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Development of barnyard millet snack food : Part I

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Barnyard millet (*Echinochloa frumentacea* L.) is a carbohydrate rich coarse grain which can be used to develop a ready-to-eat (RTE) puffed product. Cold extruded dough sheet pieces prepared from barnyard millet flour, potato mash and tapioca powder in the proportion 60:37:3 were steam cooked and then puffed using high temperature short time (HTST) process in hot air puffing machine. The experiments were designed using central composite rotatable design (CCRD) and the effect of process parameters *viz*. steaming pressure (0 – 1.43 kg cm^{-2}); steaming time (5 – 25 min); air temperature (210 – 250 °C) and puffing time (10 – 50 s) on the product quality attributes like moisture content, expansion ratio, colour (L-value), crispness and hardness were investigated and optimized using response surface methodology (RSM). The texture characteristics of puffed product were prominently dependent on moisture content while volume expansion was highly dependent on steaming pressure and puffing time. The final puffed product with optimum moisture content (0.106 kg kg^{-1} dm), expansion ratio (2.06), colour (72.19 L-value), crispness (11.65 peaks) and hardness (480.66 g) was obtained. The optimum process conditions were: steaming pressure, 0.85 kg cm^{-2}, steaming time, 10.0 min, air temperature, 234 °C and puffing time, 39 s. The sensory evaluation of the optimally developed product added with spices to enhance taste, showed the product to be highly acceptable.

Key Words : Barnyard millet, Cold extrudates, Puffing, Texture, Crispness, Responses

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INTRODUCTION

In today's modern life various RTE snack foods, such as fried chips, wafers, flakes, granules, extruded and spiced products, popcorn, puffed cereals, etc. have become integral part of consumer food habits. Popping or puffing is one of the traditional food processing methods used to prepare RTE light and crisp products. This process involves high temperature short time heat treatment to grains and gelatinized foods (Ushakumari *et al.*, 2007) or sheeted and cut pieces of dough (Nath *et al.*, 2007). Texture is one of the most important quality attributes of snack food (Mazumder *et al.*, 2007) and hot air puffing ideally makes an aerated, porous, crispy texture with added benefits of dehydration (Vernalis *et al.*, 2001).

In the past different researchers have developed RTE foods from whole grain cereals like rice (Chandrasekhar and Chattopadhyay, 1990; Mariotti *et al*., 2006), legumes (Han *et al.*, 2010), millets (Delost-Lewis *et al.*, 1992) and potato (Mukherjee, 1997) but no work has been done on preparation of hot air puffed snack food from barnyard millet flour.

Barnyard millet is one of the important minor millets, rich in minerals and fat compared to rice (Gopalan *et al.*, 1997), highest in amylose (30.47%) content (Mandelbaum *et al*., 1995), high dietary fibres

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(5.35 – 7.9%) (Dhumal *et al*., 2014), excellent for people suffering from acidity, indigestion and has hypoglycemic effect (Arora and Srivastav, 2002). Millets are hard coated grains due to which the milling of grains always results in brokens as bi-product. Though millets are nutritionally rich, the whole grain and bi-product utilization in product development is limited. So considering the importance of the RTE snack products and the need of utilization of bi-product from milling industry to prepare value added food products, present study was undertaken to develop puffed product from barnyard millet flour in Agriculture and Food Engineering Department, Indian Institute of Technology, Kharagpur, India.

METHODOLOGY

Selection of material:

Three ingredients *viz*. barnyard millet (variety, VL-172) flour as primary raw ingredient and tapioca powder and potato mash were selected as the secondary cementing raw ingredients to prepare workable dough and form well shaped cold extrudates (cut pieces of sheeted dough).

Preparation of flour and potato mash:

The barnyard millet grains were dehulled and debranned using Dehuller for barnyard millet (Singh *et al*., 2010) in three passes. These dehusked and polished kernels and tapioca granules were grinded separately in mixture grinder and flour passing through 30 mesh sieve was used (Pardeshi, 2009). The potatoes were cooked in a domestic cooker for 13 minutes and immediately removed for cooling. After complete cooling cooked potatoes were peeled and mash was prepared by hand.

