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Abstract
A ready-to-eat (RTE) puffed product was developed from barnyard millet using high temperature short time (HTST) puffing process. 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 in hot air puffing setup. The effect of process parameters viz. steaming pressure (SP), steaming time (St), hot air temperature (AT) and puffing time (Pt) on the product quality was investigated by conducting experiments using the central composite rotatable design (CCRD). Linear and quadratic models were developed using response surface methodology (RSM) to study the synergy between process parameters and responses in terms of moisture content (MC), expansion ratio (ER), colour (C - L-value), crispness (Crp) and hardness (H). SP and Pt had predominant effect on response functions in both linear and quadratic way at high level of significance (p<0.01 to p<0.001). The texture characteristics of puffed product were prominently dependent on moisture content while volume expansion was highly dependent on SP and Pt. The optimum predicted responses in terms of MC, ER, C, Crp and H were 0.106 kg kg$^{-1}$ dm, 2.06, 72.19, 11.65 peaks and 480.66 g respectively. The optimum process conditions were: SP, 0.85 kg cm$^{-2}$, St, 10.0 min, AT, 234 °C and Pt, 39 s. The developed models were statistically valid and predicted responses were close to the experimental values.

Key words: cold extrudates, puffing, colour, crispness, responses, RSM

Short running head: Development of barnyard millet puffed snack

1. Introduction

In today’s modern life various RTE (ready-to-eat) 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 preparation of expanded products from cereals and legumes is one
of the traditional food processing methods used to prepare RTE light and crisp products. Preparation of both popped and expanded products 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).

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 (Matz, 1970). Snack foods with desirable colour, texture, flavour and shape appeals to the consumer. 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 (Varnalis et al., 2001).

A number of parameters affect the degree of expansion of cereals, which are related both with the compositional characteristics of the raw material (Chen and Yeh, 2001; Jones et al., 2000; Barros et al., 2006) and the processing conditions (Chinnaswamy and Bhattacharya, 1983; Payne et al., 1989; Chandrasekhar and Chattopadhyay, 1990). Temperature of air, puffing time and initial moisture content of the material are important factors in hot air puffing.

The review of past research reveals that there are various process technologies to develop RTE foods from whole grain cereals like rice (Chandrasekhar and Chattopadhyay, 1990; Mariotti et al., 2006), legumes (Han et al., 2010), potato (Mukherjee, 1997) and millets (Delost-Lewis et al., 1992) but no work has been done on preparation of puffed snack food from barnyard millet (Echinochloa frumentacea L.) flour or composite flour made from it.

Barnyard millet is one of the important minor millets and it is rich in minerals and fat as compared to rice (Gopalan et al., 1997). Also it has highest content of amylose (30.47%) amongst minor millets (Mandelbaum et al., 1995), contains all types of essential amino acids, excellent for people suffering from acidity, indigestion and allergenic to gluten and has hypoglycemic effect (Arora and Srivastav, 2002; Kamath and Belavady, 1980), hence recommended for diabetic patient.

Considering the importance of the RTE snack products and the need of processing barnyard millet to make value added products with better storage life, present study was undertaken to develop puffed product from barnyard millet flour and optimize the process parameters. For this purpose, Central Composite Rotatable Design (CCRD) and response surface methodology (RSM) were used to fit a second order polynomial by a least square technique.

2. Materials and methods

2.1. Selection of Material
Three ingredients viz. barnyard millet flour, tapioca powder and potato mash were selected to prepare workable dough and form well shaped cold extrudates (cut pieces of sheeted dough). In the present study refined barnyard millet flour was the primary raw ingredient and tapioca powder and potato mash were used as the secondary raw ingredients. Barnyard millet (variety, VL-172) was procured from the Vivekananda Parvatiya Anusandhan Sansthan, Almora (Uttarakhand, India) and its moisture content (AOAC, 2005) was determined. Tapioca (sago) pearls and potatoes were procured from local market in Kharagpur (West Bengal), India.

2.2. 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 to remove husk and bran and prepare white kernels of uniform degree of milling. 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.

2.3. Preparation of cold extrudates

The proportion of the ingredients in the dough was decided based on the homogeneity of dough and non-stickiness so that well shaped and non-disintegrated cold extrudates formed and can be handled easily. It was found that cold extrudates formed by using barnyard millet flour (58%) and potato mash (42%) were too wet, gritty and disintegrating during handling. Therefore, tapioca powder was added to increase the intactness and reduce gritty texture of dough and extrudates. Potato mash and tapioca powder act as cementing agent to form dough. 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% of the total flour was added for taste (Fig. 1). These ingredients were mixed thoroughly in a plate with hand. In all experiments 500 g of these mixed ingredients was 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 having three openings of size 12 x 1 mm. The extruded sheet of dough was cut into pieces of 15 – 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).

