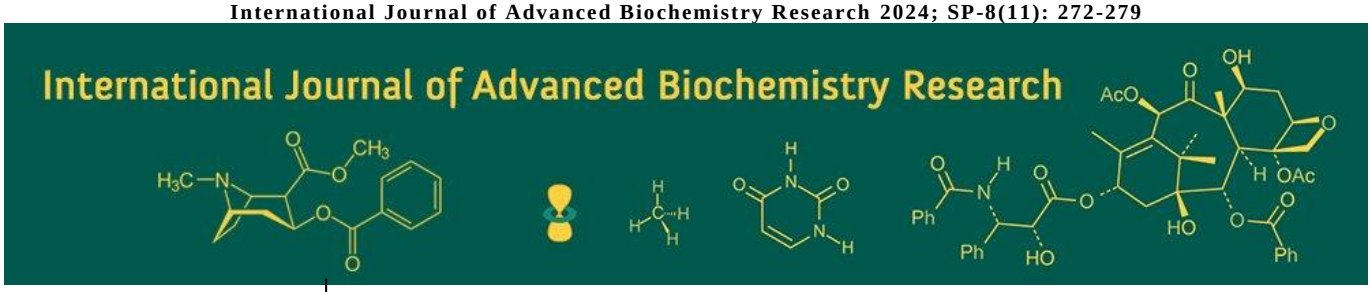

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Process optimization for hot air puffing of barnyard millet (*Echinochloa frumentacea*)

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Abstract
Hot air puffing system developed is simple, quick and easy to handle. Since the process for hot air puffing of millet grains involved heat treatments, it is necessary to verify the changes occurring during hot air puffing of barnyard millet. Millet is becoming more and more important in a time of rapidly urbanizing populations, shifting lifestyles, convenience, and, most importantly, health consciousness. People are starting to value ready-to-eat (RTE) foods for their convenience. For hot air puffing of barnyard millet, the optimum condition of process variables such as puffing temperature (PT) 310.0 °C, feed rate (FR) 7500.0 g/h, were found and the corresponding optimized quality process parameters were found to be final moisture content (FMC), expansion ratio (ER), puffing percentage (PP), whiteness index (WI), hardness (HD), and crispness (CSP) to be 4.808% db, 2.272, 72.61%, 59.04, 37.66 kg and 75.986 +ve peaks, respectively in the first pass. The unpuffed grains collected together and subjected to second pass of puffing, the unpuffed grains reduced to the tune of 0.81% from 28.39% that was found in first pass. Thus 99.19% of total barnyard millet grains were puffed, giving 72.40% of total sample weight as puffed grain and 26.79% of total sample weight as separate.

Keywords: Hot air puffing, barnyard millet, RTE

1. Introduction
Small millets are a class of small-grain cereals that include crops like foxtail millet (*Setaria italica*), proso millet (*Panicum milliaceum*), finger millet (*Eleusine coracana*), little millet (*Panicum sumatrense*), kodo millet (*Paspalum scrobiculatum*), and barnyard millet (*Echinochloa frumentacea*) (Chandan Kumar, 2015) [8].

Millets are rich in nutrients and play a significant role in many people's diets around the world. Even though millets are nutritionally better to cereals, they are still primarily consumed as food by traditional consumers and people in lower economic strata (Jaybhaye *et al*. 2014) [23].

The oldest domesticated tiny millet is barnyard millet. *Echinochloa esculenta*, known as Japanese Barnyard millet or Japanese millet, and *Echinochloa frumentacea*, known as Indian Barnyard millet, are the two main species of barnyard millet. The Billion Dollar Grass is another name for Indian barnyard millet (USDA NCRS, 2002) [42].

Barnyard Millet belongs to the family *Poaceae* and it is self-pollinated crop. The hardest millet is known as barnyard millet and known by many names, including *Sanwa* and *Jhangora* in *Hindi, Shyama* in *Sanskrit, Oodalu* in *Kannada, Kuthiravaali* in *Tamil, Udalu* and *Kodisama* in *Telgu, Shamul* in *Marathi, Sama* in *Gujarati, Shamula* in *Bengali*, and *Swank* in *Punjabi.* It is grown in numerous nations, including the United States of America, China, Japan, Malaysia, the East Indies, and India (Anuradaha *et al*. 2014) [2].

Orissa, Maharashtra, Madhya Pradesh, Tamil Nadu, Bihar, Punjab, Gujarat, and the hills of *Uttarakhand* are among the most growing regions in India (Kumar *et al*. 2000). The millet production in the world is 31.88 million metric tonnes, while India produces 33.3% of total millet in the world (FAO 2007) [7].

India is the largest producer of barnyard millet in the world, both in terms of production and area (0.146 Million ha and 0.147 Million tonnes, respectively), with an average productivity of 1034 kg/ha over the past three years. (IIMR, 2018) [22].