Preparation of cold extrudates:

After trial and error the millet flour, potato mash and tapioca powder were taken in the ratio of 60:37:3, respectively and a common salt of 1.5 per cent of the total flour was added for taste (Fig. A). These ingredients were mixed thoroughly in a plate with hand. In all experiments 500 g of these mixed ingredients were taken and then kneaded in Dolly Mini P3 Pasta machine (LaMonferra, Italy) for 20 min till granules of dough were formed. Then it was cold extruded through a die (12 x 1 mm) and the extruded sheet of dough was cut into pieces of 20 mm length using a cutter attached to the machine. These pieces were spread in a single layer on steel wire mesh and kept in a closed container covered with wet cloth in order to prevent drying of the pieces. The moisture content of these cold extrudates was 0.60 – 0.64 kg kg^{-1} dm (kg moisture per kg dry matter).

Milled barnyard millet and Tapioca granules
↓
Grinding in mixer grinder
↓
Sieving in 30 mesh sieve
↓
Hand mixing of millet flour, cooked potato mash and Tapioca powder in 60:37:3 proportions with 1.5 g common salt (about 500 g mixture)
↓
Kneading in Dolly Pasta machine for 20 min
↓
Dough granules formation
↓
Cold extrusion through die (size 12 x 1 mm) and cutting into 20 x 12 x 1 mm pieces
↓
Spreading on steel wire mesh trays in single layer
↓
Steam cooking in autoclave at 0–1.43 kg cm^{-2} pressure for 5–25 min
↓
Steam cooked product samples (0.526 kg kg^{-1} dm m.c.)
↓
HTST puffing in hot air puffing setup at 210–250 °C for 10–50 s
↓
Puffed product (0.106 kg kg^{-1} dm m.c.)

Fig. A : Process flow chart for preparation of barnyard millet puffed product

Steam cooking of cold extrudates:

Cold extrudates were kept on steel wire meshes stacked one above the other and put in autoclave for desired steaming pressure (SP) and steaming time (St) (Fig. A) for gelatinization of the starch and to give firm shape so that cooked extrudates can be handled and puffed in hot air. After steam cooking the extrudates were removed from autoclave and partially aerated to a moisture content of 0.526 kg kg^{-1} dm (36 % wb).

Experimental setup and hot air puffing:

The puffing was done in a specially designed hot air puffing setup working on the whirling bed principle at high temperature for short time (HTST). It consisted of blower, burner, plenum chamber, puffing chamber and a cyclone separator (Fig. B). The steam cooked samples (size 30 g) were fed through inlet at the top of the puffing chamber and hot air from plenum chamber was passed through vertical airflow pipe into puffing chamber through its bottom half circular opening. In puffing chamber the whirling air flow keeps the sample in fluidized state during which puffing takes place. As soon as the puffing was completed at desired air temperature (AT) and puffing time (Pt) (Fig. A) the inlet was closed and excess air was blown in and the puffed product was discharged through cyclone separator.

Moisture content (MC):

The moisture content (kg kg^{-1} dm) of samples at each stage of the process was determined by hot air oven method (AOAC, 2005) at 105 ºC for 24 h.

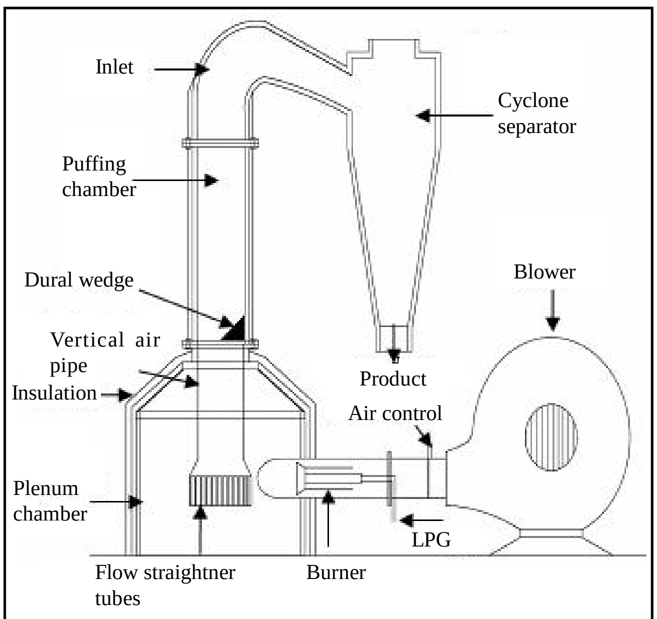

Fig. B : Schematic diagram of the hot air puffing machine

Expansion ratio (ER):