2.4. Steam cooking of cold extrudates

Cold extrudates were steam cooked for gelatinization of the starch and giving firm shape so that these extrudates can be handled and puffed in hot air. The steel wire meshes having cold extrudates were stacked one above the other and put in autoclave above the water level. After steaming for
desired pressure and (Fig. 1) time the wire meshes were removed from autoclave and kept in open air for removal of surface moisture from cooked samples. These partially aerated samples with moisture content of 0.526 kg kg\(^{-1}\) dm (36 % wb) were kept in a plastic box to prevent further drying.

2.5. Experimental setup and hot air puffing

The puffing was done in a high temperature short time (HTST) air puffing setup. A hot air puffing setup working on the whirling bed principle was designed and developed in Agriculture and Food Engineering Department, Indian Institute of Technology, Kharagpur, India. It consisted of blower, burner, plenum chamber, puffing chamber and a cyclone separator (Fig. 2).

Air was supplied by a centrifugal blower through air duct and the burner was positioned at the center in the air duct towards front end leading to plenum chamber. Air duct supplies necessary air to burner and the excess air mix with flue gases of burner in plenum chamber. The puffing chamber was mounted on the plenum chamber. The steam cooked samples were fed through inlet at the top of the puffing chamber and hot air from plenum chamber is 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 at desired temperature and time (Fig. 1) is completed the inlet is closed and excess air is blown in by air control valve and the puffed product is discharged in cyclone separator where it is separated from hot air. A sample size of 30 g was selected for each treatment. After the product was taken out from the setup, the changes in moisture content, expansion ratio, colour (L-value), crispness (+ve peaks) and hardness were measured (Nath et al., 2007; Pardeshi, 2009).

2.6. Moisture content (MC)

The moisture content of samples at each stage of the process was determined by hot air oven method (AOAC, 2005). For determination of moisture content, the samples taken out of the puffing chamber were directly collected in weighed sample box, immediately closed with airtight cap and weighed immediately in order to minimize condensation effect. After 24 hours of drying sample weights were taken. The moisture content was expressed in kg kg\(^{-1}\) dm. Mean of three replications was reported throughout the course of study.

2.7. Expansion ratio (ER)

The expansion ratio is the measure of volume expansion during puffing. For all the samples ER was determined (Eqn. 1) in terms of ratio of average bulk volume, \(V_p\) of puffed product during puffing to the average initial bulk volume \(V_i\) (Chandrasekhar and Chattopadhyay, 1991) of product before introducing in puffing system. For this purpose, the uniform strip (20 mm x 12 mm) size was chosen. The average thickness (1 mm) of 10 strips was determined using vernier caliper.
2.8. Colour (L-value)
The colour (‘L’, ‘a’ and ‘b’ values) of the puffed product was measured using Chromameter- CR – 400/410 (Konica Minolta, Japan). Each product sample was prepared in powder form and the L, a, b values were obtained from the instrument (Roy et al., 1995). It was observed that 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 or brightness of product) was considered in the present investigation. Mean of three replications was taken for each experimental sample.

2.8. Crispness (Crp) and hardness (H)
In texture analyzer, during compression and fracture propagation of dry snack foods, the force-time deformation curve (Fig. 3) represents crispness and hardness of product. Among these two, crispness is the key texture attribute of dry snack products (Heidenreich et al., 2004). The peak force needed to compress the samples is referred as a measure of hardness (Vincent, 1998) while steepness of curve 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. The studies were conducted at a pre -test speed of 1.0 mm s\(^{-1}\), test speed of 0.5 mm s\(^{-1}\) and load cell of 5.0 kg with the help of Texture Analyzer. For measurement of crispness a macro was developed which counts number of major peaks represented in the force-time deformation curve during compression (Nath and Chattopadhyay, 2007). The compression force at which product offers maximum resistance at the highest peak of graph (as shown in Fig. 3), was taken as the hardness value for that sample. Average of 5 replications was taken for both the parameters in each individual experiment.

2.9. Experimental design
In the present study, the ranges of experimental 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 velocity of air at 3.98 m s\(^{-1}\) in puffing chamber. This air velocity was sufficient to impart whirling effect to the samples being puffed. The response to variation in process parameters was measured in terms of product quality attributes viz., moisture content, expansion ratio, colour, crispness and hardness. 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 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. The center point experiment was repeated six times to calculate the reproducibility of the method (Montgomery, 2004). The treatment combination of independent variables with actual and coded values is given in Table 1. Experiments were randomized in order to minimize the effects of unexplained variability in the observed responses due to extraneous factors.

