Emerging technique for healthier frying for production of reduced-fat beetroot (*Beta vulgaris*) chips

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Abstract In the present work, the processing variables were optimized to retain betalain compound and their effect on quality attributes (oil content, breaking force and color) of fried beetroot chips. The beetroot slices were fried in lab scale vacuum fryer. Experimental design with temperature (86–153 °C), absolute pressure (1.3–9.7 kPa) and frying time (2.6–9.4 min) as independent variables which produced 20 different combinations, were studied using response surface methodology to study the effect of these variables on product responses. Multiple regression equations were obtained to describe the effects of each variable on product responses. Results predicted that optimum frying conditions namely temperature ranging from 101 to 110 °C, pressure ranging from 2.9 to 4.4 kPa and time 6.0 min required for preparing beetroot chips with oil content (Y_1) ≤ 15.7 , breaking force (Y_2) ≤ 11.53 , L* value (Y_3) ≥ 27.94 , a* value (Y_4) ≤ 17.87 , b* value (Y_5) ≥ 6.46 , betalain content (Y_6) ≥ 13.05 (mg/l) and overall acceptability (Y_7) ≥ 7.5 . Further results showed that traditionally fried beetroot chips contain 2.6 mg/l betalain, 19.68 N breaking force, 21.1 L*, 15.18 a*, 2.38 b*, overall acceptability 6.0 and 38.41 % oil content.

Keywords Beetroot · Vacuum frying · Optimization · Betalain

Introduction

Now-a-days worldwide consumers are paying more attention to healthier foodstuff with high quality attributes. Recently, researchers are exploring various alternative cooking methods in food processing to retain bioactive molecules for development of many food products related to health and wellness. Frying is a unit operation in which cooking of raw food sample is carried out using hot oil. Secondly, it results in thermal destruction of micro-organisms and enzymes. Thirdly, reduction of water activity at the surface helps the food sample to have extended shelf-life. The surface temperature rises quickly when raw food samples were immersed into the hot oil and water is vaporized as steam. The moisture loss begins from the surface exceeding the rate of evaporation from the internal portion of food, which shifts the zone of evaporation into interior part of food and crust is formed with porous structure of different sized capillaries. The moisture escapes from these capillaries during frying and hot oil gets filled into (Manjunath et al. 2014). Unlike hot air dehydration, the driving force for moisture loss is the water vapor pressure gradient between the moist interior of the food sample and the hot frying oil.

Fruits and vegetables contain high amount of sugar, that is caramelized at high temperature during frying under atmospheric conditions and lose their natural color and flavor. Besides these, several undesirable chemical changes such as hydrolysis, oxidation, thermal polymerization etc. occur in oils during frying (Blumenthal 1991; Houhoula et al. 2003; Debnath et al. 2011; Akinpelu et al. 2014). On the contrary, vacuum frying is an excellent alternative method to conventional frying (Dueik and Bouchon 2011). It is carried out under pressure well below atmospheric levels which lowers the boiling point of moisture of food

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and making it possible to reduce frying temperature and oxygen content during the process which facilitates in reduction in oil absorption, preserve natural color and flavor of final products. The vacuum frying has less adverse effect on oil quality, as well as minimal loss of vitamins and minerals.

Betalains are water-soluble nitrogen-containing pigments, found in high concentrations in beetroot (*Beta vulgaris*). Betalains consist of two sub-classes: betacyanins (red-violet pigments) and betaxanthins (yellow-orange pigments) (Delgado-Vargas et al. 2000; Stintzing and Carle 2004; Kumar et al. 2015). These compounds have antimicrobial and antiviral effects (Strack et al. 2003) and can also inhibit the cell proliferation of human tumour cells (Reddy et al. 2005). The consumption of beetroot which are rich source in anti-oxidants can contribute to protection from age-related diseases. Anti-oxidant activity in beetroot also helps in scavenging of free radicals and consequently in the prevention of diseases like cancer, cardiovascular diseases etc. (Delgado-Vargas et al. 2000). According to Gentile et al. (2004) betalain exhibits anti-inflammatory, antiradical and antioxidant activity. Several process factors of frying including frying time, temperature, absolute pressure, pre-frying treatments, post treatments and product properties have been reported to affect the qualities of the fried products (Bouchon and Pyle 2004; Ziiaifar et al. 2008; Tarmizi and Niranjana 2013). However, most of the research works using vacuum frying have been reported on potatoes and reports on other foods are scanty (Shyu et al. 2005).