The expansion ratio is the measure of volume expansion during puffing and it was determined in terms of ratio of average bulk volume, (V_p) of puffed product to the average initial bulk volume (V_i) (Segnini *et al.*, 2004) of product before introducing in puffing system.

Colour (L-value) :

The colour ('L', 'a' and 'b' values) of the puffed product was measured using Chromameter- CR – 400/ 410 (Konica Minolta, Japan) (Roy *et al*., 1995). There was not much variation in the 'a' and 'b' values with change in the process parameters upto 30 s of puffing interval. Therefore, only L-value (lightness of colour) was considered. Mean of three replications was taken for each experimental sample.

Crispness and hardness :

The peak force needed to compress the samples is referred as a measure of hardness (Vincent, 1998) while steepness of force-time deformation curve (Fig. C) during rise and sudden fall creates positive peaks which are the measures of crispness (Cruzycelis *et al*., 1996). The texture characteristics of puffed product were measured using a Stable Micro System TA-XT2 texture analyzer (Texture Technologies Corp., UK) fitted with a 25 mm cylindrical probe. Average of 5 replications was taken for both the parameters.

Experimental design:

In the present study, the ranges of experimental

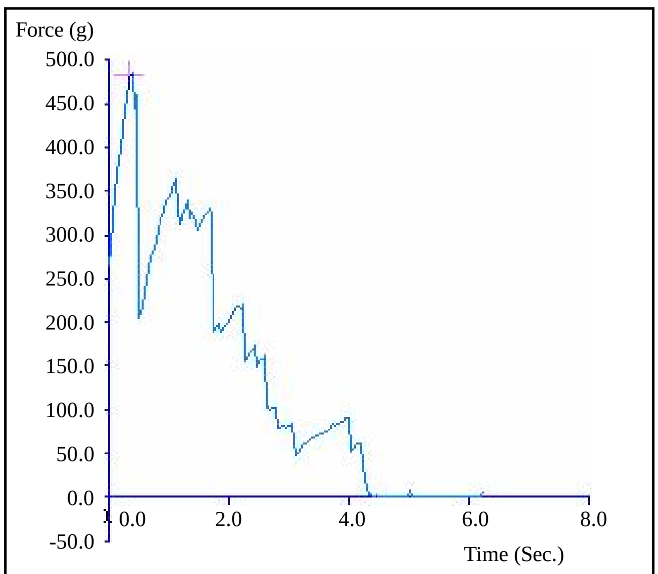

Fig. C : Typical force-time curve for crispness and hardness of barnyard millet puffed product