2.10. 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) to examine the statistical significance of the model terms (Nath et al., 2007) and for fitting the models represented by Eqn. 2. The non-significant terms were deleted by the backward elimination regression and the polynomial was recalculated. Model reduction was also used to increase the predictability of model in terms of predicted $R^2$.

The proposed second order polynomial regression model used to predict the individual responses (MC, ER, C, Crp and H) is given below.

$$y=b_0+b_1x_1+b_2x_2+b_3x_3+b_4x_4+b_5x_5^2+b_6x_6^2+b_7x_7^2+b_8x_8^2+b_9x_9x_1+b_{10}x_1x_2+b_{11}x_1x_3+b_{12}x_2x_3+b_{13}x_3x_4+b_{14}x_4x_4+\varepsilon$$

where, $b_0$ is the value of the fitted response at the center point of the design, $b_1$-$b_4$, $b_5$-$b_8$ and $b_9$-$b_{14}$ are the coefficients of polynomial for linear, quadratic and interaction terms, respectively and $\varepsilon$ is the random error.

The adequacy of developed models was determined using F values, lack-of fit test, $R^2$ (coefficient of determination) and Coefficient of variation (CV), adequate precision ratio (APR) as outlined by Lee et al. (2000) and Weng, et al. (2001). For better adequacy of the model the difference between predicted and adjusted $R^2$ should be less than 0.2 (Tripathi and Mishra, 2009) whereas the adequate precision ratio should be greater than 4 and CV should be less than 10%.

Response surfaces and contour plots were generated using Design Expert - version 7.0. The numerical and graphical optimization was also performed by the same software.

3. Results and discussion
3.1. Effect of various process parameters on response variables and predictive models
Experimental values of the response variables at different combinations of SP, St, AT and Pt are presented in Table 1. The process flow chart for BM puffed product through hot air puffing method is given in Fig. 1.

3.2. Moisture content (MC)
The values of MC of puffed product ranged between 0.074 to 0.325 kg kg\(^{-1}\) dm (Table 1). The ANOVA data (Table 2) shows a high model F value of 41.0 (p<0.001) and a non-significant lack-of-fit test which indicated that the quadratic model can be successfully used to fit the experimental data. The R\(^2\) value was calculated by a least square technique and found to be 0.97. The positive coefficient of linear term of SP increased the moisture content while negative terms of St and AT decreased MC in quadratic way with the increase in these variables. The higher F-values for linear terms (p<0.001) and moderate values for quadratic terms (at p<0.001 and p<0.05) of AT and Pt indicated their highly significant effect in reducing moisture content of puffed product. The interaction term of SP and St (p<0.001) as well as St and AT (p<0.01) have significant effect on moisture content. F-values indicated that Pt was the most influencing parameter in linear way whereas effect of St was dominant in quadratic way. The predicted R\(^2\) of 0.91 was in reasonable agreement with the adjusted R\(^2\) of 0.96 (after model reduction) which showed the adequacy of the developed model. A high APR (28.85) and low CV (7.65 %) showed that the model could be used precisely to navigate the design space. Similar relation was found by Pardeshi (2009) with regard to the effect of steaming time, air temperature and puffing time on moisture content of wheat-soy snack food.

The second order polynomial model fitted to experimental data was reduced to a form (Eq. 4) by neglecting the high error generating non-significant terms in order to predict MC in terms of actual values as given below:

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

(R\(^2\)=0.97) (4)

From Fig. 4A it can be observed that during steaming initially upto 15 min, at constant level of St the moisture content of steam cooked product decreased with increase in SP upto about 0.80 kg cm\(^{-2}\) pressure and then increased with further increase in SP at increasing rate but after 15 min onwards, there was similar trend but the change in MC was at decreasing rate. The decrease in MC after 15 min at any level of SP may be due to super heating of steam. During puffing there was continuous decrease in MC of puffed product with time at all levels of air temperature.

