RESEARCH ARTICLE OPEN ACCESS

Optimization of Process Parameters for Multi-Layer- Cum Microwave Drying Of Oyster Mushrooms (*Pleurotus Sajor Caju*)

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Abstract:
Experiments on oyster mushroom were carried out to study the effect of multi layer-cum-microwave drying process parameters viz. loading density, air velocity and power level on the quality characteristics of the dried product. Quality characteristics viz. rehydration ratio, shrinkage ratio, texture, colour, overall acceptability of dried mushroom were analyzed. The process parameters were optimized using response surface methodology for responses with significant model and non significant lack of fit. The optimum operating conditions for air velocity, loading density and power level were 3.80 m/sec 38.80 kg/m^2 and 413 W at 60^{0}C drying air temperature. Corresponding to these values of process variables, the value of rehydration ratio, shrinkage ratio, hardness, chewiness, colour change was 2.15, 0.84, 720 N, 473N and 15.50 respectively. The overall desirability was 0.78.
Keywords- Multi layer-cum-microwave drying, optimization, oyster mushroom, quality.

I. INTRODUCTION

Mushroom is the oldest single cell protein food with protein content in between low grade vegetable and high grade meat protein. Mushrooms are a more valuable source of protein than cattle or fish and are valued for its characteristic meaty biting texture and flavour. Mushroom is defined as a macro-fungus with a distinctive fruiting body, which can be hypogeous or epigeous, large enough to be seen with the naked eye and to be picked by hand (Hawksworth 2001). Mushroom contains 20-35% protein (dry weight) which is higher than those of vegetables and fruits and is of superior quality. It is also rich in vitamin (B, C, and D), minerals and water content (Royse and Schisler 1980 & Mattila *et al* 2001). Also, they are low in calories, salt, fat and are devoid of sugar, starch and cholesterol, which make them an ideal nutritional and diet supplement. Medicinal mushrooms have become important due to their antitumor, antifungal, and reducing hyper cholesterolemia activities (Chang and Buswell 1996). Apart from its food nutritional and medicine value, mushroom growing can be efficient means of waste disposal especially agriculture waste such as paddy straw, hay etc. (Mandeel 2005).

At present 3 varieties of mushrooms are being cultivated in India. These are white mushroom (*Agaricus bisporus*), the paddy-straw mushroom (*Volvariella volvacea*) and the oyster mushroom (*Pleurotus sajor-caju*). Mushrooms are highly perishable due to their high moisture content. Amongst the various methods employed for preservation, drying is an energy-intensive operation in which the water activity of the food is reduced by removal of the water. Drying is a method of preservation in which the water activity of the food is reduced.Traditionally mushrooms are dried under open sun, which results in unhygienic and poor quality products. (Chua *et al* 2001). The other drying methods are mechanical viz. thin layer drying and multi layer drying. Drying in thin layers is expensive and wastes more energy and small amounts of product are dried. In multilayer drying, more quantity of product can be dried and air can be utilized properly resulting in energy saving.

Use of Microwave is considered as the fourth generation drying technology. Waves can penetrate directly into the material, heating is volumetric (from inside out) and provides fast and uniform heating throughout the entire product.The quick energy absorption by water molecules causes rapid water evaporation, creating an outward flux of rapidly escaping vapour. Microwaves penetrate the food from all direction. This facilitates steam escape and speed heating. In addition to improving the drying rate, this outward flux can help to prevent the shrinkage of tissue structure, which prevails in most conventional air drying techniques. Hence better rehydration characteristics may be expected in microwave dried products (Khraisheh *et al* 1997; Prabhanjan 1995). Microwave processes offer a lot of advantages such as less start up time, faster heating, energy efficiency (most of the electromagnetic energy is converted to heat), space savings, precise process control and food product with better nutritional quality.

Mohanta *et al* (2011) dehydrated ginger (*Zingiber Officinale*, Cv. Suprava) slices (4 mm thick) at 25°, 40°, 50° and 60 °C at three different microwave power levels, viz. 120, 240, and 360 W in microwave assisted convective dryer up to 0.07 g moisture/g dry solid. The final product quality was better in terms of rehydration characteristics, oleoresin and volatile oil contents, hardness, color and organoleptic quality. Sahoo and Mohanty (2012) dried onion slices in microwave assisted convective dryer at 180, 360, 540 and 720 W microwave power levels and drying air temperatures of 50, 55, and 60Â°C. Drying at 360 W power level and 50Â°C drying air temperature provided considerable saving in drying time. Keeping in view the above aspects, the present study has been planned to study the effect of convective-cum-microwave drying on the quality of mushroom and to optimize the convective-cum-microwave drying characteristics viz. loading density, air velocity, microwave power.

II. MATERIAL AND METHODS

Experimental design and Statistical Analysis

Response Surface Methodology was used to optimize the multi-layer cum convective drying conditions for good quality dried product. The second order Box-Behnken design was used to work out the range of independent process variables and their levels for dried mushroom (Table 1). After coding the experimental region extended from -1 to +1 in term of X_i, the three level three factor experimental plans according to Box-Behnken design (1960) consist of 17 points of treatments combinations of the independent variables (Table 2). For each experiment, the known weight of dried mushroom was formulated as per experimental combinations by varying loading density (kg/m^2), air velocity (m/sec) and power level (Watt) and quality attributes viz. rehydration ratio, shrinkage ratio, texture, colour and overall acceptability were measured by standard procedures.The analysis was done independently for each response variable with the help of response surface methodology (RSM) by using a commercial statistical package, 'Design Expert DX 8.0.4 (Statease Inc., Minneapolis, USA, Trial Version 2010). The regression coefficients were estimated through least square method. The adequacy of the fitted model was tested through the analysis of variance showing lack of fit and coefficient of correlation (R^2). For each responses variables, N (17) observations were obtained.