The objective of this study was to optimize the frying variables (temperature, absolute pressure and time) for beetroot slices with low fat and maximum betalain retention and overall acceptability.

Materials and methods

Raw material procurement

Raw fresh beetroot and palm oil were procured from a local market in Mysore, Karnataka, India. Beetroots were packaged in polyethylene bags and stored under refrigeration (4 °C) until ready for the use.

Sample preparation

The beetroots were peeled, and sliced using mechanical slicer (Robot coupe, CL 50, USA) having 0.003 ± 0.0005 m thickness and 0.03 ± 0.001 m diameter. The slices were steam blanched for 2 min. After draining of water, slices were spread on trays and dried in ambient condition (25 ± 1 °C) for 3 h. The final moisture content of the beetroot slices was found to be 52.7 ± 0.1 %.

Vacuum frying experiments

The experiments were performed using a proto type vacuum fryer (developed at CSIR-CFTRI, Mysore, India). The fryer consists of (a) heating element inside the oil heating chamber, (b) a basket and (c) spinning system (de-oiling system) with a maximum rotational speed of 2000 rpm in frying chamber. Vacuum is achieved in the system by a vacuum pump with a maximum vacuum of <1.0 kPa. The frying process consists of loading 100 g slices into the basket for submerged frying in oil (3 l) which equals to sample to oil ratio (1:30) and creating vacuum in the vessel during frying. The basket was raised after frying and the product was allowed to spin at pre-set speed of 1500 rpm for 5 min after draining the oil into the oil heating chamber. After releasing the vacuum the beetroot chips were allowed to cool to ambient temperature (25 ± 1 °C) before storing them in polyethylene bags for further analysis.

Response surface methodology (RSM) was adopted in the experimental design. RSM emphasizes the modeling and analysis of the problem in which response of interest is influenced by different independent variables. The three variables (five levels -1.682 , -1 , 0 , $+1$, $+1.682$ of each variable) with central composite rotatable design (CCRD) was employed (Montgomery 2001). The independent variables include the frying temperature (86 – 153 °C), absolute pressure (1.3 – 9.7 kPa) and frying time (2.6 – 9.4 min). Dependent variables were oil content, breaking force, betalain content, color (L^* , a^* and b^*) and overall acceptability.

Traditional frying experiments

Frying was carried out at atmospheric pressure/open pan frying using the same fryer without applying vacuum. The frying was performed at 180 ± 2 °C for 5 min.

Product quality attributes

Estimation of oil content

The oil was estimated following AOAC (2002) method using Soxhlet fat extraction apparatus. Measurements were done in triplicates.

Color measurement (L^* , a^* , b^*)

The color of the beetroot chips were measured using color measurement apparatus (Konica Minolta, CM5, Japan). The instrument was standardized with white and black ceramic plate. The L^* , a^* and b^* values (CIE system) were measured for the different samples at 10° view angle (Ranganna 1997).

Texture analysis

Texture of beet root chip was measured using texture analyser (LLOYD-LR-5K, Ametek test and calibration instruments, United Kingdom). Breaking force was measured in terms of breaking force, which is the force required for breaking the fried product using ball probe with 50 mm diameter with standard attachment. It consists of base with two adjustable supports and one flexure unit. A flexure unit attached to the load cell. Rollers provided on both sides to support the flexure unit to minimize friction during the test. Measurements were made at a speed of 5 mm/min using 50 kg load cell. The experiments were repeated for five times and average values were reported (Debnath et al. 2003, 2009).