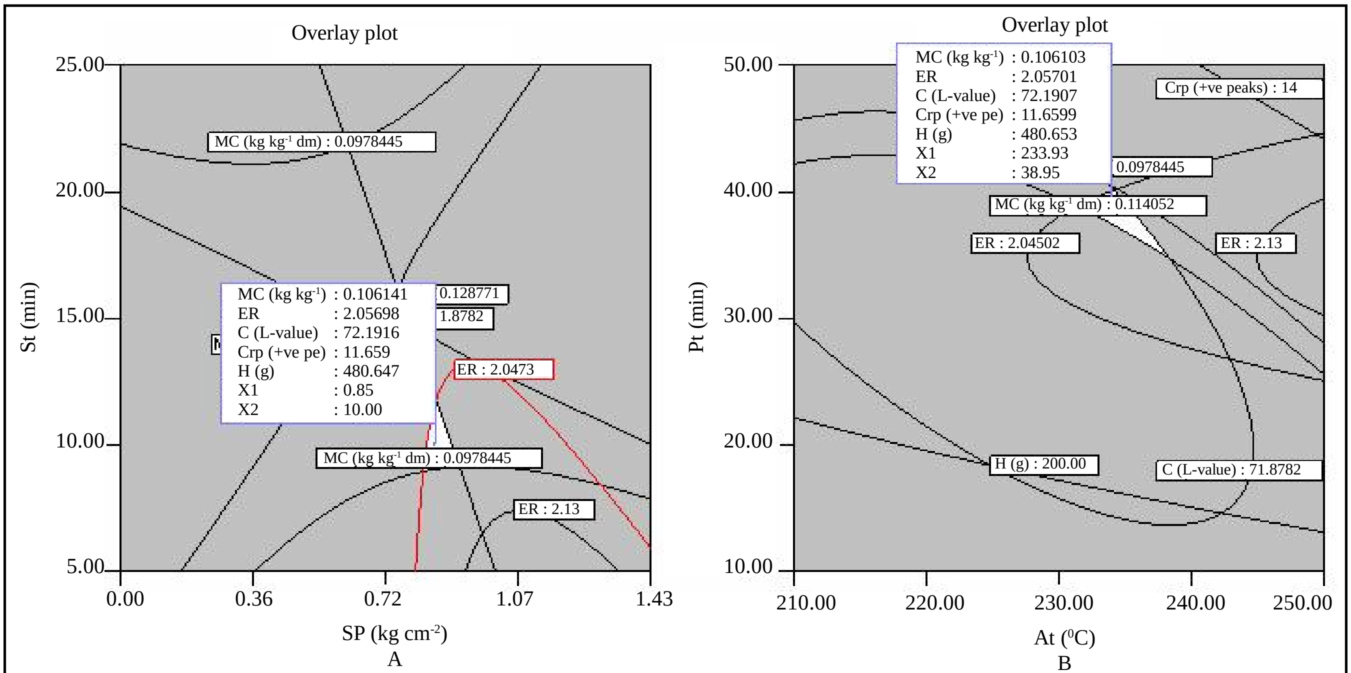

Fig. D : Superimposed contours of MC, ER, C, Crp, H and optimum levels of process parameters

parameters were selected based on literature review and preliminary trials. The process variables considered were steaming pressure, SP (0 – 1.43 kg cm^{-2}); steaming time, St (5 – 25 min); air temperature, AT (210 – 250 °C) and puffing time, Pt (10 – 50 s) at fixed air velocity of 3.98 m s^{-1}, sufficient to impart whirling effect to the samples being puffed in puffing chamber (Fig. D). The response to variation in process parameters was measured in terms of product quality attributes like moisture content (MC), expansion ratio (ER), colour (C, L-value), crispness (Crp, +ve peaks) and hardness (H) of the puffed product (Nath *et al.*, 2007; Pardeshi and Chattopadhyay, 2014). Thirty experiments were designed using central composite rotatable design (CCRD) with four independent variables and five levels of each variable to examine the response pattern (Das, 2005) and also to determine the optimum synergy of process parameters by RSM.

Statistical analysis and optimization:

For all standardized values of responses, analysis of variance (ANOVA) and multiple regression analysis were conducted using *Design Expert - version 7.0* (Statease Inc., Minneapolis, USA) for fitting the second order polynomial regression model (Eq. 1) and to examine the significance of the terms (Nath *et al.*, 2007). The non-significant terms were deleted by the backward elimination and only significant terms were considered.

$$y = b_o + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_1^2 + b_6x_2^2 + b_7x_3^2 + b_8x_4^2 + b_9x_1x_2 + b_{10}x_1x_3 + b_{11}x_1x_4 + b_{12}x_2x_3 + b_{13}x_2x_4 + b_{14}x_3x_4 + £ \quad ...(1)$$

The optimization of the process parameters was performed using *Design Expert - version 7.0*.

OBSERVATIONS AND ASSESSMENT

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

Effect of various process parameters on response variables:

Experimental values of the response variables at different combinations of SP, St, AT and Pt are presented in Table 1.