On an area of 12.45 million hectares, millets are grown in India, producing 15.53 million tonnes at a rate of 1247 kg/ha.

The fact that India produces the highest amounts of Barnyard (99.9%), Finger (53.3%), Kodo (100%), Little millet (100%) and Pearl millet (44.5%) from an area of 8.87 million hectares is noteworthy (ASSOCHAM, 2022) [41].

As compared to rice, one of the important minor millets is barnyard millet, which is higher in minerals and fat (Gopalan *et al*. 1976) [18]. Additionally, among minor millets, it has the highest concentration of amylose (30.47%) (Mandelbaum *et al*. 1995) [30], includes all types of essential amino acids, is excellent for those people suffering from acidity, indigestion and allergenic to gluten and has hypoglycemic effect (Arora *et al*. 2002; Kamath *et al*. 1980) [4, 25], hence recommended for diabetic patient.

In addition to possessing, minerals and vitamins, Barnyard millet is comparable to rice and wheat and is a great source of important nutrients including carbohydrates, lipids, proteins, and crude fiber. Barnyard millets are a good source of protein and have a low carbohydrate content, making them a natural nutraceuticals meal, particularly for people who are at a high risk for non-infectious diseases like diabetes, heart disease, obesity, and cancer. (Rajeswari and Priyadharshini, 2021) [37].

Nutritionally, Barnyard millet is a decent source of protein, which is profoundly absorbable and is an amazing source of dietary fibre. Carbohydrate present in barnyard millet is low and slowly digestible, which makes the barnyard millet a natural gift for the mankind. In barnyard millet, the significant unsaturated fats are linoleic acid and oleic acid. It shows the high level of retrogradation of amylase, which encourages the development of higher measures of resistant starch. Consequently, can be suggested for the patients with cardiovascular sickness and diabetes mellitus (Rao *et al*., 2017) [38].

Puffing of grains is an Ancient and traditional method of cooking grains for use as snacks or breakfast cereals, whether plain or with a few flavours, salt, or sweeteners (Jaybhaye *et al*. 2014) [23]. Starch is main source of nourishment for humans and offers a scope of required innovative properties. Starch preparation and structure are clearly related to the quality of the starch (Lehmann and Robin, 2007) [29]. The product gains an acceptable flavour with a pleasing aroma after puffing. As a pre-cooked, ready-to-eat ingredient, puffed grain can be used to create supplementary foods, specialty foods, and snacks (Hoke *et al.* 2005) [20].

Different RTE (ready-to-eat) snack foods, like fried chips, wafers, flakes, granules, extruded and spiced items, popcorn, puffed cereals, etc. are consumer's eating habits in today's modern society. One of the traditional food processing techniques used to create RTE light and crisp items is popping, or the manufacture of expanded products from grains and legumes (Ushakumari *et al.* 2007) [43].

The numerous initiatives, such as the creation of a continuous hot air column type electric heater-operated puffing system by Chandrashekhar in 1989 [10], an LPG-operated whirling bed type hot air puffing system for puffing potato cubes, later used by Khodke in 2002 [27] for puffing freeze-thaw dried potato cubes, a potato-based cold extrudate by Nath in 2007 [33], Yeole *et al*. 2013 [44] for puffing sago-based cold extrudates and (Pardeshi, 2009) [34] for puffing wheat- and rice-based cold extrudates, are on record. Jaybhaye (2014) [23] developed an LPG-operated hot air puffing system. Babar (2020) [6] developed a continuous hot air puffing system (CHAPS) based on an electric heating system. Balaji (2020) [7], reported a continuous hot air multi grain puffing system (CHAMPS).

The impact of popping in characteristics of starches isolated from pearl millet, ragi, and foxtail millet is studied by Muralikrishna *et al*. (1986) [31]. Birefringence was completely lost as a result of popping. At pregelatinization temperatures, these starches also showed somewhat increased solubility and swelling power. The breaking down of starch granules during popping resulted in lower cold paste, setback viscosity, and relative viscosity.

There are four types of millet that can be popped: foxtail millet, finger millet, barnyard millet, and proso millet. Proso millet had the highest popping yield (92.77%) and expansion volume (6.51), followed by foxtail millet, finger millet, and barnyard millet (Srivastava *et al*. 1998) [39].

Snack food is a significant sector of the food industry. Adapt to the shifting preferences and needs of consumers, as well as their desire for something special that appeals to a broad range of individuals. Puffing is the most simple, affordable, and rapid traditional way for making ready-to-eat snack products and weaning meal formulas; popping and puffing have been used for hundreds of years. Although barnyard millet is still underutilized, it has the ability to produce food and nourishment and is more nutritious than cereals. Therefore the objective of study was to optimized the hot air puffing of Barnyard millet.