3.3. Expansion ratio (ER)

The expansion ratio of the product varied from 1.02 to 2.13 (Table 1). From ANOVA (Table 2) data set, high model F-value and R\(^2\) indicated that the quadratic model can be fitted at high level of
significance (p<0.001). The linear and quadratic terms of SP and Pt have highly significant effect on expansion ratio (p<0.001) whereas the linear term of AT (p<0.05) and interaction of SP and St (p<0.01) have moderate effect on expansion of the product. The negative sign of linear regression coefficients and positive sign of quadratic coefficients of estimate indicated that there was increase in ER with the increase in process parameters initially but decreased it when the parameters were increased at higher levels (as shown in Fig. 4B). The lack of fit was non-significant and predicted \( R^2 \) obtained after model reduction (0.68) was in reasonable agreement with the adjusted \( R^2 \) (0.84) as the difference between predicted and adjusted \( R^2 \) was less than 0.2. The APR and CV (%) for this model were 17.92 and 6.15 respectively. All these tests of fit suggested the goodness of fit of developed regression model (Eq. 5) and it can be used as a good predictor for the expansion ratio.

\[
ER = -2.01 + 2.8475 \times SP + 6.5 \times 10^{-3} \times AT + 0.081 \times Pt - 0.0548 \times SP \times St - 1.1268 \times SP^2 - 1.15 \times 10^{-3} \times Pt^2
\]  
\( \text{R}^2=0.89 \)  

The response surface and contour plots (Fig. 4B) were generated for the fitted model (Eq. 5) as a function of two variables while keeping other two variables at their central values. 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 about 35 s of puffing interval. After 40 s of puffing time ER reduced due to hardening effect of air temperature on product. This trend was similar to the findings reported by Pardeshi (2009) but different than that for puffing of potato snacks (Nath et al., 2007) wherein the temperature was more influential than puffing time. This may be due to the difference in nature of product. The ER was similar to that obtained for wheat-soy snack (Pardeshi, 2009) but less than 2.16 for potato cubes (Mukherjee, 1997) and 4.7 for potato snack food (Nath et al., 2007).

3.4. Colour (L-value)

The experimental values of colour 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 can be used to fit the experimental data. The negative quadratic effect and positive linear effect of Pt in terms of coded values (Table 4.2) reveals that at low levels increase in Pt improved the colour (L-value) of product but prolonging Pt further decreased the colour.

The high F value of 51.2 for linear effect of SP indicated that SP was the most influencing parameter (p<0.001) that imparted dull and slightly brown colour to the steam cooked samples and AT had
least influence (p<0.05) on colour. Only one interaction term of AT and Pt was significant (p<0.01) while quadratic terms of AT and Pt (p<0.05 and p<0.01 respectively) had significant effect on colour. Predicted $R^2$ (0.56) was in reasonable agreement with the adjusted $R^2$ (0.75). The low CV (2.23 %), high APR (which should be greater than 4) of 14.57 and non-significant lack-of-fit indicated the adequacy of the developed model. The quadratic equation relating response colour with independent variables in terms of actual values after deleting the non-significant terms is given in eq. 6.

$$C = -285.544 - 7.1732 \times SP - 0.1697 \times St + 3.9822 \times AT - 0.0126 \times At \times Pt$$

$$- 8.0 \times 10^{-3} \times AT^2 - 8.7 \times 10^{-3} \times Pt^2$$

\[ (R^2=0.85) \] (6)

From Fig. 5A it can be observed that SP and St had linear effects and L-value decreased with increase in steaming pressure and time similar to the findings reported by Shao and Huang (2008). In case of puffing process, there is an improvement in L-value with increase in both AT and Pt initially and reaches to a maximum and again starts decreasing when AT and Pt are increased beyond 240 °C and 40 s respectively. After initiation of puffing, when product gets expanded rapidly upto 30 s puffing time there was increase in L-value. It is evident from Fig. 4.3 that expansion ratio is higher for 20 – 30 s puffing interval which coincides with high L-values during the corresponding interval. Thus, brightness of product increased due to expansion during puffing (Louka and Allaf, 2004). After 40 s of puffing time the L-value reduced slowly due to non-enzymatic browning of product surface (Chandrashekhar and Chattopadhyay, 1991). Similar time lapse in developing colour difference during dehydration of potato was reported by Mishkin et al. (1983), who observed that browning occurred only after a certain time of exposure which was more than 40 min with drying air at 80 °C temperature.

3.5. Crispness (Crp)

It could be observed that the values of Crp were ranged between 4 and 15 (Table 1). The linear model could be fitted to the experimental data and statistical significance for linear terms was tested (Table 2). The model could be fitted with moderate F value of 5.6 and $R^2$ value of 0.75 at high significance level (p<0.001). All the linear regression coefficients were positive (Table 4.2) indicating improvement in Crp with increase in these variables. The interaction (2F1) model was tried to fit the experimental data but all interaction terms were non-significant and the model was reduced to linear form. The high F-values of linear terms of SP (16.3) and Pt (26.7) shows their highly significant (p<0.001) effect on crispness of puffed product. AT had comparatively less influence (p<0.05) on Crp than that of Pt (p<0.001) while the effect of St was not significant. The reasonable agreement between predicted (0.60) and adjusted $R^2$ (0.68), high APR (14.39) and non-
significant lack-of-fit indicated the adequacy of the developed model and it can be used to navigate the design space.