Moisture content (MC):

During puffing there was continuous decrease in MC of puffed product with time at all levels of air temperature. The values of MC of puffed product ranged between 0.074 to 0.325 kg kg^{-1} dm (Table 1). Puffing temperature (AT) and time (Pt) and steaming time (St) had significant effect in reducing MC of puffed product. Similar relation was found by Pardeshi and Chattopadhyay (2014) with regard to the effect of steaming time, air temperature and puffing time on moisture content of rice-soy snack food. The ANOVA data (Table 2) shows a high model F value of 41.0 (p<0.001) the fitness of quadratic model. The regression model fitted to MC data was reduced to a form (Eq. 2) to predict MC in terms of actual values as given below:

$$\textbf{MC} = -3.21 - 0.1751 \times SP + 0.034 \times AT - 8.19 \times 10^{-3}\, Pt + 8.71 \times 10^{-3} \times SP \times St + 2.31 \times 10^{-4} \times St \times AT + 0.0861 \times SP^2 - 6.1 \times 10^{-4} \times St^2 - 8.9 \times 10^{-5} \times AT^2 + 5.64 \times 10^{-5} \times Pt^2$$

$(R^2 = 0.97)$ ...(2)

Expansion ratio (ER):

There was increase in ER with the increase in process parameters initially but decreased when the parameters were increased at higher levels. It was observed that ER increased with increase in SP upto 0.72 kg cm^{-2} at all levels of St to reach to maxima and started decreasing when SP and St were increased above 1.15 kg cm^{-2} and 10 min, respectively. During puffing there was sharp increase in ER with Pt at all levels of AT upto

Table 1 : Experimental design (4 factors, 5 levels) and corresponding values of responses (quality parameters) obtained during hot air puffing of BM product