2. Materials and Methods

The present research, "Process Optimization for Hot Air Puffing of Barnyard Millet," was carried out in 2023-2024 at the Post Graduate Institute of Post-Harvest Technology and Management, Department of Food Grains and Seeds, Killa-Roha, Dist. Raigad during the year 2023-24.

2.1 Puff Preparation

Preliminary (Fig. 1) trials were conducted with Barnyard millet to determine the suitability for its puffing in semi-automated continuous hot air puffing system.

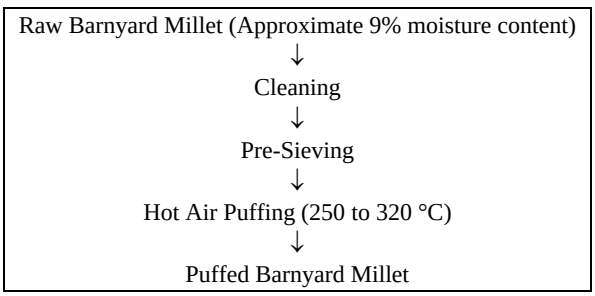

Fig 1: Flowchart of Sample preparation for Barnyard Millet Puffing

2.2 Selection of Process Parameters
Depending on the needs of various cereal grains and millets, the puffing machine can be adjusted to varied puffing temperatures (ambient to 350 °C) 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%), whiteness index (WI), hardness (HD, kg), and crispness (+ve peaks), process parameters like air velocity (2-4 m/s) were varied, while the puffing temperature (PT) and feed rate (FR) were varied from 250 to 320 °C and 4058 to 10000 g/h, respectively.

2.3 Optimization
The CCRD design (Table 1) guided the continuous hot air puffing experiments, and Design Expert (Stat-Ease, DX11), a commercial statistical program, was used to apply RSM to the experimental data. To produce the highest quality HTST air-puffed grain, the relative effects of the process variables (feed rate, moisture content, and puffing temperature) on the responses were examined. As a result, the multigrain continuous hot air puffing processes were improved. Final moisture content (FMC, % db), hardness (HD), crispness (CSP peak +ve), color (L* value), and expansion ratio (ER) were the responses that were examined.
The levels of experimental variables, such as puffing temperature (PT, °C) and feed rate (FR, g/h), were computed based on the aforesaid statistical design and are shown in Table 1.

2.4 Evaluation of Response Parameters:
Grain samples were hot air puffed, and the different reaction factors were taken into account to optimize the process parameters. The experimental setup for the continuous hot air puffing method used to develop grains is explained in this section. Under experimental design, the levels and combinations of treatments are described, along with the process parameters such as puffing temperature, feed rate for puffing grains based on puffed grain qualities, namely final moisture content, expansion ratio, puffing percentage, Whiteness index, and hardness and crispness (peak +ve).

2.4.1 Measurement of Moisture content (% db)
The moisture content of samples at each stage of the process was determined by hot air oven method (AOAC, 1984) [3].

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

2.4.2 Expansion ratio (ER) measurement
The expansion ratio was determined by recording the ratio of the volume of expanded millet to that of raw millet of equal weight (Chinnaswamy & Bhattacharya, 1983) [12, 13].
The expansion ratio was calculated as,

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

where,
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 Barnyard Millet. The puff and unpuff grains were separated using a sieve. The puffing percentage was calculated by following formula (Delost-Lewis *et al*, 1992) [14].

$$\text{Puffing Percentage (PP)} = \frac{\text{Wt.of puff kernel}}{\text{Original sample wt.}} \times \times 100$$

2.4.4 Whiteness index measurement
The colour (L*, a* and b* value) was measured using hunter lab colorimeter as followed by Katkar *et al*. (2024) [26]. The L* values, which denotes degree of whiteness (black=0 and white=100), was chosen to represent the colour of samples.
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:
The hardness is defined as the greatest peak force experienced during the initial compression cycle (first bite). The hardness is measured by using texture analyser.
Historically, crispness was defined as the quality of fracturing into many small pieces under compressive pressure and associated with brittleness.
The tests for texture analysis of puffed Barnyard Millet are conducted on Texture Analyzer (Model- TA-XT*plus*).

