Mushroom Research 23 (2) : 199-206, 2014

Optimization of convective drying parameters for osmosed button mushroom (*Agaricus bisporus*)

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ABSTRACT

The full factorial completely randomized design (CRD) was adopted for analysis. Two independent process variables (drying temperature and air velocity) having five levels of drying temperature (45, 55, 65, 75 and 85^{o}C) and three levels of air velocity (1.0, 1.5 and 2.0 m/s), a total of fifteen experiments were performed for maximizing ascorbic acid and colour (L-value) and minimizing water activity and drying time as responses for each treatment. Influence of various factors were analysed using ANOVA technique. Second order model was fitted in independent variables and various responses using multiple regression analysis. The optimization of input parameters (drying temperature and air velocity) was carried out using numerical optimization technique with the help of design expert 8.0.6 statistical software. The optimum operating conditions were:drying temperature 65^{o}C and air velocity 2.0 m/s. At this optimum point, drying time, ascorbic acid, colour (L-value) and water activity were predicted to be 450min, 26.71mg/100g dm, 60.99 and 0.321 respectively.

Keywords: Button mushroom, convective drying, temperature, air-velocity

Osmotic pre-treatment makes drying more efficient both in terms of removed water and achieved water activity (Erle and Schubert, 2001). But, it will not give a product of sufficiently low moisture content to be considered as a shelf stable, therefore, osmosed product needs to be further dried, through air, vacuum or freeze drying. The combination of osmotic dehydration with hot air drying, which is called ‘osmo-convective drying’ has been proposed by many researchers (Kar and Gupta, 2003; Murumkar *et al*., 2006; Shukla and Singh, 2007; Jain *et al*., 2006; Vishal *et al*., 2009; Dehkordi, 2010 and Pisalkar *et al*., 2011).The main purpose of drying products is to allow longer periods of storage, minimize packaging requirements and reduce shipping weights.

The stability and quality of the osmo-dried product were governed mainly by its water activity and colour. Therefore, these responses as well as ascorbic acid content were also considered for optimizing the input parameters.The drying temperature, air velocity and time affect the rate of drying and are to be considered as important parameters in air drying of osmotically dehydrated mushroom samples. The minimum and maximum levels of drying air temperatures were considered to be 45 and 85^{o}C respectively, since lower temperature may prolong the drying process resulting in ill-economy, while higher temperature may affect the product quality like browning. The air velocity also affect drying time, specially in final stage of drying, which helps in attaining the final moisture content quickly. Velocity levels were selected between 1.0 and 2.0 m/s.

Thus, the goal of this study was to optimize air drying conditions for the production of osmo-convectively dried mushroom samples with maximum ascorbic acid and colour (L-value) and minimum water activity and drying time.

MATERIALS AND METHODS

Materials selection and sample preparation

Fruit bodies of *Agaricus bisporus* variety, having about 87-91 per cent moisture content (wb), was procured on daily basis from All India Coordinated Research Project on Mushroom, Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan. Freshly harvested, firm, dazzling white, mature mushrooms of uniform size were manually sorted and selected as the raw material for all the experiments. Mushrooms of uniform size were thoroughly washed under tap water to remove adhering impurities. They were then dried on a blotting paper, and then cut into 5±0.5 mm thick slices with the help of sharp stainless steel knife. Common salt (Brand name Tata) was used as an osmotic agent and was procured from the local market of Udaipur. The brine solution of desired concentration was prepared by dissolving the required quantity of salt (w/v) in tap water.

Osmotic dehydration and optimization

Based on the results of preliminary investigations on water loss and salt gain, the ranges of input parameters such as solution temperature (35-55°C); brine concentration (10-20%) and duration of osmosis (30-60 min) were fixed and optimized on the basis of targeted salt gain (2.98%)for further experimentation of optimization. The optimum salt gain was decided on the basis of consumer's taste panel. The brine to sample ratio was taken as constant at 5:1, which was also suggested by various researchers for various fruits and vegetables (Kar and Gupta, 2003; Pokharkar and Prasad, 2002; Pisalkar *et al.*, 2011; Jain *et al.*, 2011 and Mehta *et al.*, 2014).