Table 1: Independent process variables and their levels for mushroom

Independent variables	Symbol	Levels		
		-1	**0**	**+1**
Loading Density (kg/m^2)	X_1	26	39	52
Air Velocity (m/sec)	X_2	3	4	5
Power level (Watt)	X_3	270	540	810

Table 2: Experimental structure with coded and actual levels of the process variables for the dried mushroom using Box-Behnken design

Experiment/ sample no.	Loading density (X_1)		Air velocity (X_2)		Power level (X_3)	
	Actual	**Coded**	**Actual**	**Coded**	**Actual**	**Coded**
1	39	0	4	0	540	0
2	39	0	3	-1	810	1
3	39	0	4	0	540	0
4	26	-1	4	0	810	1
5	39	0	5	1	810	1
6	52	1	4	0	810	1
7	52	1	4	0	270	-1
8	52	-1	3	-1	540	0
9	39	0	4	0	540	0
10	52	1	5	1	540	0
11	39	0	4	0	540	0
12	39	0	5	1	270	-1
13	39	0	4	0	540	0
14	26	-1	3	-1	540	0
15	26	-1	5	1	540	0
16	26	-1	4	0	270	-1
17	39	0	3	-1	270	-1

Experimental Procedure

2.1 Experimental setup

The experimental set-up for multi layer drying of mushroom comprised of an experimental dryer (Make-SATAKE) with electrically heated hot air system capable of supplying air upto a temperature of 70°C. A centrifugal blower capable of delivering air velocity upto 5.4 m/s was fitted in the dryer. The blower was powered with 0.75 kW, 1410 rpm, 3 phase, 230-Volt electric motor with a direct online starter. The hot air was sucked by the blower through the heaters and was thrown into the drying chamber. These chambers had a screen at the bottom with approximate 1 mm hole diameter. The dryer was started half hour before actual drying experiment to achieve steady state conditions. The mushroom was put into the drying boxes according to the desired loading density to get the required bed depth. The drying was carried out at 60°C. The sample was dried to a moisture content of 27% wb (36.90 % db) in the multi layer drying and thereafter the sample was shifted to microwave oven for removal of remaining moisture final moisture content ie.6.89 % wb (7.40 % db). The experimental setup for microwave drying of mushroom comprised of a household microwave operating at 2450MHz and capable of running at different power levels viz. 270, 540, 810, 1080, 1350 W at 20%, 40%, 60%, 80% and 100% respectively. Microwave heats food by bombarding it with electromagnetic radiation in the microwave spectrum causing polarized molecules in the food to rotate and build up thermal energy in a process known as dielectric heating. The samples were allowed to come to room temperature, packed and stored. Three replications were taken for each experiment to get an average values.

2.2 Preparation of samples

Fresh oyster mushroom was procured from local market in Ludhiana and brought to the Food Engineering laboratory of the department. The oyster mushroom was cut manually and the colour and moisture content of fresh mushroom was noted. Mushroom was pretreated with citric acid @40 gm/lit (Brennan and Gormely 2000). The solution was drained out. The samples were then soaked with a filter paper and thereafter subjected to drying run according to required loading densities.

2.3 Determination of Quality Parameters

The quality parameters that were analysed were rehydration ratio, shrinkage ratio, texture, colour and overall acceptability.

2.3.1 Rehydration ratio:-Rehydration ratio was evaluated by soaking known weight (5-10 g) of each sample in sufficient volume of water in a glass beaker (approximately 30 times the weight of sample) at 95°C for 20 minutes. After soaking, the excess water was removed with the help of filter paper and samples were weighed. In order to minimize the leaching losses, water bath was used for maintaining the defined temperature (Ranganna 1986). Rehydration ratio (RR) of the samples was computed as follows:

$$\text{Rehydration ratio, } RR = \frac{W_r}{W_d}$$

Where,

W_r = Drained weight of rehydrated sample in grams; W_d = Weight of dried sample used for rehydration in grams

2.3.2 Shrinkage ratio:- The shrinkage ratio of dried sample was measured by toluene displacement method. Shrinkage ratio was calculated as the percentage change from the initial apparent volume (Rangana 1986).

$$\text{Shrinkage ratio} = \frac{V_r}{V_0}$$

Where, V_r= Volume displaced by rehydrated sample; V_0 = Volume displaced by fresh sample, ml

2.3.3 Texture:-Texture (hardness and chewiness) of the dehydrated samples was determined with the help of Texture Analyzer TA-Hdi. The samples were compressed by spherical probe. The pre-test speed was set at 1.5 mm/s, post test speed was set at 10 mm/s whereas; test speed of 2 mm/s was set during compression. The height of the peak during compression cycle was defined as hardness and chewiness (g).