Expt.	Independent variables[a]				Responses[b*]				
No.	SP	St	AT	Pt	MC	ER	C	Crp	H
1	1.07(+1)	20(+1)	240(+1)	40(+1)	0.131 ±0.014	1.81 ±0.11	67.18 ±0.54	15 ±1.56	551.8 ±3.52
2	1.07(+1)	20(+1)	240(+1)	20(-1)	0.267 ±0.006	1.78 ±0.16	70.46 ±1.30	10±1.37	263.5±3.21
3	1.07(+1)	20(+1)	220(-1)	40(+1)	0.122 ±0.006	1.8 ±0.16	72.20 ±1.41	11±1.64	447.1±4.67
4	1.07(+1)	20(+1)	220(-1)	20(-1)	0.284 ±0.010	1.75 ±1.13	68.34 ±1.47	8±2.45	221.4±6.53
5	1.07(+1)	10(-1)	240(+1)	40(+1)	0.102 ±0.012	2.10 ±1.10	69.95 ±3.48	14±2.43	533.6±4.52
6	1.07(+1)	10(-1)	240(+1)	20(-1)	0.196 ±0.014	1.95 ±1.13	71.44 ±2.46	11±2.52	374.5±4.12
7	1.07(+1)	10(-1)	220(-1)	40(+1)	0.137 ±0.008	2.05 ±1.10	73.31 ±1.37	12±1.65	428.4±3.13
8	1.07(+1)	10(-1)	220(-1)	20(-1)	0.275 ±0.012	1.88 ±2.07	71.39 ±0.42	8±2.37	151.8±4.52
9	0.35(-1)	20(+1)	240(+1)	40(+1)	0.090 ± 0.006	1.75 ±1.15	72.93 ±2.40	11±3.22	389.3±3.42
10	0.35(-1)	20(+1)	240(+1)	20(-1)	0.206 ±0.010	1.65± 2.08	75.05 ±1.23	10±3.34	234.5±5.34
11	0.35(-1)	20(+1)	220(-1)	40(+1)	0.108 ±0.013	1.73 ±0.09	78.90 ±1.22	9±3.18	345.6±3.17
12	0.35(-1)	20(+1)	220(-1)	20(-1)	0.203 ±0.019	1.54 ±1.08	74.41 ±1.32	7±3.24	143.6±6.2
13	0.35(-1)	10(-1)	240(+1)	40(+1)	0.108 ±0.005	1.58 ±1.10	74.12 ±2.28	11±2.23	315.3±4.10
14	0.35(-1)	10(-1)	240(+1)	20(-1)	0.224 ± 0.012	1.49 ±1.12	74.50 ±0.47	8±2.41	163.5±2.87
15	0.35(-1)	10(-1)	220(-1)	40(+1)	0.166 ±0.005	1.52 ±2.15	77.73 ±0.46	9±2.34	264.6±3.46
16	0.35(-1)	10(-1)	220(-1)	20(-1)	0.266 ±0.013	1.34 ±1.14	75.00 ±1.51	6±3.16	128.2±4.26
17	1.43(+2)	15(0)	230(0)	30(0)	0.238 ±0.019	1.59 ±2.06	67.84 ±1.26	10±1.25	338.8±2.94
18	0.00(-2)	15(0)	230(0)	30(0)	0.204 ±0.010	1.08 ±2.06	79.58 ±1.43	4±4.61	361.6±8.51
19	0.71(0)	25(+2)	230(0)	30(0)	0.122 ±0.013	1.95 ±1.07	68.52 ±1.52	9±2.45	432.1±3.36
20	0.71(0)	5(-2)	230(0)	30(0)	0.109 ±0.010	1.78 ±1.12	74.72 ±2.31	7±3.31	368.2±3.23
21	0.71(0)	15(0)	250(+2)	30(0)	0.125 ±0.006	2.13 ±1.07	68.78 ±2.53	10±3.34	571.5±2.71
22	0.71(0)	15(0)	210(-2)	30(0)	0.158 ±0.008	1.79 ±2.09	69.60 ±1.54	8±2.46	328.8±3.33
23	0.71(0)	15(0)	230(0)	50(+2)	0.074 ±0.011	1.88 ±1.07	67.70 ±2.50	12±2.63	460.0±2.77
24	0.71(0)	15(0)	230(0)	10(-2)	0.325 ±0.010	1.02 ±1.13	70.07 ±0.32	5±3.53	29.0±9.28
25	0.71(0)	15(0)	230(0)	30(0)	0.201 ± 0.011	2.10 ±1.13	73.60 ±0.75	11 ±2.5	381.1 ±2.37
26	0.71(0)	15(0)	230(0)	30(0)	0.189 ±0.012	1.93 ±1.13	74.50 ±1.50	10 ±3.37	407.5 ±2.52
27	0.71(0)	15(0)	230(0)	30(0)	0.192 ±0.011	2.02 ±1.08	73.70 ±1.40	10 ±3.43	426.5 ±3.29
28	0.71(0)	15(0)	230(0)	30(0)	0.178 ±0.011	1.96 ±1.08	71.98 ±1.42	7 ±3.16	415.4 ±3.36
29	0.71(0)	15(0)	230(0)	30(0)	0.166 ±0.012	1.89 ±1.10	73.39 ±1.61	11 ±3.29	316.0 ±3.33
30	0.71(0)	15(0)	230(0)	30(0)	0.179 ±0.013	1.88 ±1.06	74.83 ±1.30	10 ±2.24	435.2 ±4.41

[a] SP – Steaming pressure; St – Steaming time; AT – Air temperature; Pt – Puffing time
[b] MC – Moisture content; ER – Expansion ratio; C – Colour; Crp – Crispness; H - Hardness
[*] Values of responses are given as means ± standard deviation of three replications for MC, ER, C and five replications for Crp and H

about 35 s of puffing interval. From ANOVA (Table 2) data set, high model F-value and R^2 indicated that the quadratic model (Eq. 3) can be fitted at high level of significance ($p<0.001$).

$$ER = -2.01 + 2.8475 \times SP + 6.5 \times 10^{-3} \times AT + 0.081 \times Pt - 0.0548 \times SP \times St - 1.1268 \times SP^2 - 1.15 \times 10^{-3} \times Pt^2 \quad (R^2 = 0.98) \qquad ...(3)$$

The expansion ratio of the product varied from 1.02 to 2.13 (Table 1). The ER was higher than 1.99 obtained for wheat-soy snack (Pardeshi and Chattopadhyay, 2014) and 1.67 for tapioca powder-peanut product (Yewale and Chattopahyay, 2013).

