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Evolution of feeder for continuous hot air puffing of Fryums

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Abstract
Fryums are cereal-based snacks that are pre-prepared for frying and are much appreciated in numerous Indian households. They consist of dehydrated, sun-dried dumplings that resemble fragile products. They enlarge instantaneously when subjected to deep frying. They are ingested either as a snack or as an accompaniment to a meal. The manufacturing of Fryums was traditionally confined to households, but it has recently transformed into a cottage and small-scale industry. It also provides a product that is hygienic, secure, and devoid of oil. Individuals are gravitating towards RTE foods due to their convenience in today's hectic, metropolitan lifestyle.Puffing in whirling hot air is a viable technique for generating RTE foods, as it alleviates some disadvantages linked to sand puffing, salt puffing, high-pressure puffing, and oil frying. The phenomenon of whirling transpires when an uneven distribution of air elevates the object by pneumatic transport while gravity pulls it downward. This research focusses on the development and assessment of a feeder for the optimisation and quality evaluation of hot air puffing of Fryums, emphasising critical process variables. The trials utilised a Central Composite Rotatable Design (CCRD), establishing optimal puffing settings with a puffing temperature (PT) of 260 °C and a feed rate (FR) of 6500 g/h in a single-pass in a hot air puffing machine. Under these conditions, the resultant puffed product attained a moisture content of 6.077% db, an expansion ratio (ER) of 5.669, a puffing percentage (PP) of 97.12%, a whiteness index of 89.64, a hardness of 2667.579 g, and a crispness of 12.25 positive peaks. The technology offers a healthier alternative to traditional frying and roasting techniques, as it does not use oil.

Keywords: CCRD, Fryums, Feeder, HTST, Hot air puffing, RTE

1. Introduction

Prepared foods are produced through various methods including extrusion cooking, puffing, popping, flaking, frying, and toasting. The range of RTE food products includes extruded snacks, puffed cereals, popcorn, rice flakes, and fried fryums. Homemade Indian delicacies like *Papad, Kurdai*, and *Chakali* offer delightful flavours when fried or roasted (Pardeshi *et al*., 2010) [16]. The ideal grains for puffing consist of rice, wheat, oats, or pearl barley, which undergo processes such as cleaning, conditioning, and depericarping (for instance, employing a wet scouring technique). Flavouring additives like sugar, malt syrup, and salt are included in the flaked products (Kent *et al*., 1994; Nath and Chattopadhyay, 2007) [10, 14]. Puffed products, mainly sourced from cereals, are greatly appreciated as convenient snacks because of their cost-effectiveness and crunchy textures. The process of puffing effectively creates a light, airy texture reminiscent of snacks, while simultaneously offering the benefits associated with dehydration. The integration of puffed products with diverse flavours and their packaging in moisture-resistant plastic film pouches presents considerable potential for improving the acceptance and consumption of these items (Arya *et al*., 1992; Nath and Chattopadhyay, 2007) [14].

All grains contain a considerable quantity of starch. In its unprocessed form, starch remains insoluble, lacking any discernible flavour, and is not appropriate for human consumption. It is necessary to boil it to make it digestible and acceptable (Pardeshi *et al*., 2014) [17]. As a result, rice and wheat, being the main cereals, in conjunction with soybean for enhancement, can be employed in the production of ready-to-eat foods. The expansion of cereals was a result of the swift increase in moisture within the starch granules during the high-temperature-short-time (HTST) heating process of the grains (Chandrasekhar *et al*., 1989) [5].

The process of puffing in whirling hot air presents a viable approach for the production of ready-to-eat foods, addressing several limitations linked to traditional methods such as sand puffing, salt puffing, high-pressure puffing, and oil frying. The occurrence of whirling is attributed to an uneven distribution of air, which elevates the object through pneumatic transport while simultaneously causing it to descend under the influence of gravity. This leads to a rotational motion upon attaining a specific altitude, induced by uneven air velocity. The circular motion of the product prolongs its residence time in the hot air zone, thereby enhancing the efficiency of heat and mass transfer between the hot air and the particle layer through optimal gas-solid interaction. As a result, the mechanism of the hot air whirling bed demonstrates enhanced efficacy in the puffing process when its attributes are fine-tuned for specific products (Mukherjee *et al*., 1997; Babar and Pardeshi, 2017) [13, 2].

The phenomenon of puffing arises from the swift expansion of moisture contained within the starch granules during the high-temperature-short-time (HTST) heating process of the grains (Chandrashekhar *et al*., 1989) [4]. The puffing process is classified into two primary types: the pressure drop process and the atmospheric pressure process, both defined by the sudden application of heat (Matz *et al*., 1970) [12]. Sand puffing, air puffing, oil puffing, and roller puffing serve as illustrations of atmospheric pressure processes (Chandrashekhar *et al*., 1989) [4], whereas gun puffing is characterised as a pressure drop process (Hoseney *et al*., 1986; Pardeshi *et al*., 2014) [7, 17].

