diseases. Therefore, among responses, these parameters were attempted to be maintained whereas other parameters were kept within range. Under these criteria, the uncoded optimum operating conditions for development of sweet potato flour and tomato pomace extrudate were 137.01°C of barrel temperature, 343.48 rpm of screw speed, 13.86% of feed moisture and 21.31% of tomato pomace. The responses predicted for these optimum process conditions resulted to lateral expansion of 129.90%, bulk density, 0.32 g/cm^3; water solubility index, 18.71; water absoption index, 4.44 g/g; hardness, 29.52; maltose content, 9.44; lycopene content, 3.01 and overall acceptability, 6.96 with desirability, 0.880. The suitability of the model developed for predicting the optimum response values was tested using the recommended optimum conditions of the variables and was also used to validate experimental and predicted values of the responses.

Conclusion

In the experiment the product responses were almost equally affected by changes in tomato pomace level, feed moisture, extrusion temperature and by screw speed.

Increase in barrel temperature resulted in maximum expansion, minimum hardness and maximum WAI. Higher tomato pomace proportion in feed composition showed minimum L value of color, minimum expansion, maximum bulk density, minimum WAI and maximum WSI whereas minimum moisture content is sought for higher crispiness, lower hardness, higher expansion and lower bulk density of developed extrudates. In this experiment, numerical optimization studies resulted in 137.01°C of barrel temperature, 343.48 rpm of screw speed, 13.86% of feed moisture and 21.31% of tomato pomace as optimum variables to produce acceptable extrudates.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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