OPTIMIZATION OF PROCESS PARAMETERS OF FINGER MILLET – SOY PASTA USING RESPONSE SURFACE METHODOLOGY

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Abstract— The experiment was conducted to develop cold extrudate with microwave puffing to prepare pasta. The cold extrudate was obtained from finger millet flour, soy flour and potato mash in Dolly mini P3 pasta machine and puffed in microwave oven. A four factor five level response surface methodology central composite rotatable design (CCRD) was adopted to study the effect of process parameters convective heating temperature (CT), convective heating time (Ct), microwave power, % of 1350W (MP) and microwave puffing time (Mt) on the quality of product. Analysis of variance indicates that quadratic effects significantly ($p<0.001$) affected the response in terms of moisture content (MC), expansion ratio (ER), hardness (HD), crispness (CSP) , colour (L-value) and colour difference (ΔE). The optimal microwave puffing of the cold extrudate could be conducted by convective heating at 200 $^{\circ}$**C** for 300 sec followed by microwave puffing with 90 % of 1350 W for 90 sec. The optimum predicted responses in terms of MC, ER, HD, CSP, L-value and ΔE value were 0.088 kg/kg dm. 2.58,1424.93 g, 20.21 +ve peaks, 49.93 and 16.98 respectively.

Keywords— Millet, finger millet, soybean, pasta, extrusion technology, microwave puffing, response surface methodology

INTRODUCTION

Pasta is a staple food of traditional Italian cuisine, now renowned worldwide. Pasta products, traditionally manufactured from durum wheat semolina, known to be the best raw material suitable for pasta production. Pasta is a source of carbohydrates (74–77%, dm) whose interest is increasing due to its nutritional properties, particularly its low glycaemic index (GI—a measure of carbohydrate quality). Pasta also contains 11–15% (dm) proteins but is deficient in lysine and threonine. Therefore, many researchers have focused on improving the quality of pasta by the addition of other ingredient.

At present, small millets account for less than 1% of food grains produced in the world [8]. Finger millet (Ragi, Eleusine coracana) is an important staple food in the eastern and central Africa as well as some parts of India. Finger millet is rich in calcium (344mg %) and potassium (408mg %) and has a good amino acid profile which is closer to milk. Various nutritional and health benefits of finger millet were discussed especially chronic disease preventive potential. Finger millet being low cost millet with higher dietary fiber contents, several micronutrients and phytonutrients with practically no reports of its adverse effect, deserves attention. Soybean is a rich source of soluble carbohydrate, proteins (rich in lysine), lipids, dietary fiber, minerals and vitamins. Fortification of soybean in other millets is use to improve bone health, brain functionality, body immunology and also controls heart attack and prevent cancer [3][4] and also solving the problem of protein-energy malnutrition.

Extrusion technology is one of the contemporary food processing technologies applied to food and can be applied to mitigate the problems associated with processing of traditional cereal based products in terms of improvement in functionality, physical state and shelf stability. It offers many advantages over other process technologies in terms of, preparation of ready – to – eat foods of desired shape, size, texture and sensory characteristics at relatively low processing cost [27]. In puffing process the starchy food stuff is expanded with sudden application of heat at atmospheric pressure or by sudden pressure drop in high pressure chamber at high temperature. Snack foods with desirable colour, texture, flavor and shape appeals to the consumer. Texture is one of the most important quality attributes of snack food [17] and hot air puffing ideally makes an aerated, porous, crispy texture with added benefits of dehydration.

Response surface method (RSM) is a statistical – mathematical tool which uses quantitative data in an experimental design to determine, and simultaneously solve multivariate equations, to optimize processes or products [23]; it has been successfully used for developing, improving and optimizing processes [30].

The review of past research reveals that there are various process technologies to develop RTE foods from whole grain cereals like rice, legumes, potato and millets but no work has been done on preparation of puffed food from finger millet (Eleusine coracana) flour and soybean flour blend with potato mash. In developing countries, the commercial processing of these locally grown grains into value-added food products is an important driver for economic development [28]. Considering the nutritional importance of finger millet and to make value added products, present study was undertaken to develop finger millet-soy product.

MATERIAL AND METHOD

Production of flours and potato mash

The finger millet was sorted and winnowed manually. The finger millet flour was obtained by grinding the finger millet grain in the mixer grinder and soybean was processed into cooked soy flour to remove all anti-nutritional factors. Soybean grains were cleaned to remove immature grains, and other foreign materials. The clean grains were blanched at 100 °**C** for 30 min. The blanched grains were drained and then dried at 65°**C** for 24 hr. Flours passing through 40 mesh sieve were used. The potatoes was cooked in a domestic cooker for 13 minutes and immediately removed for cooling. After complete cooling cooked potatoes was peeled and mash was prepared by hand.

Preparation of material for puffing

The basic ingredients were selected as finger millet flour, soybean flour and potato mash. The finger millet flour, soybean flour and potato mash was taken in the ratio of 45:10:45, respectively and a common salt of 1.5% of the total flour were added for taste. These ingredients were mixed thoroughly in a plate with hand. The mixed ingredients was taken and then kneaded in Dolly Mini P3 Pasta machine (LaMonferra, Italy) for 10-15 min till granules of dough were formed. Then it was cold extruded through a die in rectangular shape [20][21].

Experimental design for Convective Heating and Microwave Puffing

The convective heating and microwave puffing was done in the microwave oven. The Combo Microwave oven available in laboratory of AICRP on Post Harvest Technology, Dr. PDKV, and Akola was used for the experimentation of microwave puffing. The process parameters like convective heating temperature, convective heating time, microwave power and microwave heating time, on the basis of product qualities viz., final moisture content, expansion ratio, hardness, crispness, colour score and colour difference are described under experimental design along with the levels and combinations of treatments.

Moisture content

The moisture content of the sample was determined by using hot air oven (0 to 300°**C**) as described by AOAC (1984).

