Optimization of pneumatic sheet extrusion of whole wheat flour *poory* dough using response surface methodology

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Abstract Pneumatic extrusion of whole wheat flour dough is a challenge in the preparation of *Poory*. In the present study, the pneumatic extrusion process variables (pneumatic pressure, rate of extrusion) and quality of deep fried product (oil uptake, frying time, puffed height) was evaluated to get *Poory* of maximum overall sensory quality, minimum shear and minimum oil uptake. These parameters depend on the moisture content of wheat dough. Response surface methodology was demonstrated to be an efficient tool for the optimization of process parameters of pneumatic extrusion. The results indicated that extrusion pressure ranging from $3\sim6\times10^5$ Pa for the whole wheat flour dough with added moisture of 56~60 % was found to give a uniform rate of extruded sheet. It was observed that submerged frying time for the extruded dough sheet was in the range of 35~40 s, with the temperature of the vegetable oil to be in the range of 180~185 °C. Oil uptake during frying was about 12 ± 1 % and the textural shear force was found to be 9.9 N with an overall sensory score of 7.2 ± 0.5 on nine point scale. The experimental errors for all attributes were non-significant ($p>0.05$) and thus optimum variables predicted by the model are found suitable.

Keywords *Poory* · Dough sheeting · Pneumatic extrusion · Response surface methodology · Oil uptake · Sensory quality

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Introduction

Poory, Indian traditional puffed bread considered as either a meal or snack item, is the second largest consumed product next to chapatti or unleavened bread. *Poory* a circular shaped deep fried and puffed product has a soft and pliable texture with typical aroma. Generally *Poory* is prepared by rolling 25×10^{-3} kg of whole-wheat flour dough to a thickness of about 1.3×10^{-3} m and diameter being $100\sim150\times10^{-3}$ m, followed by deep fat frying in oil at 180–185 °C for over 35~40 s (20 s on each side). Puffed product (*Poory*) becomes brown on either side after frying. Traditionally rolling of dough sheet is done manually by a roller, which is tedious and unhygienic. To address these challenges, it is essential to automate (mechanization) the process of sheeting to maintain product quality. Automation not only helps in improved quantity and quality but also in hygiene and energy conservation. Pneumatic extrusion of whole wheat flour dough sheet for *Poory* preparation offers a challenge, as many parameters are involved in this operation (Desrumaux et al. 1999) such as rheological properties (Angioloni and Rosa 2005; Peressini and Sensidoni 2009; Mohammed et al. 2012; Engmann et al. 2005; Mitsoulis and Hatzikiriakos 2009; Peck et al. 2006), effect of ingredient, moisture content, process variables such as feed rate, thickness of die and frying oil temperature (Anderson and Ng 2001; Hagenimana et al. 2006) and has effect on the final product quality (Ali et al. 1996; Ryu and Ng 2001; Hagenimana et al. 2006). Hence, it is necessary to understand the complex processes that occur during pneumatic extrusion and deep frying so that improvements can be effected by optimizing the formulation and the process leading to better automation (Blumenthal and Stier 1991).

The moisture content of the dough plays a very important role. The pneumatic pressure, rate of extrusion, oil content in the final product, frying time and puffed height of the product

are parameters that depend on the moisture content of wheat dough. From the consumer's point of view, the deep fat fried *Poory* has to puff well, cook properly and absorb less fat during frying. On characterization of different traditional cereal based fried products, it was found that *Poory* has the highest fat content of 24 %, while it ranged between 5 and 13 % for other foods (Sharavathy et al. 2001). To cope up with the increasing demand for Ready-to-eat *Poory*, mechanization of *Poory* preparation becomes imperative. Hunter (1959) reported response surface methodology (RSM) to be an effective tool in optimizing the conditions when independent variables have a combined effect. The RSM technique has been used for optimizing formulations of bread, cake and cookie (Henselman et al. 1974; Kissel 1967; Palomar et al. 1994). It was also used for optimizing the conditions for boondi, an Indian traditional food (Ramasamy and Susheelmma 2005), optimization of process parameters for boondi preparation (Venkateshmurthy et al. 2008), Tandoori roti, *Poory* and *parotta* (Indrani and Venkateswara 2001; Saxena and Haridas 1996; Vatsala et al. 2001). Extrusion of food materials such as dough is a broad area of industrial activity. Therefore, the present study was designed to evaluate the pneumatic extrusion process variables and quality of deep fried product and to optimize the processing conditions to get *Poory* of maximum overall sensory quality, minimum shear and minimum oil uptake.