2.3.4 Colour:- Colour is one of the important parameters, which is an indicative of the commercial value of the product. The basic purpose was to get an idea of the comparative change in colour of fresh, dried and rehydrated material. Colour was determined using Hunter Lab Miniscan XE Plus Colorimeter (Hunter 1975).

$$\text{Colour change } \Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$$

Where ΔL, Δa and Δb are deviations from L, a and b values of fresh sample.

ΔL = L dried sample – L fresh sample; + ΔL means sample is lighter than fresh, - ΔL means sample is darker than fresh.

Δa = a dried sample- a fresh sample, + Δa means sample is redder than standard, - Δa means sample is greener than standard

Δb = b dried sample –b fresh sample, + Δb means sample is yellower than standard, - Δb means sample is bluer than standard

III RESULTS AND DISCUSSION

The response and contour plots were generated for different interaction of three independent variables, keeping the value of other variables constant. Such a three dimensional surfaces could give accurate geometrical representation and provide useful information about the behaviour of the system within the experimental design. The complete experimental results for convective -cum- microwave drying of mushroom have been presented in Table 3.

3.1 Rehydration ratio

The rehydration ratio of dried mushroom varied in the range of 1.40 to 2.40 with an average value of 1.9. The maximum rehydration ratio (2.40) was found at 39 kg/m² loading density, 4 m/s air velocity and 540 W power level; while minimum rehydration ratio (1.40) was found for 26 kg/m² loading density, 4 m/s air velocity and 270 W power level. RR increased with increase in both loading density and air velocity in multi layer drying (Fig 1) and increased with increase in both power level and loading density in microwave drying (Fig 2). The results corroborated from the Analysis of Variance (ANOVA) showed that the quadratic terms of LD (p value: 0.0292) & PL (p value: 0.0046) are significant at 5% level of significance.

Table 3 Experimental data of drying of oyster mushroom for response surface analysis by convective-cum-microwave drying

Loading Density (kg/m²)	Air Velocity (m/s)	Power (W)	RR	SR	Texture (N)		Color	OA
					Hardness	Chewiness		
26	3	540	2.00	0.89	1675	1749	18.19	70.37
26	4	270	1.40	0.81	1180	552	18.76	70.15
26	4	810	1.80	0.75	1777	1386	21.90	66.66
26	5	540	2.10	0.82	2666	764	20.26	77.77
39	3	270	2.10	0.75	857	744	15.74	62.96
39	3	810	2.00	0.83	2376	1904	19.50	55.55
39	4	540	2.40	0.96	800	473	15.00	68.05
39	4	540	2.20	0.79	879	513	15.80	77.77
39	4	540	2.28	0.86	946	653	16.40	77.77
39	4	540	2.28	0.90	780	489	14.20	76.34
39	4	540	2.10	0.90	1485	847	17.00	76.38
39	5	270	1.70	0.75	850	508	17.87	48.15
39	5	810	2.00	0.87	2930	1323	18.76	48.15
52	3	540	2.00	0.98	1080	580	22.98	68.96
52	4	270	1.80	0.75	720	596	17.84	56.25
52	4	810	2.00	1.00	1308	1082	18.57	81.48
52	5	540	2.10	1.00	1114	1025	14.89	62.96

Fitting of model on	Df	Sum of Squares	Mean sum of squares	F Value	p-value (Prob > F)
Rehydration Ratio	9	0.76	0.085	3.73	0.0483
Shrinkage ratio	9	0.11	0.012	4.66	0.0273
Hardness	9	6.351E+006	7.057E+005	3.86	0.0444
Chewiness	9	3.056E+006	3.396E+005	11.16	0.0022
Colour	9	81.69	9.08	4.69	0.0269
Overall acceptability	9	1415.46	157.27	4.03	0.0397

Table 4: Analysis of variance (ANOVA) for model fitting

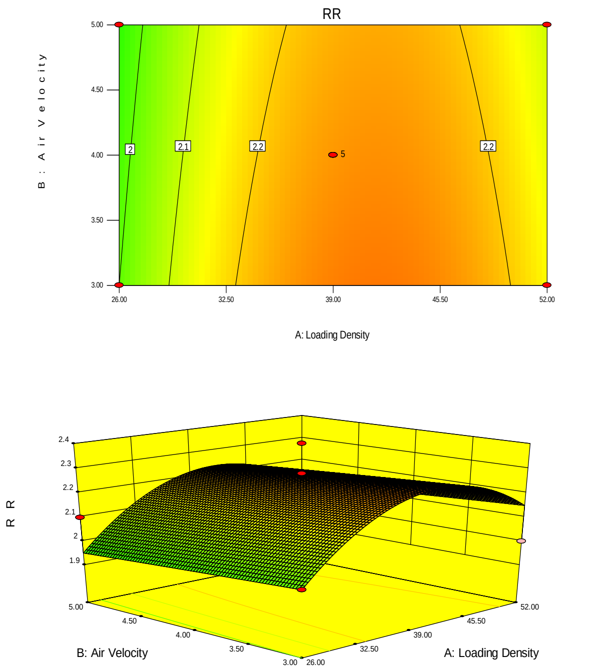


Fig 1: Contour and response surface plots showing effect of loading density and air velocity on RR