The linear relationship between response and independent variables in terms of actual values after deleting the non-significant terms (eq. 4.4) is given as:

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

(7)

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 20 – 25 s time interval. The puffed product retained its soft texture due to relatively low rate of moisture removal during puffing period which resulted in marginal increase in crispness of product (Mazumder et al., 2007). As a result of this there was not considerable increase in crispness with corresponding increase in AT and Pt. 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 at moisture content of around 0.106 kg kg\(^{-1}\) dm. Therefore, the model \( R^2 \) value was low and CV was more than 10 % which is not desired. The crispness values of BM snack food are close to those obtained by Pardeshi (2009) for wheat-soy snack (15 peaks) and Nath et al. (2007) for potato snacks (14 peaks).

3.6. Hardness (H)

The data recorded for H after each set of experiment (Appendix I) was analyzed by using backward regression. It could be observed that the values of H were ranged between 29.0 and 571.5 g. The quadratic model was tried to fit to the experimental data and statistical significance for linear and quadratic terms was calculated as shown in Table 2. The model F-value (8.3) and \( R^2 \) value (0.89) were moderate but quadratic model could be fitted with high level of significance (\( p<0.001 \)). The positive linear and negative quadratic regression coefficients (Table 4.2) indicated that with the increase in process parameters at low and medium levels there was increase in H but at higher levels these parameters could not increase H further. Puffing time was most influencing factor than the other and it affected the hardness of puffed product in both linear (at \( p<0.001 \)) as well as quadratic way (\( p<0.001 \)). AT was second most influencing factor (\( p<0.001 \)) while effect of SP was least but it affected H in linear and quadratic way (\( p<0.01 \) and \( p<0.05 \) respectively) which is evident in Fig 5B. Though the CV was high (17.1 %), the reasonable agreement between predicted \( R^2 \) (0.62) and adjusted \( R^2 \) (0.80), high APR value (19.72) and non-significant lack of fit shows that the model can be used to navigate the design space.
The regression equation describing the effects of the process variables on $H$ in terms of actual levels of variables (after deleting non-significant terms) is given in equation 8.

$$H = -1619.818 + 337.4705 \times SP + 4.918 \times AT + 38.0212 \times Pt - 160.0452 \times SP^2 - 0.4631 \times Pt^2$$

($R^2 = 0.89$)  

From response surface and contour plots (Fig. 5B) it can be observed that effect of SP was significant during steaming and in case of puffing effect of Pt was dominant over AT and 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 temperature and time 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 (2009) for wheat-soy snack food.

3.7. Optimization

Numerical and graphical optimizations were carried out for the process parameters of HTST air puffing to obtain puffed product of optimum quality. To perform this operation a criteria was given in the program and simultaneous optimization of the multiple responses was carried out using Design-Expert 7.0. In the criteria, the desired goals for independent variables were set within the range taken for experiments and those for responses were chosen to minimize moisture content and maximize expansion ratio, colour, crispness and hardness. In the results of numerical optimization ten applicable solutions (desirability 0.76 – 0.77) were found from optimization process and for more precise values of the responses a solution having maximum desirability value (0.77) was selected. It is evident that SP 0.8 kg cm$^{-2}$, St 10.0 min, AT 238 °C and Pt 39.35 s were the optimum process parameters and the corresponding optimum values of responses 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.

In graphical optimization the superimposed contours of all responses for SP and St (Fig. 6A) and AT and Pt (Fig. 6B) and their intersection zone for minimum MC, maximum ER, maximum C (L-value), maximum Crp and maximum H indicated the following operational ranges of process parameters which could be considered as the optimum range.

- **Steaming pressure (SP):** 75 – 87 kg cm$^{-2}$
- **Steaming time (St):** 8 – 12 min
- **Puffing temperature (AT):** 232 – 237 °C
- **Puffing time (Pt):** 37 – 40 s

In order to verify the optimum conditions of responses experiments were conducted at optimum process parameters. The predicted (theoretically) as well as experimentally obtained responses (mean
of five measurements) at the above process conditions are given in Table 3. The low values of CV (<10%) and closeness between the experimental and predicted values of quality parameters indicated the suitability of the corresponding models.