Expansion Ratio

Expansion ratio was measured using rape seed displacement method [24]. For this the following expression was used:

$$\text{Expansion ratio} = \frac{\text{volume after puffing}}{\text{volume before puffing}} \qquad \dots (1)$$

Textural Measurement (Hardness and Crispness)

The texture characteristics of puffed product in terms of hardness and crispness were measured using a Stable Micro System TA-XT2 texture analyzer (Texture Technologies Corp., UK) fitted with a 5 mm dia. circular punch. The studies were conducted at a pre test speed of 1.0 mm/s, test speed of 0.5 mm/s, distance of 30% strain, and load cell of 5.0 kg. Hardness value was considered as mean peak compression force and expressed in grams and crispness was measured in terms of major positive peaks. For measurement of crispness a macro was developed which count number of +ve peaks obtained in the product during compression. For measurement of crispness a macro was developed which counts number of major peaks obtained in the product during compression. Average values of 10 replications are reported.

Colour measurement (L value and ∆E)

The colour score (L value) and colour difference (∆E) was measured using a simple digital imaging method [31]. A scanner was used to measure colour by scanning the colour image of the sample [30]. Once the colour images of the samples were scan, the colour was analyzed quantitatively using Photoshop 8.0 [1]. Photoshop can display L, a* and b* value in the palette and Histogram window.

Experimental design and optimization

The process variables considered were convective heating temperature (190 to 230 °**C**), convective heating time (120 to 360 sec), microwave power (60 to 100 % of 1350 W), microwave heating time (0 to 120 sec). The experimental design was applied after selection of the ranges. Thirty experiments were performed according to a second order central composite rotatable design (CCRD) with four variables and five levels of each variable. Experiments were randomized in order to minimize the effects of unexplained variability in the observed responses due to extraneous factors. The center point in the design was repeated six times to calculate the reproducibility of the method [15]. Microwave puffing experiments were conducted according to the CCRD design and RSM was

applied to the experimental data using a commercial statistical package, Design Expert - version 8.0 (Stat-ease Inc., Minneapolis, USA).
The following second order polynomial response surface model (Eq. 1) was fitted to each of the response variable (Y_k) with the independent variables (X_i)

$$Y_k = b_{k0} + \sum_{i=1}^{4} b_{ki} X_i + \sum_{i=1}^{4} b_{kii} X_i^2 + \sum_{i \neq j=1}^{4} b_{kij} X_i X_j \quad \ldots (2)$$

Where b_{k0}, b_{ki}, b_{kii}, and b_{kij} are the constant, linear, quadratic and cross-product regression coefficients, respectively and Xi are the coded independent variables of X_1, X_2, X_3 and X_4.
Numerical optimization technique of the Design-Expert software was used for simultaneous optimization of the multiple responses. The desired goals for each factor and response were chosen. The aim may apply to either factors or responses. The possible aim is: maximize, minimize, target, within range, none (for responses only). All the independents factors were kept within range while the responses were either maximized or minimized. In order to search a solution optimizing multiple responses, the goals are combined into an overall composite function, D(x), called the desirability function [16], which is defined as:

$$D(x) = (d_1 \times d_2 \times .... \times d_n)^{1/n} \quad \ldots (3)$$

Where, d_1, $d_2 \ldots d_n$ are desirability of responses and n is the total number of responses in the measure.
Desirability is an objective function that ranges from zero outside of the limits to one at the goal. It reflects the desirable ranges for each response (d_i). The desirable ranges are from zero to one (least to most desirable, respectively). The numerical optimization finds a point that maximizes the desirability function. The characteristics of a goal may be altered by adjusting the weight or importance (Stat ease, 2002).

Table 1 Levels, codes and intervals of variation for microwave puffing process

Name of process variable	Range	Code (X_i)	LEVELS					Interval of variation
			X_{i1}	X_{i2}	X_{i3}	X_{i4}	X_{i5}	
			-2	-1	0	+1	+2	
Convective heating temperature, °C	190-230	X_1	190	200	210	220	230	10
Convective heating time, sec	120-360	X_2	120	180	240	300	360	60
Microwave Power, % of 1350 W	60-100	X_3	60	70	80	90	100	10
Microwave heating times, sec	0-120	X_4	0	30	60	90	120	30

RESULT AND DISCUSSION

Experimental values of the response variables at different combinations of CT, Ct, MP and Mt are presented in Table 1. Response surface analysis was applied to the experimental data using a commercial statistical package 'Design Expert-version 8.0'. The second order polynomial response surface model (Eq. 2) was fitted to each of the response variable (Y_k). ANOVA and Regression analysis were conducted for fitting the statistical significance of the model model terms examined. Analysis of variance showed that the models are highly significant ($p \leq 0.001$) for all the responses are given in Table 2. The estimated regression coefficients of the quadratic polynomial models for the response variables, along with the corresponding R^2 and coefficient of variation (CV) values are given in Table 3.
The lack of fit (Table 2), which measures the fitness of the model, did not result in a significant F-value in case of moisture content, expansion ratio, hardness, crispness, colour value and colour difference, indicating that these models are sufficiently accurate for predicting those responses. The coefficient of determination (R^2) values of all responses are quite high (>0.9) indicating a high proportion of variability was explained by the data and the RSM models were adequate. As a general rule, the coefficients of variation should not be greater than 10%. In this study, the coefficients of variation was less than 10% for all the responses, a relatively lower value of the coefficient of variation indicates better precision and reliability of the experiments carried out.

Effect of various process parameters on final moisture content (MC, kg/kg dm) during microwave puffing

The quadratic model was fitted to the experimental data and statistical significance for linear and quadratic terms was calculated for MC as shown in Table 2. The experimental range of MC from 0.066 to 0.291 kg/kg dm was obtained with proportion of 45:10:45.

The regression equation describing the effect of the process variables on MC of finger millet-soy pasta in terms of actual level of variables are given as.

$$MC = 0.458 - 5.99 \times CT - 4.93 \times Ct + 0.018 \times MP - 4.48\times10\text{-}3 \times Mt - 1.40 \times10\text{-}5 \times Ct \times MP + 1.86 \times 10\text{-}5 \times Ct2 + 2.16 \times 10\text{-}5 \times Mt^2 \quad \ldots (4)$$

The analysis of variance (ANOVA) data (Table 2) shows a high model F value of 26.69 ($p<0.001$) and a non significant lack of fit test which indicated that quadratic model can be successfully used to fit the experimental data. The higher F-values for linear terms ($p<0.001$) and moderate values for quadratic terms ($p<0.001$) of microwave puffing time (Mt) indicated that their highly significant effect in reducing moisture content of puffed product and followed by convective heating time (Ct), microwave power (MP) and convective heating temperature(CT) had less influencing effect on moisture content. The interaction term of Ct and MP have less significant effect on moisture content (MC). The negative linear regression coefficients and positive quadratic regression coefficient of estimate (Table 3) indicated that there was decrease in moisture content with the increase in process parameters.