Materials and methods

Wheat flour

Whole wheat flour (Brand: Annapurna, Make: ITC foods (P) Ltd., India), salt and sunflower refined oil were procured from the local supermarket.

Chemical characteristics and sieve analysis of the flour

Standard methods (AACC 2000) were followed to determine the moisture, ash, gluten and damage starch content of the flour. Particle size distribution was carried out using a Buhler Plan sifter (model MLU 300, M/s Buhler, Uzwil, Switzerland) wherein 0.2 kg of flour was sieved for 10 min and the fractions over each sieve were collected, weighed and percentage over tailings were calculated. The mixing profile of the dough was studied using a farinograph (Brabender, Duisburg, Germany) according to the standard AACC (2000).

Experimental design

Oil uptake, instrumental shear value and overall sensory score (which are the sum of various quality characteristics taking into account the surface colour, hand feel, texture and taste)

were the three responses measured. Optimal product quality should have maximum sensory score, and minimum shear value and oil uptake.

Preparation of *Poory* and its evaluation

Whole wheat flour dough (*Poory* dough) was prepared by mixing a predetermined quantity of whole wheat flour, salt and water in a planetary mixer (Model: BERJAYA, I/BSP-BM20, Malaysia) for 5 min. After resting the dough for 15 min, it was fed into the pneumatic extruder (Fig. 1) and sheeted by application of compressed air. The extruder works at a pressure ranging from 3 to 6×10^{-5} kg/cm² and has an extrusion capacity of 0.8–1 m/min. The extrusion is followed by frying at 180–185 °C.

Automatic pneumatic dough sheeting device

The automatic pneumatic dough sheeting device was designed and developed by Venkateshmurthy and Jayaprakashan (1991) earlier, for extrusion of dough sheet. Subsequently an improved automatic device for pneumatic extrusion of dough into sheet and shaping, cutting of extruded sheet (for preparation of *Poory*) and other similar Indian traditional foods, developed by (Venkateshmurthy et al. 2008), is as shown in Fig. 1. It comprises of two major sub-assemblies, namely, the pneumatic sheeting unit and a dough sheet conveyor. Both these units are integrated to produce dough sheet continuously in large-scale. The Automatic pneumatic dough sheeting device for pneumatic extrusion of dough into sheet and shaping, cutting of extruded sheet consists of a cylindrical vessel (1) having flanges (2 & 3) at its top and bottom. Top cover plate (4) has provision for housing suitable gaskets to make the extruder leak proof and cover plate has quick fix Coupling (5) on its top at its centre for admitting compressed gas into the vessel. Cylindrical vessel is provided with an isolator (6) with suitable handle and an air vent. The isolator is provided with a rubber 'O' ring (7) to make the isolator leak proof. A die plate (8) having slit thickness of 1.5×10^{-3} m and length of 180×10^{-3} m is fixed gas tight on to the cylindrical vessel (1) with a suitable gasket. A receiver (of the compressor) containing compressed air/gas (9) is used for holding gas under pressure. The top cover plate and top portion of the vessel has additional means such as bolt and nut to make the cylindrical vessel gas tight. The die plate (8) has provision for mounting a geared motor (10) which imparts rotary motion to the cutter (11) to cut the dough sheet to the required length. A cutter (11) is mounted on a horizontal shaft (12). Cleaning wiper (13) is provided to clean the cutter. A conveyor is placed at the bottom of the cylindrical vessel

Fig. 1 Automatic pneumatic dough sheeting device

for transfer of cut dough sheet. Conveyor assembly is provided with set of roller, namely, driven roller (14) and a drive roller (15). The rollers are mounted in between two side plates (16) and food grade belt (17). A geared motor (18) drives the food grade belt and the linear velocity of the belt is varied by varying the speed of the geared motor.