Numerical multi response technique was carried out for optimization of process parameters such as temperature, concentration of brine and duration of osmosis. The process parameters for osmotic dehydration process were numerically optimized for desirability function having equal importance (+) to all the three process parameters and equal importance (+++++) to two responses. The goal setting begins at a random starting point and proceeds up the steepest slope on the response surface for a maximum value of water loss and targeted value of salt gain.The optimum operating conditions were found to be brine temperature of 44.89°C, brine concentration of 16.53% and osmosis period of 47.59 min. At this optimum point, water loss and salt gain were predicted to be 40.55 per cent and 2.98 per cent, respectively.

Convective drying and optimization

Osmo-dehydrated products obtained at optimized conditions were further dried at temperature of 45, 55, 65, 75 and 85°C with air velocities of 1.0, 1.5 and 2.0 m/s. The stability and quality of the osmo-dried product were governed mainly by its water activity and colour. Therefore, these responses as well as ascorbic acid and drying time were also considered for optimizing the input parameters.

RESULTS AND DISCUSSION

As per two independent variables (drying temperature and air velocity) having five levels of drying temperature and three levels of air velocity, total fifteen experiments were performed as enumerated in Table 1 for maximizing ascorbic acid and colour (L-value) and minimizing water activity and drying time as responses for each treatment.The optimization of input parameters (drying temperature and air velocity) was carried out using numerical optimization technique with the help of design expert 8.0.6 statistical software.

Table 1. Experimental layout for two-variable randomized factorial design

Sl. No.	Temperature, ^{0}C	Air velocity m/s	Drying time, min	Ascorbic acid, mg/100g dm	Colour (L-value)	Water activity, a_w
1	85	1.5	300	23.29	39.11	0.239
2	45	1.5	720	26.49	42.80	0.411
3	85	1.0	330	24.48	38.71	0.249
4	85	2.0	270	22.14	40.02	0.228
5	65	1.0	510	28.83	56.35	0.342
6	55	2.0	480	26.09	50.37	0.362
7	65	1.5	480	27.45	57.79	0.334
8	45	2.0	660	25.31	44.31	0.401
9	65	2.0	450	26.71	60.99	0.321
10	75	1.5	390	25.88	52.65	0.287
11	45	1.0	780	27.45	40.84	0.418
12	55	1.0	600	28.12	47.11	0.381
13	75	2.0	330	24.21	53.87	0.274
14	55	1.5	540	27.02	49.44	0.374
15	75	1.0	420	27.33	49.66	0.294

Ascorbic acid

In the present study, the ascorbic acid content of fresh mushroom sample was 105.29 mg/100 g dm, whereas ascorbic acid content of osmo-convectively dried mushroomsample was ranging between 22.14 to 28.83 mg/100 g dm (Table 2). It revealed that in all the dried samples, the loss of ascorbic acid was greater than 75 per cent compared to fresh sample. Individual effect of temperature on ascorbic acid revealed that the retention of ascorbic acid was found to be increased with decrease in drying temperature from 85 to 65°C and it decreased with further decrease in drying air temperature to 45°C (Table 2, Fig 1). The loss of ascorbic acid at higher temperature (85°C) is the maximum probably because its thermal sensitivity (Hawlader *et al.*, 2006) but comparative higher loss at lower temperature (45°C) might be due to long period of exposure

Table 2. Effect of temperature (T), velocity (V) and their interaction on ascorbic acid

Temp (°C) \ Velocity (m/s)	1.0	1.5	2.0	Mean
45	27.45	26.49	25.31	26.41
55	28.12	27.02	26.09	27.07
65	28.83	27.45	26.71	27.66
75	27.33	25.88	24.21	25.80
85	24.48	23.29	22.14	23.30
Mean	27.24	26.02	24.89	