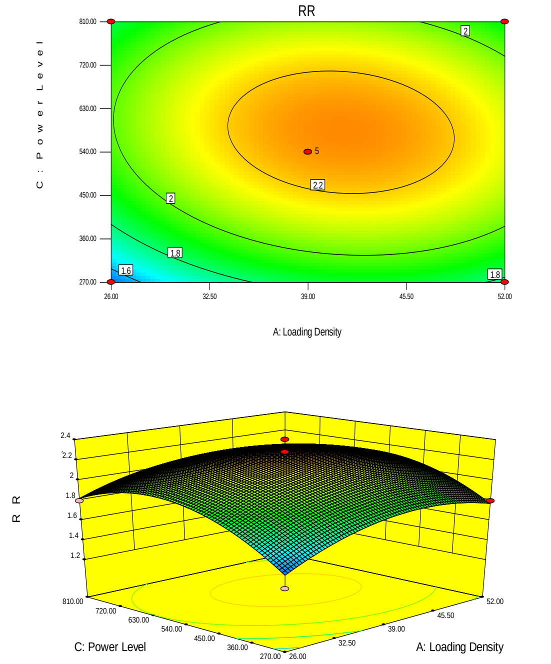


Fig 2: Contour and response surface plots showing effect of loading density and microwave power level on RR

3.2 Shrinkage ratio

The shrinkage ratio of mushroom varied in the range of 0.75 to 1.00 with an average value of 0.875. The maximum shrinkage ratio (1.00) was found at 52 kg/m² loading density, 4 m/s air velocity and 540 W power level; while minimum shrinkage ratio (0.75) was found at 26 kg/m² loading density, 4 m/s air velocity and 810 W power level. SR increased with increase in loading density and decreased with increasing air velocity (Abasi *et al* 2009) in multi layer drying (Fig 3) and decreased with increase in both power level and loading density in microwave drying (Fig 4). This is due to outward flux of vapour and generated vapour pressure (Feng, Tang, Cavalieri and Plumb, 2001). The results corroborated from the Analysis of Variance (ANOVA) showed that the linear terms of LD (p-value: 0.0140) & PL (p-value: 0.0311), cross product term of LD & PL (p-value: 0.0185) and quadratic term of PL (p-value: 0.0096) are significant at 5% level of significance.

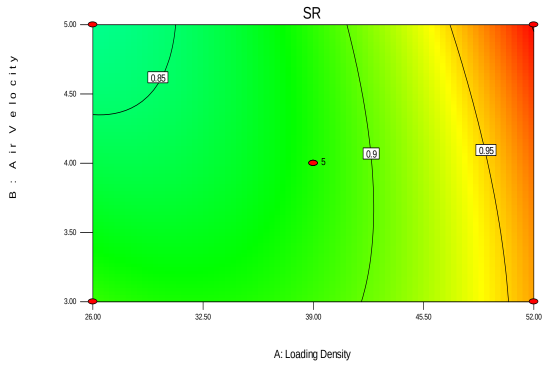


Fig 3: Contour and response surface plots showing effect of loading density and air velocity on SR

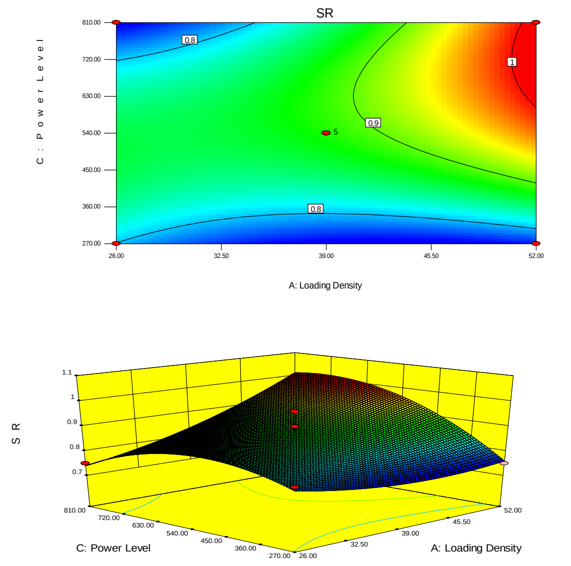


Fig 4: Contour and response surface plots showing effect of loading density and microwave power level on SR

3.3 Texture

The hardness of mushroom varied in the range of 720 to 2930 N with an average value of 1825 N. The maximum hardness (2930 N) was found at 39 kg/m² loading density, 5 m/s air velocity and 810 W power level; while minimum hardness

(720 N) was found at 52 kg/m² loading density, 4 m/s air velocity and 270 W power level. In multi layer drying, hardness decreased with increasing loading density and increased with increasing air velocity (Fig 5). In microwave drying, hardness decreased with increase in loading density and increased with increase in power level (Fig 6). The results corroborated from the Analysis of Variance (ANOVA) showed that linear terms of LD (p-value: 0.0385) & PL (p-value: 0.0055) and quadratic term of AV (p-value: 0.0269) are significant at 5% level of significance.