Pan fryer

A stainless steel pan having oil holding capacity of 5 L was used for frying of cut square *Poory* sheets. The oil/pan was heated by a stove, fired by Liquid Petroleum Gas (LPG) as the fuel source. A solid state temperature controller is provided, which regulates LPG flow and helps in maintaining the temperature of oil over a range of 180–185 °C. Cut square *Poory* sheet was transferred into the hot oil of the fryer and fried manually for 20 s on one side and 20 s on reverse side. Puffed product was removed from oil, cooled in a tray and packed in polypropylene pouches till further analysis.

Moisture content and oil uptake

The moisture content of *Poory* was determined by measuring weight loss of *Poory* upon drying in an oven at 105 °C for 4 h

and continued drying until constant weight. The oil content of *Poory* was determined using soxhlet apparatus on a moisture-free sample with petroleum ether for 16 h in triplicates. Oil content of the *Poory* was expressed as percentage on moisture free basis (ISI standard methods 1989).

Shear strength

The shear strength of the *Poory* was determined as the maximum force required to shear a *Poory* strip of 0.02 m width and 0.025 m long using a texture analyzer (model- TA -HDi, Stable Micro Systems, Surrey, UK) with a Warner – Bratzler shear attachment with a cross head speed of $100 \times 10^{-3} \text{ m min}^{-1}$ and load cell of 10 kg, in triplicates.

Experimental setup

Response surface methodology (RSM) has been widely applied in the food industry for optimizing complex processes and products (Lee et al. 2006; Sin et al. 2006). The RSM used in the present study is a central composite design (CCD) involving two different independent variables (pressure and water content). The range was fixed based on the prior trials. In the central composite design, the total number of experimental combinations was 13

(including four centre points replicated). Experiments were conducted in a randomized fashion.

The dependent variables selected for this study were texture shearing strength, fat uptake and overall sensory quality. Moisture content of product was also measured for the better understanding of the oil uptake. An empirical model, describing the relationships among the dependent variable and the independent variables in a second-order equation, was developed (Eq. 1). Design-based experimental data were matched (Giovanni 1983) according to the following second-order polynomial equation:

$$y = \beta_0 + \sum_{j=1}^k \beta_j X_j + \sum \beta_{jj} X_j^2 + \sum \sum_{i < j} \beta_{ij} X_i X_j \quad (1)$$

where 0, i, ii and ij are regression coefficients for intercept, linear, quadratic and interaction coefficients respectively and X_i and X_j are coded independent variables.

The goodness of fit of the second-order equation was expressed by the coefficient of determination R^2 , and its statistical significance was determined by the F -test. Response surface plots were obtained based on the effect of the levels of two parameters (at five different levels each) and their interactions on the response keeping the other two parameters at their optimal levels. The optimization technique was used to find out the optimum combination/formulation by numerical method. The criteria response values were fixed depending upon their desirability. When more than one local optimum was detected, the best formulation was properly selected. The experimental design and response variables are given Table 1.

Sensory evaluation

Consumer acceptance test

A panel of twenty untrained consumers evaluated the *Poory*. Consumers were requested to evaluate acceptability of the product. A nine-point hedonic scale was used to determine the acceptability rate (Meilgaard et al. 2007; Resurreccion 1998) with 1=dislike extremely, 5=neither like nor dislike and 9=like extremely. The product was prepared according to the experimental design and served to the panelists. The panelists tested four samples per session (three session total). Each sample was coded by a three-digit number and presented in a random order.