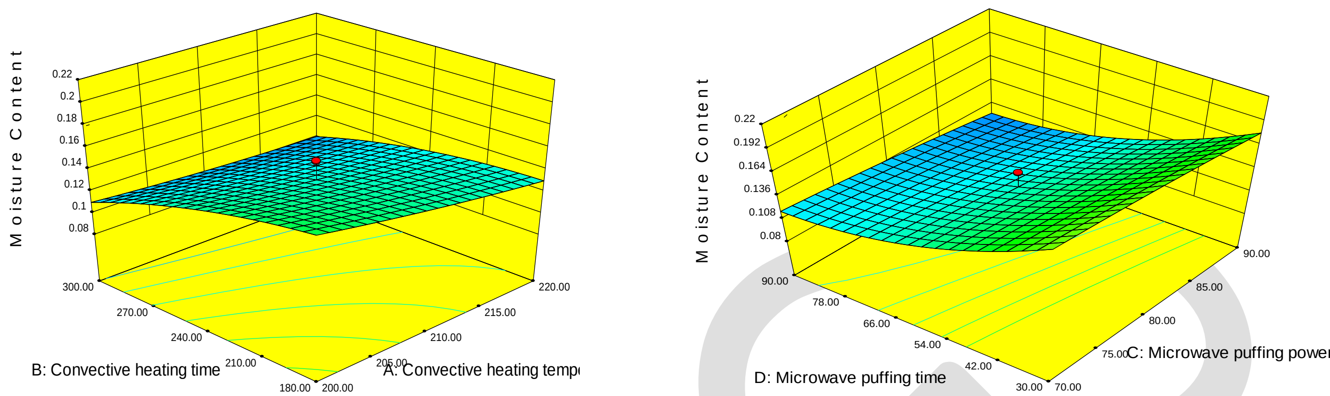
From Fig 1(a and b) shows moisture content of finger millet-soy pasta as a function of convective heating temperature (CT), convective time (Ct), microwave puffing power (MP) and microwave puffing time (Mt) respectively. From Fig 4.1(a) shows maximum (0.16 kg/kg, dm) and minimum (0.11 kg/kg, dm) values of MC were observed at CT=200-203 °**C** / Ct=180-200 sec and CT=280-300 °**C** / Ct=216-220sec respectively. It was observed from Fig 4.1(b) that maximum (0.20 kg/kg, dm) and minimum (0.10 kg/kg, dm) values of MC observed at MP=70-73 % of 1350W/ Mt=30-36 sec and MP=85-90 % of 1350W/ Mt= 88-90 sec respectively.

Table 2 CCRD with uncoded values and experimental result for response variables of finger millet-soy pasta

Run	Process variables				Responses					
	CT	Ct	MP	Mt	MC	ER	HD	CSP	L value	ΔE
1	200	180	90	90	0.15	2.178	2000	16	43.75	16.07
2	210	360	80	60	0.068	2.421	1443.73	20	46	12.48
3	210	240	80	60	0.128	2.184	1537.42	14	42.25	10.71
4	210	240	80	120	0.119	1.999	1422.18	19	47.75	19.26
5	220	300	90	30	0.129	2	1798.92	12	44.75	13.56
6	200	180	90	30	0.229	2.367	1692.16	6	34	6.53
7	220	300	70	30	0.18	1.234	1521.76	15	37.25	8.07
8	210	120	80	60	0.129	2.149	1715.88	11	36	7.8
9	210	240	100	60	0.086	2.182	1823.37	16	45.77	15.06
10	200	300	90	30	0.154	2.458	1625.65	10	36	8.41
11	220	180	70	30	0.211	1.199	1431.32	12	37.48	7.25
12	210	240	80	60	0.149	2.273	1449.29	14	44.25	12.51
13	230	240	80	60	0.1	2.118	1523.43	16	48.25	16.47
14	200	180	70	90	0.123	2.098	1839.75	8	44	13.28
15	200	300	70	90	0.108	2.211	1245	15	49.55	14.98
16	190	240	80	60	0.169	2.361	1720.42	10	43.75	13.83
17	210	240	80	60	0.112	2.785	1467.49	9	39.5	8.8
18	220	300	70	90	0.107	2.333	1267.52	15	46.25	13.18
19	210	240	80	60	0.148	2.389	1538.12	12	46	8.93
20	200	300	90	90	0.072	2.786	1493.22	22	50.25	17.12
21	200	300	70	30	0.163	1.882	1585.84	13	45	8.97
22	220	180	90	90	0.098	2.219	1723.87	19	49.75	13.99
23	210	240	80	0	0.291	1.021	1400	6	29.1	6.81
24	200	180	70	30	0.23	1.345	1536.66	6	31.75	7.06
25	210	240	80	60	0.121	2.149	1590.31	11	42	8.51
26	210	240	80	60	0.131	2.168	1429.56	10	43.25	12.56
27	220	300	90	90	0.066	2	1789.84	22	50.34	18.39
28	220	180	70	90	0.116	2.247	1365.58	12	37.25	6.68
29	220	180	90	30	0.201	1.823	1268.4	10	46	11.16
30	210	240	60	60	0.153	1.098	1657.37	11	41	11.21

In figure the parentheses denote coded level of variables: CT, convective temperature: Ct, convective time: MP, microwave power: Mt, microwave time: MC, moisture content: ER, expansion ratio: HD, hardness: CSP, crispness: L value, colour score: ΔE, colour difference

The above finding revealed that during convective heating and microwave puffing there was continuous decrease in MC of finger millet-soy pasta with time at all level of convective temperature and microwave power respectively. Optimum moisture content of 11.03 %,(d.b) and 3.35 %,(d.b) was obtained for RTE potato soy snacks at optimized temperature and time by [17] with HTST process and [19] with oven toasting method respectively



a) At MP = 80% and Mt=60 sec **b) At CT = 210 °C and Ct = 240 sec**

Fig. 1 The response surface plots showing the effect of (a) CT and Ct and (b) MP and Mt on MC (kg/kg dm) for microwave puffing.