Estimation of betalain content

Oil absorbed by beetroot chips during vacuum frying was extracted using hexane by solvent extraction, de-oiled chips were powdered and 0.1 g of de-oiled sample was dissolved in 10 ml of 50 % ethanol. The mixture was stirred for 10 s and the homogenate was centrifuged at 6000 rpm for 10 min. The supernatant was separated as it is after centrifugation and the same was repeated for 2 more times to ensure maximum extraction of betalain content. The supernatant was used for determination of betalain content. The content of betacyanins and betaxanthins in the extracts was determined using spectrophotometer at 480 and 538 nm with a UV–Vis spectrometer, respectively according to the methods of (Ravichandran et al. 2013).

Sensory evaluation of the product

Evaluation of sensory attributes was performed in a booth room at 22 ± 2 °C under fluorescent light (ASTM 1996). The fried products were served in a porcelain plate coded with three digit numbers to the ten panelists familiar with sensory evaluation. They were briefed about the product evaluation. The overall acceptability of beetroot chips was evaluated using a hedonic scale with 9-points in which 9 represents 'like extremely', 5 represents 'neither like' nor 'dislike' and 1 represents 'dislike extremely'.

Statistical analysis of responses

Coded variables related to responses [oil content, color (L^* , a^* and b^*), breaking force, betalain content and overall acceptability] for the different experimental combinations (x_i , $i = 1, 2$, and 3) were given by a second degree polynomial Eq. (1),

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + \varepsilon \quad (1)$$

The coefficients of the polynomial were represented by β_0 (constant), $\beta_1, \beta_2, \beta_3$ (linear effects), $\beta_{12}, \beta_{13}, \beta_{23}$ (interaction effects), $\beta_{11}, \beta_{22}, \beta_{33}$ (quadratic effects) and ε random error. Data were modeled by multiple regression analysis. The statistical significance of the terms for each response was examined by ANOVA (Juvvi et al. 2012). The statistical analysis of the data and three-dimensional (3D) plotting were performed using Design Expert Software 'DE-6' (Stat-Ease, Minneapolis, USA). The adequacy of regression model was checked by R^2 , *Adjusted R²*, *Adequate Precision* and *Fisher's F-test* (Montgomery 2001). The regression coefficients were used to make statistical calculation to generate three-dimensional plots from the regression model.

Results and discussion

Diagnostic checking of the model

Seven responses in the experiments namely, oil content (Y_1), breaking force (Y_2), L^* -value (Y_3), a^* -value (Y_4), b^* -value (Y_5), betalain content (Y_6) and overall acceptability (Y_7) were measured. The seven responses under different combinations as explained in the design (Tables 1, 2) were analyzed using the analysis of variance (ANOVA) appropriate to the experimental design. These responses were presented by the coefficients for the actual functional relations of second order polynomials for predicting responses (Y_i) (Table 3). The insignificant terms were not considered based on student's t-ratio (Khuri and Cornell 1987). The ANOVA for the data obtained using CCRD indicated that the sum of squares due to regression (first and second-order terms) were significant (Table 4). The high values of coefficient of determination (R^2 ,

Table 1 Variables and their levels for CCRD

	Symbols	−1.682	−1	0	1	1.682	Mean	SD
Temperature (°C)	X_1	86.36	100	120	140	153.64	120	24.75
Absolute pressure (kPa)	X_2	1.3	3	5.5	8	9.7	5.5	3.09
Time (min)	X_3	2.64	4	6	8	9.4	6	2.560

Coded values = (actual value-mean)/standard deviation (SD)

Table 2 The CCRD (coded and uncoded levels) employed for development of vacuum fried beetroot chips and the responses (oil content, breaking force, color L* value, color a* value, color b* value, betalain content and overall acceptability) of developed fried chips

