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ORIGINAL ARTICLE

HTST Whirling Bed Hot Air Puffing of Wheat based RTE Foods: A Micro Level Case Study

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Abstract

The cold extrudate prepared from blend of wheat-soy flour at requisite initial moisture could be optimally steamed at 0.70 kg/cm^2 for 10.75 min and HTST air puffed at 215 °C for 30 s followed by oven toasting at 113 °C for 27 min to prepare RTE snack foods. The composition of product except the fat content was unaltered during process. The study on phenomena of mass transfer and heat transfer and scanning electron microscopy revealed their stage-wise inter relations during the process. The puffed snack foods prepared were consumer acceptable and having shelf life of more than six months.

Key words: HTST, Puffing, Wheat, RSM, Optimization, Heat and mass transfer, SEM.

1. Introduction

Newer technologies for processed food products and changing life styles have increased the demand for convenience foods. Ready-to-eat (RTE), quick cooking and instant foods have become very common largely due to today's life styles and the demand for quick-to-serve foods.

All cereals contain a large proportion of starch. In its natural form, the starch is insoluble, tasteless, and unsuited for human consumption. To make it digestible and acceptable it must be cooked (Kent and Evers, 1994). Pulse proteins are deficient in sulphur containing amino acids, particularly in methionine, and in tryptophan. It is only in case of soybean that the tryptophan level is equal to the FAO provisional pattern. Overall most satisfying pulse protein from standpoint of the FAO provisional pattern is that of soybean (Manay and Shadaksharswamy, 2004). Therefore, being major among the cereals, rice and wheat as basic ingredient and soybean for fortification can be used for preparation of RTE foods. The RTE foods are prepared by extrusion cooking, puffing, popping, flaking, frying, toasting, etc. Puffing of cereals results from the sudden expansion of moisture present in the interstices of the starch granules during the high-temperature-short-time (HTST) heating of the grains (Chandrasekhar and Chattopadhyay, 1989). The puffing process can be broadly classified as atmospheric pressure process with sudden application of heat and pressure drop process (Matz, 1970).

The cold extrudate prepared, using Dolly Pasta Machine (LaMonferrina Make), from flour of cereals like wheat was thought to get puffed in hot air. The flat and rectangular shaped fresh cold extrudate after requisite steaming found to show puffing effect in whirling bed hot air at temperature of more than 200 °C. The puffing effect was improved with increase in moisture content. However, the cold extrudate prepared from wheat at moisture content more than 0.5385 kg/kg dry matter basis was too soft to handle. Therefore, it was thought to puff the steamed cold extrudate prepared from cereal flour added with higher possible moisture. The present work was undertaken with the objectives for optimizing the process parameters for preparation of soy fortified wheat based RTE snack foods using HTST fluidized bed air puffing, studying the variation in chemical composition of the puffed product at various stages during process, studying mass and heat transfer during process and micro structural variation in the product during process of puffing in view of understanding the way of, reasons to and effect of the process of the puffing.

This study leads to the development of a process technology for preparation of HTST air puffed cereal based RTE snack foods. This product would be highly crisp, stable and having longer shelf life in airtight containers, at room condition.

2. Materials and Methods

2.1 Raw Materials

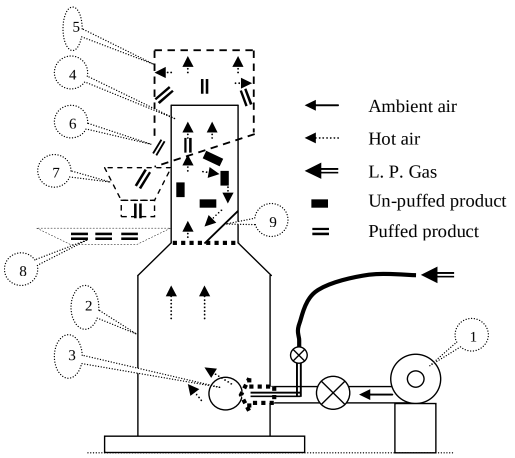
The refined wheat (Cv. *Sharbati*) flour (30 mesh) was the primary raw material for preparation of snack foods in the present investigation. The flour was kept open in tray overnight in order to improve its whiteness (Manay and Shadakharaswamy, 2004). Soy (*Glycine max* Cv. JS 335) flour (30 mesh) (prepared following the process given by Khetarpaul *et al.* (2004) was used as the secondary raw material to enrich the protein content of the final product.

2.2 Sample Preparation

On basis of preliminary trials, the flat shaped strips of cold extrudate prepared using refined wheat flour by adding calculated amount of chilled (5 °C) water to obtain moisture of 0.481 kg/kg dm of granules (as indicated in the manual) added with 2 % common salt, in Dolly Mini P3 pasta machine (LaMonferrina Make, Italy) were prepared for further experimentation (Pardeshi, 2008).

2.3 Experimentation for HTST Air Puffing

These cold extrudates obtained were steamed in autoclave at varied steaming pressure (SP) of 0 to 140 kPa for varied steaming time (St) of 0 to 20 min followed by HTST air puffing in whirling bed hot air puffing system (patented by Chattopadhyay and Mukherjee (2007) (Fig 1) at varied puffing temperature (PT) of 200 to 240 °C for varied puffing time (Pt) of 15 to 35 s in order to optimize the process parameters for optimal response parameters like final moisture content (MC, kg/kg dm), Expansion ratio (ER), Colour (C, L-value), Hardness (HD, g) and Crispness (CSP).



