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Effect of process variables on mass transport data during osmotic dehydration of button mushroom (*Agaricus bisporus*) slices

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ABSTRACT : The preliminary experiment for mass transport data of button mushroom (*Agaricus bisporus*) were performed for fixing the levels of input variables for further experimentation such as kinetics and optimization of osmotic dehydration as well as air drying. After the preparatory steps, the preliminary experiment was studied for wide range of process variables such as duration of osmosis (30, 45, 60, 90, 120 min), salt concentration (5, 10, 15, 20, 25%), brine temperature (25, 35, 45, 55, 65°C) and brine to sample ratio (3:1, 4:1, 5:1, 6:1, 8:1 R). The response parameters were mainly water loss and salt gain.

KEY WORDS : Osmotic dehydration, Concentration, Water loss and salt gain

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In recent years, the use of mushroom for medicinal and food products has increased considerably. The high proteins, sterols, macro-elements and low calorie content make mushroom ideal food ever for patients, old people, pregnant ladies and children and also for prevention of cardiovascular diseases (Poongkodi and Sakthisekaran, 1995). Presence of more than 90 per cent moisture content, mushrooms are highly perishable and start deteriorating immediately after harvest. It can not be stored for more than 24 hours at ambient temperature (Lal Kaushal and Sharma, 1995; Giri and Prasad, 2007). They develop brown colour on the surface of the cap due the enzymatic action of phenol oxidase, this results in shorter shelf life. In view of their high perishable nature, the fresh mushrooms have to be processed to extend their shelf life for off season use.

There should be a technique to reduce the reliance on fossil fuels and challenges in fruits and vegetables drying are to reduce the moisture content of the product to a level where microbiological growth not occur and simultaneously keep the nutritive value high in final product. Hence, a new method osmotic dehydration is used to water removal, at low temperature with low energy consumption. Since this process cannot remove moisture to a level that will avoid microbial growth, it is a method suitable only for pre-treatment prior to drying (Torringa *et al*., 2001; Shukla and Singh, 2007). This partial dehydration of the fruit and vegetables with reduced energy consumption and heat damage has received attention in recent years as a technique for production of intermediate moisture foods and shelf-stable foods (Jayaraman and Gupta, 1992).

Many researchers studied osmotic dehydration of many fruits and vegetables, such as apple, banana, mango, guava, grape, citrus fruits, cherry, carrot, etc. (Pokharkar *et al.,* 1997; Sethi *et al*., 1999). Very few attempts have been made to study osmotic dehydration characteristics of button mushroom. Therefore, a preliminary experiment was proposed to investigate the wide range of process variables (such as duration of osmosis, salt concentration, brine temperature and brine to sample ratio) on mass transport data (such as water loss and solid gain) during osmotic dehydration of button mushroom to fix the levels of input variables for further experimentation (such as kinetics and optimization of osmotic dehydration as well as air drying).

METHODOLOGY

Selection of raw materials :

Mushroom of *Agaricus bisporus* variety, having about (89-91%) moisture content (w.b.), was procured on daily basis from All India Co-ordinated 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 medium sized were selected as the raw material for all the experiments. Common salt (Brand name Tata) used as an osmotic agent, was procured from the local market.

Sample and solution preparation :

Button mushrooms were thoroughly washed under tap water to remove adhering impurities and dried on a blotting paper, and then cut into 5±0.5 mm thick slices with the help of sharp stainless steel knife. The brine solution of desired concentration was prepared by dissolving the required quantity of salt (w/v) in tap water. Moisture content of fresh as well as osmotically dehydrated mushroom slices were determined by method as suggested by Ranganna (2000).

Experimental set up for osmotic dehydration :

A small capacity laboratory temperature controlled water bath of size 30 cm x 20 cm x 20 cm (approximate capacity, 5 litres) was used as osmotic dehydration unit. The unit consists of osmotic dehydration chamber, temperature indicator and electric pump. The heating chamber made of stainless steel sheet, has an immersion heater (500 Watt) connected to the bottom of the osmotic chamber. The temperature of the osmotic solution in the chamber is controlled with the help of a thermostat. A water level indicator is also provided. Temperature sensor is also provided to determine the temperature of the brine solution.