Numerous initiatives have been undertaken, including the invention of a continuous hot air column type electric heater-operated puffing system by Chandrasekhar and Chattopadhyay (1989) [5]. Additionally, the LPG-operated whirling bed type hot air puffing system utilised by Chattopadhyay and Mukherjee (1997) [13] for the puffing of potato cubes has been further applied by Khodke and Chattopadhyay (2004) [11] for puffing freeze-thaw dried potato cubes. Furthermore, Nath and Chattopadhyay (2007) [14] have explored puffing of potato-based cold extrudate the electrically operated heating system, specifically the continuous hot air puffing system (CHAPS) developed by Babar and Pardeshi (2017) [2] for the puffing of Fryums, along with the continuous hot air multigrain puffing system developed by Balaji (2020), has been documented in previous studies (Katkar *et al*., 2023) [9].

The continuous hot air multigrain puffing system, an advancement of the original system developed by Balaji (2020), has undergone enhancements by the Department of Post-Harvest Management of Food Grains and Seeds at the Post Graduate Institute of Post Harvest Technology and Management in Killa-Roha, Dist. Raigad, Maharashtra, India. The outlined puffing system demonstrates superior insulation and automation capabilities, facilitating a streamlined operation for grain feeding, uniform puffing, and the effective discharge of puffed material. The evaluation encompasses the expansion of diverse cereals and millets (Katkar *et al*., 2024) [9]. As a result, this investigation was carried out to evaluate the existing continuous hot air puffing system for Fryums and to confirm that the hot air puffed product is free from sand contamination, while also reducing the extended exposure of workers to elevated temperature conditions.

2. Material and Methods

The research, titled 'Development and Evaluation of Feeder for Continuous Hot Air Puffing of Fryums,' was carried out at the Department of Food Grains and Seeds, Post Graduate Institute of Post-Harvest Technology and Management, located in Killa-Roha, Dist. Raigad, (18°25'35.16312" N, 73°10'45.77484" E) over the period from 2023 to 2025.

2.1 Sample preparation for Fryms puffing

Wheat based Cylindrical shaped Fryums selected for puffing and evaluation, the experiment with two variables i.e., puffing temperature (as 220, 260 and 300ºC) and feed rate of material (as 3000, 4000, 6500, 9000 and 10000 g/hr) was conducted following Central Composite Rotatable Design (CCRD).

2.2 Selection of process parameter

Depending on the needs of the various materials, the puffing machine can be adjusted to varied puffing temperature (ambient to 350 ºC) and feed rates (up to 10,000 g/h). In order to find the ideal process condition with respect to the response parameters like final moisture content (FMC, % db), expansion ratio (ER), puffing percentage (PP, %). Process parameters like puffing temperature (PT) and feed rate (FR) were varied from 250 to 320 ºC, 2000 to 8000 g/h and 8 hrs to 30 hrs respectively.

2.3 Process Optimization - CCRD Design

In this study, a two-factor and five-level CCRD design of experiment was used. The process factors of interest were Puffing time, Puffing Temperature. Each process factor was chosen for five different levels. Here -1.414, −1, 0, +1, +1.414 represent low, medium, and high levels, respectively. In accordance, 13 runs were conducted under identical environmental conditions. fThe results of experiments were analyzed by response surface methodology using the statistical software *Design Expert.*

Table 2.1: Experimental Variables and their Levels coded and actual values.

Coded		Actual	
A	B	A	B
Center point			
0	**0**	260	6500
0	0	260	6500
0	0	260	6500
0	0	260	6500
0	0	260	6500
Box Point			
-1	**-1**	230	4000
-1	+1	230	9000
+1	1	290	4000
+1	+1	290	9000
Star Point			
0	**-1.4142**	260	3000
0	+1.4142	260	10000
-1.4142	0	220	6500
+1.4142	0	300	6500

After the conduction of each experiment as planned in Table 1, the response parameters measured to optimize said process parameters.

2.4 Evaluation of response parameters

After hot air puffing of Fryums samples, the various response parameters were considered for the purpose of optimization of process parameters. The process parameters like puffing temperature, feed rate, and moisture content for puffing fryums on the basis of puffed Fryums qualities namely final moisture content, hardness, crispness (peak +ve), Whiteness index (WI), and expansion ratio are described under experimental design along with the levels and combinations of treatments.