1. Blower, 2. Heating chamber, 3. Provision for ignition, 4. Puffing column, 5. Perforated collector cage, 6. Product inlet-outlet provision, 7. Collecting hopper, 8. Collecting tray, 9. Dural wedge

Fig 1: Schematic diagram of the set up for high temperature short time (HTST) air puffing system

The experiments for above four variables were conducted at five levels (-2,-1,+1,+2) using Central Composite Rotatable Design (CCRD) (Montegomary, 2001). The data was analyzed using Response Surface Methodology (RSM) technique with the help of commercial statistical package, *Design Expert - version 7.0.* The numerical and graphical optimization was also performed by the same software for the optimum process parameters for minimum final moisture content (MC, kg/kg dm) (estimated as per AOAC, 1984), maximum expansion ratio (ER) (determined as per Chandrashekhar, 1989), maximum colour (C, L-value) (Yam *et al.*, 2004), maximum hardness (HD, g) and maximum crispness (CSP, +ve peaks) determined using TPA Texture Analyser (UK make). The desired hardness was taken as maximum because the product was having 0.5 mm thickness, and therefore bearing low hardness. The second order polynomial response surface model was fitted to each of the response variables with the independent variables. The velocity of whirling bed was fixed as constant i.e., 3.95 m/s for wheat based, because it was observed to be sufficient to impart whirling effect at 200 °C, resembling to that for puffing of potato based RTE snack foods prepared by Nath *et al.* (2007).

2.4 Oven Toasting

After HTST air puffing, the optimally prepared wheat-soy snack foods were further subjected to oven toasting because of its high moisture contents (0.1742 kg/kg dm) and low crispness (12 +ve peaks). The oven toasting performed to optimize oven toasting temperature (OTT, °C) and oven toasting time (OTt, min) for minimum final moisture content (FMC, kg/kg dm) of the product, maximum color (C, L-value), maximum hardness (HD, g) and maximum crispness (CSP, +ve peaks) in CCRD using RSM. For this purpose an electrically heated oven (50-300°C) was used. The relative effect of the process variables i.e., OTT (75-135 °C) and OTt (10-30 min) on the responses was studied and oven toasting process parameters were optimized in order to get best quality HTST air puffed and oven toasted wheat-soy RTE snack foods.

2.5 Measurement of Temperature of Product for Heat Transfer Analysis

The temperature air at inlet and outlet of the puffing column of the used HTST hot air puffing system was measured by 26 gauge iron-constantan thermocouple connected to a six channel temperature indicator of range (0-400 °C) as described by Mukherjee (1997). For measurement of average temperature of material, the highly insulated thermo-pack was prepared (Pardeshi and Chattopadhyay, 2014a) in the laboratory as shown in Fig 2.

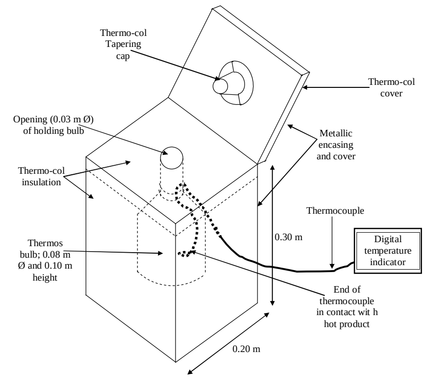


Fig 2: Thermo-pack prepared for measurement of average temperature of puffing product

This had provision for receiving the product coming out of the puffing system and closing the insulating cover immediately. The hot product collected into the bulb, was coming in contact with thermocouple inserted into it. Initially the temperature was increasing for 3-4 seconds and getting reduced thereafter. The maximum notable temperature was recorded for further purpose. The noted temperatures were calibrated with actual temperature of product as suggested by Pardeshi and Chattopadhyay (2014a). The Fig 3 shows the calibration and relation between actual temperature and temperature noted by the thermo-pack instrument. This shows that the difference was higher at higher temperatures and gradually decreased with lowering down of product temperature. This may be due to the fact that at higher temperature, due to higher temperature gradients, the loss of heat would be more as compared to that at lower temperatures.

From Fig 3, the relation between noted temperature (x) and actual temperature (y) of the product was developed and is as given below (Pardeshi and Chattopadhyay, 2014a),

$$y = 1.1049\,x - 1.1214 \qquad (R^2 = 0.9983) \qquad (1)$$

This equation could be used for calibration purpose. The noted temperature of product was converted using above Eq. 1, in order to obtain actual temperature of puffing product at given interval of time. Each experiment was replicated five times.

The process of heat transfer from air to material was analyzed by experimentally determining the average temperature of product.

2.6 Study of Mass and Heat Transfer during Fluidized Bed Air Puffing

The mass transfer kinetics (Pardeshi *et al.*, 2009; Pardeshi and Chattopadhyay, 2010; Pardeshi and Chattopadhyay, 2014b) and heat transfer studies (Pardeshi *et al.*, 2008; Pardeshi *et al.*, 2014b) for wheat-soy snack foods, after optimal steaming, was carried out at various HTST air puffing temperatures from 200 to 240 °C. The time of sampling was taken at every 5 s upto 35 s and later upto 50 s. The heat transfer coefficients for puffing products were determined using Colburn analogy (Colburn, 1933; Chilton and Colburn, 1934; Pardeshi *et al.*, 2008). The material temperature was measured using thermo-pack system specially prepared for the purpose. The equations for predicting the product temperature were fitted to the experimental data and were verified with the results obtained theoretically.