4. Conclusions
The optimization techniques of CCRD and RSM were effective in design of experiments and optimization and successfully exhibited the effect of process parameters (SP, St, AT and Pt) on the responses (MC, ER, C, Crp and H) hot air puffed product from barnyard millet flour, tapioca powder and potato mash. The regression models were found to be statistically valid and represented adequate information about the behaviour of responses with change in process parameters. Response values predicted by the models could be obtained experimentally at the optimum conditions of process parameters with non-significant difference.

5. References:


6. Legends of figures:
   Fig. 1. Process flow chart for preparation of barnyard millet puffed product
   Fig. 2. Schematic diagram of hot air puffing setup
   Fig. 3. Typical force-time curve for crispness and hardness of puffed product
   Fig. 4. Response surface showing the effect of process parameters on (A) moisture content (MC) and (B) expansion ratio (ER) of barnyard millet puffed product
   Fig. 5. Response surface showing the effect of process parameters on (A) colour (C) and (B) hardness (H) of barnyard millet puffed product
   Fig. 6. Superimposed contours of MC, ER, C, Crp and H at various levels of process parameters
Table 1: Experimental design (4 factors, 5 levels) and corresponding values of responses (quality parameters) obtained during hot air puffing of barnyard millet product

<table>
<thead>
<tr>
<th>Expt. No.</th>
<th>Independent variables</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SP St AT Pt MC ER C Crp H</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.07(+1) 20(+1) 240(+1) 40(+1)</td>
<td>0.131 ±0.014 1.81 ±0.11 67.18 ±0.54 15 ±0.56 551.8 ±3.52</td>
</tr>
<tr>
<td>2</td>
<td>1.07(+1) 20(+1) 240(+1) 20(-1)</td>
<td>0.267 ±0.006 1.78 ±0.16 70.46 ±0.30 10±0.37 263.5±3.21</td>
</tr>
<tr>
<td>3</td>
<td>1.07(+1) 220(-1) 40(+1)</td>
<td>0.122 ±0.006 1.8 ±0.16 72.20 ±0.41 11±0.64 447.1±2.67</td>
</tr>
<tr>
<td>4</td>
<td>1.07(+1) 220(-1) 20(-1)</td>
<td>0.284 ±0.010 1.75 ±0.13 68.34 ±0.47 8±0.45 221.4±3.53</td>
</tr>
<tr>
<td>5</td>
<td>1.07(+1) 10(-1) 240(+1) 40(+1)</td>
<td>0.102 ±0.012 2.10 ±0.10 69.95 ±0.48 14±0.43 533.6±2.52</td>
</tr>
<tr>
<td>6</td>
<td>1.07(+1) 10(-1) 240(+1) 20(-1)</td>
<td>0.196 ±0.014 1.95 ±0.13 71.44 ±0.46 11±0.52 374.5±4.12</td>
</tr>
<tr>
<td>7</td>
<td>1.07(+1) 10(-1) 220(-1) 40(+1)</td>
<td>0.137 ±0.008 2.05 ±0.10 73.31 ±0.37 12±0.65 428.4±3.13</td>
</tr>
<tr>
<td>8</td>
<td>1.07(+1) 10(-1) 220(-1) 20(-1)</td>
<td>0.209 ±0.010 1.65 ±0.08 75.05 ±0.23 10±0.34 234.5±2.34</td>
</tr>
<tr>
<td>9</td>
<td>0.35(-1) 20(+1) 240(+1) 40(+1)</td>
<td>0.090 ±0.006 1.75 ±0.15 72.93 ±0.40 11±0.22 389.3±4.32</td>
</tr>
<tr>
<td>10</td>
<td>0.35(-1) 20(+1) 240(+1) 20(-1)</td>
<td>0.206 ±0.010 1.52 ±0.15 77.73 ±0.46 9±0.34 264.6±3.46</td>