2.5 Statistical analysis and optimization:
The multiple responses were optimized simultaneously using the Design-Expert software's numerical optimization technique. Every reaction and factor had its desired goals selected. Either factors or reactions may be included by the objectives. The following are the possible outcomes: none (for answers only), target, minimize, maximize, and within range. While the answers were either maximized or minimized, all of the independents' factors were maintained within range. The goals are merged into an overall composite function, D(x), also known as the desirability function Myers and Montgomery (2004) [32], in order to search for a solution optimizing several responses.
A position that optimizes the desire function is discovered through numerical optimization. A goal's attributes can be changed by modifying its weight or priority (Stat-Ease, DX11). In order to get the optimum result, graphic optimization was also done for the hot air puffing process parameters. Using Design-Expert software, contour plots were superimposed for each answer in relation to process factors for graphical optimization.
The ranges of variables that could be thought of as the ideal range for the best product quality in terms of responses were indicated by 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. By averaging those ranges of variables, the ideal mix of process and product factors for hot air puffing circumstances was determined.

3. Result and Discussion
Using Design Expert software (Stat-Ease, DX11) for Central Composite Rotatable Design (CCRD), the data was examined. The outcomes are shown in the details below

Table 1: Response details obtained for optimization of process parameters for puffing of barnyard millet

Sr. No.	Puffing temperature (PT, °C)	Feed rate (FR, g/h)	Moisture content (MC. % db)	Expansion ratio (ER)	Puffing percentage, %	WI	HD, kg	CSP, +ve peaks
1	260 (-1)*	4928 (-1)	5.37098	2.101	44.5777	47.098	28.566	58.7411
2	310 (+1)	4928 (-1)	3.53319	2.089	54.6641	50.598	57.403	116.273
3	260 (-1)	9130 (+1)	5.80357	1.971	22.7409	34.781	21.924	45.4894
4	310 (+1)	9131 (+1)	5.24862	2.290	81.4925	62.91	30.456	62.5091
5	250 (-1.414)	6957 (0)	5.93502	2.067	29.8984	35.349	19.916	41.4841
6	320 (+1.414)	6957 (0)	3.87931	2.286	63.6230	60.442	51.894	102.283
7	285 (0)	4058 (-1.414)	3.99568	2.164	60.8899	42.736	50.049	99.604
8	285 (0)	10000 (+1.414)	6.00087	1.950	54.8777	47.268	18.912	39.4814
9	285 (0)	6957 (0)	4.76451	2.186	65.4850	57.204	37.970	77.5036
10	285 (0)	6957 (0)	7.14285	2.208	62.2640	46.983	13.994	29.6686
11	285 (0)	6957 (0)	5.80357	2.176	67.2460	52.171	21.924	45.4894
12	285 (0)	6957 (0)	6.24297	2.197	62.8430	48.314	15.232	32.1397
13	285 (0)	6957 (0)	5.49389	2.129	65.2940	52.908	26.673	54.9649

3.1 Effect of Puffing temperature (°C) and Feed rate (g/h) on moisture content (MC, % db) during hot air puffing of Barnyard Millet

It could be observed from Fig. 2, MC, % db increased with increase in feed rate and decrease with increase in temperature. Similar findings were reported by Dhumal *et al*. (2014) [15] for an RTE barn yard millet and potato snack, by Pawar (2018) [35] for HTST microwave puffing of sprouted soy fortified millet flour-based snack, and by Pawar *et al*. (2014) [36] for an RTE snack sorghum-soy fortified.

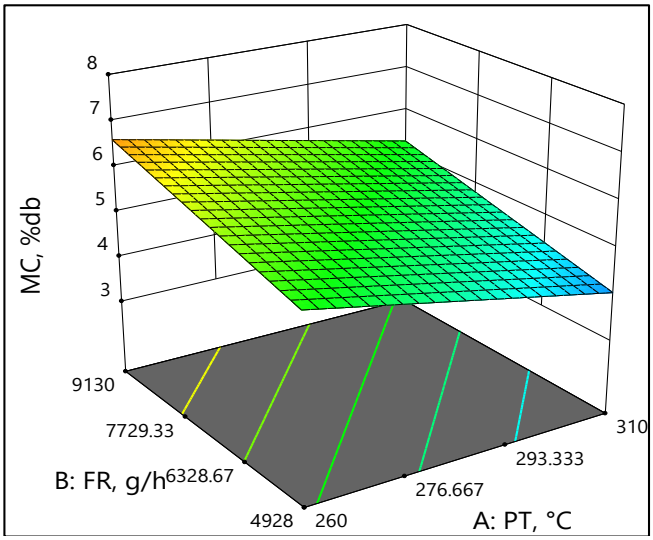

Fig 2: Contour and Surface response graph showing the effect of Puffing Temperature (PT) and Feed rate (FR) on Final Moisture Content (MC, % db) for puffing of Barnyard Millet.

It could be seen (Fig 3) that as the puffing temperature increased from 250 to 320 ℃ ER increase slightly. As feed rate increased from 4058 g/h – 10000 g/h ER slightly decreased. As increase both temperature and feed rate exapansion ratio increases. The increase in PT increased the expansion. This is due to the fact that high barrel temperatures cause starch gelatinization and, as a result, greater expansion reported by (Dottie, 2021) [16].