Statistical analysis

The consumer data were decoded and calculated to mean and standard deviation, statistically significant differences ($p < 0.05$) in data were tested by the Duncan test. All data analysis, response surfaces, ANOVA, regression and optimization were performed using statistical version 5.5 statistical software (Statsoft, Tulsa, OK, USA).

Results and discussion

Dough characteristics

The whole-wheat flour used in the study had a moisture content of 8.29 % (w/w), ash 1.27 % and 12.1 % of protein content. Damage starch was 14.76 %. Reasonable amounts of

Table 1 Experimental design and response variables

Sl. No	Independent variables				Response variables (<i>Poory</i>)			
	Pressure		Added moisture		Moisture content (%)	Oil uptake (%)	Texture (shear force) (N)	Overall quality score (max. 9)
	Actual $\times 10^5$ Pa	Coded	Actual (%)	Coded				
1	3.44	−1.000	56.46	−1.000	24.72	12.55	10.6	7.2
2	3.44	−1.000	63.53	1.000	25.65	13.25	9.5	6.5
3	5.56	1.000	56.46	−1.000	26.88	12.15	11.5	7.0
4	5.56	1.000	63.53	1.000	31.5	15.26	8.3	6.5
5	3.00	−1.414	60.00	0.000	27.12	13.15	8.4	8.2
6	6.00	+1.414	60.00	0.000	28.93	12.95	8.1	7.5
7	3.44	0.000	55.00	−1.414	23.01	11.57	11.4	6.5
8	4.50	0.000	65.00	1.414	32.14	15.66	7.8	6.5
9 ^a	4.50	0.000	60.00	0.000	30.43	14.03	8.3	7.0

^a Centre point replicated four times

protein and damage starch were found to be suitable for *Poory* making. Similar observations were reported by Vatsala et al. (2001), wherein flour of similar damage starch was found to be suitable for *Poory* making. The particle size distribution analysis of the whole wheat flour showed 83 % of the flour passed through six Tyler mesh (219×10^{-6} m). Farinograph water absorption, dough development time and dough stability values were 69.5 %, 7.0 min and 4.8 min, respectively. Mixing tolerance index was found to be 47 BU indicating that the flour obtained was from wheat of medium hard variety. Frying time, temperature and height of fall were maintained at 40 s, 180–185 °C and 80×10^{-3} m, respectively. Addition of fat softened the dough and accordingly the pressure required to extrude the dough decreased. However addition of fat increased the frying time by 3–5 s, as the fat has to be heated from room temperature to the frying temperature of the product.

The dough was extruded through the slit into a rectangular sheet and the rate of extrusion was in the range of 125×10^{-3} – 456×10^{-3} m/min (Table 2) by the application of compressed air. Square sheet had a width ranging from 73×10^{-3} – 78×10^{-3} m (Table 2) and was cut to a length of dimension of 75×10^{-3} m (to give a square shape) with a thickness of the sheet was in the range of 1.40×10^{-3} – 1.50×10^{-3} m. Variation in thickness of sheet was due to the elastic nature of the dough, resulting in increased thickness. Slit width of 1.5×10^{-3} m yielded *Poory* sheet ranging from 2.1×10^{-3} – 2.4×10^{-3} m thickness (Table 2) and 2×10^{-3} m was found to be optimum. In order to obtain a continuous sheet in the *Poory* sheeting device with good surface finish and machineability, added moisture was reduced from 66 % to 62 %. These characteristics were found to improve further when the added moisture was reduced from 62 to 56 %, for whole-wheat flour and the corresponding pressure required to extrude the dough was found to be in the range of 3 – 6×10^5 Pa, respectively. Higher extrusion pressure at lower moisture content was due to the stiffness of the whole wheat flour dough. Extruded sheet

was automatically transferred onto the conveyor and moved to the deep fat fryer.

Dough rheology relates to dough handling properties and the tendency of the dough to spring back and is a critical factor in the evaluation of dough sheeting properties. Several methods have been employed to characterise the rheological properties of dough, including the Farinograph and Extensograph methods (ICC 1996; Bloksma and Bushuk 1988).