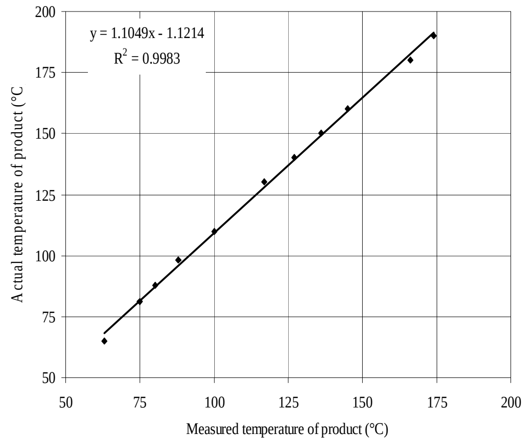
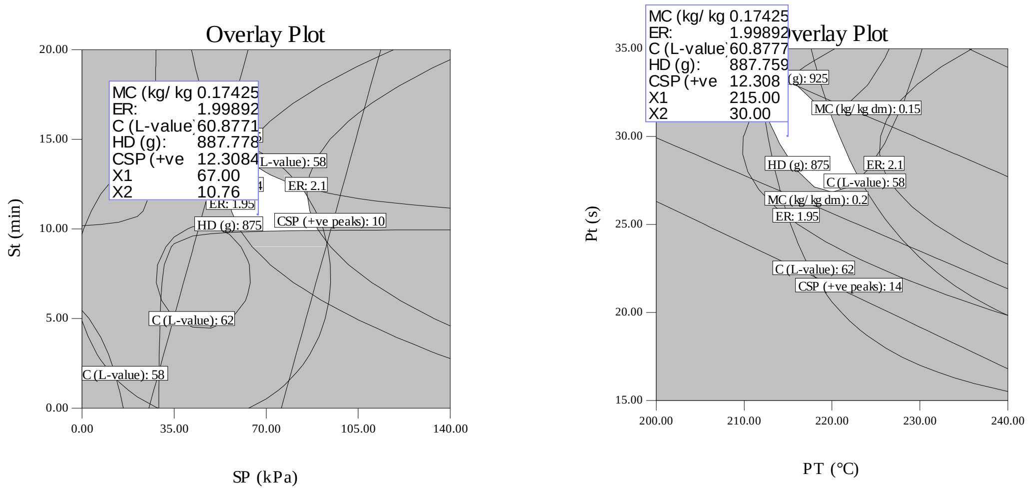


Fig 3: Calibration chart for reading actual temperature of product from temperature measured using thermo-pack

3. Results and Discussion

3.1 Optimization of Process Parameters for HTST Air Puffing of Wheat Based Cold Extrudate

The experimental data on MC (kg/kg dm), ER, C (L-value) and CSP (+ve peaks) were fitted to second order polynomial regression equation by stepwise analysis (StatEase, 2002), as in Eq. 2 to 5, respectively. The data on HD (g) could not be well fitted to any -



(A) (B)

Fig 4: Superimposed contours for MC (kg/kg dm), ER, C (L-value) and CSP (+ve peaks) for RTE wheat snack foods at varying (A) steaming pressure (SP) and steaming time (St) and (B) puffing temperature (PT) and puffing time (Pt)

equation since its model term was non-significant, value of R^2 (0.4965) was very low and the lack of fit was significant, therefore it was not considered as response for optimization (Pardeshi *et al.*, 2014a).

$$MC = 0.79093 - 1.83348\times10^{-4}\times SP - 6.78142\times10^{-4}\times St - 1.6841\times10^{-3}\times PT - 7.83876\times10^{-3}\times Pt \quad (\mathbf{R^2=0.9749}) \quad (2)$$

$$ER = -3.8622 + 5.0357\times10^{-4}\times SP + 0.11863\times St + 9.625\times10^{-3}\times PT + 0.1872\times Pt - 4.93562\times10^{-3}\times St^2 - 3.18563\times10^{-3}\times Pt^2 \quad (\mathbf{R^2=0.9583}) \quad (3)$$

$$C\,(L-value) = -8.2 + 0.18167\times SP + 1.11\times St + 0.32542\times PT + 5.61333\times Pt - 0.02725\times PT\times Pt - 1.96939\times10^{-3}\times SP^2 - 0.076\times St^2 \quad (\mathbf{R^2=0.9037}) \quad (4)$$

$$CSP = 34.94975 - 0.079369\times SP + 0.15008\times St - 0.055542\times PT - 0.23325\times Pt \quad (\mathbf{R^2=0.7716}) \quad (5)$$

From superimposed contour plots shown in Fig 4 (A) and (B), the optimized levels of process variables for steaming of cold extrudate and its HTST hot air puffing were as given below;

Steaming Pressure
= 67.00 ~ 70 kPa; Steaming time = 10.75 min
Puffing Temperature
= 215.00 °C; Puffing time = 30.00 s

3.2 Oven Toasting of Wheat-soy HTST Air Puffed RTE Snack Foods

In similar way shown above, the second order polynomial regression equation by stepwise analysis (StatEase, 2002), as in Eq. 6 to 9, were fitted for wheat-soy snack foods to see effect of OTT and OTt on responses viz., FMC (kg/kg dm), C (L-value), HD (g) and CSP (+ve peaks) are shown in equations 6 to 9,

$$FMC = -0.12784 + 4.07685\times10^{-3}\times OTT + 7.34907\times10^{-3}\times OTt - 2.39995\times10^{-5}\times OTT^2 - 2.35777\times10^{-4}\times OTt^2 \quad (\mathbf{R^2=0.97163}) \quad (6)$$

$$C\,(L-value) = -98.23437 + 2.9697\times OTT - 0.014626\times OTT\times OTt - 0.013537\times OTT^2 \quad (\mathbf{R^2=0.91373}) \quad (7)$$

$$HD = 2033.40468 - 8.17175\times OTT - 7.23594\times OTt \quad (\mathbf{R^2=0.88642}) \quad (8)$$

$$CSP = -42.3947 + 0.83184\times OTT + 0.14465\times OTt - 6.55328\times10^{-3}\times OTT\times OTt - 2.50833\times10^{-3}\times OTT^2 + 0.019442\times OTt^2 \quad (\mathbf{R^2=0.91089}) \quad (9)$$

From superimposed contour plots shown in Fig 5, the optimum conditions of process variables for oven toasting of wheat-soy HTST air puffed snack foods was as below;

Oven Toasting Temperature (PT)
= 113 °C; Oven toasting time (Pt) : 27 min

The hardness and crispness of HTST air puffed RTE snack foods developed were comparable with that of commercially available similar products (Pardeshi, 2009).