Preliminary experiment :

The preliminary experiment was studied for wide range of process variables such as:

- Temperature of brine, T : 5 levels (25,35,45 ,55,65 ± 1°C)
- Salt concentration, C : 5 levels (5,10, 15, 20, 25)
- Duration of osmosis, θ : 5 levels (30 , 45, 60 , 90 , 120)
- Brine to sample ratio, R : 5 levels (3:1, 4:1, 5:1, 6:1, 7:1)

In general, following maximum levels were adopted for the four parameters, temperature as 45^{0}C; concentration as 15 per cent; ratio of brine solution to sample as 5:1 and duration of osmosis as 60 min, as suggested by earlier workers (Jain, 2007; Pokharkar and Prasad, 2002 and Borkar *et al.*, 2011) for various fruits/vegetables. Four sets of experiments were conducted by varying one factor at a time and other variables were kept constant as shown in Table A. The response parameters were water loss and salt gain.

In every experiment mushroom samples of approximately 50g were completely immersed in 250 g salt solution contained in a 500 ml glass beaker. The beakers were placed inside the constant temperature water bath. The brine solution in the beakers was manually stirred at regular intervals to maintain uniform temperature. One beaker was removed from the water bath at designated time (experimental run A of Table A) and the samples were immediately removed and placed on tissue paper to soak the surface moisture. The samples were weighed and their moisture contents were determined. The same procedure was adopted for other experiments (experimental run B, C and D of Table A) by varying one factor at a time.

The initial moisture content of mushroom samples was determined as suggested by Ranganna (2000) and was found in the range 87-91 per cent (wb). The effect of process variables like duration of osmosis (θ), salt concentration (C) and its temperature (T) during osmotic dehydration of mushroom samples on mass reduction, water loss and salt gain was determined. These experiments were replicated thrice and their average values have been reported (Table 1 to 4). In the process of osmotic dehydration, a sample is placed in the hypertonic solution and due to concentration difference water comes out from sample to solution. Simultaneously transports of solids take place from solution to sample and vice versa. The mass transport in terms of water loss, mass reduction and salt gain were studied as detailed below.

Mass transport data for osmotic dehydration :

Lenart and Flink (1984) were first to define terminologies, for mass transport data during osmotic concentration and same have been used by various researchers such as Silveira *et al.* (1996) and Kaleemullah *et al.* (2002) and in this study also as follows:

Water loss (WL) :

Water loss was calculated as the net loss of water from food material on an initial mass basis as :

$$\mathbf{WL} = \frac{\mathbf{W_{si} X_{swi} - W_{s\theta} X_{sw\theta}}}{\mathbf{W_{si}}} \times \mathbf{100} \qquad ......(1)$$

Mass reduction (WR) :

Mass reduction was calculated as the net mass reduction of the food material on initial mass basis as :

Table A : Levels of input variables for mass transport data during osmotic dehydration

Variables	Experimental runs			
	A	B	C	D
Brine temperature, T	25, 35, 45, 55 and 65	45	45	45
Salt concentration, C	15	5, 10, 15, 20 and 25	15	15
Duration of osmosis, θ	60	60	15, 30, 45, 60, 90 and 120	60
Brine to sample ratio, R	5:1	5:1	5:1	3:1, 4:1, 5:1, 6:1 and 7:1

$$WL = \frac{W_{si}X_{swi} - W_{s\theta}X_{sw\theta}}{W_{si}} \times 100 \qquad ......(2)$$

Salt gain (SG) :

Solid gain was calculated as a net uptake of solids by food material on an initial mass basis as :

$$SG = \frac{W_{s\theta}(1 - X_{sw\theta}) - W_{si}(1 - X_{swi})}{W_{si}} \times 100 \qquad ......(3)$$

From Eqns (3) and (4), the solid gain (SG) can be correlated with mass reduction (MR) and water loss (WL) as:

$$SG = WL - WR \qquad ......(4)$$

where,

WL = water loss (g water per 100 g initial mass of sample)

WR = mass reduction (g mass per 100 g initial mass of sample)

SG = solid gain (g solids per 100g initial mass of sample)

W_{si} = initial mass of sample, g

$W_{s\theta}$ = mass of the sample after time θ, g

X_{swi} = water content as a fraction of the initial mass of the sample

$X_{sw\theta}$ = water content as a fraction of the syrup at time θ

■ RESULTS AND DISCUSSION

The results of the present study as well as relevant discussions have been presented under following sub heads:

Duration of osmosis :

The mass transport data for water and salt from mushroom samples and brine solution with duration of osmosis for 15 per cent salt solution at 45°C temperature having brine to sample ratio (R) as 5:1 are presented in Table 1and Fig. 1. It is inferred from the table that mass reduction, water loss and salt gain of sample increased with increase in duration of osmosis. The mass reduction and water loss increased from 0 to 41.19 and 45.07 per cent, respectively as the duration of osmosis increased from 0 to 120 min. The salt gain was also found to increase during this period from 0 to 3.88 per cent, while concentration of brine after osmotic dehydration was reduced from 15 to 10.8 per cent.