Colour (C):

During puffing, there was an improvement in L-value due to expansion of product with increase in both AT and Pt initially and reached to a maximum and again started decreasing when AT and Pt were increased beyond 240 °C and 40 s, respectively. After 40 s of puffing time the L-value reduced slowly due to non-enzymatic browning of product surface (Chandrasekhar and Chattopadhyay, 1990). The L-value decreased with increase in steaming pressure and time similar to the findings reported by Shao and Huang (2008). In present study the experimental values of colour (*L-value)* were in the range of 67.18 to 79.58. The ANOVA for colour (Table 2) of the puffed product indicated moderate model F value (8.74) and R^2 value (0.85) significant at $p<0.001$ suggesting that the quadratic model (Eq. 4) can be used to fit the experimental data.

$$C = -285.544 - 7.1732 \times SP - 0.16797 \times St + 3.9822 \times AT - 0.0126 \times At \times Pt - 8.0 \times 10^{-3} \times AT^2 - 8.7 \times 10^{-3} \times Pt^2 \quad (R^2 = 0.85) \qquad ...(4)$$

Crispness (Crp):

During puffing it was observed that as puffing initiates and advances moisture is trapped in the puffed product and vaporized moisture is slowly removed till 15 – 20 s time interval. The puffed product retained its soft texture due to relatively low rate of moisture removal during initial puffing period which resulted in marginal increase in crispness of product (Mazumder *et al.*, 2007).

Table 2 : Analysis of variance (ANOVA) showing the effect of independent variables on MC, ER, C, Crp and H of BM puffed product

Source of variation	df	Co-efficients of estimate					F values				
		MC	ER	C	Crp	H	MC	ER	C	Crp	H
Model	14						41.0^{***}	8.74^{***}	5.9^{***}	5.6^{***}	8.3^{***}
Intercept	0	0.184	1.963	73.663	9.432	397.522					
x_1	1	0.008	0.149	-2.587	1.207	39.676	8.9^{**}	33.7^{***}	51.2^{***}	16.3^{***}	9.9^{**}
x_2	1	-0.001	0.010	-0.848	0.208	15.196	0.3^{NS}	0.2^{NS}	5.5^{*}	0.5^{NS}	1.5^{NS}
x_3	1	-0.013	0.049	-0.720	0.958	49.196	18.8^{***}	3.7^{*}	4.0^{*}	10.3^{**}	15.3^{***}
x_4	1	-0.061	0.112	0.041	1.542	102.362	437.3^{***}	18.9^{***}	0.1^{NS}	26.7^{***}	66.3^{***}
x_1x_2	1	0.016	-0.098	-0.490	-0.312	-15.368	19.4^{***}	9.9^{**}	1.2^{NS}	0.7^{NS}	1.0^{NS}
x_1x_3	1	-4.4×10^{-4}	-0.011	0.202	0.062	15.881	0.1^{NS}	0.2^{NS}	0.2^{NS}	0.1^{NS}	1.1^{NS}
x_1x_4	1	-6.4×10^{-4}	-0.010	-0.232	0.312	19.043	3.3^{NS}	0.1^{NS}	0.3^{NS}	0.7^{NS}	1.5^{NS}
x_2x_3	1	0.012	-0.010	-0.050	0.062	-8.281	11.2^{**}	0.1^{NS}	0.1^{NS}	0.1^{NS}	0.3^{NS}
x_2x_4	1	-0.004	-0.013	0.011	-0.187	9.181	1.2^{NS}	0.2^{NS}	5.8×10^{-4NS}	0.3^{NS}	0.4^{NS}
x_3x_4	1	0.002	-0.013	-1.267	-0.062	-5.418	0.4^{NS}	0.2^{NS}	8.2^{*}	0.1^{NS}	0.1^{NS}
x_1^2	1	0.011	-0.146	0.372	–	-21.122	16.5^{***}	36.1^{***}	1.2^{***}	–	3.5^{*}
x_2^2	1	-0.015	-0.011	-0.167	–	-7.776	31.9^{***}	0.2^{NS}	0.2^{NS}	–	0.4^{NS}
x_3^2	1	-0.009	0.013	-0.774	–	4.724	10.7^{**}	0.3^{NS}	5.3^{NS}	–	0.2^{NS}
x_4^2	1	0.005	-0.114	-0.851	–	-46.688	4.3^{*}	22.8^{***}	6.4^{***}	–	15.7^{***}
L-of fit	10						1.5^{NS}	2.8^{NS}	4.2^{NS}	1.0^{NS}	2.5^{NS}
R^2		0.97	0.89	0.85	0.75	0.89					
Adj R^2		0.96	0.84	0.75	0.68	0.80					
Pred R^2		0.88 (0.91)	0.44 (0.68)	0.35 (0.56)	0.46 (0.60)	0.43 (0.62)					
APR		28.85	17.92	14.57	14.39	19.72					
CV (%)		7.65	6.15	2.23	14.12	17.10					