S. No.	Independent variables s			Dependent variables						
	Frying temperature X_1 Coded x_1	Absolute pressure X_2 Coded x_2	Frying time X_3 Coded x_3	Oil content (%) Y_1	Breaking force (N) Y_2	L* Y_3	a* Y_4	b* Y_5	Betalain content (mg/l) Y_6	Overall acceptability Y_7
1	−1	−1	−1	15.08	14.86	27.8	16.64	7.85	16.83	7.5
2	1	−1	−1	15.86	13.8	25	17.1	6.18	13.94	7.0
3	−1	1	−1	16.73	14.2	27	18.01	7.10	14.37	6.5
4	0	0	0	15.54	9.66	28.85	17.61	5.74	12.06	7.5
5	1	1	−1	19.03	12.01	25.71	19.32	5.90	11.95	6.4
6	0	0	0	16.11	10.32	28.03	18.76	4.68	10.13	8
7	−1	1	1	17.03	12.6	21.30	15.04	6.41	11.33	7.0
8	−1.682	0	0	15.86	13.68	28.63	16.86	8.28	14.86	7.0
9	0	−1.682	0	15.31	10.44	27.33	19.52	6.57	14.38	8
10	0	0	0	16.33	10.67	27.80	16.38	5.88	11.50	7.6
11	1.682	0	0	21.86	9.31	19.18	21.0	3.54	9.73	6.5
12	−1	−1	1	18.41	11.38	23.66	17.51	6.78	13.83	7.3
13	0	0	−1.682	16.63	11.77	29.69	16.3	5.83	13.61	6.2
14	1	1	1	20.06	10.8	19.47	17.30	5.00	10.31	6.2
15	0	1.682	0	17.06	12	24.62	17.87	3.86	11.03	6.4
16	0	0	0	18.23	9.88	26.66	17.53	4.16	10.76	7.5
17	0	0	1.682	19.59	10.18	27.46	14.13	1.86	9.34	7.8
18	0	0	0	15.69	11.06	27.10	18.3	4.84	10.54	7.4
19	1	−1	1	19.7	10.68	21.52	16.96	4.80	8.25	6.8
20	0	0	0	15.13	9.36	30.422	17.56	5.13	11.48	7.5

Table 3 Regression coefficients of second order polynomial and their significance for oil content, breaking force and color L*, a*, b*, betalain content and overall acceptability

Coefficients	Oil content	Breaking force	L* value	a* value	b* value	Betalain content	Overall acceptability
X_0	16.17*	10.12*	28.21*	17.70*	5.03*	11.07**	7.59*
X_1	1.28**	−0.96*	−1.75*	0.76*	−1.04*	−1.50**	−0.20 ^{ns}
X_2	0.49 ^{ns}	0.11 ^{ns}	−0.66 ^{ns}	−0.096 ^{ns}	−0.42 ^{ns}	−0.77*	−0.38*
X_3	0.99*	−0.88*	−1.71*	−0.58*	−0.78*	−1.50**	0.19*
X_1^2	0.93*	0.74*	−1.94*	0.36 ^{ns}	0.56 ^{ns}	0.51*	−0.32*
X_2^2	−0.011 ^{ns}	0.64*	−1.21 ^{ns}	0.28	0.32 ^{ns}	0.65*	−0.16 ^{ns}
X_3^2	0.67*	0.55 ^{ns}	−0.29 ^{ns}	−0.95*	−0.17 ^{ns}	0.22 ^{ns}	−0.23 ^{ns}
X_{12}	0.41 ^{ns}	−0.28 ^{ns}	0.23 ^{ns}	0.46 ^{ns}	0.13 ^{ns}	0.63*	0.013 ^{ns}
X_{13}	0.16 ^{ns}	0.094 ^{ns}	0.015 ^{ns}	$−7.5 \times 10^{-03}$	−0.065 ^{ns}	−0.16 ^{ns}	−0.087 ^{ns}
X_{23}	−0.73*	0.47 ^{ns}	−0.54 ^{ns}	−0.72*	0.11 ^{ns}	0.50 ^{ns}	0.088 ^{ns}

* Significant at $P < 0.05$, ** significant at $P < 0.001$ and ^{ns} non significant

Table 4) also suggest that the model fitted well with the experimental data. The R^2 is the proportion of variability in response values explained by or accounted for the model (Myers 1971; Montgomery 1984; Rastogi et al. 2010).