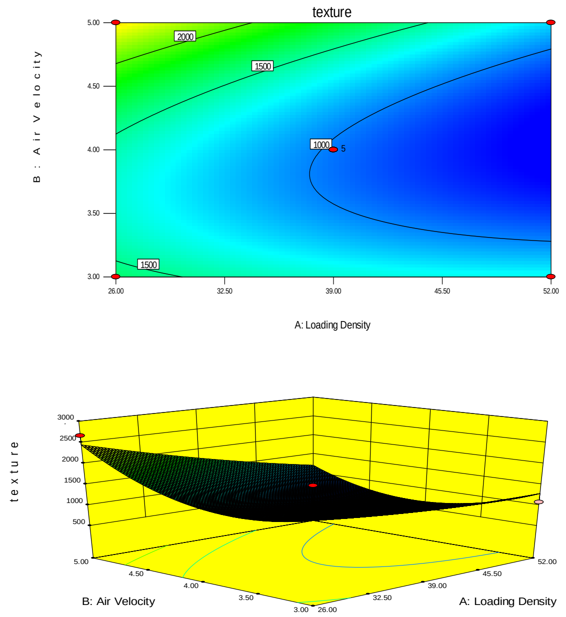


Fig 5: Contour and response surface plots showing effect of loading density and air velocity on texture (hardness)

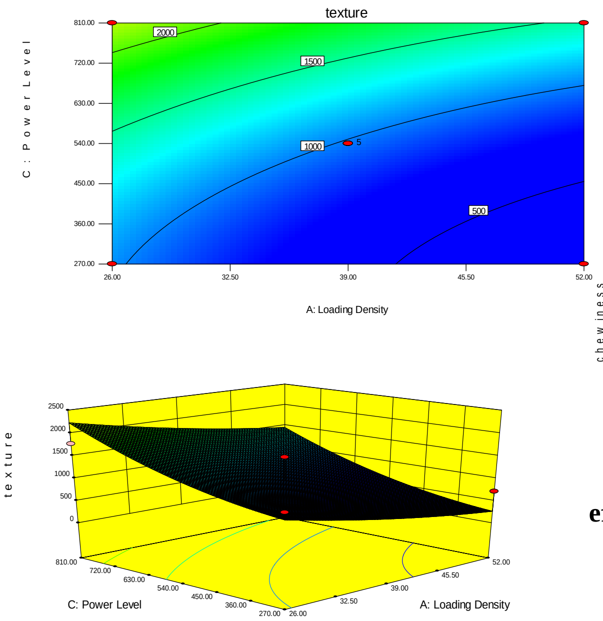


Fig 6: Contour and response surface plots showing effect of loading density and microwave power level on texture (hardness)

The chewiness of mushroom varied in the range of 473 to 1904 N with an average value of 1188 N. The maximum chewiness (1904 N) was found at 39 kg/m² loading density, 3 m/s air velocity and 810 W power level; while minimum chewiness (473 N) was found at 39 kg/m² loading density, 4 m/s air velocity and 540 W power level. In multi layer drying, chewiness decreased with increase in both loading density and air velocity (Fig 7). In microwave drying, chewiness increased with increase in both loading density and power level (Kotaliwale *et al* 2007) (Fig 8). The results corroborated from the Analysis of Variance (ANOVA) showed that linear term of LD (p-value: 0.0499), AV (p-value: 0.0337) & PL (p-value: 0.0003), cross product term of LD & AV (p-value: 0.0037) and quadratic term of AV (p-value: 0.0052) are significant at 5% level of significance.

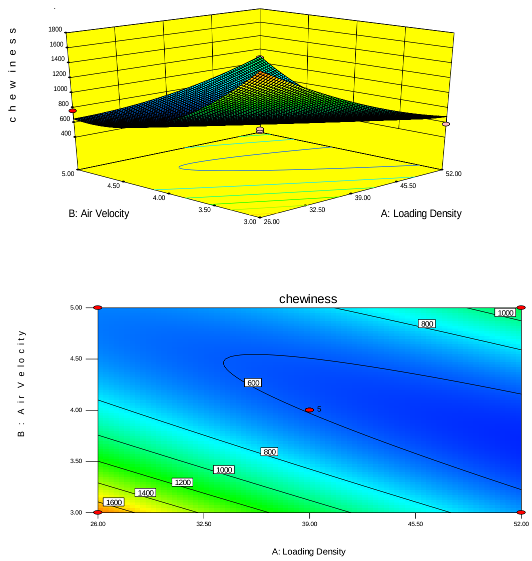
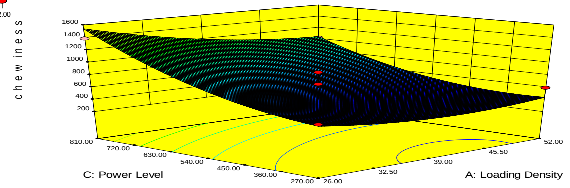


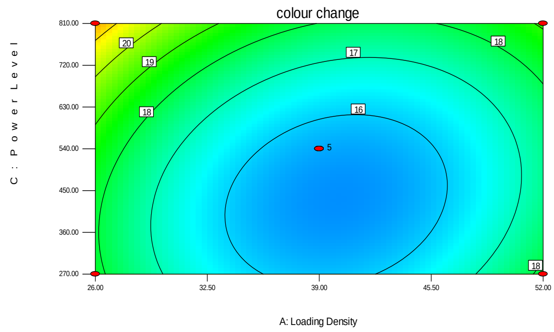
Fig 7: Contour and response surface plots showing effect of loading density and air velocity on chewiness