Table 3 ANOVA for different models

Variables	df	F value					
		MC	ER	HD	CSP	L	ΔE
Model	14	26.687	9.46	8.03	23.67	12.18	9.98
Intercept	0						
A-CT	1	13.98*	7.844*	8.32*	27.87*	4.80	0.42
B-Ct	1	52.30**	4.016	6.19*	71.90**	26.09**	14.24**
C-MP	1	15.53*	30.67***	20.00***	24.60*	10.92*	17.67**
D-Mt	1	208.80***	33.78***	0.51	129.04***	78.65***	72.17***
CT X Ct	1	2.59	2.498	23.47***	6.49*	4.69*	1.36
CT X MP	1	3.19	2.321	1.23	0.34	19.29**	7.75
CT X Mt	1	0.04	2.707	0.001	1.88	6.56*	7.91
Ct X MP	1	5.69*	0.020	2.67	0.96	4.96*	0.03
Ct X Mt	1	3.85	0.098	24.29***	0.34	0.79	1.04
MPX Mt	1	0.003	11.24**	7.72*	52.56**	0.76	1.98
CT^2	1	0.48	0.010	2.69	1.33	4.19	10.05**
Ct^2	1	6.98*	0.039	1.03	13.84*	0.82	0.75
MP^2	1	0.49	16.04**	11.56**	2.78	0.25	2.39
Mt^2	1	52.11**	23.55***	2.23	0.41	5.91*	2.15
Lack of Fit	10	0.89^{NS}	0.530^{NS}	2.48^{NS}	0.072^{NS}	1.01^{NS}	0.63^{NS}

ns, not significant. *Significant at P < 0.05. **Significant at P < 0.01. ***Significant at P < 0.001

Effect of various process parameters on final expansion ratio (ER) during microwave puffing

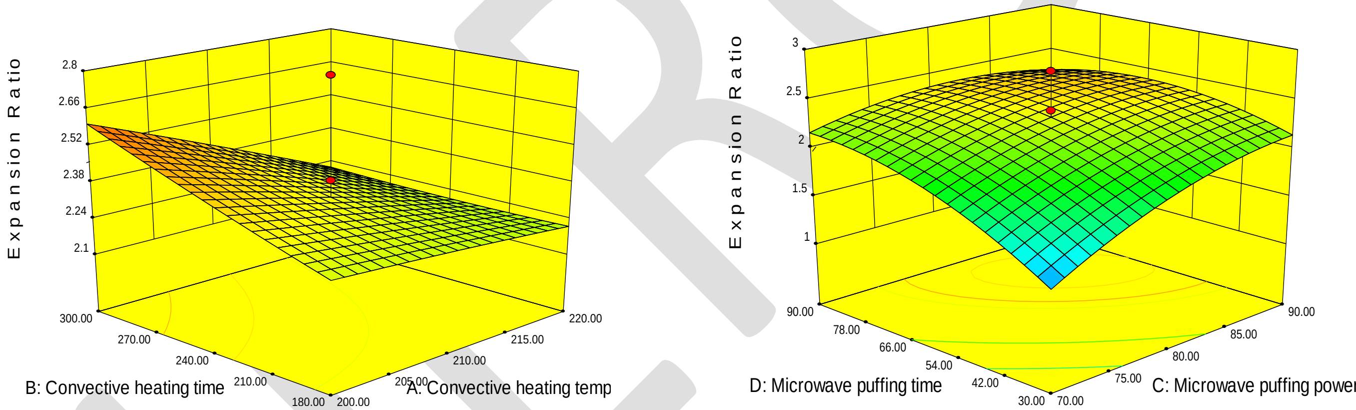
The observations for expansion ratio with different combination of the process parameter were recorded as shown in (Table 2). Maximum volume of expansion of 2.786 obtained 90 % of 1350 W microwave power for 90 s. The quadratic model was fitted to the experimental data and statistical significance for linear and quadratic terms was calculated for ER as shown in Table 2. The regression equation describing the effect of the process variables on expansion ratio of finger millet-soy pasta in terms of actual level of variables are given as:

$$ER = - 28.78 + 0.079 \times CT + 0.462 \times MP + 0.021 \times Mt - 5.68 \times 10^{-4} \times MP \times Mt - 1.54 \times 10^{-3} \times MP^2 - 2.07 \times 10^{-4} \times Mt^2 \quad ... (5)$$

It could be observed from ANOVA (Table 2) data that a high model F value of 9.46 and R^2 value of 0.898 indicated that the quadratic model can be fitted at high level of significance ($p<0.001$). The high F value of linear and quadratic terms of MP and Mt have highly significant effect on expansion ratio ($p<0.001$) followed by linear term CT and interaction term of MP and Mt have moderate effect on expansion ratio of the product. The negative linear (CT) and interaction (MP and Mt) regression coefficient indicated (Table 3) that expansion ratio (ER) decreased with increase of these process parameters at linear level. The positive linear and negative quadratic regression coefficient of MP and Mt indicated that there was increase in expansion ratio with the increase in process parameters initially but decreased it when the parameters were increased at higher level.

Fig 2(a) shows that maximum (2.5) and minimum (2.25) values of expansion ratio were observed at CT= 200-206 $^{\circ}$**C** / Ct = 260-300 sec and CT = 210-218 $^{\circ}$**C** / Ct = 180-300 sec respectively and it could be observed that CT and Ct had linear effects and ER decreased with increase in convective heating temperature. The Fig 2 (b) shows that maximum (2.4) and minimum (1.7) value of expansion ratio were observed at MP = 80-90% of 1350W/ Mt = 59- 85 sec and MP = 74-76% of 1350W/ Mt = 42-48sec respectively and it can be observed that ER was higher at higher microwave puffing power and puffing time.