Kumar and Jozef (2003) reported that wheat dough to be a non-Newtonian material and its viscosity depends on moisture content, temperature and shear rate assuming on the flow geometry.

Response optimization

Effect of added moisture

The textural properties of deep fried products would vary due to rapid reduction in moisture during deep fat frying which involves high rates of heat and mass transfer. The structure and texture formation take place due to parameters such as added moisture, frying oil temperature, frying time, material to oil ratio etc. The moisture data were subjected to ANOVA, which revealed that the pressure and water addition and their interaction were highly significant ($p < 0.05$). Results also indicated a local optimum, where the moisture content was maximum with a value of 32.06 % when the pressure and water addition were 5.16×10^5 Pa and 63.17 %, respectively. The regression coefficients are provided in Table 3. The high R^2 values of 0.908 indicated that over 90 % of the variance can be explained by the fitted polynomial equation. The response surface generated for moisture as a function of pressure and added moisture is depicted in Fig. 2. It is worth to mention that small amount of moisture in the final product is required, to have desirable texture (tearing strength, Table 1).

Table 2 Response parameters of extrusion

Added moisture (%)	Extrusion pressure $\times 10^5$ Pa	Extrusion rate (m/min) $\times 10^{-3}$	Sheet width (m) $\times 10^{-3}$	Thickness (m) $\times 10^{-3}$	Puffed height (m) $\times 10^{-3}$	Initial weight of dough sheet (kg)	Final weight of product, after frying, (kg)
56.46	5.56	287.6	75.0	2.33	37.63	0.0138	0.0133
56.46	3.44	191.5	74.5	2.15	40.65	0.0133	0.0128
63.53	5.56	340.0	77.7	2.38	38.01	0.0137	0.0131
55.00	3.44	124.8	73.7	2.39	33.75	0.0134	0.0129
65.00	4.50	456.2	75.9	2.35	32.79	0.0124	0.0121
60.00	3.00	368.7	73.7	2.28	39.97	0.0118	0.0117
60.00	4.50	412.6	75.3	2.31	41.24	0.0123	0.0117
60.00	5.99	367.7	76.2	2.32	39.94	0.0133	0.0117
60.00	4.50	412.6	75.3	2.31	41.24	0.0123	0.0117
60.00	4.50	412.6	75.3	2.31	41.24	0.0123	0.0117

Table 3 Regression coefficient of dependent variables

Dependent parameters		Regression Co-efficient	Standard error	<i>t</i>	<i>p</i>
Moisture	Mean/Interc.	−377.612*	128.040	−2.949	0.021*
	(1) Pressure(L)	1.685	9.308	0.181	0.861
	Pressure(Q)	−1.486*	0.409	−3.633	0.008*
	(2) Moisture(L)	12.832*	4.352	2.949	0.021*
	Moisture(Q)	−0.110*	0.037	−2.951	0.021*
	1 L by 2 L	0.216	0.142	1.517	0.173
					$R^2=0.9087$
Fat	Mean/Interc.	−63.005	45.952	−1.371	0.213
	(1) Pressure(L)	−2.629	3.340	−0.787	0.457
	Pressure(Q)	−0.567*	0.147	−3.866	0.006*
	(2) Moisture(L)	2.425	1.562	1.553	0.164
	Moisture(Q)	−0.022	0.013	−1.668	0.139
	1 L by 2 L	0.132	0.051	2.584	0.036*
					$R^2=0.9286$
Texture	Mean/Interc.	27838.323*	5528.326	5.036	0.002
	(1) Pressure(L)	777.191	401.877	1.934	0.094
	Pressure(Q)	14.679	17.653	0.832	0.433
	(2) Moisture(L)	−920.616*	187.891	−4.900	0.002
	Moisture(Q)	7.936*	1.615	4.914	0.002
	1 L by 2 L	−15.235*	6.148	−2.478	0.042
					$R^2=0.9123$
Overall quality	Mean/Interc.	−197.470*	27.950	−7.065	0.000
	(1) Pressure(L)	−2.635	2.032	−1.297	0.236
	Pressure(Q)	0.202	0.089	2.267	0.058
	(2) Moisture(L)	7.078*	0.950	7.451	0.000
	Moisture(Q)	−0.060*	0.008	−7.333	0.000
	1 L by 2 L	0.012	0.031	0.395	0.705
					$R^2=0.9069$