FFig 8: Contour and response surface plots showing effect of loading density and microwave power level on chewiness

3.4 Colour

The colour change of mushroom varied in the range of 14.20 to 22.98 with an average value of 19.00. The maximum colour change (22.98) was found at 52 kg/m² loading density, 3 m/s air velocity and 540 W power level; while minimum colour change (14.2) was found at 39 kg/m² loading density, 4 m/s air velocity and 540 W power level. Colour change increased with increase in both loading density and air velocity in multi layer drying (Fig 9). Both these results are in agreement with (Chauca *et al* 2002) who have reported color changes of banana during drying in terms of 'L' and 'a' values. Colour change decreased with increasing loading density and increased with increase in power level in microwave drying (Fig 10) (Maskan, 2001). The results corroborated from the Analysis of Variance (ANOVA) showed that the cross product term of LD & AV (p-value: 0.0082) and quadratic term of LD (p-value: 0.0104) are significant at 5% level of significance.



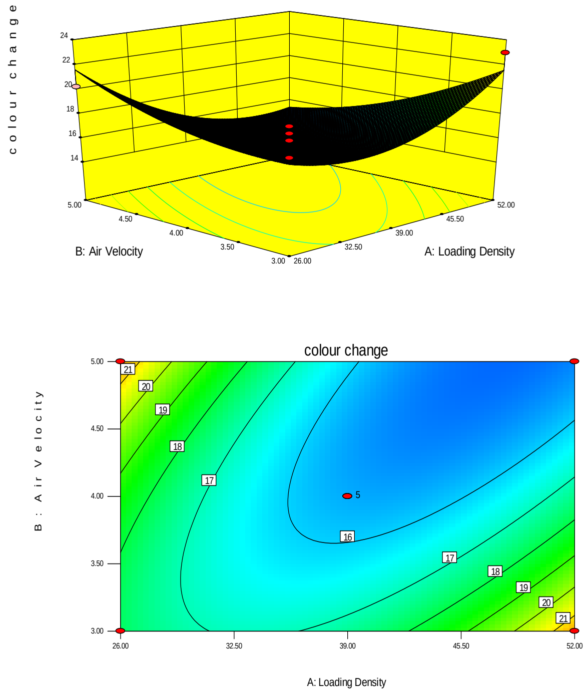
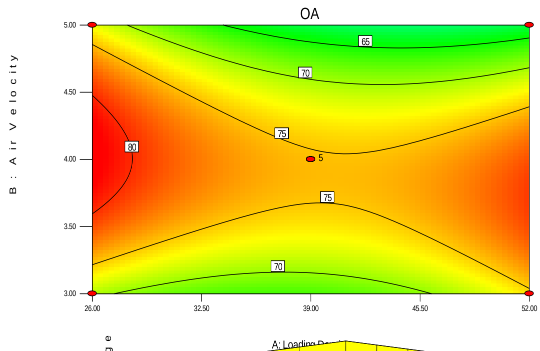


Fig 9: Contour and response surface plots showing effect of loading density and air velocity on colour change



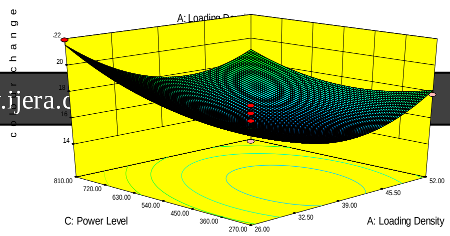


Fig 10: Contour and response surface plots showing effect of loading density and microwave power level on colour change

3.5 Overall acceptability

The overall acceptability of mushroom slices varied in the range of 48.15 to 81.48 with an average value of 64.81. The maximum overall acceptability (81.48) was found at 52 kg/m² loading density, 4 m/s air velocity and 810 Watt level; while minimum overall acceptability (48.15) was found at 39 kg/m² loading density, 5 m/s air velocity and 810 Watt level. OA decreased with increase in loading density and increased with increase in air velocity in multi layer drying (Fig 11). OA decreased with increase in both power level and loading density in microwave drying (Fig.12). The results corroborated from the Analysis of Variance (ANOVA) showed that the quadratic terms of AV (p-value: 0.0109) and PL (p-value: 0.0082) are significant at 5% level of significance.

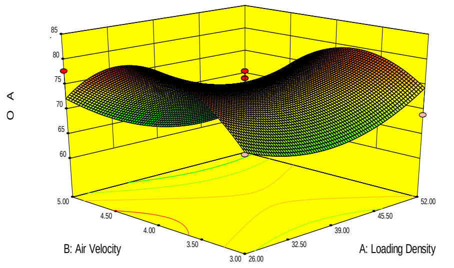


Fig 11: Contour and response surface plots showing effect of loading density and air velocity on overall acceptability