High expansion is primarily dependent on starch content in the raw material to be puffed. Potato flour is rich in starch while soy flour adds more protein in the product and therefore addition of soy flour showed significant reduction in expansion ratio [19]. This ER was similar to that obtained 2.90 of extrudate product prepared from finger millet, maize and full fat soy flour by [22], 2.06 for barnyard millet puffed product by [10].



(a) At MP = 80% and Mt=60 sec **(b) At CT = 210°C and Ct = 240 sec**

Fig. 2 The response surface plots showing the effect of (a) CT and Ct and (b) MP and Mt on ER for microwave puffing.

Effect of various process parameters on Hardness (HD, g) during microwave puffing

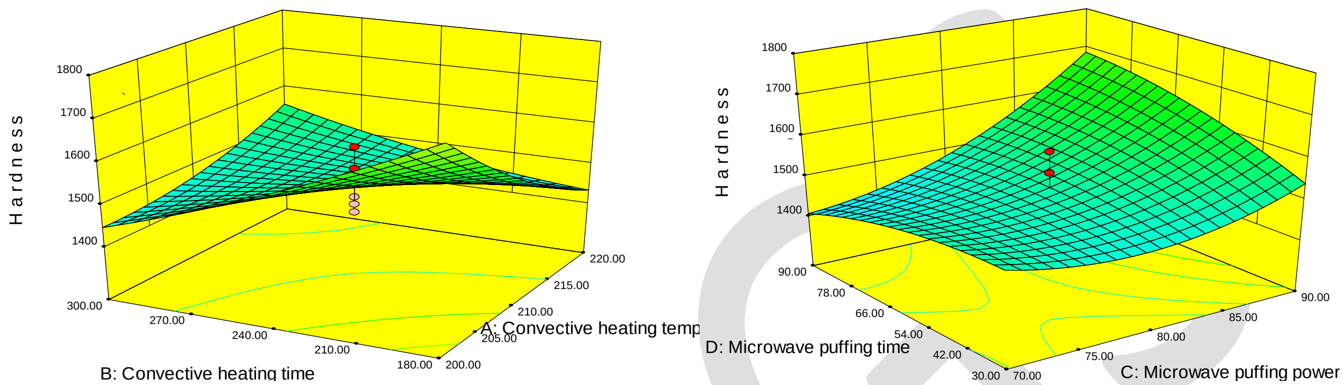
It could be observed (Table 2) that the values of hardness ranged between 1248 g and 2000 g within the combination of variables studied. The regression equation describing the effect of the process variables on hardness of finger millet-soy pasta in terms of actual level of variables are given as

$$HD = 32416.14 - 183.238 \times CT - 41.563 \times Ct - 161.485 \times MP + 0.1779 \times CT \times Ct - 0.0603 \times Ct \times Mt + 0.0204 \times MP \times Mt + 0.5721 \times MP^2 \quad \ldots(6)$$

Analysis of variance (ANOVA) showed (Table 2) that the model F value of 8.029 and R^2 value of 0.88 were moderate but quadratic model could be fitted with high level of significance ($p<0.001$). The F values of linear terms of MP and interaction terms of CT and Ct as well as Ct and Mt have highly significant effect on Hardness ($p<0.001$) whereas linear term of CT and quadratic term of MP have moderate effect on hardness (HD) of the product. The positive and negative sign of linear and quadratic regression coefficient of estimate indicated (Table 3) that hardness (HD) increase and decrease with the increase these process parameters. However positive and negative regression coefficient of interaction terms suggested that increase and decrease of these process parameters resulted in decrease and increase of hardness value.

Fig 3 (a) shows that hardness of finger millet-soy pasta as a function of CT and Ct, maximum (1700 g or 16.67 N) and minimum (1500 g or 14.70) values of hardness were observed at CT = 200-205°**C** / Ct = 180-210 sec and CT = 215-220 °**C** / Ct = 270-300 sec respectively. Fig 3 (b) shows that hardness of finger millet-soy pasta as a function of MP and Mt, maximum (1650) and minimum (1450) values of hardness were observed at MP = 85-90% of 1350W/ Mt = 66-90 sec and MP = 70-77% of 1350W/ Mt = 72-90 sec respectively. Similar finding had been reported by [17] for hardness of HTST air puffed potato snack.

Hardness of extrudate product have high value (59.68 N) due to incorporation of soy flour while least value (15.39 N) due to high amount of finger millet flour [22]. While Chandrashekhar (1989) reported that decrease in hardness with increase in expansion ratio in case of rice puffing. Similar finding also reported by [18] in HTST air puffed potato snack. These finding were in accordance with the present study.



(a) AT MP= 80 % and Mt=60 sec **(b) AT CT=210°C and Ct=240 sec**

Fig. 3 The response surface plots showing the effect of (a) CT and Ct and (b) MP and Mt on HD for microwave puffing.

Table 4 Regression coefficients of the second order polynomial model for the response variables (in coded units)

Variables	**df**	**Coefficient of estimate**					
		MC	**ER**	**HD**	**CSP**	**L**	**ΔE**
Model	14						
Intercept	0	0.131	2.324	1502.03	11.66	42.87	10.33
A-CT	1	-0.011	-0.114	-51.87	1.37	0.99	0.21
B-Ct	1	-0.021	0.082	-44.76	2.21	2.31	1.25
C-MP	1	-0.011	0.227	80.44	1.29	1.49	1.39
D-Mt	1	-0.041	0.238	12.85	2.96	4.01	2.81
CT X Ct	1	0.005	-0.079	106.73	-0.81	-1.19	0.47
CT X MP	1	-0.006	-0.076	24.44	-0.19	2.432	1.13
CT X Mt	1	-0.001	0.082	-0.70	-0.44	-1.42	-1.14
Ct X MP	1	-0.008	-0.007	36.02	-0.31	-1.23	-0.07
Ct X Mt	1	0.007	-0.015	-108.57	0.19	0.49	0.41
MPX Mt	1	0.0001	-0.168	61.22	2.31	0.49	0.51
CT^2	1	0.001	-0.003	27.61	0.28	0.86	0.98
Ct^2	1	-0.007	0.007	17.07	0.91	-0.38	-0.27
MP^2	1	-0.002	-0.153	57.22	0.40	0.21	0.48
Mt^2	1	0.019	-0.186	-25.10	0.15	-1.03	0.45
Lack of Fit	10						
R^2		0.961	0.90	0.882	0.96	0.92	0.90
Adj. R^2		0.925	0.80	0.772	0.92	0.84	0.81
Pred. R^2		0.838	0.62	0.407	0.91	0.65	0.63
CV		10.00	9.77	5.63	9.76	5.20	13.93