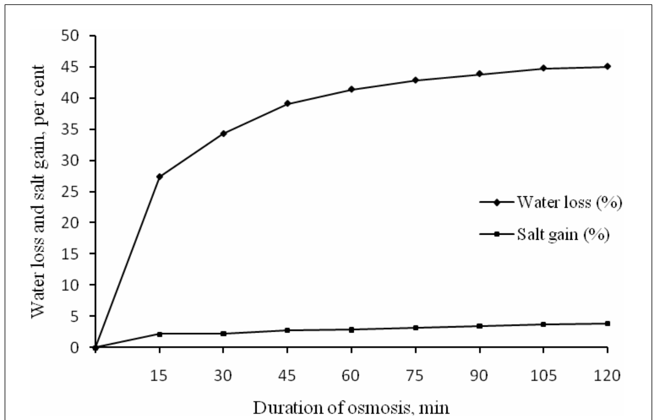

Fig. 1: Effect of duration of osmosis on water loss and salt gain (Temp.=45°C, Conc.=15% and R'=5:1)

It is clear from the Fig. 1 that the water loss and salt gain though increased with duration of osmosis, the rate decreased at later stage and equilibrium could not be achieved even after 120 min. Water loss was maximum (27.41 per cent) in the beginning (first 15 min of osmosis). The rate of increase of water loss was further decreased by 6.90, 4.83, 2.27, 1.46, 1.03, 0.90 and 0.27 per cent point in 15 to 30 min, 30 to 45 min, 45 to 60 min, 60 to 75 min, 75 to 90 min, 90 to 105 and 105 to 120 min, respectively.

Similarly, the salt gain increased steadily with increase in duration of osmosis, but equilibrium could not be achieved even after 120 min of osmotic dehydration. Salt gain was maximum (2.18 per cent) in first 15 min of osmosis and it was 2.89 per cent after 60 min of osmosis. With further advance of time (just after 60 min), the rate of increment of salt gain was

Table 1 : Effect of duration of osmosis on mass transport for osmotic dehydration of mushroom samples (T = 45°C; C = 15%; R' = 5:1)

Duration of osmotic dehydration, min.	Initial mass, g	Final mass, g	FMC, % (wb)	Mass reduction, %	Water loss, %	Salt gain, %	Concentration of brine after osmotic dehydration, %
0	50.03	50.03	90.66	0.00	0.00	0.00	15.0
15	50.01	37.40	84.58	25.23	27.41	2.18	13.1
30	50.00	33.98	82.92	32.04	34.31	2.26	12.7
45	50.12	31.89	80.94	36.36	39.14	2.78	12.3
60	50.99	31.35	80.10	38.52	41.41	2.89	12.0
75	50.02	30.17	79.20	39.67	42.87	3.20	11.8
90	50.06	29.83	78.45	40.40	43.90	3.49	11.4
105	50.31	29.64	77.81	41.07	44.80	3.73	11.1
120	50.04	29.40	77.51	41.19	45.07	3.88	10.8

kept on reducing as the duration of osmosis increased. This reduction was by 0.31, 0.29, 0.24 and 0.15 per cent point as the duration of osmosis increased from 60 to 75 min, 75 to 90 min, 90 to 105 min and then 105 to 120 min, respectively (Table 2).

Therefore, the osmosis duration of 60 min was found to be sufficient for the process of osmotic dehydration of mushroom sample. The water loss (WL) and salt gain (SG) in mushroom samples were co-related with duration of osmosis by fitting third order polynomial model as below :

$$WL = 8.754 \times 10^{-5}\,\theta^3 - 0.021\,\theta^2 + 1.621\,\theta + 2.531 \quad ......(5)$$
$$R^2 = 0.97$$

$$SG = 5.911 \times 10^{-6}\,\theta^3 - 0.001\,\theta^2 + 0.106\,\theta + 0.280 \quad ......(6)$$
$$R^2 = 0.94$$

Brine to sample ratio :

The effect of brine to sample ratio (R) on mass transport was analyzed by keeping temperature and concentration of brine fixed as 45^{0}C and 15 per cent, respectively for 60 min duration of osmosis. The initial moisture content of the samples was 87.50 per cent. The results are presented in the Table 2.

It can be observed from the Table 2 that the variation in brine to sample ratio affected the soluble solid concentration, mass reduction, water loss and salt gain and it also showed the similar pattern to that of duration of osmosis. As the brine to sample ratio was increased from 3:1 to 8:1, mass reduction, water loss and salt gain were increased from 28.08 to 39.28 per cent, 30.03 to 42.82 per cent and 1.95 to 3.54 per cent, respectively in 60 min of osmotic dehydration.The concentration of brine decreased up to 11.2 to 13.1 per cent during osmotic dehydration, while initial concentration of the brine was 15 per cent.