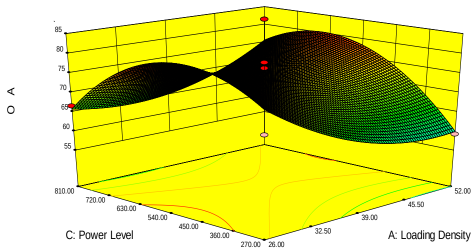
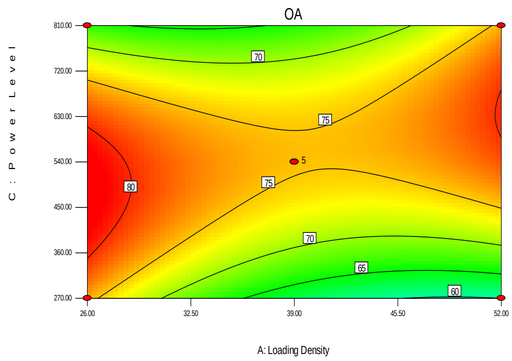


Fig 12: Contour and response surface plots showing effect of loading density and microwave power level



on overall acceptability

3.6 Optimization of Convective-cum-microwave drying of mushroom

The optimum values of process parameters and responses are presented in Table 6. The process conditions for multi layer drying of mushroom were optimized using numerical optimization technique. The main criteria for constraints optimization were maximum possible rehydration ratio, hardness and overall acceptability and minimum possible shrinkage ratio, color change (Themelin *et al* 1997; Ade-Omowaye *et al* 2002). The contour plots for each response were generated for different interaction of any two independent variables. In order to optimize the process conditions for multi layer drying of mushroom by numerical optimization technique, equal importance of '3' was given to three process parameters (*viz.* loading density, air velocity and microwave power level) and responses (i.e. rehydration ratio, shrinkage ratio, color, hardness, chewiness and overall acceptability). The conditions were experimentally verified with deviation of +0.10%. The optimum operating conditions for loading density, air velocity and microwave power level was 38.80 kg/m^2 and 3.86 m/sec at 60^0C and 413.6 W power level. Corresponding to these values of process variables, the value of rehydration ratio, shrinkage ratio, texture (hardness and chewiness), colour change and overall acceptability were 2.15, 0.84, 739 N, 473 N, 15.50 and 72.50 respectively. The overall desirability was 0.78.

Table 6: Optimum values of process parameters and responses

Process parameters	**Goal**	**Lower limit**	**Upper limit**	**Importance**	**Optimization level**
A: Loading Density (kg/m²)	in range	26	52	3	38.80
B: Air Velocity (m/s)	in range	3	5	3	3.86
C: Power level (W)	in range	270	810	3	413
Responses					predicted value
Rehydration ratio	Maximize	1.40	2.40	3	2.15
Shrinkage ratio	Minimize	0.75	1.00	3	0.84
Hardness	Minimize	720	2930	3	739
Chewiness	in range	473	1904	3	473
Colour change (E)	Minimize	14.20	22.98	3	15.50
Overall acceptability	Maximize	48.15	81.48	3	72.50