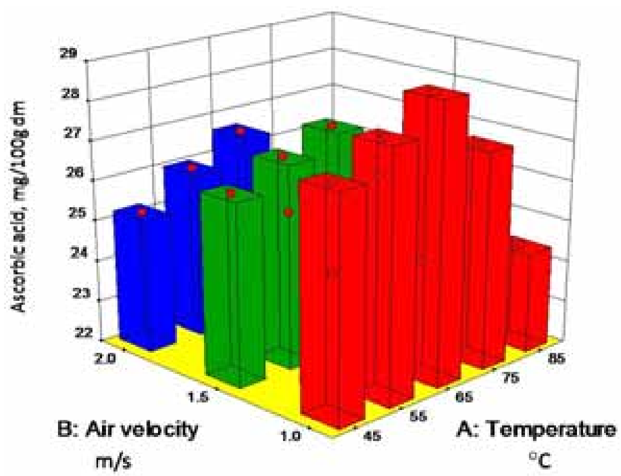

Fig. 1. Response surface showing the effect ofprocess variables on ascorbic acid retention during convective dehydration of osmosed mushroom sample

(e.g. 660 to 780 min for 2.0 m/s to 1.0 m/s air velocity, respectively) required to dry the sample at 45°C. Similar results are quoted by Miranda *et al.* (2009a). As regard to individual effect of temperature the sample dried with drying air temperature 65°C was found better and recorded significantly highest ascorbic acid (27.66 mg/100 g dm). Similarly, with respect to individual effect of velocity, the sample dried with lower velocity (1.0 m/s) recorded highest ascorbic acid (27.24 mg/100 g dm). As the velocity increased the ascorbic acid was found to be decreased slightly.

The ANOVA with respect to ascorbic acid is shown in Table 3. The table shows that the effects of temperature, air velocity, and their interaction on ascorbic acid are significant at 1 per cent level of significance. From Table 2, it revealed that the sample with the highest retention of ascorbic acid (28.83 mg/100 g dm) was the one dried at 65°C temperature and 1.0 m/s drying air velocity and was significantly superior over all other samples.

Second order regression model was found best fitted to the experimental data (Table 2). This model [Eqn. (1)] shows the effect of drying temperature (T) and air velocity (V) on ascorbic acid.

$$\text{Ascorbic acid} = 8.126 + 0.762T - 1.873V - 0.006T^2 + 0.164V^2 - 0.015TV \quad ....(1)$$

$R^2 = 0.98$

Colour (L-value)

Colour is often used as an indication of quality and freshness for food products. Hence, it has become important for food processors to be able to evaluate and grade their products based on colour. The colour of dried mushroom product was measured in terms of L-value (brightness/darkness) and shown in Table 4. The L-value of fresh mushroom sample was about 39.84. The L-values of osmo-convectively dried mushroom sample at various experimental conditions were ranged from 38.71 to 60.99 (Table 4). As the temperature increased, L-value of colour was increased from 45°C to 65°C, means sample became lighter in colour and thereafter decreased at 75°C (Table 4, Fig 2) which may be due to discolouring the

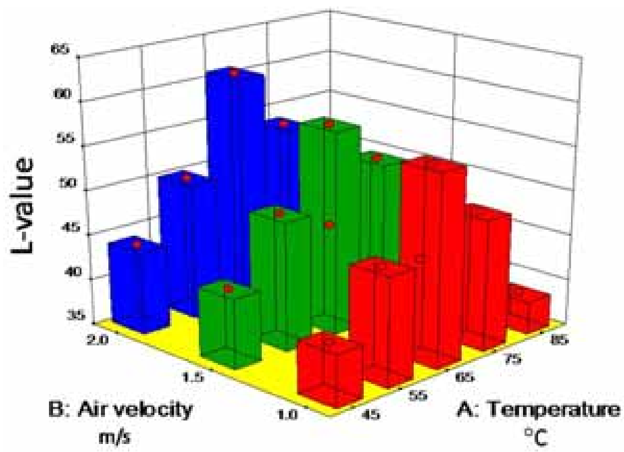

Fig. 2. Response surface showing the effect ofprocess variables on colour (L-value) during convective dehydration of osmosed mushroom sample

Table 3. Analysis of variance for two factor CRD for ascorbic acid

Source	DF	SS	MSS	F_{cal}	SE (m) ±	CD at 5%	C.V.%
T	4	102.55	25.64	723.13**	0.0628	0.1813	0.72
V	2	41.44	20.72	584.35**	0.0486	0.1404	
T x V	8	1.44	0.18	5.07**	0.1087	0.3140	
Error	30	1.06	0.04				
Total	44						