The effect of temperature, time and absolute pressure on responses such as oil content, breaking force, L*-value, a*-value, b*-value, betalain content and overall acceptability are reported by the coefficient of second order polynomials. Few response surfaces based on these

Table 4 Analysis of variance for the fitted polynomial model as per CCRD

Source of variation	Df	Sum of squares						
		Oil content (Y ₁)	Breaking force (Y ₂)	L* (Y ₃)	a* (Y ₄)	b* (Y ₅)	Betalain content (Y ₆)	Overall acceptability (Y ₇)
Regression	9	62.61	41.04	159.91	36.08	32.40	84.55	5.34*
R _s dual								
Lack of fit	5	2.59	8.92	35.72	4.59	9.37	3.58	1.00 ^{ns}
Pure error	5	5.98	2.06	9.10	3.28	2.14	2.59	0.23
Total error	10	8.57	10.98	44.82	7.87	11.51	6.17	1.23
Grand total	19	71.17	52.03	204.73	43.95	43.91	90.72	6.57
R ²		0.88	0.79	0.78	0.82	0.74	0.93	0.81

* Significant at $P < 0.05$, ** significant at $P < 0.001$ and *ns* non significant

Fig. 1 **a** Response surface plots for the (i) oil content and (ii) a* as a function of time and absolute pressure at temperature 120 °C. **b** Response surface plot for the betalain content as a function of temperature and absolute pressure at time 6 min

coefficients are shown in Fig. 1a (i & ii) and b. The response surfaces were selected based on the observation of the data and initial optimization of the individual responses. In general, exploration of the response surfaces indicated a complex interaction between the variables.

Effect of absolute pressure and frying time on oil content and a* values

At the lowest level of absolute pressure (1.3 kPa, coded value -1.682), the oil content and a* values were found to increase with an increase in time (Fig. 1a (i & ii)). The

Fig. 2 Contour plots showing the effect of temperature and absolute pressure on **a** oil content, **b** breaking force, **c** L^* value, **d** a^* value, **e** b^* value, **f** betalain content and **g** overall acceptability. For all experiments time was kept constant for 6 min

increase of a^* values with increase in time may be attributed to increase in residence time leading to maillard reaction (between reducing sugars and amino acids) during frying (Marquez and Anón 1986). At the highest level of absolute pressure the oil content was found slightly decrease initially with an increase in time then increase with an increase in time (Fig. 2). This may be due to absorption of heat by the wet solid from oil leading to drying of outer surface material rendering in diffusion gradient. The moisture gets escaped from the interior portion of the product in the form of vapor leads to pressure gradient. The spaces left behind by the evaporating moisture being occupied by the oil. The relationship observed between oil content of beetroot chips and frying time was in agreement with that observed by other researchers who found that an increase in time increased the quantity of oil absorbed by vacuum fried gold kiwifruit slices (Diamante et al. 2011). At the highest level of absolute pressure a^* values was found to decrease with an increase in time and reach up to 14 (Fig. 1a (ii)).

At the lowest level of time (2.6 min, coded value -1.682) the oil content and a^* values of beetroot chips were found to increase with increase in absolute pressure (Fig. 1a (i & ii)). At the highest level of time (9.4 min, coded value 1.682) the oil content values were found to marginal decrease with increase in absolute pressure whereas a^* values decrease with increase in absolute pressure.

Effect of temperature and absolute pressure on betalain content

The betalain content of beetroot chips was found to vary in the range from 8.25 to 16.83 with an average value of 12.01 (Table 2). The coefficients of the model and other statistics were presented in the Tables 3 and 4. For all the levels of temperatures, betalain content of beetroot chips were found to decrease with an increase in absolute pressure (Fig. 1b). At the highest level of absolute pressure (9.7 kPa coded value 1.682) the betalain content of beetroot chips were found to decrease with an

Table 5 Optimum conditions for maximum L^* value, b^* value, betalain content, overall acceptability as well as minimum oil content, breaking force and a^* values within range