2.4.1 Measurement of Moisture content (% db)

The moisture content of the sample was determined by using hot air oven (0 to 300°C). The weighed samples were subjected to remove moisture at 130 ± 2 °C for 90 min.
The moisture content was determined using the hot air oven method according to the ASAE Standard S352.2 (ASAE, 1997) by using the following relationship (Katkar et al., 2023) [9].

$$\text{Moisture content} = \frac{\text{Initial weight (g)} - \text{Final weight (g)}}{\text{Initial weight (g)}} \times 100$$

2.4.2 Expansion ratio (ER) measurement

Expansion ratio is the ratio of volume of final product after puffing to the volume of raw product before puffing. It is the physical quality attribute, which is desired to be maximum, when puffed. Maximum expansion ratio indicates good quality of puffing. Expansion ratio is determined by taking initial volume of sample fed (V_1) and expanded volume of puffed sample (V_2) (Chandrasekhar, 1989) [5]. The expansion ratio was calculated as,

$$\text{Expansion Ratio (ER)} = \frac{V2}{V1} \times 100$$

where, s
V_1 - Initial volume of sample fed
V_2 - Expanded volume of puffed sample

2.4.3 Puffing Percentage (PP) measurement

The puffing percentage was calculated for puffed Fryums. The puffing percentage was calculated by following formula, (Katkar et al., 2023) [9].

$$\text{Puffing Percentage (PP)} = \frac{\text{Puffed product (Np)}}{\text{Total product in feed sample (Nt)}} \times 100$$

where,
Np = Puffed product
Nt =Total number of grains in the sample

2.4.4 Whiteness index measurement

The colour (L*, a* and b* value) was measured using hunter lab colorimeter as followed by Khodke (2002). The L* values, which denotes degree of whiteness (black=0 and white=100), was chosen to represent the colour of samples. The colour (L*, a* and b* value) and was measured using a simple digital imaging method Yam and Papadakis (2004).
From L*, a* and b* values whiteness index is measured in terms of CIE Lab by the formula.

$$\text{Whiteness index (WI)} = 100 - \sqrt{(100 - L*)^2 + a*^2 + b*^2}$$

2.4.5 Hardness and Crispness

Hardness is defined as the maximum peak force during the first compression cycle (first bite). The hardness value depicts the texture perception of the consumer at first bite. It was measured using a Texture Analyzer.

2.4.6 Numerical optimization

Numerical optimization technique of the Design-Expert software was used for simultaneous optimization of the multiple responses. The desired goals for each factor and response were chosen. All the independents' factors were kept within range while the responses were either maximized or minimized. In order to search a solution optimizing multiple responses, the goals are combined into an overall composite function, D(x), called the desirability function Myers *et al*., (2004). Desirability is an objective function that ranges from zero outside of the limits to one at the goal. It reflects the desirable ranges for each response (di). The desirable ranges are from zero to one (least to most desirable, respectively). The numerical optimization finds a point that maximizes the desirability function. The characteristics of a goal may be altered by adjusting the weight or importance (Stat-Ease, DX11). Graphical optimization was also carried out for the process parameters for hot air puffing obtaining the best product. For graphical optimization, super imposition of contour plots for all responses was done with respect to process variables using Design-Expert software. The superimposed contours of all responses for puffing temperature, feed rate and their intersection zone for minimum final moisture content and puffing percentage, maximum expansion ratio, hardness (in the range), maximum crispness, whiteness index, sensory colour, flavour and texture indicated the ranges of variables which could be considered as the optimum range for best product quality in terms of responses. The optimum combination of product and process variables for hot air puffing conditions were derived by averaging those ranges of variables.

Table 2.2: The responses details obtained for Optimization of process parameters for puffing of Fryums

Fryums Puffing Optimization Data					
Temperature, (°C)	**Feed rate, (g/h)**	**Moisture Content, (% db)**	**Expansion Ratio**	**Puffing Percentage**	**Whiteness Index**
260	6500	5.5	5.7	96.7	88.9
260	6500	7.8	5.4	98.4	90.0
260	6500	5.1	5.9	98.4	94.4
260	6500	6.0	5.3	96.7	86.6
260	6500	5.4	5.7	96.7	88.9
230	4000	9.4	6.0	95.4	72.2
230	9000	6.1	5.8	94.1	55.5
290	4000	4.0	6.3	90.2	38.9
290	9000	3.6	6.1	86.9	44.4
260	3000	3.2	6.6	90.8	66.6
260	10000	4.4	6.0	92.8	68.7
220	6500	8.8	5.0	85.2	77.7
300	6500	2.8	7.2	100	33.3

3. Result and Discussion

3.1 Effect of various process parameters on moisture content (MC, % db) during hot air puffing of Fryums

As indicated in Fig. 3.1, there is a rise in temperature typically results in elevated moisture content, particularly at lower flow rates (up to 4000 g/h). As the temperature escalates from 220 °C to 300°C, moisture content increases. Conversely, at higher feed rates (exceeding 4000 g/h), moisture content begins to decline after attaining a specific temperature range, approximately between 240°C and 250°C. Since the lack of fit is not significant, an equation can be established.