**Significant at 1% level

Table 4. Effect of temperature, velocity and their interaction on colour (L-value)

Temp (°C) \ Velocity (m/s)	1.0	1.5	2.0	Mean
45	40.84	42.80	44.31	42.65
55	47.11	49.44	50.37	48.97
65	56.35	57.79	60.99	58.37
75	49.66	52.65	53.87	52.06
85	38.71	39.11	40.02	39.28
Mean	46.53	48.35	49.91	

sample slightly because of elevated temperature. The drying air temperature 65°C was found better and recorded significantly highest colour (L-value = 58.37). Similar results are quoted by Shrivastava (1999), Singh *et al*., (2008) and Murumkar *et al.* (2006). Increase in velocity also resulted in increased colour (L-value) slightly. The sample dried with 2.0 m/s drying air velocity was found significantly superior in recording better colour (L-value = 49.91).

From Table 5 it can be seen that temperature, air velocity and their interactions are significant at 1 per cent level of significance. The sample with highest L-value (60.99) was the one dried at 65°C temperature and 2.0 m/s air velocity and was significantly superior over rest of the samples dried with all other combinations of temperature and velocity (Table 4).

Second order regression model for colour (L-value) was fitted to the experimental data (Table 4). This model [Eqn. (2)] shows the effect of drying temperature (T) and air velocity (V) on colour (L-value).

$$\text{Colour (L-value)} = -113.874 + 5.021T + 7.188V - 0.039T^2 - 0.540V^2 - 0.034TV \quad ...2$$
$$R^2 = 0.91$$

Water activity

The water activity of fresh mushroom sample was 0.911 whereas water activities of osmo-convectively dried samples with all combinations of temperatures and velocities were ranging between 0.228 and 0.418 (Table 6). As regards to individual effect of temperature, it revealed that as the temperature increased water activity decreased significantly (Fig 6). The sample dried at 85°C drying air temperature was having significantly lowest (0.238) water activity. Similarly as air velocity increased, water activity decreased significantly but the rate was comparatively less. The sample dried with 2.0 m/s drying air velocity shown significantly lowest (0.228) water activity.

The ANOVA for water activity is presented in Table 7. From this table, it can be seen for temperature, air velocity and for interaction that the effect of drying temperature, air velocity, and their interactions were significant

Table 5. Analysis of variance for two factor CRD for colour (L-value)

Source	DF	SS	MSS	F_{cal}	SE (m) ±	CD at 5%	C.V.%
T	4	2553.83	563.46	324.11**	0.4395	1.269	2.72
V	2	118.96	59.18	34.21**	0.3404	0.983	
T x V	8	45.87	5.73	3.30**	0.7612	2.198	
Error	30	52.15	1.74				
Total	44						

**Significant at 1% level

Table 6. Effect of temperature, velocity and their interaction on water activity

Temp (°C) \ Velocity (m/s)	1.0	1.5	2.0	Mean
45	0.418	0.411	0.401	0.410
55	0.381	0.374	0.362	0.372
65	0.342	0.334	0.321	0.332
75	0.294	0.287	0.274	0.285
85	0.249	0.239	0.224	0.238
Mean	0.336	0.329	0.317	

on water activity at 1 per cent level of significance. Table 6 revealed that the sample with lowest water activity (0.228) was one dried at 85°C drying air temperature and 2.0 m/s drying air velocity and was significantly superior over the sample dried by all other combinations of temperature and velocity.

The model that fits well to the experimental data was second order regression model [Eqn. (3)]. This model shows the effect of drying temperature and air velocity on water activity (a_w).

Water activity (a_w) = $0.540 - 0.002T + 0.010V - 0.00002T^2 - 0.008V^2 - 0.00009VT$ ...3

$R^2 = 0.99$

Optimization of independent variables for production of osmo-convectively dried mushroom sample

Optimization is a process of making compromises between responses, to achieve a common target. Numerical optimization was carried out using design-expert 8.0.6 statistical software.The goal was fixed to be in the range for ascorbic acid, colour (L-value), water activity and drying time. The goal seeking begins at a random starting point and proceeds up and down the steepest slope on the response for a maximum or minimum value of the response respectively. All the responses and independent variables were given similar (+++) importance. The goal setup for optimization is given in the Table 8.