Independent variables									
Temperature (°C) (X_1)	Absolute pressure (kPa) (X_2)	Time (min) (X_3)	Oil content	Breaking force (N)	L	a^*	b^*	Betalain content (mg/l)	Overall acceptability
<i>Conditions for minimum oil content</i>									
113 °C (−0.32)	1.3 (−1.68)	6 (0.0)	14.86 (15.22)	11.52 (11.97)	25.61 (26.39)	18.81 (18.68)	6.78 (7.09)	14.38 (15.07)	7.6 (7.8)
<i>Conditions for minimum breaking force</i>									
133 °C (0.66)	5.6 (0.06)	6 (0.0)	16.91 (17.47)	10.16 (9.8)	24.93 (26.16)	19.32 (18.38)	4.39 (4.60)	9.81 (10.28)	7.0 (7.3)
<i>Conditions for maximum L</i>									
110 °C (−0.47)	4.7 (−0.32)	6 (0.0)	16.41 (15.68)	11.22 (10.72)	27.38 (28.73)	17.18 (17.55)	5.56 (5.83)	12.4 (12.29)	7.4 (7.7)
<i>Conditions for in range a^*</i>									
115 °C (1.00)	7.8 (1.00)	6 (0.0)	17.11 (16.31)	10.83 (11.07)	25.51 (26.76)	18.47 (17.62)	4.89 (5.13)	10.65 (11.14)	7.0 (7.1)
<i>Conditions for maximum b^*</i>									
86 °C (−1.7)	5.5 (0.02)	6 (0.0)	15.86 (16.69)	13.27 (13.88)	26.87 (25.57)	16.86 (17.41)	8.13 (8.40)	15.34 (15.03)	6.5 (7.0)
<i>Conditions for maximum betalain content</i>									
101 °C (−0.93)	1.43 (−1.63)	6 (0.0)	15.21 (15.58)	11.61 (12.73)	28.86 (26.38)	17.92 (18.88)	7.87 (8.21)	15.08 (16.84)	7.7 (7.7)
<i>Conditions for maximum overall acceptability</i>									
113 °C (−0.34)	2.5 (−1.21)	6 (0.0)	16.03 (15.39)	11.18 (11.22)	28.55 (27.70)	18.37 (18.19)	6.51 (6.48)	13.51 (13.79)	7.5 (7.8)

<5 % variation between predicted and experimental values

Fig. 3 Superimposed contour plots showing the shaded overlapping area for which oil content (Y_1) ≤ 15.75 , breaking force (Y_2) ≤ 11.6 , L^* value (Y_3) ≥ 28.06 , a^* value (Y_4) ≤ 18.06 , b^* value (Y_5) ≥ 6.49 , betalain content (Y_6) ≥ 13.55 and overall acceptability (Y_7) ≥ 7.6

increase in temperature and reach up to 10.06. At the lowest level of absolute pressure (1.3 kPa, coded value -1.682), betalain content of beetroot chips were observed to decrease with increase in temperature. This may be due to the fact that the betalains are known to be sensitive to oxidation and temperature that has an impact on their color stability (Herbach et al. 2006). The degradation of betalain content with increase in temperature has been reported by Garcia-Barrera et al. (1998). Vacuum treatment includes removal of available oxygen or under low oxygen levels favor the pigment to be partially recovered after degradation (Von Elbe et al. 1981; Roy et al. 2004).