</tr>
<tr>
<td>11</td>
<td>0.35(-1) 20(+1) 220(-1) 40(+1)</td>
<td>0.108 ±0.013 1.73 ±0.09 78.90 ±0.22 9±0.18 345.6±3.17</td>
</tr>
<tr>
<td>12</td>
<td>0.35(-1) 20(+1) 220(-1) 20(-1)</td>
<td>0.203 ±0.019 1.54 ±0.08 74.41 ±0.32 7±0.24 143.6±4.22</td>
</tr>
<tr>
<td>13</td>
<td>0.35(-1) 10(-1) 240(+1) 40(+1)</td>
<td>0.108 ±0.005 1.58 ±0.10 74.12 ±0.28 11±0.23 315.3±4.10</td>
</tr>
<tr>
<td>14</td>
<td>0.35(-1) 10(-1) 240(+1) 20(-1)</td>
<td>0.224 ±0.012 1.49 ±0.12 74.50 ±0.47 8±0.41 163.5±2.87</td>
</tr>
<tr>
<td>15</td>
<td>0.35(-1) 10(-1) 220(-1) 40(+1)</td>
<td>0.166 ±0.005 1.52 ±0.15 77.73 ±0.46 9±0.34 264.6±3.46</td>
</tr>
<tr>
<td>16</td>
<td>0.35(-1) 10(-1) 220(-1) 20(-1)</td>
<td>0.266 ±0.013 1.34 ±0.14 75.00 ±0.51 6±0.16 128.2±4.26</td>
</tr>
<tr>
<td>17</td>
<td>1.43(+2) 15(0) 230(0) 30(0)</td>
<td>0.238 ±0.019 1.59 ±0.06 67.84 ±0.26 10±0.25 338.8±2.94</td>
</tr>
<tr>
<td>18</td>
<td>0.00(-2) 15(0) 230(0) 30(0)</td>
<td>0.204 ±0.010 1.08 ±0.06 79.58 ±0.43 4±0.61 361.6±2.51</td>
</tr>
<tr>
<td>19</td>
<td>0.71(0) 25(+2) 230(0) 30(0)</td>
<td>0.122 ±0.013 1.95 ±0.07 68.52 ±0.52 9±0.45 432.1±3.36</td>
</tr>
<tr>
<td>20</td>
<td>0.71(0) 5(-2) 230(0) 30(0)</td>
<td>0.109 ±0.010 1.78 ±0.12 74.72 ±0.31 7±0.31 368.2±3.23</td>
</tr>
<tr>
<td>21</td>
<td>0.71(0) 15(0) 250(+2) 30(0)</td>
<td>0.125 ±0.006 2.13 ±0.08 68.78 ±0.53 10±0.34 571.5±2.71</td>
</tr>
<tr>
<td>22</td>
<td>0.71(0) 15(0) 210(-2) 30(0)</td>
<td>0.158 ±0.008 1.79 ±0.09 69.60 ±0.54 8±0.46 328.8±3.33</td>
</tr>
<tr>
<td>23</td>
<td>0.71(0) 15(0) 230(0) 50(+2)</td>
<td>0.074 ±0.011 1.88 ±0.07 67.70 ±0.50 12±0.63 460.0±2.77</td>
</tr>
<tr>
<td>24</td>
<td>0.71(0) 15(0) 230(0) 10(-2)</td>
<td>0.325 ±0.010 1.02 ±0.13 70.07 ±0.32 5±0.53 29.0±4.28</td>
</tr>
<tr>
<td>25</td>
<td>0.71(0) 15(0) 230(0) 30(0)</td>
<td>0.201 ±0.011 2.10 ±0.13 73.60 ±0.75 11 ±0.5 381.1±2.37</td>
</tr>
<tr>
<td>26</td>
<td>0.71(0) 15(0) 230(0) 30(0)</td>
<td>0.189 ±0.012 1.93 ±0.13 74.50 ±0.50 10±0.37 407.5±2.52</td>
</tr>
<tr>
<td>27</td>
<td>0.71(0) 15(0) 230(0) 30(0)</td>
<td>0.192 ±0.011 2.02 ±0.08 73.70 ±0.40 10±0.43 426.5±3.29</td>
</tr>
<tr>
<td>28</td>
<td>0.71(0) 15(0) 230(0) 30(0)</td>
<td>0.178 ±0.011 1.96 ±0.08 71.98 ±0.42 7±0.16 415.4±3.36</td>
</tr>
<tr>
<td>29</td>
<td>0.71(0) 15(0) 230(0) 30(0)</td>
<td>0.166 ±0.012 1.89 ±0.10 73.39 ±0.61 11±0.29 316.0±3.33</td>
</tr>
<tr>
<td>30</td>
<td>0.71(0) 15(0) 230(0) 30(0)</td>
<td>0.179 ±0.013 1.88 ±0.06 74.83 ±0.30 10±0.24 435.2±2.41</td>
</tr>
</tbody>
</table>

* SP – Steaming pressure; St – Steaming time; AT – Air temperature; Pt – Puffing time
* 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
Table 2: Analysis of variance (ANOVA) showing the effect of independent variables on moisture content, expansion ratio, colour, crispness and hardness of barnyard millet puffed product