The second order-polynomial equation for Moisture (Y_1) is given as Eq. 2

$$\begin{aligned}
 Y_1 = & -377.612 + (1.685 \times P) + (-1.486 \times P^2) \\
 & + (12.832 \times M) + (-0.110 \times M^2) \\
 & + [0.216 \times (P \times M^2)] \quad (2)
 \end{aligned}$$

where P is pressure (Pa) and M is moisture content

Liao et al. (2007) reported that water content of dough exhibited consistent effects on the maximum extensional viscosity with a significant power relationship. As water content increases, less resistance to extension of sheeted dough is displayed, and the plasticizing effect of the water makes the dough sheet softer and flexible. Reducing water will remove the plasticizing effect of the water molecule and make the dough viscous and hard to flow.

Edwards et al. (1996) reported that rheological properties were contributed to mainly by the elastic character of the

doughs. Water absorption and formulation significantly affected the elastic modulus (G'). Dough stiffness showed an inverse relationship to water absorption. When compared to doughs prepared without additive, NaCl had little effect on dough stiffness. NaOH greatly increased dough stiffness.

Fat

Fat content is greatly influenced by the added moisture to the dough and it was observed to be directly proportional to the added moisture in the operating range of 56~60 %. Excess added moisture was found to result in oily surface, which was highly undesirable. A product with oily appearance or greasy surface will have low sensory scores and unacceptable from the consumer point of view. The ANOVA results indicated that added moisture influences the oil uptake significantly ($p<0.05$). Their interaction also showed significant effect on the oil content. The regression coefficients are given in Table 3 and R^2 value was 0.982. The response surface as a function of

Fig. 2 Response surface for moisture content fat content, instrumental texture shear values and sensory overall quality of *Poory* as a function of added moisture and extrusion pressure

moisture addition and pressure is presented as Fig. 2. It is clear from the response surface that the interaction between pressure and moisture addition enhanced the oil uptake and the extent was more than the individual effects, indicating a synergy.

The second order-polynomial equation for Fat (Y_2) is given as Eq. 3

$$\begin{aligned}
 Y_2 = & -63.005 + (-2.629 \times P) + (-0.567 \times P^2) \\
 & + (2.425 \times M) + (-0.022 \times M^2) \\
 & + [0.132 \times (P \times M^2)]
 \end{aligned} \quad (3)$$

While elasticity may be critical for finished product qualities, it causes issues in industrial production of dough products, where large heaps of doughs are shaped into thin sheets using sheeting rolls.

Predicting dough thickness during sheeting through a better understanding of dough rheology is an ongoing area of research in cereal sciences. In a review paper, Dobraszczyk and Morgenstern (2003) reported that rheological analyses for dough had failed to estimate dough elasticity and thus, were unable to predict thickness for doughs exiting sheeting rolls.

Vatsala et al. (2001) reported that frying time and temperature significantly influence the fat uptake and *puri* quality.

Texture measurement

Texture of *Poory* was analysed for its shear strength using a texture analyzer did vary significantly between the different experimental design points (Table 1). The regression coefficients are as shown in Table 3. The results indicated that pressure had a very significant influence on the texture and

its interaction with added moisture also showed significant influence on the textural shearing strength. The coefficient of determination as indicated by R^2 values (0.912) was found to be very high, which signifies the developed model to be adequate to fit the experimental data.