3.3 Soy Fortification in Wheat Based HTST Air Puffed RTE Snack Foods

The fresh cold extrudate was prepared from refined wheat flour at moisture content of 0.5384 kg/kg dm, adding soy flour at various levels upto 10 %. The -

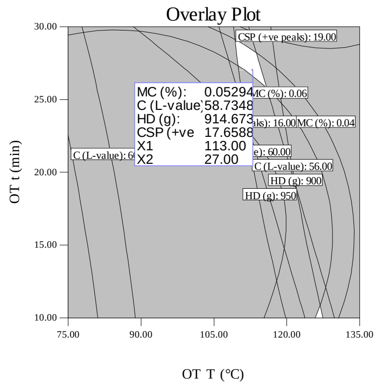


Fig 5: Superimposed contours for MC (kg/kg dm), C (L-value), HD (g) and CSP (+ve peaks) for oven toasting of HTST air puffed RTE (wheat-soy snack foods at varying OTT (°C) and OTt (min)

changes in different physical quality parameters were as given in Table 1.

From the Table 1, it could be observed that MC (kg/kg dm), ER, CSP and colour (a-value) did not vary significantly (Montgomery, 2001) with change in soy proportion in refined wheat flour used for preparation of HTST air puffed snack foods while colour (L-value), colour (b-value) and HD changed significantly. The decrease in colour (L-value) and colour (b-value) indicated increase in brownness and yellowness, respectively of the HTST air puffed snack foods prepared with increase in soy proportion. The brownness and HD imparted due to soy flour upto 7.5% was at par with snack foods prepared from refined wheat flour. The yellowness of HTST air puffed wheat-soy (7.5% soy flour) RTE snack food was significantly higher than that prepared from refined wheat flour.

Fig 6: The optimal wheat-soy ready-to-eat snack food sample

Considering more number of physical quality parameters unaltered due to soy fortification upto 7.5 %, it was taken as optimal one. The optimal sample of wheat-soy RTE snack food is shown in Fig 6. The complete flow of the process is depicted in Fig 7.

3.4 Mass Transfer Kinetics

The mass transfer study revealed that the Page's Model (Eq. 10) could be best fitted to moisture removal behaviour with puffing time at puffing temperature of 200 to 240 °C (Fig 8 and 9). The heating of product in HTST whirling bed, upto first 8 to 10 s, caused surface moisture removal. The further heating caused phase conversion of entrapped moisture into vapours, leading to initiation of puffing. The further expansion of vapours inside the product led to impart puffing effect, upto 15 s of puffing time. During this period rate of moisture removal were drastically reduced. The continual heating caused development of cracks along puffing wall and escaping of vapours causing accelerated rate of moisture removal with further expansion.

$$MR = \exp^{(-kt^n)}$$

$[R^2=0.992; P_0\ (\%) = 3.653]$ (10)

where,
$k = 1.24 \times 10^{-6}\ T^3 - 0.00082\ T^2 + 0.181051\ T - 13.2727$
$n = -3.7 \times 10^{-5}\ T^3 + 0.024534\ T^2 - 5.40293\ T + 396.8774$
and T is in °C.

The values of effective moisture diffusivity (D_{eff}) ranged between 1.15623 x 10^{-9} and 2.58631 x 10^{-9} m^2/s for wheat-soy snack foods. The activation energy, *Ea* was determined as 2341.824 kJ/kg for wheat-soy snack foods during HTST air puffing for temperature range under consideration.

The close observation of the graphical representation of the ER versus moisture content at different puffing temperatures (Fig 10) indicated some distinct phenomenon. At puffing temperature of 200 and 230 °C, a little increase in ER (0 to 10 % of optimal level of ER, i.e., 1.97 occurring at stage D) was observed with moisture content up to 0.395 kg/kg dm (within initial 8 to 10 s of puffing time) as shown in stage A. This indicated that there was surface moisture removal, leading to case hardening.

The case hardening, subsequently, prevents further moisture removal from within the product. From level of moisture content of 0.395 to 0.365 kg/kg dm (during next 10 to 18 s of puffing time) as shown in stage B, the entrapped moisture, due to continual heating, gets evaporated inside the product leading to sudden expansion of product. This could be indicated by faster increase in ER (upto 40 to 50 % of optimal level of ER; stage E). Due to unbearable vapour pressure developed within the product, the development of cracks along puffed walls of the product might be taking place, leading to further moisture removal and continued expansion. This phenomenon could be well proved by observing scanning electron micrographs shown in Fig 11. The further expansion (remaining 50 % of optimal one) took 10 more seconds of puffing time reducing moisture up to 0.175 kg/kg dm as shown in stage C. On the other hand, the ER was found to be increasing with decrease in moisture content for puffing at 240 °C as shown in Fig 10. Due to high puffing temperature, the rate of heat transfer would be higher than rate of mass transfer from beginning itself. This might have caused overlapping of faster case hardening, change of phase of entrapped moisture and development of cracks along walls of puffing product. The stagewise photographs of the puffing product are shown in Fig 11.