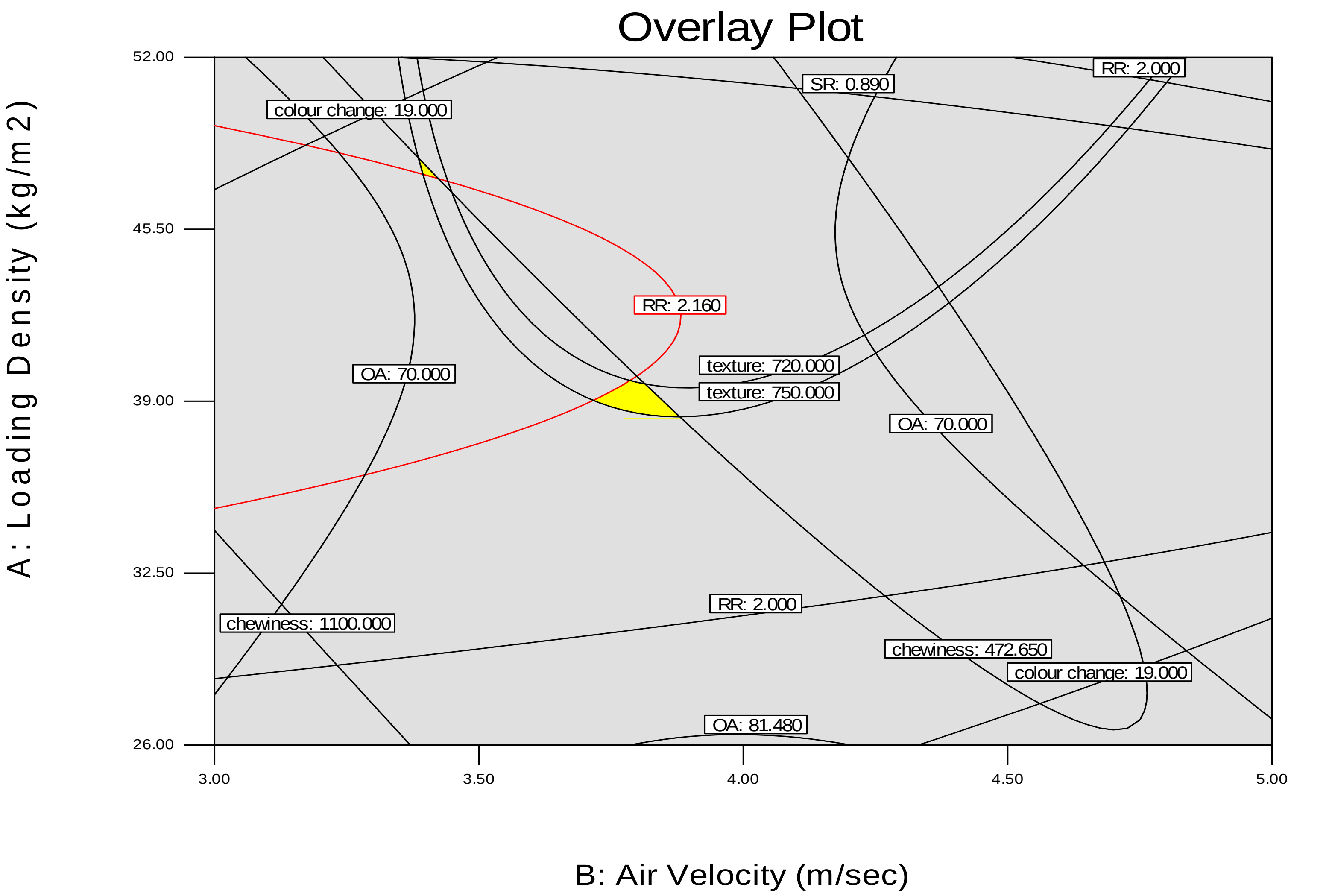


Fig 13: Superimposed contour plot of different responses for optimization of convective cum microwave dehydration of mushroom.

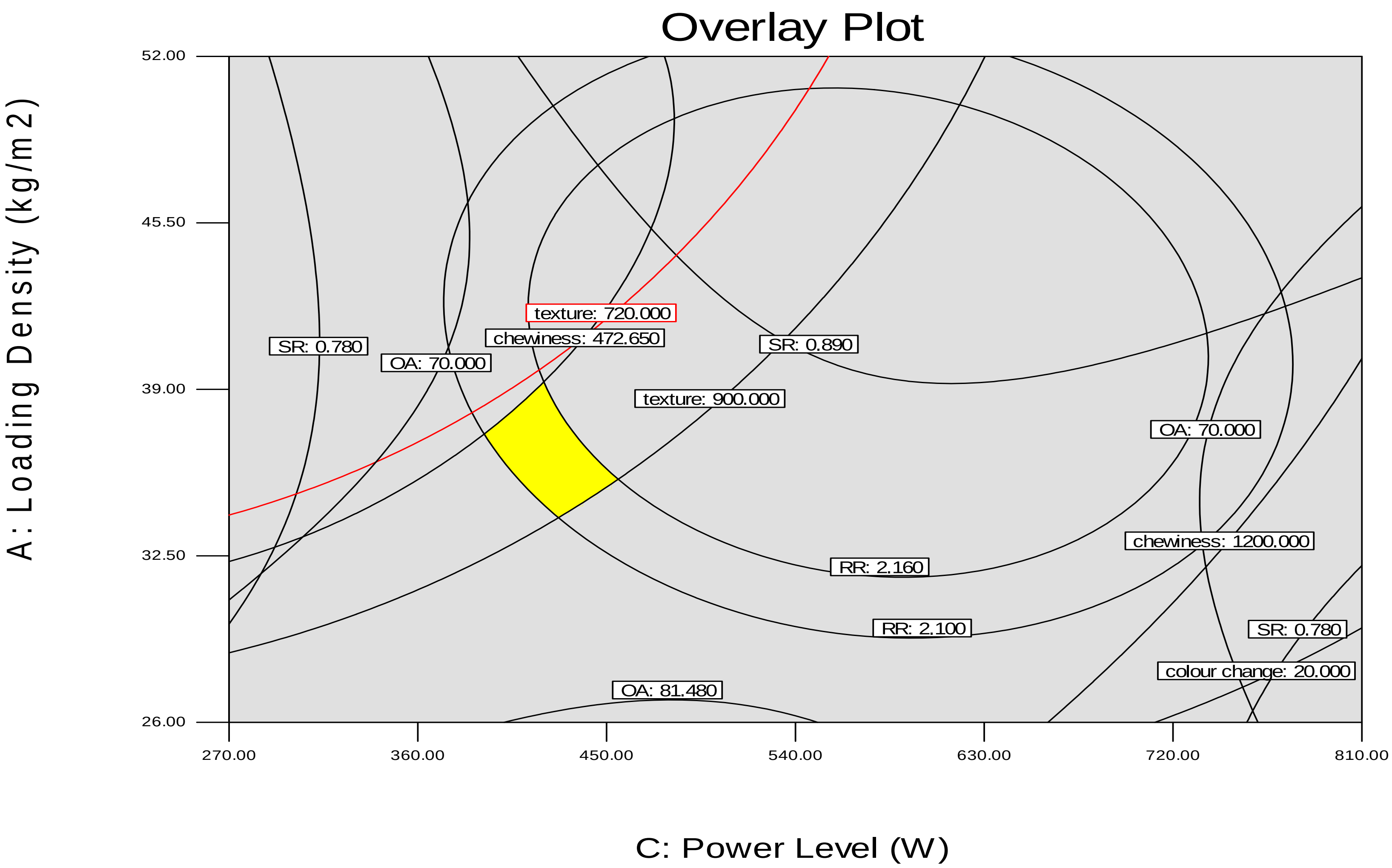


Fig 14: Superimposed contour plot of different responses for optimization of convective cum microwave dehydration of mushroom

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