Based on above mentioned criteria the optimization was carried out. Out of 15 combinations of categorise factor levels (Table 1), 13 solutions were found. Among them, one that suited the criteria most i.e. maximizes ascorbic acid and colour and minimizes water activity and drying time, was selected. The most suitable optimum point is given in the Table 9. Thus convective drying of osmotically dehydrated mushroom sample with 65°C drying air temperature and 2.0 m/s air velocity is best for optimum response (ascorbic acid =26.71mg/100g dm, colour =60.99, water activity =0.321 and drying time =450min) among the range of variables taken for the study.

Sensory Evaluation

Osmo-convectively dried product (optimized conditions) and convectively dried product (drying air temperature-65°C, velocity-2.0m/s) were served for the evaluation to the panellists at a time. Panellists were requested

Table 7. Analysis of variance for two factor CRD for water activity

Source	DF	SS	MSS	F_{cal}	SE (m) ±	CD at 5%	C.V.%
T	4	0.1668	0.0417	49133.05**	0.0003	0.0009	0.28
V	2	0.0029	0.0015	1720.60**	0.0002	0.0007	
T x V	8	0.0000	0.0000	3.65**	0.0005	0.0015	
Error	30	0.0000	0.0000				
Total	44						

**Significant at 1% level

Table 8. Constraints for optimization for convective drying of osmotically dehydrated mushroom sample

Sl.N	Parameter	Goal	Lower limit	Upper limit	Importance
1.	Temperature, °C	Is in range	45	85	3
2.	Air velocity, m/s	Is in range	1.0	2.0	3
3.	Ascorbic Acid, mg / 100g dm	Maximum	22.14	28.83	3
4.	Colour (L-value)	Maximum	38.71	60.99	3
5.	Water activity	Minimum	0.228	0.418	3
6.	Drying time, min.	Minimum	270	780	3

Table 9. Optimum levels of variables for convective drying of osmotically dehydrated mushroom sample

S. No.	Variable	Optimum level
1.	Drying air temperature, °C	65
2.	Air velocity, m/s	2.0

to mark the product according to their liking.The sensory evaluation was carried out for colour,taste,appearance and over all acceptability. The average scores of all the panelists were computed.The independent sample t test was applied to compare between convectively dried and osmo-convectively dried product for various organoleptic characteristics (Table 10).

The difference between convectively dried and osmo-convectively dried product was significant for taste, appearance and overall acceptability at 1 per cent level of significance (Table 10) whereas colour was non-significant. Hence the osmo-convectively dried product was found superior with respect to taste, appearance and overall acceptability as compared to convectively dried product (without osmo). The osmo-convectively dried product was appreciated by the panellist because of its salty taste, but convectively dried product (without osmo) showed no taste. It is in agreement with an earlier study (Torringa *et al*., 2001; Allaeddini and Emam-Djomeh, 2004 and Vishal *et al*., 2009) where osmotic pre-treatment was able to improve quality of dried product.

CONCLUSIONS

It was found that convective drying at 65°C temperature and 2.0m/s velocity for 450min time was the most efficient set of conditions for the drying of osmo-dehydrated mushroom samples by product with maximum ascorbic

Table 10. Mean sensory score data for individual characters

Character	Mean		Sd		SEd	t
	Convectively dried	Osmo-convectively dried	Convectively dried	Osmo-convectively dried		
Colour	72.93	73.73	2.404	2.939	0.980	0.816^{NS}
Taste	67.27	77.60	3.973	2.293	1.184	8.725**
Appearance	65.53	76.40	3.720	2.165	1.111	9.779**
Overall acceptability	66.33	76.53	3.244	2.100	0.998	10.223**

** Significant at 1% level, **NS** - Non-significant acid (26.71 mg/100g dm), maximum L-value (60.99) and minimum water activity (0.321).

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