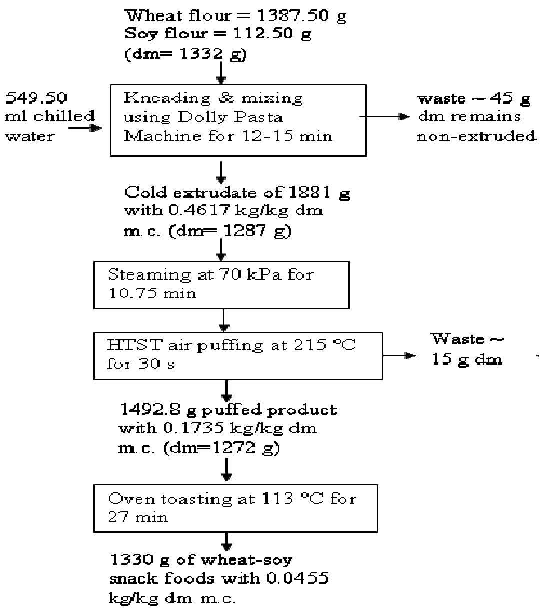


Fig 7: The process flow chart for preparation of wheat-soy ready-to-eat snack foods

3.5 Material Temperature during Puffing of Wheat-soy Snack Foods

For the HTST air puffing of wheat-soy snack foods, the inlet and outlet air temperature in puffing column measured using copper-constant thermocouples and average temperature of product measured are shown Fig 12 and 13.

The experimental coefficients of Eq. 11 were determined by plotting TR versus puffing time (t).

$$TR = Ae^{-K_H t} \qquad (11)$$

During puffing time upto 10 to 20 s, the predicted product temperatures were highly deviating from experimentally measured product temperatures. This is due to the fact that during this period, the phase conversion i.e., moisture to vapour (no moisture removal) must be taking place without increase in temperature and therefore the moisture ratio (Fig 8) and product temperature (Fig 12 and 13) were observed to be constant during 10 to 20 s of puffing period. Here, the heat supplied by puffing air has been utilized for the purpose of conversion of moisture into vapours, which in turn exerts the increased pressure from within inside the material leading to expansion of the product and thus imparts the puffing effect. Factually, the completion of puffing process is ensured at appropriate minimum level of final moisture content of the puffed product as it governs the desirable levels of qualities like colour (L-value), hardness and crispness resulting into better acceptability of the product. The final moisture content attained during puffing is function of temperature of product and time of puffing (Pardeshi and Chattopadhyay, 2010; Pardeshi and Chattopadhyay, 2014b). Considering this fact and behavior of puffing process and to ensure exact prediction of product temperature towards end of puffing process, the constants ‘A’ and ‘K_H’ of Eq. 11 were correlated with puffing air temperature, for puffing time of 10 s to 50 s, and were as given below,

$$TR = Ae^{-K_H t}$$
(R=0.9825, P_0=1.869 %) (12)

where,
$A = 0.47128 + 0.001001 \times T$
$K_H = 0.1108943 + 0.00086314 \times T + 1.85714 \times 10^{-6} \times T^2$

Using the Eq. 12, final predictions were made as shown in Fig. 4, for wheat-soy snack foods. It could be observed that the predictions were close enough to the experimental data with correlation coefficient of 0.9825 and P_0(%) values of 1.869 for wheat-soy snack foods.

From Table 2, it could be seen that irrespective of air temperature, the average material temperature attained by wheat-soy snack foods was about 110-111°C to initiate puffing effect. However, the time required to attain the said temperature varied from 20 s at 200 °C to 10 s at 240 °C. The average material temperature attained by wheat-soy snack foods after reaching the optimum puffing effect (ER=2.00) was varied from 138 °C in 49s at 200°C air temperature and 137°C in 45 s at 210°C while this temperature was 123°C at 220 to 240 °C with decreasing requisite time from 30 s to 26.5 s.

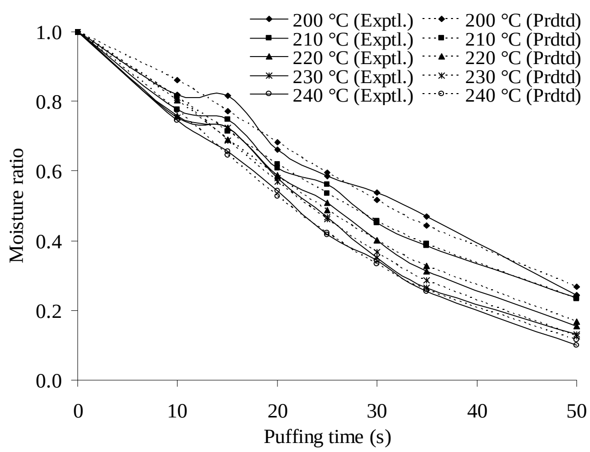


Fig 8: Variation in moisture ratio of puffing product with puffing time for wheat-soy snack foods

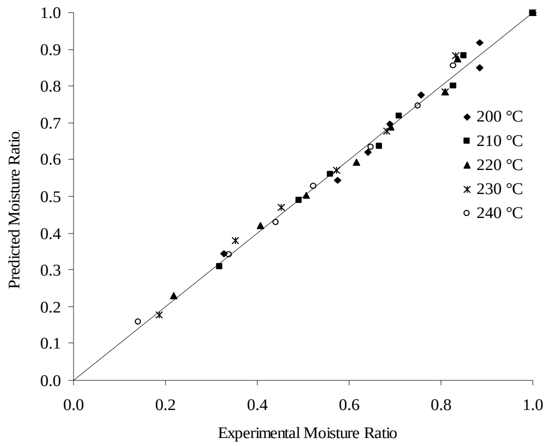


Fig 9: Experimentally determined and predicted moisture ratios during puffing of wheat-soy snack foods

From Eq. 11 and Fig 4, it could be predicted that for wheat-soy snack foods, at optimum puffing temperature of 215 °C (Pardeshi, 2008, Pardeshi *et al*, 2014b), the average material temperature attained at initiation of puffing effect would be 110 °C after 16 s and the said temperature to attain optimum expansion would be 125 °C after 30 s.