The least squares technique yielded an R^2 value of 0.7583, signifying a satisfactory match between the model and the data. The model's relevance is demonstrated by an F-value of 19.69 ($P<0.01$). The constructed model was considered adequate for response prediction, as indicated by the substantial F-value of lack of fit. The Adjusted R^2 of 0.7100 and the model adequacy assessment with a predicted R^2 0.6116 are in reasonably in agreement. This model is suitable for navigating the design space.

The comparative impact of each element on the MC may be discerned by the F-values. The F-values indicated that PT, °C exerted the greatest influence, followed by F, in relation to MC. Response surface and contour plots (Fig. 3.1) were created to illustrate the combined effect of two factors on the MC, based on the fitted model (Eq. 3.1).

$$MC, \%db = 24.44750 - 0.070503\times PT - 1.23446E\text{-}0.8 \times FR^2 \quad (3.1)$$

The reduction in moisture content of puffed products at higher puffing temperatures and longer durations has been reported by Mukherjee (1997) [13] in the HTST air puffing of potato cubes, Nath and Chattopadhyay (2007) [14] in the HTST air puffing of potato-soy snack foods, Pawar (2017) in the HTST microwave puffing of sprouted soy fortified millet flour-based ready-to-eat snacks, and Babar and Pardeshi (2017) [2] in their examination of the puffing characteristics of rice-based Fryums.

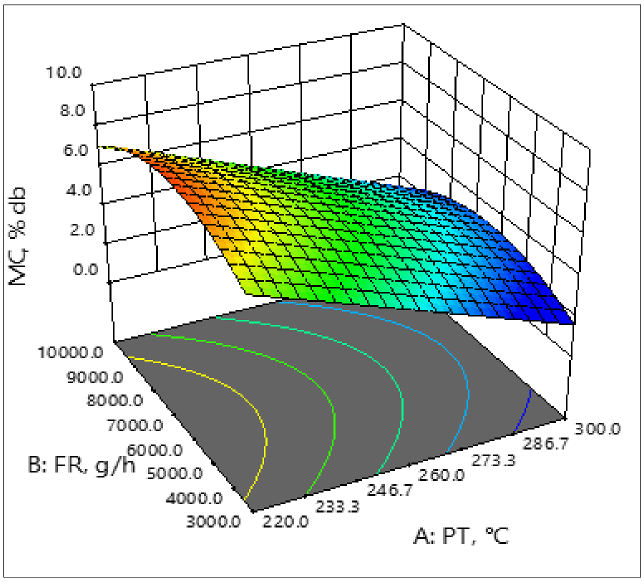

Fig 3.1: The contour and response surface plots showing the effect of Puffing Temperature (PT) and Feed rate (FR) on Moisture Content (MC %db) for puffing of Fryums.

3.2 Effect of various process parameters on expansion ratio (ER) during hot air puffing of Fryums grain

As the puffing temperature escalates from 220 °C to 230°C, the expansion ratio (ER) rises from 5.0 to roughly 5.9, indicating a moderate rate of increase. Conversely, from 230°C to 260°C, the ER experiences a minor decline, decreasing from 5.9 to 5.7. As the feed rate escalated from 3000 g/h to 10000 g/h, there was a slight reduction in the ER. With an increase in temperature and feed rate, the expansion ratio exhibited a decrease.

The R^2 value, which was 0.9118, indicates a satisfactory fit between the model and the data. The model's significance is indicated by the F value of 14.48 ($P<0.01$). The model obtained did not exhibit a significance F value for lack of fit. This model was sufficient to navigating the design space due to a substantial lack of fit.

The F values suggested that Temperature (°C) was the most influential factor, followed by with FR, g/h, and FR^2 showing moderate effectiveness, while PT^2 had a lesser impact on ER. The quadratic term $(PT \times FR)^2$ demonstrated minimal effectiveness in relation to ER. The regression equation describing the effects of the process variables on expansion ratio in terms of actual levels of variables is given as Equation below.

$$ER = 18.08755 - 0.093845\times PT - 0.000728 \times FR + 0.000215 \times PT^2 + 6.3488E\text{-}0.8 FR^2 - 4.76052E\text{-}11 PT \times FR^2 \quad (3.2)$$

A comparable finding was reported by Babar and Pardeshi (2017) [2], where the expansion ratio increased with puffing temperature. Initially, it rose with an increase in feed rate from 50 to 100 g/min, before subsequently declining. Similar findings were observed by Jog et al., (2024) while studying about barnyard millet puff and Pardeshi and Chattopadhyay (2010) [16] noted the elevated feed rate facilitated an extended residence time, thereby leading to an initial rise in the expansion ratio up to a feed rate of 100g/min. However, subsequent increases in the feed rate resulted in overcrowding, which diminished the expansion effect.