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>Coefficients of estimate</th>
<th>F values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>MC</td>
<td>ER</td>
</tr>
<tr>
<td>Model</td>
<td>14</td>
<td>41.0***</td>
<td>8.74***</td>
</tr>
<tr>
<td>Intercept</td>
<td>0</td>
<td>0.184</td>
<td>1.963</td>
</tr>
<tr>
<td>x₁</td>
<td>1</td>
<td>0.008</td>
<td>0.149</td>
</tr>
<tr>
<td>x₂</td>
<td>1</td>
<td>-0.001</td>
<td>0.010</td>
</tr>
<tr>
<td>x₃</td>
<td>1</td>
<td>-0.013</td>
<td>0.049</td>
</tr>
<tr>
<td>x₄</td>
<td>1</td>
<td>-0.061</td>
<td>0.112</td>
</tr>
<tr>
<td>x₁x₂</td>
<td>1</td>
<td>0.016</td>
<td>-0.098</td>
</tr>
<tr>
<td>x₁x₃</td>
<td>1</td>
<td>-4.4 x 10⁻⁴</td>
<td>-0.011</td>
</tr>
<tr>
<td>x₁x₄</td>
<td>1</td>
<td>-6.4 x 10⁻⁴</td>
<td>-0.010</td>
</tr>
<tr>
<td>x₂x₃</td>
<td>1</td>
<td>0.012</td>
<td>-0.010</td>
</tr>
<tr>
<td>x₂x₄</td>
<td>1</td>
<td>-0.004</td>
<td>0.011</td>
</tr>
<tr>
<td>x₃x₄</td>
<td>1</td>
<td>0.002</td>
<td>-0.013</td>
</tr>
<tr>
<td>x₁²</td>
<td>1</td>
<td>0.011</td>
<td>0.146</td>
</tr>
<tr>
<td>x₂²</td>
<td>1</td>
<td>-0.015</td>
<td>0.011</td>
</tr>
<tr>
<td>x₃²</td>
<td>1</td>
<td>-0.009</td>
<td>0.013</td>
</tr>
<tr>
<td>x₄²</td>
<td>1</td>
<td>0.005</td>
<td>-0.114</td>
</tr>
<tr>
<td>L-of fit</td>
<td>10</td>
<td>1.5NS</td>
<td>2.8NS</td>
</tr>
</tbody>
</table>

R² 0.97 0.89 0.85 0.75 0.89
Adj R² 0.96 0.84 0.75 0.68 0.80
Pred R² 0.88 0.44 0.35 0.46 0.43
(0.91) (0.68) (0.56) (0.60) (0.62)
CV (%) 7.65 6.15 2.23 14.12 17.10

x₁, x₂, x₃ and x₄ 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
Table 3: Comparison between the model predicted and experimental values of responses for barnyard millet puffed product during hot air puffing

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Predicted</th>
<th>Experimental ± SD</th>
<th>Variation (%)</th>
<th>CV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MC (kg kg(^{-1}) dm)</td>
<td>0.106</td>
<td>0.104 ± 0.006</td>
<td>1.88</td>
<td>5.77</td>
</tr>
<tr>
<td>ER</td>
<td>2.060</td>
<td>2.04 ± 0.040</td>
<td>0.97</td>
<td>1.98</td>
</tr>
<tr>
<td>C (L-value)</td>
<td>72.190</td>
<td>71.48 ± 0.850</td>
<td>0.98</td>
<td>2.60</td>
</tr>
<tr>
<td>Crp (+ peaks)</td>
<td>11.660</td>
<td>12.00 ± 0.560</td>
<td>2.92</td>
<td>4.42</td>
</tr>
<tr>
<td>H (g)</td>
<td>480.660</td>
<td>487.6 ± 4.100</td>
<td>1.45</td>
<td>0.84</td>
</tr>
</tbody>
</table>
Figure 1.

Milled barnyard millet & Tapioca granules

Grinding in mixer grinder

Sieving in 30 mesh sieve

1.5% Common salt

Hand mixing of millet flour, Cooked potato mash & Tapioca powder in 60:37:3 proportions (about 500 g mixture)

Kneading in Dolly Pasta machine for 20 min

Dough granules formation

Cold extrusion through die (size 12 x 1 mm) & 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 cut pieces or 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.)

Process flow chart for preparation of barnyard millet puffed product
Figure 2.

Schematic diagram of hot air puffing setup.
Figure 3.

Typical force-time curve for crispness and hardness of barnyard millet puffed product
Figure 4.

Response surface showing the effect of process parameters on (A) moisture content (MC) and (B) expansion ratio (ER) of barnyard millet puffed product.
Figure 5.

A

B

Response surface showing the effect of process parameters on (A) colour (C) and (B) hardness (H) of barnyard millet puffed product
Figure 6.

Superimposed contours of MC, ER, C, Crp and H at various levels of process parameters