3.2 Effect of Puffing temperature (°C) and Feed rate (g/h) on expansion ratio (ER) during hot air puffing of Barnyard Millet

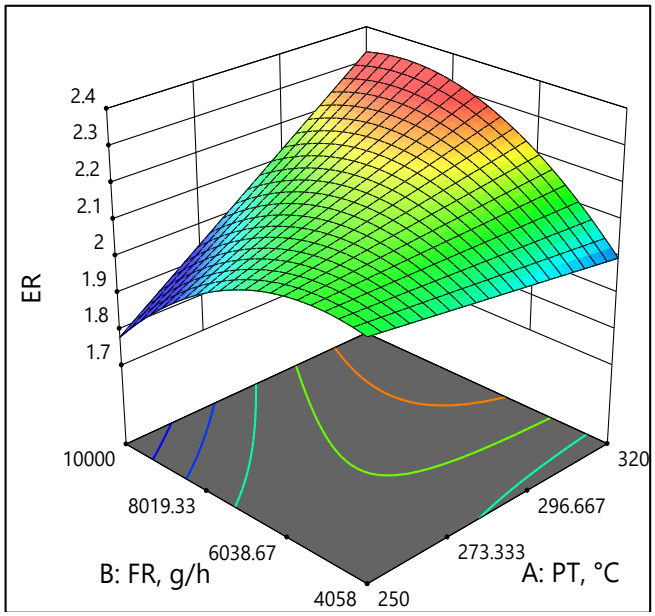

Fig 3: Contour and Surface response graph showing the effect of Puffing Temperature (PT) and Feed rate (FR) on Expansion Ratio (ER) for puffing of Barnyard Millet.

3.3 Effect of Puffing temperature (°C) and Feed rate (g/h) on Puffing percentage, % of puffed Barnyard Millet

The Fig. 4 show that puffing percent increase with increase in temperature up and again decrease after certain limit. Feed rate indicated that PP increased with increased feed rate from 4058 to 10000 g/h. But at very high temperature i.e 320 °C and very high feed rate 10000 g/h PP increased. Slightly similar results found by Katkar *et al*., (2024) [26]. The puffing percentage increased with increasing feed rate from 50 g/min to 150 g/min reported by (Babar and Pardeshi, 2017) [5].

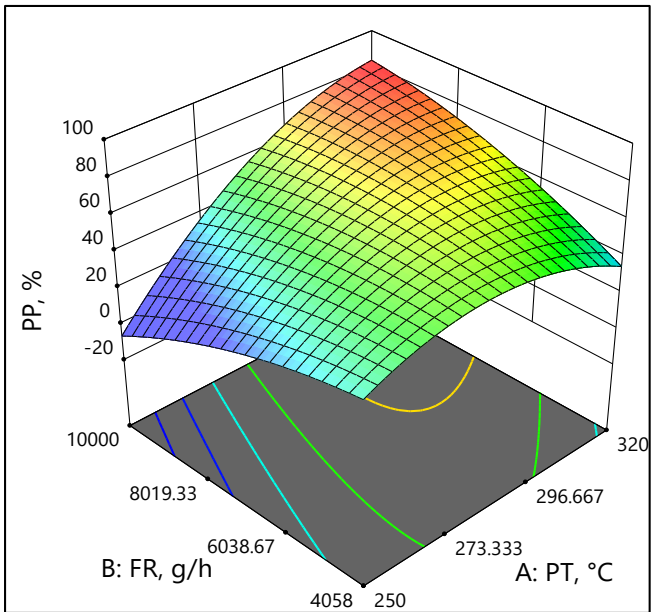

Fig 4: Contour and Surface response graph showing the effect of Puffing Temperature (PT) and Feed rate (FR) on Puffing Percentage (PP) for puffing of Barnyard Millet.

3.4 Effect of Puffing temperature (°C) and Feed rate (g/h) on Whiteness index (WI) of puffed barnyard millet.

It could be seen from Fig. 5, that as the puffing temperature increased from 250-320 ℃, WI of puffed barnyard millet was increased, and WI index decreases with increase in feed rate. The similar observations were recorded by Katkar *et al*., (2024) [26], for effect of puffing temperature and feed rate on WI of puffed rice, and that ranges from 66.07 to 71.06 at temp range 240 to 270 ℃.