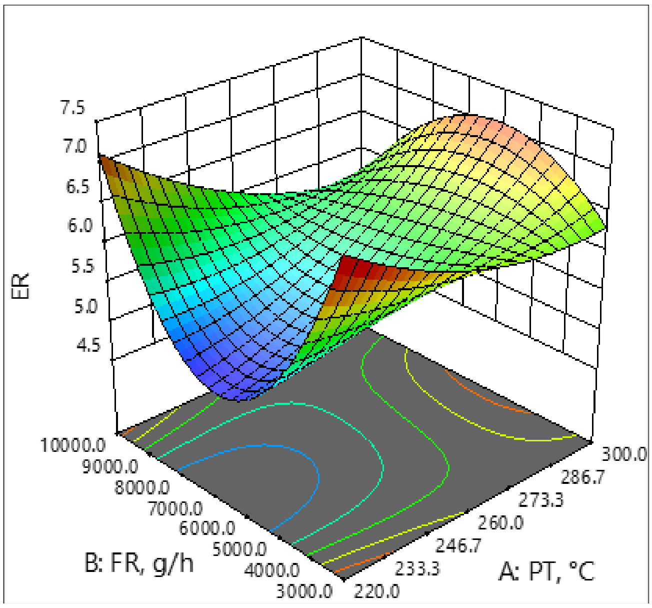

Fig 3.2: The contour and response surface plots showing the effect of Puffing Temperature (PT) and Feed rate (FR) on Expansion Ratio (ER) for puffing of Fryums.

3.3 Effect of various process parameters on puffing percentage (PP) during hot air puffing of Fryums

The puffing temperature (PT) and the feed rate (FR) significantly affect the puffing percentage; however, the temperature exerts the most substantial influence. Typically, elevated temperatures lead to an increase in the puffing percentage, with the maximum temperature evaluated (300

°C) resulting in the highest puffing percentage recorded, which was 100%. Under moderate temperatures of approximately 260 °C and feed rates around 6,500 g/h, the puffing percentage remained elevated (96.7-98.4%), indicating that the conditions for optimal expansion were achieved.

The least squares technique was employed to determine the R^2 value, which was 0.9847, indicating a satisfactory fit between the model and the data. The model's significance is indicated by the F-value of 64.24 ($P<0.01$). The F-value of lack of fit was not statistically significant, suggesting that the model that was developed was sufficient for predicting the response. In addition, the model's adequacy was assessed using a predicted R^2 of 0.9510, which indicated that it was not in reasonable agreement with the adjusted R^2 of 0.9693. The regression equation that outlines the influence of the process variables on PP, expressed in terms of the actual levels of these variables, is presented as follows Equation 3.3 expressed below.

$$PP,\% = -173.66535 + 3.40843 \times PT - 0.059937 \times FR - 0.009339 \times PT^2 + 9.7648E-06\ FR^2 + 9.6798E-07 \times PT^2 \times FR - 3.93419E-08 \times PT \times FR^2 \quad (3.3)$$

The influence of puffing temperature and feed rate on puffing percentage was significant at elevated levels of both variables. Figure 4.3 illustrates that the puffing percentage increased with rising puffing temperature, while it decreased with an increase in feed rate. The higher temperature may have allowed more Fryums to puff up within a specific timeframe at home. Conversely, the increased feed rate likely resulted in uneven exposure of the fryums to the puffing conditions, potentially due to a greater quantity present. Babar and Pardeshi (2017) [2] obtained comparable results in the examination of the puffing properties of rice-based fryums. Above 255 °C, the PP increases with temperature.

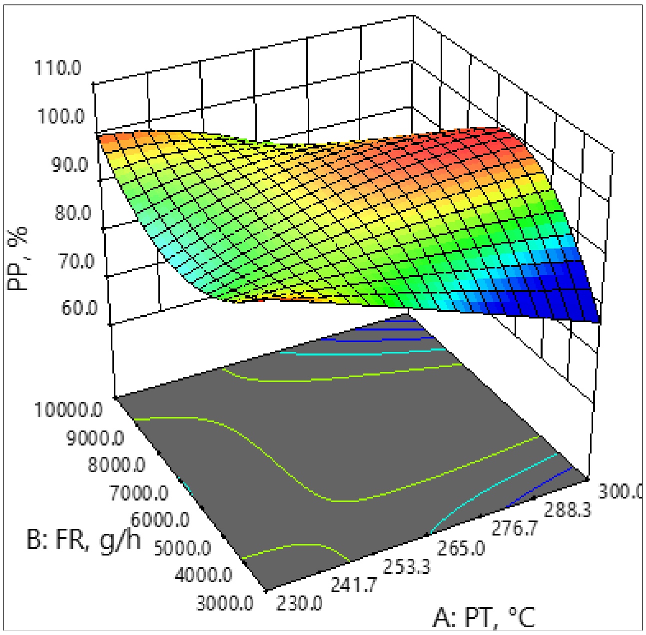

Fig 3.3: The contour and response surface plots showing the effect of Puffing Temperature (PT) and Feed rate (FR) on Puffing Percentage (PP) for puffing of Fryums