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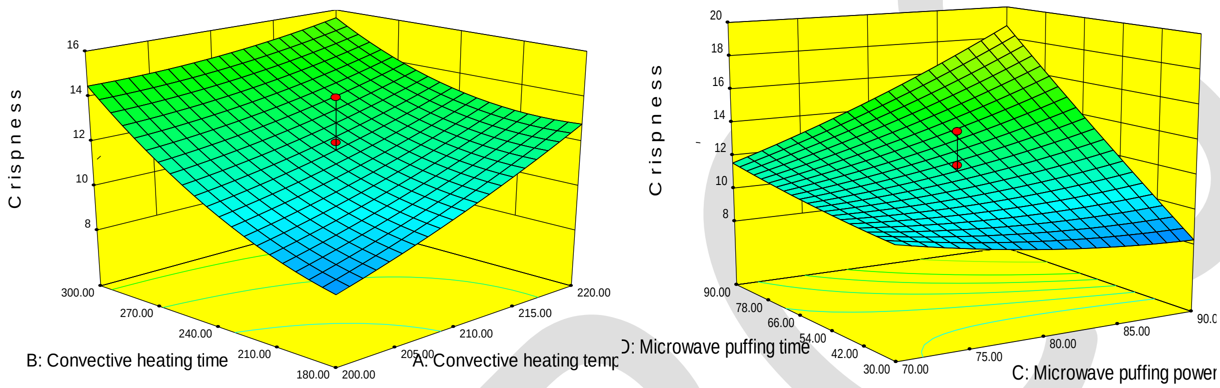
Effect of various process parameters on Crispness (CSP) during microwave puffing

It was observed that the value of CSP was ranged between 3.00 and 22.00 with different combinations of the process parameters are presented in Table 2. The quadratic model was fitted to the experimental data and statistical significance for linear and quadratic terms was calculated for CSP. The regression equation describing the effects of the process variables on CSP in terms of actual levels of variables is given as,

$$CSP = 33.239 - 0.481 \times CT + 0.235 \times Ct - 0.464 \times MP - 0.257 \times Mt - 1.354 \times 10^{-3} \times CT \times Ct + 7.708 \times 10^{-3} \times MP \times Mt + 2.517 \times Ct^2 \quad \dots (7)$$

The model F value of 23.67 and R^2 value of 0.96 at high significant level ($p<0.001$) was calculated by a least square technique, showing good fit of model to the data. The F values ($p<0.001$)) of linear terms and interaction term (MP and Mt) have highly significant effect on CSP whereas quadratic term of Ct and interaction term of CT and Ct ($p<0.01$) have moderate effect on crispness of the product. All linear and quadratic regression coefficients (Table 3) were positive indicating improvement in CSP with increase in these variables.



(a) At MP = 80% and Mt=60 sec **(b) At CT = 210°C and Ct = 240 sec**

Fig. 4 The contour and response surface plots showing the effect of (a) CT and Ct and (b) MP and Mt on CSP for microwave puffing.

Fig 4(a) shows crispness of finger millet-soy pasta as a function of CT and Ct. Maximum (14) and minimum (10) values of crispness were observed at CT = 216-220 °**C** / Ct = 288-300 sec and CT = 206-210 °**C** / Ct = 288 sec respectively. Fig 4(b) shows crispness of finger millet-soy pasta as a function of MT and Mt. Maximum (18) and minimum (9) values of crispness were observed at MP = 86-90% of 1350W/ Mt = 80-90 sec and MP = 78-90% of 1350W/ Mt = 30-40 sec respectively.

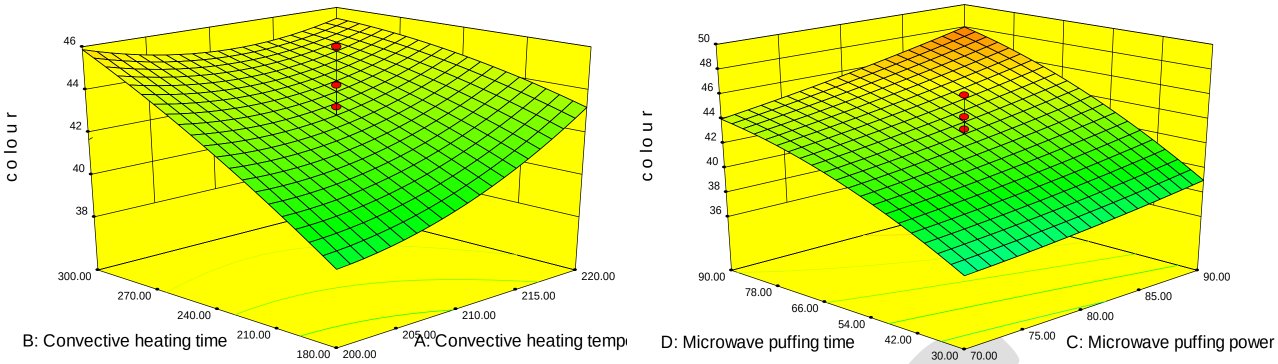
As a result of this there was no considerable increase in crispness with corresponding increase in CT and Mt. When puffing was continued after 30 sec, pores and cracks were developed in the microstructure of the product as a result of which vaporized moisture get released rapidly due to which there was considerable improvement in crispness and at the end of 90 sec the product achieved crispness value of 22 peak at moisture content of around 0.062 kg/kg dm. [11] recorded maximum crispness of 37 during the production of optimized RTE dehydrated potato cube.