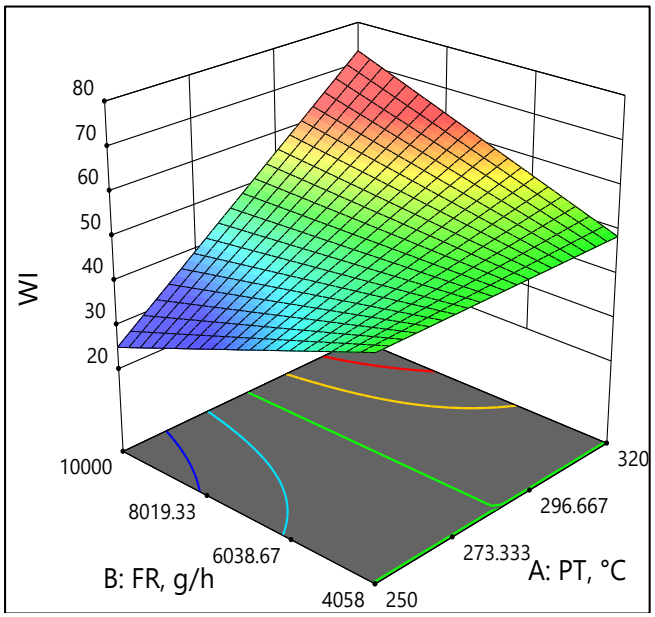

Fig 5: The contour and response surface plots showing the effect of Puffing Temperature (PT) and Feed rate (FR) on Whiteness Index (WI) for puffing of Barnyard Millet

In case of hardness, Fig. 6 indicate that HD increases with increase in temperature from 250 to 320 ℃. As feed rate increase, HD decreases and again increase**.** Similar phenomenon was found by Pawar, 2018 [35]. Katkar *et al*., (2024) [26] reported that with increase in puffing temperature HD increase upto its maxima of about 250 ℃. Also similar observation recorded by Balaji, (2020) [7].

3.5 Effect of puffing temperature (°C) and Feed rate (g/h) on Hardness (kg) of puffed barnyard millet.

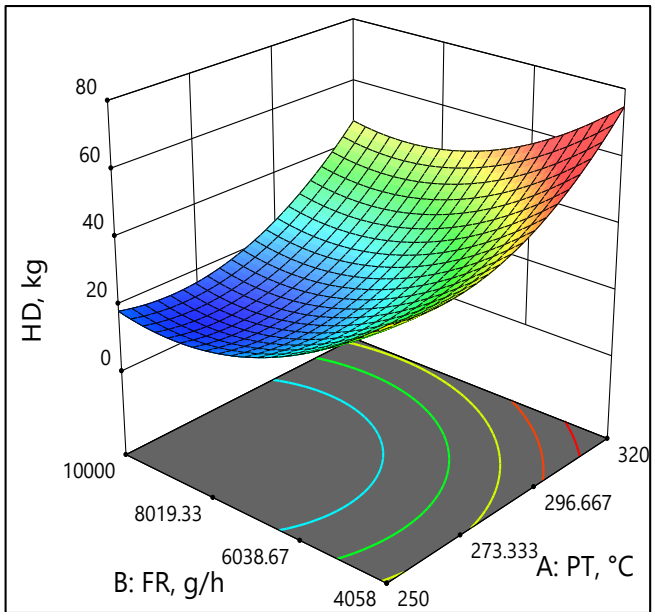

Fig 6: The contour and response surface plots showing the effect of Puffing Temperature (PT) and Feed rate (FR) on Hardness (HD, kg) for hot air puffing of Barnyard Millet.

3.6 Effect of various process parameters on crispness (CSP +ve peaks) during hot air puffing of barnyard millet grain

Fig. 7 depicted that CSP (+ve peaks) constantly increase with increase in temperature and decrease with increase in feedrate and again start to increase from feedrate 8019.33g/h. Similar results found by Balaji, (2020) [7], crispness of kutki grain puffed increased with increase in temperature.

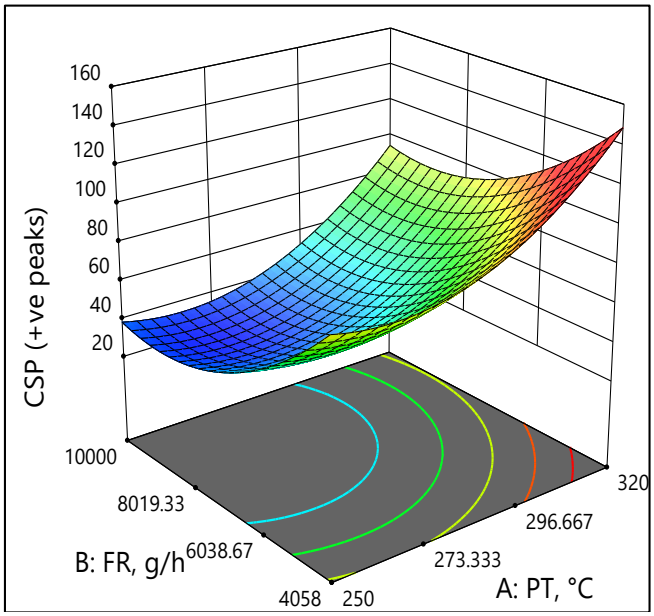

Fig 7: The contour and response surface plots showing the effect of Puffing Temperature (PT) and Feed rate (FR) on Crispness (CSP, +ve peaks) for hot air puffing of Barnyard Millet.