3.4 Effect of Various Puffing Processes on whiteness index (WI) during hot air puffing of Fryums

The observed values of WI ranged from 33.3 to 94.4. The quadratic model was applied to the experimental data, and the statistical significance of the linear term PT, °C (for feed rate), The R^2 value was determined using a least squares method, yielding a result of 0.9630, which indicates a strong fit of the model to the data. The Model F-value of 52.09 indicates that the model demonstrates statistical significance. F-value indicating lack of fit was found to be non-significant for the derived model. The equation demonstrates that the model developed is suitable for accurately predicting the response.

Further, the predicted R^2 of 0.8482 demonstrated a satisfactory alignment with the adjusted R^2 of 0.9445. The analysis indicated that the terms deemed non-significant were excluded from the model. Therefore, this model may serve as a tool for exploring the design space. The regression equation that articulates the influence of the process variables on WI, expressed in terms of the actual levels of these variables, is presented in Equation 3.4

$$WI = -1299.08301 + 11.15032 \times PT + 0.000097 \times PT \times FR - 0.023532 \times PT^2 - 1.97086E-06\ FR^2 \quad (3.4)$$

The F values demonstrated that A-Temperature emerged as the most significant factor, succeeded by the interaction term PT x FR and the quadratic term PT^2. The quadratic term FR^2 demonstrated minimal effectiveness in relation to WI. The optimal whiteness index (WI) is achieved at a moderate puffing temperature of 260 °C, combined with a mid-range feed rate of 6,500 g/h. Both extremely low and extremely high temperatures, as well as feed rates, result in a decrease in WI.

The WI experiences a substantial increase as the temperature rises from low to moderate (230 °C to approximately 260 °C). The most significant expansion and starch gelatinisation occur at a temperature of approximately 260°C. The results of Katkar et al., (2023) [9] in Whiteness index regarding the lightness of Puffed White Rice were comparable.

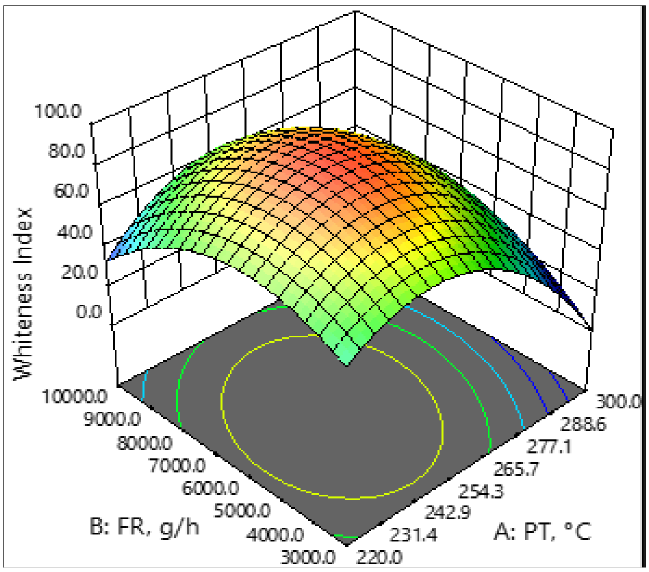

Fig 3.4: The contour and response surface plots showing the effect of Puffing Temperature (PT) and Feed rate (FR) on Whiteness Index (WI) for puffing of Fryums

Table 3.1: Table showing effect of Different Puffing methods on Hardness and Crispness of Fryums.

Puffing Methods	Hardness (g)	Crispness(+ve Peaks)
Oil Puff	1179.246	6.25
Sand Puff	2835.035	4.25
Air Puff	2667.579	12.25

3.5 Effect of Various Puffing Processes on Hardness (HD, g) during hot air puffing of Fryums

The hardness using TPA texture analyser (Section 3.7.4) for hot air puffed, sand puffed and oil puffed Fryums samples. It was clear that the values of HD were between 1179.246(g) and 2835.035(g) for all three samples. The treatments had a very strong effect on hardness (F = 14.93, p = 0.005), which means that the type of puffing method has a big impact on the hardness parameter. There was a significant difference in hardness of oil puffed and sand puffed samples whereas, hot air puffed samples were at par with sand puffed samples with respect to hardness. This shows the oil puffed samples were too soft as compared to sand puffed and hot air puffed. If the p-value for treatment is 0.005, that means there is only a 0.5% chance that the big differences in hardness were just random chance. The model's good fit also demonstrates that it may be used to navigate the design space and discover the best hardness for commercial production.