Surface heat transfer coefficients were calculated from Colburn factor to be from 130.244 to 122.752 W/m^2 °C for wheat-soy snack foods, decreasing with increase in puffing air temperature from 200 to 240 °C.

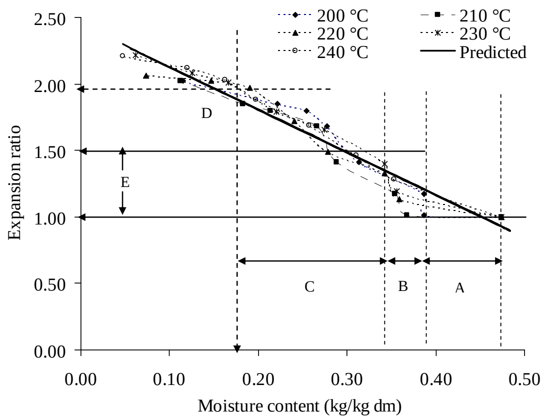


Fig 10: Comparison of experimental and calculated expansion data at given moisture content of wheat-soy snack foods during HTST air puffing

Stage E: Sudden increase in ER; Stage A: Case hardening (in all cases); Stage C: Puffing proceeds with continual decrease in moisture content; Stage D: Optimum level of puffing (ER = 1.99 and moisture content=0.175 kg/kg dm)

The similar results were noted from relation between expansion ratio and moisture content of puffing product. The development of cracks could well proved by observing Scanning electron micrographs in both the cases. The phenomenal sketches of product at different stages during puffing are shown in Fig 14.

3.6 Micro Structural Study of Wheat-soy Snack Foods during HTST Air Puffing

At the optimum conditions of puffing process, i.e, fresh cold extrudate steamed at 70 kPa for 10.75 min and puffed at 215°C for 30 s, the wheat-soy snack foods were puffed. The samples were taken at various stages of puffing as below,

1. Before puffing (0 s) : intact dough particles
2. Puffing initiated (12-13 s): expanded and intact particles
3. Puffing advanced (21-22 s): cracks developed
4. Puffing completed (30 s): cracks widened & structure collapsed

The scanning electron micrograph of puffed wheat-soy snack foods at the stages mentioned above are shown in Fig 15, as ws-01, ws-02, ws-03 and ws-04, respectively. From these micrographs, it could be observed that at initiation of puffing, the dough particles were expanded but remained intact (ws-02) while in the stage of advanced puffing, the cracks developed (ws-03) along the walls of puffing product were observed as mentioned earlier.

A B C D

Fig 11: Stagewise development during hot air puffing of wheat-soy snack foods

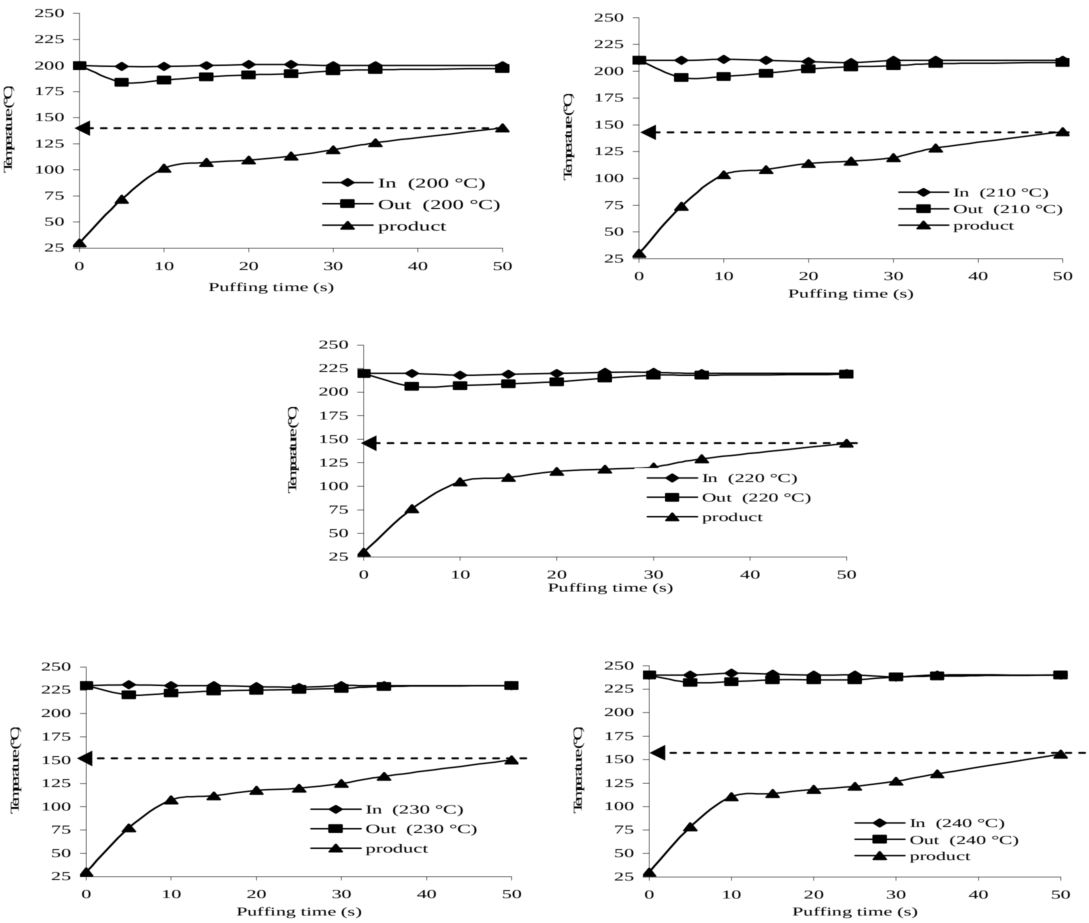


Fig 12: Temperature (°C) of inlet and outlet of puffing column and average temperature (°C) of wheat-soy snack foods during puffing