Effect of various process parameters on colour (L value) during microwave puffing

The experimental values of colour were in the range of 29.1 to 50.34 and data recorded for colour (L value) after each set of experiment shown in Table 2. The regression equation describing the effects of the process variables on L value in terms of actual levels of variables is given as,

$$L\ value = 603.36 - 4.739 \times CT + 0.656 \times Ct - 4.866 \times MP + 1.067 \times Mt - 1.999 \times 10^{-3} \times CT \times Ct + 0.0243 \times CT \times MP - 4.7270 \times 10^{-3} \times CT \times Mt - 2.0552 \times 10^{-3} \times Ct \times MP - 1.137 \times 10^{-3} \times Mt^2 \quad \dots (8)$$

It could be observed from ANOVA (Table 2) that model F-value (12.18) and R^2 value (0.92) highly significant ($p<0.001$) and the linear terms and interaction term of CT and MP shows their highly significant ($p<0.001$) effect on colour of puffed product. Whereas quadratic term of Mt and interaction terms ($p<0.01$) have moderate effect on colour of product. The all linear regression coefficient were positive indicating improvement in colour with increase in these variables while negative quadratic regression coefficient was indicated that further increase of this process parameter resulted decrease of colour.



(a) At MP = 80% and Mt=60 sec **(b) At CT = 210°C and Ct = 240 sec**

Fig. 5 The response surface plots showing the effect of (a) CT and Ct and (b) MP and Mt on colour (L value) for microwave puffing.

Fig 5 (a) showed L value of finger millet-soy pasta as a function of convective heating temperature (CT) and convective heating time (Ct). Maximum (44) and minimum (40) value of CL were observed at CT= 215-220 °**C** / Ct= 240-270 sec and CT=205-210 °**C** / Ct= 180-210 sec, respectively. While Fig 5 (b) showed L value of finger millet-soy pasta as a function of microwave puffing power (MP) and microwave puffing time (Mt). Maximum (46) and minimum (38) values of CL were observed at MP=80-90% of 1350W/ Mt= 66-90 sec and MP=70-82 % of 1350W / Mt= 30-42 sec respectively.

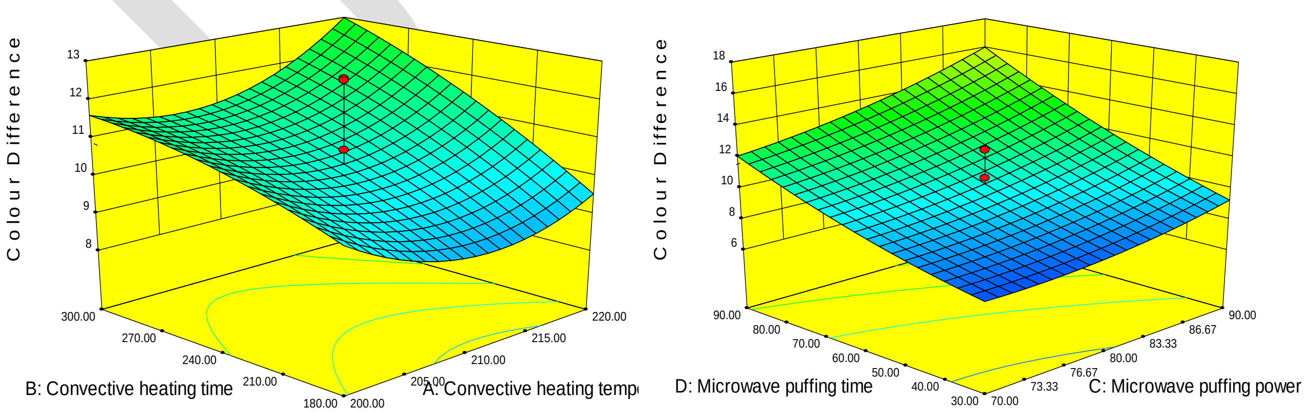
In case of puffing process, there is improvement in L-value with increase in both MP and Mt initially and reaches to a maximum. After initiation of puffing, when product gets expanded rapidly upto 60 sec microwave puffing time, there was increase in L-value. After 90 sec of puffing time the L-value reduced slowly due to non-enzymatic browning and pigment destruction reactions of product surface [6].

Effect of various process parameters on colour difference (ΔE) during microwave puffing

It could be observed that the values of colour difference (ΔE) were ranged between 6.53 to 19.26 and the ANOVA for colour difference (Table 2) of the puffed product indicated moderate model F value (9.98) and R^2 value (0.90) highly significant at $p<0.001$ suggesting that the quadratic model can be used to fit the experiment data. The quadratic equation relating response colour difference with independent variable in terms of actual values after deleting the non significant terms is given as

$$\Delta E = 637.57 + 0.1127 \times Ct - 3.0857 \times MP + 0.6252 \times Mt + 0.0113 \times CT \times MP - 0.0038 \times CT \times Mt + 0.0098 \times CT^2 \quad \ldots(9)$$

The analysis of variance showed that the high F value of 72.17 for linear term of Mt was most influencing parameters ($p<0.001$) followed by MP and Ct. While quadratic terms of CT ($p<0.001$) and interaction terms CT and MP as well as CT and Mt ($p<0.01$) were found to be least influence on colour difference. The entire positive linear regression coefficient of estimate (Table 4.6) indicated that colour difference values increase with increase of these processing parameters. However, positive and negative coefficient of their quadratic term (CT) and interaction term of (CT and Mt) suggested that the ΔE value increase and decrease with increase the these process parameters respectively. Similar finding was obtained by [17] for RTE potato-soy snack. The regression model explained 90 % of the total variability in ΔE value.



(a) At MP = 80% and Mt=60 s **(b) At CT = 210°C and Ct = 240 s**

Fig. 6 The contour and response surface plots showing the effect of (a) CT and Ct and (b) MP and Mt on Sensory colour score (CL) for microwave puffing.