The oil puffing has the lowest hardness at 1,179 g, indicating a somewhat soft texture. Sand puffing produces the most rigid material (2,835 g), indicating that the structure is significantly more robust and brittle. Air puffing reduces the rigidity (2,667 g) compared to sand, indicating that the structure may experience slight relaxation when subjected to convective heating. Babar and Pardeshi (2017) [2] observed a similar phenomenon in the puffed characteristics of rice-based Fryums.

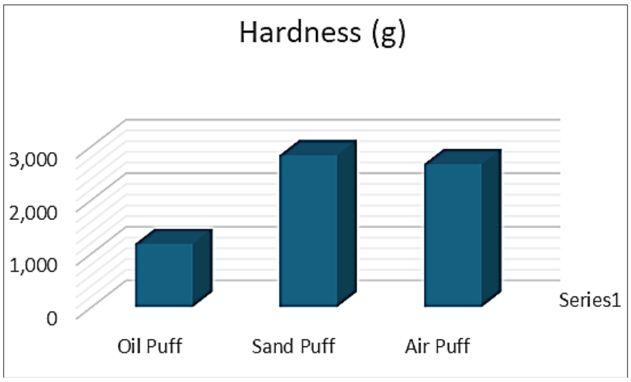

Fig 3.5: The Bar Graphs showing the effect of Various Puffing Processes on Hardness (HD, kg) for hot air puffing of Fryums.

3.6 Effect of various Puffing Processes on crispness (CSP +ve peaks) during hot air puffing of Fryums

The Crispness using TPA texture analyser (Section 3.7.4) for hot air puffed, sand puffed and oil puffed fryums samples. It was clear that the values for of oil puffed, sand puffed and air puffed Fryums were recorded as 6.25 4.25 and 12.25 (+ ve peaks) respectively. The treatments had a very strong effect on hardness (F = 28.364, p = 0.0011), which means that the type of puffing method has a big impact on the Crispness parameter. There was a significant difference in crispness of oil puffed and sand puffed samples whereas, hot air puffed samples were at par with sand puffed samples with respect to Crispness. This shows the oil puffed samples were too soft as compared to sand puffed and hot air puffed. If the p-value for treatment is 0.005, that means there is only a 0.5% chance that the big differences in crispness just random chance.

The process by which the puffing is done is the most crucial factor that affects how crispy Fryums are (F = 28.364, p = 0.001). The order of sand, oil, and air affects how crisp something is. This is because of differences in how heat moves and the microstructures that form as a result.

Sand Puffing has the lowest crispness (4.25 peaks), which means it has a denser, less crispy texture. Oil Puffing makes things moderately crispy (6.25 peaks), which shows that the structure is moderately crisp. Air Puffing gets the most crispness (12.25 peaks), showing that it has a better lightweight, porous structure.

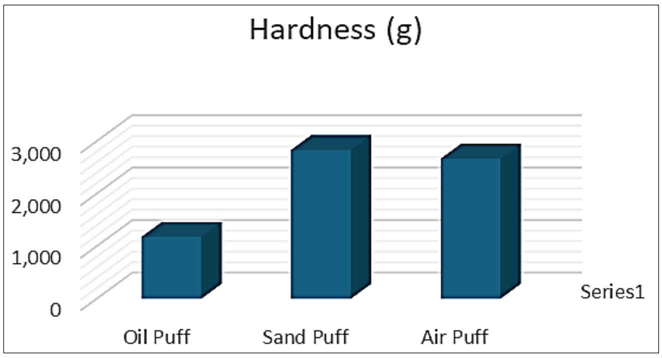

Fig 3.6: The Bar Graphs showing the effect of Various Puffing Processes on Crispness (CSP, +ve peaks), for hot air puffing of Fryums

3.7 Optimization of hot air puffing process for Fryums

The Optimization of process parameters for continuous hot air puffing of Fryums on variables Puffing Temperature PT, °C and FR, g/h. The combined contours of all responses for Puffing temperature (PT, °C) and feed rate (FR, g/h), together with their overlapping area for a minimum moisture content (% db), maximum expansion ratio, maximum water intake, hardness, kilogrammes in range, and maximum crispness score, define the variable ranges that can be considered optimal for attaining the highest product quality. The optimal values of process variables, derived from the superimposed contours, are illustrated in Fig. 3.7 and summarized in Table 3.2.

The data obtained was examined using the response surface method, indicating that the ideal conditions for puffing Fryums are a puffing temperature of 260 °C and a feed rate of 6000 g/h. The recorded optimal responses are as follows: final moisture content (FMC, % db) at 5.1, expansion ratio (ER) at 5.9, puffing percentage (PP, %) at 98.4%, whiteness index (WI) at 94.4, hardness (HD, kg) at 2663.44 g, and crispness (+peaks) at 12.19. The observations indicate that the expansion ratio, puffing percentage, and whiteness index were elevated when compared to the samples prepared under alternative treatments from the same variety of Fryums.