These cracks might have been developed due to internal pressure built up and causing escaping of vapours generated due to phase conversion of moisture. The stage of completion of puffing (ws-04) shows that the cracks were further widened the structure was collapsed showing bigger void spaces and air vacuoles encircled by the product particles.

3.7 Study on Variation in Chemical Composition of Wheat-soy Snack Foods at Various Stages during Process and Sensory Evaluation of Optimal Products

The initial fat content in wheat-soy flour ingredient was merely 1.82 % db. From Table 3, the fat content was observed to reduce significantly (by 63.18 %) during preparation of cold extrudate. Further, the fat reduced by 8.25% (significantly) during steaming action. No significant reduction in fat content of product during puffing and oven toasting was observed. No significant change in protein content was observed

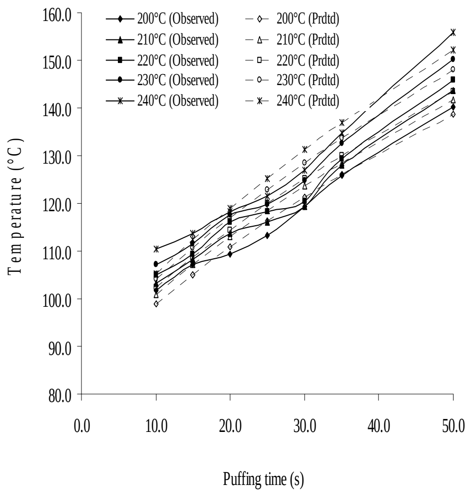


Fig 13: Observed and predicted average temperature snack foods during puffing

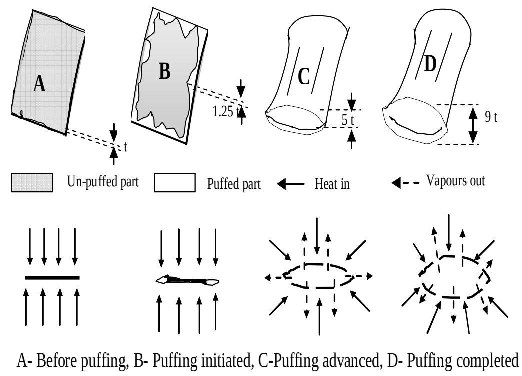


Fig 14: Change in puffing product at different stag during puffing at 220 °C

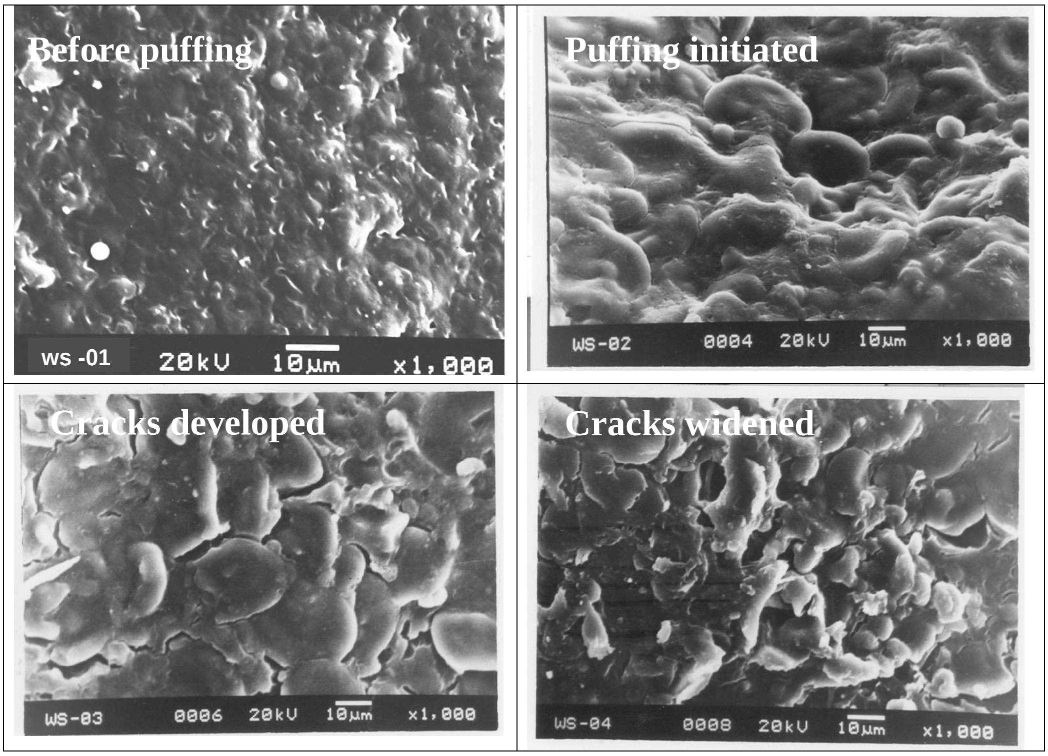


Fig 15: Scanning electron micrographs of wheat-soy snack foods at different stage during puffing