Optimization of conditions for vacuum fried beetroot chips

In the present study, the operational parameters were optimized using response surface methodology. The values of second order polynomial Eq. (1) for maximum L^* values, b^* values, betalain content and overall acceptability as well as minimum oil content, breaking force and a^* values are within the range based on the coefficient provided in Table 3. The analysis of variance of the fitted polynomial models have been given in Table 4, which indicated that the variable such as time (X_3) was constant for all the responses (Table 5). Hence in order to deduce workable optimum conditions, the graphical optimization technique was adopted by fixing time (X_3) as pre-determined optimum condition (6 min). The contour plots for the response were generated as shown in Fig. 2a–g and compared visually. The multi factor and multi-response systems thus could be drastically reduce the time required for the investigation of the systems. The specifications necessary for each response were first set and these also served as constraints for optimization (Rastogi and Rashmi 1999). An acceptable compromise was made following the criteria for the oil content (Y_1) ≤ 15.75 (%), breaking force (Y_2) ≤ 11.53 (N), L^* value (Y_3) ≥ 27.94 , a^* value (Y_4) ≤ 17.87 , b^* value (Y_5) ≥ 6.46 , betalain content (Y_6) ≥ 13.05 (mg/l) and overall acceptability (Y_7) ≥ 7.5 . These conditions were chosen based on the observation of the superimposition of contour plots. The contour plots were superimposed (Fig. 3) and the regions that the best satisfied of all the constraints were selected as the optimum conditions and based on that a combination (A, B, C and D)

Table 6 Feasible optimum conditions and predicted and experimental value of response at optimum conditions

Optimum condition	Conditions A		Conditions B		Conditions C		Conditions D	
	Coded	Actual	Coded	Actual	Coded	Actual	Coded	Actual
Temperature ($^{\circ}\text{C}$) (X_1)	−0.47	110	−0.56	107	−0.78	104	−0.92	101
Vacuum pressure (kPa) (X_2)	−1.05	2.9	−0.90	2.9	−0.98	3.1	−0.43	4.4
Time (min) (X_3)	0	6.0	0	6.0	0	6.0	0	6.0
Responses	Pred. value	Experimental	Pred. value	Experimental	Pred. value	Experimental	Pred. value	Experimental
Oil content	15.44	15.70	15.48	15.27	15.56	15.39	15.73	15.61
Breaking force	11.18	11.53	11.38	10.83	11.60	11.36	11.58	11.22
L^*	28.08	28.20	28.09	28.36	28.07	28.57	28.33	27.94
a^*	18.05	17.81	18.05	17.87	18.03	17.62	17.57	17.58
b^*	6.50	6.79	6.75	6.46	6.99	6.65	6.75	6.49
Betalain content	13.72	13.05	13.09	13.43	14.40	13.68	13.57	13.96
Overall acceptability	7.8	7.5	7.8	8.0	7.8	8.0	7.6	7.5

<5 % variation between predicted and experimental values

Table 7 Comparative results of parameters in beetroot chips

	Oil uptake (%)	Breaking force (N)	L*	a*	b*	Betalain content (mg/l)	Overall acceptability
Atmospheric frying	38.41 ± 0.3	19.68 ± 0.2	21.10 ± 0.5	15.18 ± 0.2	2.38 ± 0.1	2.6 ± 0.1	6.0 ± 0.3
Vacuum frying	15.39 ± 0.4	11.36 ± 0.2	28.57 ± 0.5	17.62 ± 0.3	6.65 ± 0.2	13.68 ± 0.02	7.5 ± 0.2

are selected from the shaded area (Table 6) (Rastogi et al. 2010; Priyanka et al. 2013). Superimposition of contour plots indicated that time 6 min, temperature 101–106 °C and absolute pressure 2.51–3.97 kPa fulfilled the above mentioned criteria for optimization.

Validation of results

The suitability of the model equations for predicting the optimum response values was tested using recommended optimum conditions as determined by graphical optimization approach. These conditions were validated experimentally and compared with the predicted values obtained from the model (Eq. 1). The experimental values were found to be in agreement with the predicted values. The Table 7 showed decrease in oil content, breaking force and increase in betalain content, color (L*, b*, a*) and overall acceptability values in case of vacuum fried beetroot chips as compared to atmospheric fried beetroot chips.

Conclusion

It may be concluded that vacuum frying could be an efficient alternative method of frying. The vacuum frying can be used to reduce oil content during production of fried foods such as beetroot chips with higher retention of betalain content (13.68 mg/l) as compared to atmospheric fried beetroot chips (2.6 mg/l). The super imposition of contour plots indicated that frying time 6 min, temperature 101–110 °C and vacuum 2.9–4.4 kPa. Therefore, this emerging technique for production of healthy fried snack foods could be beneficial for food processing industries.

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