x_1, x_2, x_3 and x_4 are the coded terms of steaming pressure (SP), steaming time (St), air temperature (AT) and puffing time (Pt), respectively;
Values in parenthesis are obtained after model reduction
*** P<0.001, ** P<0.01, * P<0.05, NS=Non-significant

When puffing was continued after 20 s, pores and cracks were developed in the microstructure of product as a result of which vaporized moisture gets released rapidly due to which there was considerable improvement in crispness and at the end of 40 s the product achieved crispness value of 13-15 peaks. In this study the Crp values were ranged between 4 and 15 (Table 1). The optimum value was close to those obtained by Pardeshi and Chattopadhyay (2014) for wheat-soy snack (10.4 peaks) and Nath *et al.* (2007) for potato snacks (14 peaks) and Yewale and Chattopahyay (2013) for tapioca-peanut product (12.1). The linear model could be fitted to the experimental data (Eq. 5) as given below:

$$Crp = -19.6161 - 3.3544 \times SP + 0.0958 \times AT + 0.1542 \times Pt \quad (R^2 = 0.75) \quad ...(5)$$

Hardness (H):

It was observed that effect of SP was significant during steaming and in case of puffing effect of Pt was dominant over AT and at constant level of AT, increase in Pt increased the hardness continuously till it attained maxima at around of 35 s of puffing time. Similar findings have been reported by Nath *et al.* (2007) for hardness of puffed potato snacks (which was very high from 1200 – 2932 g). In present study the product gained the strength with the progress of puffing and reached to maximum hardness value of 470 – 550 g at higher levels of AT and Pt combinations. The low hardness values were due to the soft nature, less thickness and hollow core of puffed product. Similar results were reported by Pardeshi and Chattopadhyay (2014) for wheat-soy snack food (928.5 g). The values of H were ranged between 29.0 and 571.5 g (Table 1). The quadratic model could be fitted with high level of significance ($p<0.001$) as given in Eq. 6.

$$H = -1619.818 + 337.4705 \times SP + 4.918 \times AT + 38.0212 \times Pt - 160.0452 \times SP^2 - 0.4631 \times Pt^2 \quad (R^2 = 0.89) \quad ...(6)$$

Optimization:

Numerical and graphical optimizations were carried out by simultaneous optimization of the multiple responses using *Design-Expert 7.0* for the puffing process parameters to obtain puffed product of optimum quality. The optimum values of process parameters *viz*., SP, St, At and Pt were 0.8 kg cm^{-2}, 10.0 min, 238 ^oC and 39.35 s, respectively.

Conclusion :

It can be concluded that milled fractions and dehulled broken grains of barnyard millet can be used to prepare puffed RTE product by incorporating it with potato mash and tapioca powder in the ratio of 60:37:3. The optimum values of product qualities like MC, ER, C, Crp and H were 0.106 kg kg^{-1} dm, 2.06, 72.19, 11.65 (+ve peaks) and 480.66 g, respectively.

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