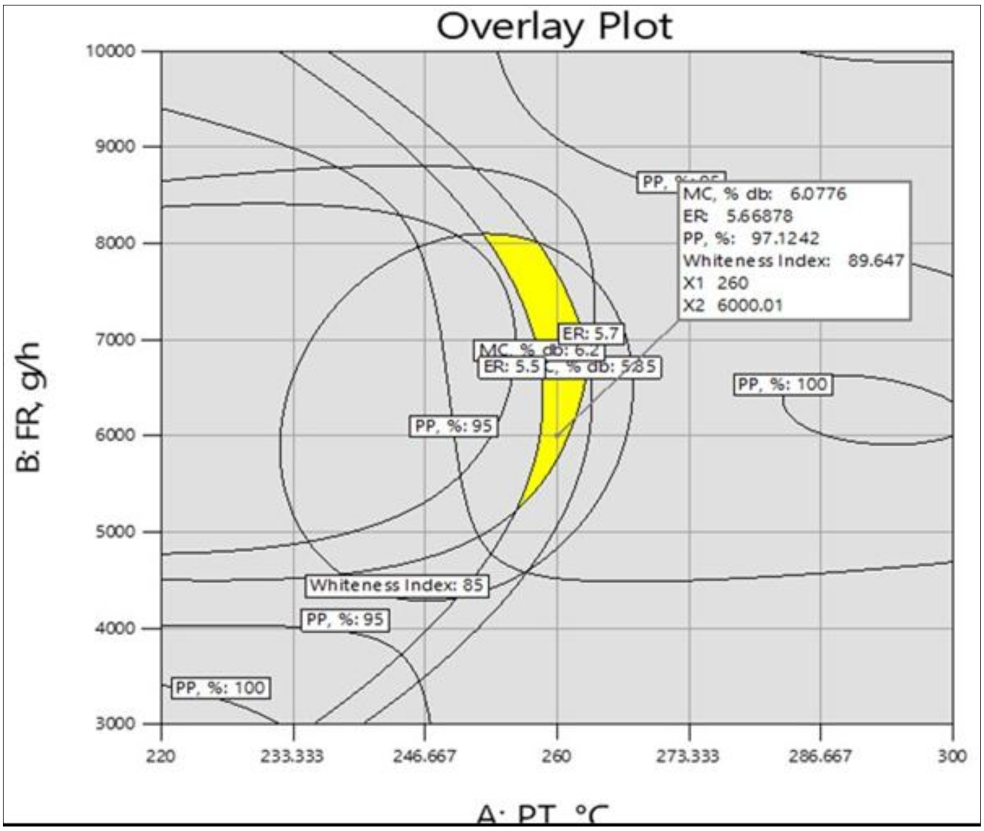

Fig 3.7: Superimposed contours for FMC (% db), ER, PP, WI, HD and CSP (+ve peaks) for hot air puffing of Fryums at varying (A) hot air puffing temperature (PT) and feed rate (FR)

Table 3.2: Software generated optimum conditions of independent variables with the predicted values of responses for hot air puffing of Fryums

No.	Puffing Temp. (°C)	Feed rate, g/h	MC, (% db)	ER	PP, (%)	WI	HD, (g)	CSP, (+ve peaks)	Desirability	
1	260	6000.00	6.07	5.66	97.12	89.64	2667.57	12.25	0.590	**Selected**
2	260.	6234.98	6.09	5.64	97.27	89.89	2663.44	12.19	0.586	

Conclusions

The developed Feeder for continuous hot air puffing of Fryums allows continuous automated feeding of raw material and the continuous exit of puffed Fryums. The developed Feeder for continuous hot air puffing system is safe and user-friendly. The Fryums feeder was successfully designed and developed, transitioning from manual to automated feed mechanisms. Teflon sheets are utilised to prevent heat conduction within a feeder, which can disrupt the puffing process of Fryums. The implementation of these sheets has effectively resolved the issue. The optimized quality response parameters obtained as final moisture content (MC, % db), Expansion ratio (ER), Puffing percentage (PP, %), Whiteness index (WI), Hardness (HD, kg), and Crispness (CSP, No. of +ve peaks) were determined to be 6.077, 5.669, 97.12%, 89.64, 2667.579g, and 12.25+ve peaks, respectively. The developed Fryums feeder was found to be suitable for the processing of mid-scale Fryums puffing, and it has the potential to be scalable to a variety of Fryum sizes (20-60 mm). The system provides a healthier alternative to conventional roasting methods that do not involve the use of oil. Fryums with low residual moisture, high crispiness, minimal heat damage, and exceptional texture consistency were produced through high-temperature short-time fluidised-bed air puffing. These Fryums matched or out-performed their traditional oil-fried counterparts in sensory attributes.

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