Table 1: Effect soy flour proportion on different quality parameters of HTST air puffed snack foods prepared using refined wheat flour

Sl. No.	Soy (%)	Moisture content (MC, kg/kg dm)	Expansion ratio (ER)	Colour (L-value)	Colour (a-value)	Colour (b-value)	Hardness (HD, g)	Crispness (CSP), +ve peaks
1	0.00	0.165	1.99	60.56[a]	8.67	12.57[a]	928.50[a]	10.40
2	2.50	0.163	2.03	61.50[a]	9.47	13.70[a]	925.00[a]	11.67
3	5.00	0.166	2.05	61.00[a]	9.33	15.90[b]	925.47[a]	11.50
4	**7.50**	**0.164**	**2.05**	**60.94[a]**	**8.33**	**15.33[b]**	**928.53[a]**	**10.67**
5	10.00	0.162	1.96	58.23[b]	8.17	18.37[c]	938.13[b]	10.67
	Fcal	0.868[NS]	0.727[NS]	18.881	1.805[NS]	50.642	6.390	3.250[NS]
	CD (5%	0.0052	0.181	1.248	1.777	1.275	11.895	1.429

F-table (5%;4,10)= 3.48; The columnwise values supersripted by similar letters are at par with each other

Table 2: Time required to initiate and complete puffing and the corresponding average temperature attained at different puffing air temperature

Temp., °C	Time (s) required to initiate expansion (ER=1.25)	Average temp. (°C) of product reached at initiation of expansion (ER=1.25)	Time (s) required to attain optimum expansion (ER=2.00)	Average temp. (°C) of product reached at optimum expansion (ER=2.00)
200	20.0	111.0	49.0	138.0
210	19.0	111.0	15.0	137.0
220	15.0	110.0	30.0	123.0
230	14.0	110.0	27.5	123.0
240	10.0	110.0	26.5	123.0

Table 3: Composition of product at various stages during process of preparation of HTST air puffed wheat-soy snack foods

Stage of Product	Fat, % db	Protein, % db	Ash, % db	Carbohydrate +Fibre, % db*	Moisture content, % db	Energy, kcal/100 g product
Wheat flour + 7.5% full fat soy flour	1.82 (±0.017)[a**$]	14.22 (±0.17)	2.51 (±0.13)	81.45[a]	12.60 (±0.12)[a]	363.20
Fresh cold extrudate	0.67 (±0.025)[b]	14.00 (±0.20)	2.50 (±0.18)	82.83[b]	46.17 (±0.17)[b]	303.29
After steaming	0.52 (±0.020)[c]	13.72 (±0.12)	2.49 (±0.15)	83.27[b]	47.35 (±0.39)[c]	301.16
After puffing	0.52 (±0.008)[c]	13.81 (±0.75)	2.51 (±0.14)	83.16[b]	17.35 (±0.24)[d]	346.68
After oven toasting	0.51 (±0.013)[c]	13.64 (±0.18)	2.50 (±0.11)	83.35[b]	4.55 (±0.20)[e]	381.31
CD (5%)	0.042	NS	NS	0.837	0.570	

* By difference, ** The columnwise values superscripted by similar letters are at par with each other, $ Values in parenthesis are SD

during the entire process. The moisture content, at each stage, was observed to change significantly.

Though the water was added to flour to make up moisture content upto 0.5384 kg/kg dm, the actual moisture content of fresh cold extrudate was observed to be 0.4617 kg/kg dm. This may be due to evaporation of moisture from surface of product during preparation and handling. During steaming, a little but significant addition of moisture was observed, which may be due to incorporation of vapours inside the product and leading to some cooking of the product. The HTST air puffing could reduce the moisture of puffing product from 0.4735 kg/kg dm to 0.1735 kg/kg dm. During the oven toasting the moisture of puffed product was further reduced upto 0.0455 kg/kg dm. The significant variation in carbohydrate (including fibres) was seen during preparation of fresh cold extrudate, which may be due to change in other composition, mainly fat content. However, it remained unchanged during steaming, puffing and oven toasting. The calorific value of final RTE product was calculated to be 381.31 kcal/100 g.

The sensory evaluation indicated that the HTST air puffed RTE snack foods applied with commercially available local spices named as *chat masala* were comparable with commercially available similar snack foods. The HTST air puffed wheat-soy snack foods could be stored in Metallic polyester (35 micron) package at low to moderate RH (35-65%) and ambient temperature of 30°C, for considerably long shelf life of 222 days, i.e. more than six months.

4. Conclusions

The wheat-soy cold extrudate prepared by adding 7.5% soyflour and 0.5384 kg/kg dm initial moisture content could be optimally steamed at 0.67 kg/cm^2 for 10.75 min, and HTST air puffed at 215 °C for 30 s followed by oven toasting at 113 °C for 27 min to prepare wheat-soy RTE snack foods. During the process of preparation of HTST air puffed RTE snack foods, the biochemical changes were minimum except in fat content. The Page Model could be best fitted to moisture removal behaviour with puffing time at puffing temperature of 200 to 240 °C. Surface heat transfer coefficients were calculated from Colburn factor to be from 130.244 to 122.752 W/m^2 °C for wheat-soy snack foods, decreasing with increase in puffing air temperature from 200 to 240 °C. The product temperature attained by wheat-soy snack foods was about 110-111 °C to initiate puffing effect. The development of cracks in wall of puffing product caused due to pressure built up inside the product due to accumulation of vapours after advancement of puffing could be proved by the scanning electron microscopic study. The prepared RTE snack food applied with commercially available local spices named as *chat masala* was well comparable with commercially available similar snack foods and was having shelf life of more than six months.

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