3.7 Optimization of Hot Air Puffing process parameter for Barnyard Millet Grain.

The ranges of variables that could be thought of as the ideal range for the best product quality were indicated by the superimposed contours of all responses for puffing temperature (PT, °C) and feed rate (FR, g/h), as well as their intersection zone for minimum MC (% db), maximum ER, maximum PP, maximum WI, minimum HD, and maximum CSP. Fig. 8 and Table 2 present the range of ideal values for process variables that were derived from the superimposed outlines.

Table 2: Software generated optimum conditions of independent variables with the predicted values of responses for hot air puffing of Barnyard Millet grain

Solution Number	PT, °C	FR, g/h	MC, %db	ER	PP, %	WI	HD, kg	CSP (+ve peaks)	Desirability	
1.	**310.0**	**7500.0**	**4.808**	**2.272**	**72.61**	**59.04**	**37.66**	**75.986**	**0.758**	**Selected**
2.	311.5	7499.9	4.768	2.278	72.50	59.64	39.07	79.700	0.746	

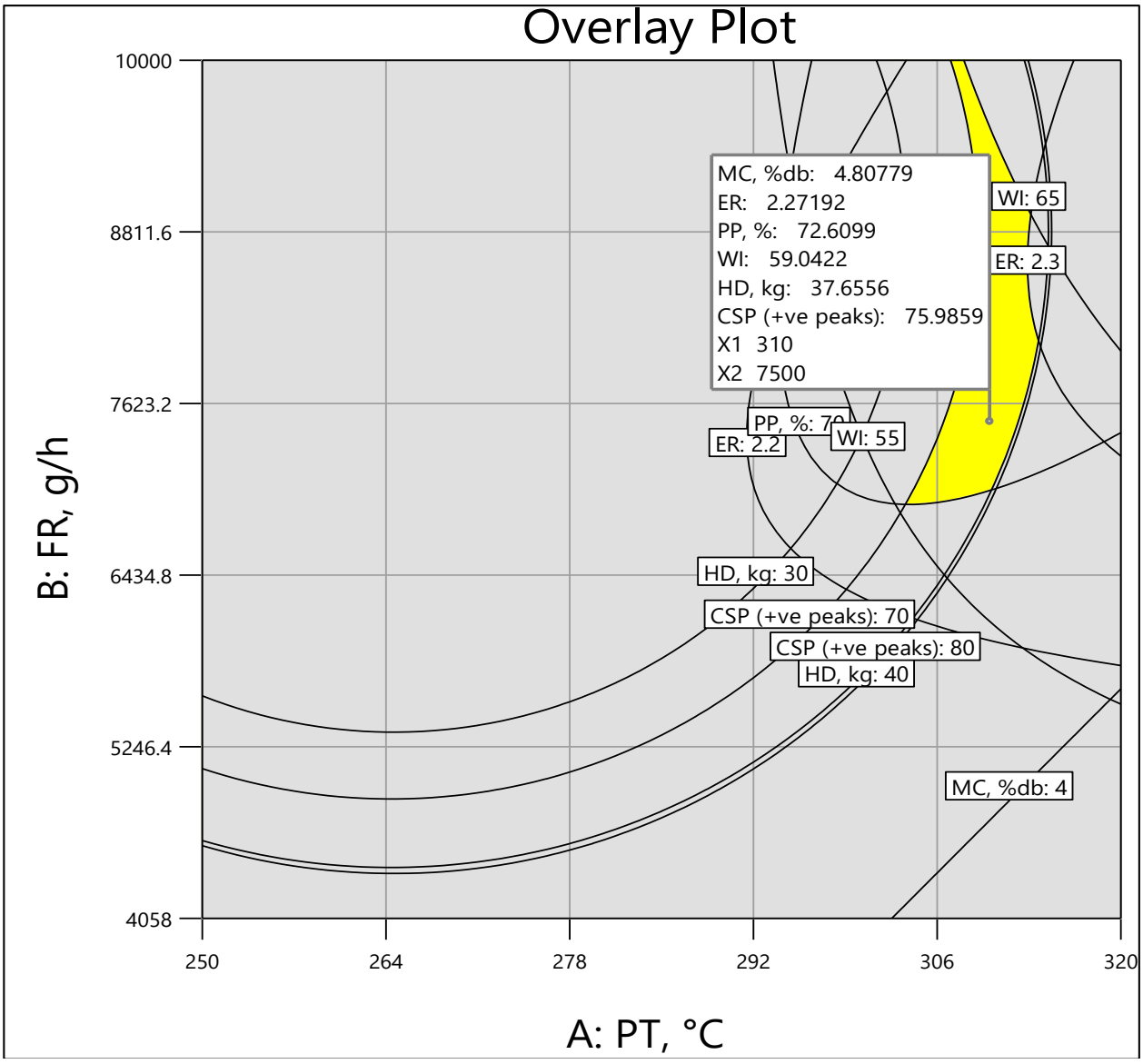

Fig 8: Overlay plot for optimization of Puffing Temperature (°C) and Feed Rate (g/h).