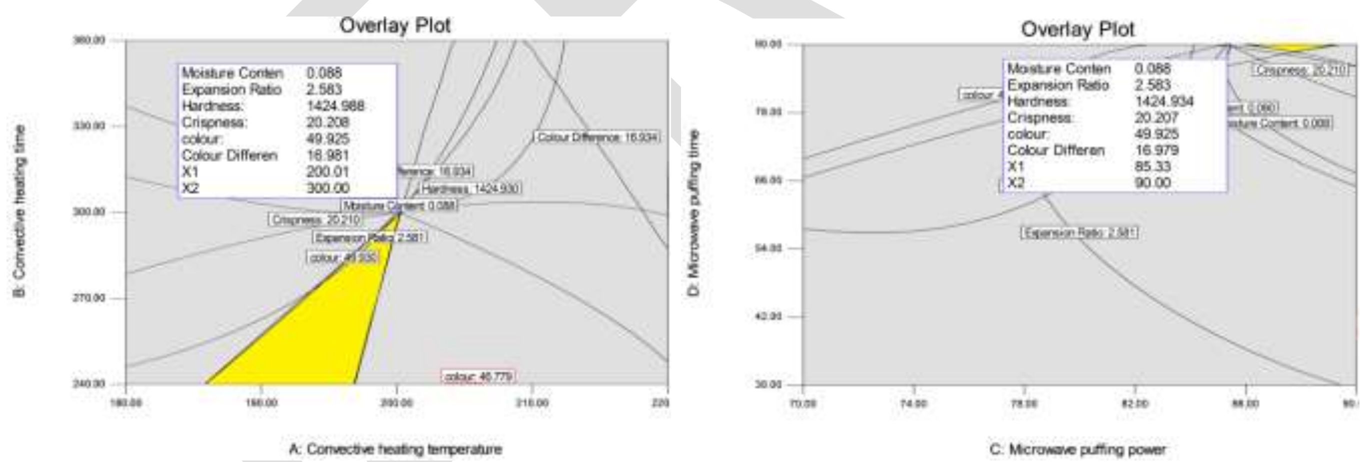
Table 5 Optimization criteria for different process variables and responses for microwave puffing of finger millet-soy pasta

Process parameter	**Goal**	**Lower limit**	**Upper limit**
CT, °**C**	is in range	200	220
Ct, sec	is in range	180	300
MP, % of 1350W	is in range	70	90
Mt, sec	is in range	30	90
MC, kg/kg dm	minimize	0.066	0.291
ER	maximize	1.021	2.786
HD, g	minimize	1245	2000
CSP, +ve peaks	maximize	6	22
L value	maximize	33.1	54.34
ΔE	maximize	6.53	19.26

Optimization of puffing process for finger millet-soy pasta

Numerical and graphical optimization was carried out for the process parameters for microwave puffing for obtaining the best product. To perform this optimization, Design-Expert program (Version 8.0) of the STAT-EASE software (Stat-Ease, 2002), was used for simultaneous optimization of the multiple responses. The desired goals for each factor and response were chosen as shown in Table 4.

Table 5 shows that the software generated ten optimum conditions of independent variables with the predicted values of responses. Solution No.1, having the maximum desirability value (0.877) was selected as the optimum conditions of puffing. The optimum values of process variables obtained by numerical optimization.



(a) At MP = 80% and Mt=60 sec **(b) At CT=210^{0}C and Ct = 240sec**

Fig. 7 Superimposed contour for MC (kg/kg dm), ER, CSP (+ve peaks), colour (L value) and colour difference (ΔE) for microwave puffing of finger millet-soy pasta at (a) CT and Ct and (b) MT and Mt.

Verification of the model for microwave puffed finger millet-soy pasta

Microwave puffing experiments were conducted at the optimum process condition and the quality attributes of the resulting product were determined. The observed experimental values (mean of 5 measurements) and values predicted by the equations of the model. The values of C.V. (<10%) and closeness between the experimental and predicted values of the quality parameters indicated the suitability of the corresponding models. No significant differences between the actual and predicted values were found at $p \leq 0.05$.

The optimum process parameters were obtained from the responses in terms of MC, ER, H, CSP, L value and ΔE by the numerical optimization method and the minimum MC (0.088 kg/kg dm), maximum ER (2.58), minimum H (1425 g), maximum CSP (20.21), maximum L-value (49.95) and maximum ΔE (16.98) were obtained at the process condition of convective heating temperature (200 °C), convective heating time (300 sec), microwave power (85.39 % 1350 W) microwave heating time (90 sec).

Table 6 Solutions generated by the software for microwave puffing process

CT	Ct	MP	Mt	MC	ER	HD	CSP	L value	ΔE	Desirability	Remark
200	300	85.33	90	0.088	2.58	1425	20.21	49.93	16.98	0.870	Selected
200	300	85.43	90	0.088	2.58	1427	20.25	49.91	16.99	0.870	
200	299.98	85.04	90	0.089	2.58	1418	20.10	49.97	16.95	0.870	
200	299.91	84.35	90	0.090	2.59	1404	19.82	50.07	16.86	0.870	
200	299.88	84.28	90	0.090	2.59	1403	19.79	50.08	16.85	0.869	
200	300	87.02	90	0.086	2.57	1462	20.88	49.69	17.21	0.869	
200	299.76	84.89	89.87	0.089	2.59	1416	20.00	49.96	16.90	0.869	
200	300	85.23	89.46	0.088	2.59	1424	20.07	49.85	16.86	0.867	
200.36	300	84.25	89.82	0.089	2.58	1403	19.74	49.98	16.75	0.867	
200	300	89.21	90	0.082	2.55	1516	21.79	49.39	17.55	0.865	

CONCLUSION

The optimization technique of CCRD and RSM was used in design of experiments and optimization of the effect of process parameters for microwave puffing for development of finger millet soy pasta using moisture content , expansion ratio, hardness, crispness, colour value and colour difference as responses. The responses (MC, ER, HD, CSP, L-value and ΔE) of puffed finger millet-soy pasta by microwave puffing process were dependent significantly on the process variables namely, convective heating temperature, convective heating time, microwave puffing power and microwave puffing time for developing finger millet-soy pasta. Microwave puffing temperature and microwave puffing time had the maximum influence, whereas the effects of convective heating temperature and convective heating time was comparatively less on the quality attributes of finger millet soy pasta. The regression models were found to be significantly valid and represented adequate information about the behavior of response with change in process parameters.

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