The second order-polynomial equation for Texture (Y_3) is given as Eq. 4

$$Y_3 = 27838.323 + (777.191 \times P) + (14.679 \times P^2) + (-920.616 \times M) + (7.936 \times M^2) + [-15.235 \times (P \times M^2)] \quad (4)$$

Patel and Chakrabarti-Bell (2013) indicated that besides baking, elasticity affects handling of doughs during processing. Doughs expand exiting cutters, rounders, dividers, moulders and sheeting rolls. This springback can be a barrier in processing doughs, especially in sheeting methods as it defeats the objective of the process. Except breads, most bakery products, e.g. noodles, flat breads, chapattis and pastry doughs, are made by sheeting doughs. Breads are not usually made by sheeting, although the technique offers many advantages. It has the potential to produce consistent quality products at high rates. The robustness of doughs (thus flours) to withstand small changes in the amount of water added during mixing is also a factor that affects perceptions of sheetability.

Overall quality

Sensory overall quality (OQ) scores as affected by the pressure and added moisture content are given as response surface in Fig. 2. From the response surface and regression results (Table 3), it is clear that added moisture plays a crucial role in determining the OQ of the product and it also significantly affects the sensory quality. From Table 1, it can be observed that shear force increased with a decrease in moisture content of the product and vice-versa. These results indicate that small amount of moisture content in the product is necessary for tearing and chewing of the product. In other words, a product which has very low moisture content will have a 'dry' mouth

Table 4 Quality parameters of *Poori* samples

Pressure ($\times 10^5$ Pa)	Water (%)	Moisture (%)	Fat uptake (%)	Texture (N)	Overall quality (9)
3.0	57.0	Predicted values			
		25.36	12.2	10.1	7.2
		Experimental values			
		25.1 $\pm$ 1.1	13.5 $\pm$ 1.2	10.3 $\pm$ 0.8	7.0 $\pm$ 0.5
		26.4 $\pm$ 1.3	14.5 $\pm$ 1.6	8.8 $\pm$ 0.6	7.5 $\pm$ 0.5
		26.5 $\pm$ 1	14.7 $\pm$ 1.2	9.9 $\pm$ 0.7	6.9 $\pm$ 0.5

feel and a product with very high moisture content will have rubbery, dough like texture and both are undesirable.

The second order-polynomial equation for Overall quality (Y_4) is given as Eq. 5

$$Y_4 = -197.470 + (-2.635 \times P) + (0.202 \times P^2) + (7.078 \times M) + (-0.060 \times M^2) + [0.012 \times (P \times M^2)] \quad (5)$$

Vatsala et al. (2001) indicated that sensory score which is a major attribute of the product gets affected when sub optimum levels of water is used.

Validation of optimum results

The optimum combination of independent variables, which was located in the numerical optimization, was chosen to validate the results predicted by the empirical model. This optimum combination was subjected to the same experimental and analytical procedures applied at the beginning of this study. The predicted and experimental results are presented in Table 4. The experimental errors for all attributes are non-significant and are less than $p < 0.05$. Thus, the optimum variables predicted by the model are found suitable.

Conclusions

Response surface methodology was demonstrated to be an efficient tool for the optimization of process parameters of pneumatic extrusion for the preparation of *Poori* sheet. The results indicated that extrusion pressure ranging from $3 \sim 6 \times 10^5$ Pa for the whole wheat flour dough with an added moisture of 56~60 % was found to give uniform rate of extruded sheet, with a production capacity of 500~600 nos/h. It was observed that the submerged frying time for the extruded dough sheet was in the range of 35~40 s and the temperature of the vegetable oil to be in the range of 180~185 °C. Puffed height of the *Poori* was in the range of $33 \sim 41 \times 10^{-3}$ m which is equal to the puffed height of traditional method of preparation. Oil up take during frying is 12.24 % and the textural shear force was found to be 9.9 N with an overall score of 7.2 ± 0.5 on 9 point scale. The experimental errors for all attributes were non-significant ($p > 0.05$) and thus optimum variables predicted by the model are found suitable.

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