The response surface method was used to analyze the data, and it was discovered that the ideal conditions for puffing barnyard millet were 310 °C for the puffing temperature and 7500 g/h for the feed rate. The optimal responses were 4.808% for the final moisture content (FMC, % db), 2.272 for the expansion ratio (ER), 72.61% for the puffing percentage (PP, %), 59.04 for the whiteness index (WI), 37.66 kg for the hardness (HD, kg), and 75.986 for crispness (+peaks).

From Table 2, the optimal condition with processing parameters, as Puffing temperature of 310 °C and Feed rate of 7500 g/h, could result into the actual response parameters of Moisture content, Expansion ratio (ER), Puffing percentage (%), Whiteness Index (WI), Hardness (kg) and crispness (CSP) as 4.808% db, 2.272, 72.61%, 59.04, 37.66 kg and 75.986 +ve peaks, respectively. The resultant 72.61% puffed grain mass was found to comprise of 77.54% puffed grain and 22.46% separated husk. Whereas, the remaining 28.39% unpuffed grains could get puffed in second pass at the same puffing condition. The second pass could minimize the unpuffed grains to the tune of 0.81% from 28.39% found in first pass. Thus 99.19% of total

barnyard millet grains were puffed, giving 72.40% of total sample weight as puffed grain and 26.79% of total sample weight as separated husk.

3.8 Bio-chemical Analysis

Table 3 shows that in puff Barnyard Millet Moisure content, ash content and and fat content decreases and protein increases. There is no major effect of puffing shown on carbohydrate content of puff grain.

Table 3: The proximate composition of hot air puffed barnyard millet grains

r. No.	Parameters	Unit	Barnyard Millet			
			Raw		Puffed	
			wb	Db	Wb	Db
1	Moisture Content	%	9.25	10.25	4.55	4.76
2	Ash	%	1.97	2.17	1.25	1.31
3	Fat	%	3.90	4.20	2.80	2.94
4	Protein	%	10.79	11.89	11.37	14.07
5	Carbohydrate	%	74.09	81.74	79.6	81.68

According to Ushakumari *et al*. (2007) [43], the popped foxtail millet had significantly higher calorie and carbohydrate values compared to raw millets but significantly reduced crude fat and crude fiber levels. This is mostly due to the outer coat of grain's increased fat and fiber levels. The popping process doesn't affect the protein, fat, crude fibre similarly total carbohydrate and ash content reduced slightly after popping (Anjitha *et al*., 2012) [1].

4. Conclusion

Optimization of hot air puffing of Barnyard Millet done by using various processing parameters like final moisture content (% db), expansion ratio, puffing percentage (%), whiteness index, hardness (kg) and crispness (+ve peaks) with respect to Puffing temperature (°C) and Feed Rate (g/h). With a capacity of 2000 to 10000 g/h, the system may be adjusted to any puffing temperature between 150 and 350 °C and an air velocity between 1.5 and 6 m/s.

For hot air puffing of barnyard millet, the ideal values of process variables such as puffing temperature (PT) 310.0 °C, feed rate (FR) 7500.0 g/h, in a single pass while puffed in a hot air puffing machine, were found and the resulting optimized actual quality process parameters were found to be final moisture content (FMC) 4.808%db, expansion ratio (ER) 2.272, puffing percentage (PP) 72.61%, whiteness index 59.04, hardness (HD) 37.66 kg, and crispness (CSP)) 75.986 +ve peaks, respectively. The resultant 72.61% puffed grain mass was found to comprise of 77.54% puffed grain and 22.46% separated husk. Whereas, the remaining 28.39% unpuffed grains could get puffed in second pass at the same puffing condition. The second pass could minimize the unpuffed grains to the tune of 0.81% from 28.39% found in first pass. Thus 99.19% of total barnyard millet grains were puffed, giving 72.40% of total sample weight as puffed grain and 26.79% of total sample weight as separated husk.

Moisure content, ash content and and fat content during puffing of barnyard millet decreases and protein increases. There is no major effect of puffing shown on carbohydrate content of puff grain.

5. References

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