Although, water loss increased with increase in brine to sample ratio, the rate of increment was higher up to brine to sample ratio of 5 and subsequently it reduced. When brine to sample ratio increased from 3:1 to 4:1, the water loss increased by 5.31 per cent point and then after by 4.87 per cent point when the ratio was increased to 5:1. With further increase in brine to sample ratio (6:1, 7:1 and 8:1), water loss did not increase much (only 1.06, 0.90 and 0.65 per cent point).

Similarly, the salt gain was relatively higher up to brine to sample ratio of 5:1 and then slowed down considerably (Fig. 2). When brine to sample ratio increased from 3:1 to 4:1, the salt gain increased by 0.53 per cent point and then gain was increased by 0.38 per cent point when ratio was further increased to 5:1. However, afterwards when brine to sample ratio was further increased (6:1, 7:1 and 8:1) salt gain did not increase much (only 0.32, 0.19 and 0.17 per cent point).

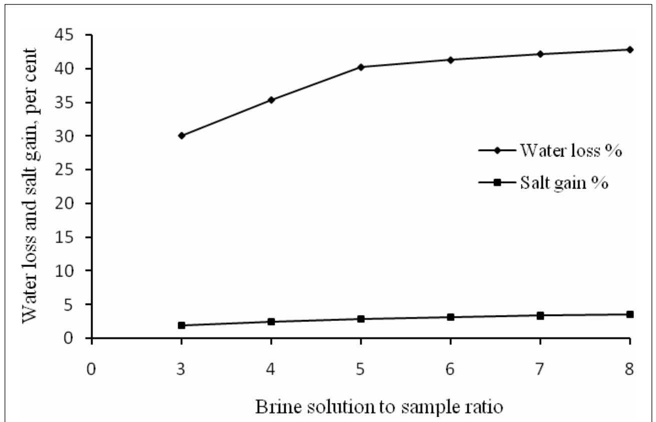

Fig. 2: Effect of brine to sample ratio on water loss and salt gain (Temp.=45^{0}C; Conc.=15% and duration=60 min)

It is evident from the Fig. 2 that when brine to sample ratio was increased from 3:1 to 4:1 and from 4:1 to 5:1, significant rise in water loss and salt gain was observed, with further rise in brine to sample ratio did not increase water loss and salt gain appreciably. However, equilibrium could not be achieved in the experiments (Table 2). Shahabuddin *et al.* (1990); Pisalkar *et al.* (2008) and Jain *et al.* (2011) reported similar trends for pineapple, melon, aloe-vera and papaya, respectively. Therefore, the brine to sample ratio of 5:1 was taken for all the subsequent investigations. The water loss (WL) and salt gain (SG) in mushroom samples were co-related with brine to sample ratio (R) by fitting third order polynomial and linear model, respectively as below :

$$WL = 0.110\,R^3 - 2.518\,R^2 + 19.582\,R - 9.191 \quad ......(7)$$
$$R^2 = 0.99$$

$$SG = 0.312\,R - 1.488 \quad ......(8)$$
$$R^2 = 0.96$$

Table 2 : Effect of brine to sample ratio on mass transport for osmotic dehydration of mushroom samples (T = 45^{o}C, C = 15% and θ = 60 min)

B S ratio, (R)	Initial mass, (g)	Final mass, (g)	FMC, % (wb)	Mass reduction (%)	Water loss (%)	Salt gain (%)	Concentration of brine after osmotic dehydration (%)
3:1	50.07	36.01	79.91	28.08	30.03	1.95	11.2
4:1	50.10	33.64	77.69	32.86	35.34	2.48	11.4
5:1	50.13	31.41	75.48	37.34	40.21	2.86	11.8
6:1	50.09	31.01	74.68	38.09	41.27	3.18	12.2
7:1	50.02	30.61	74.07	38.80	42.17	3.37	12.6
8:1	50.03	30.38	73.58	39.28	42.82	3.54	13.1

Salt concentration :

The effect of salt concentration (C) on water loss and salt gain for 60 min of osmosis was studied at constant brine temperature as 45°C, brine to sample ratio as 5:1 and initial moisture content as 88.01 per cent. The results of the study are presented in Table 3. It can be observed that by increasing the salt concentration from 5 to 25 per cent, water loss and salt gain both increased from 30.16 to 41.88 per cent and 2.12 to 3.72 per cent, respectively, while the mass reduction was in the range of 28.04 to 38.16 per cent. After osmotic dehydration, the concentration of brine decreased and was observed in the range of 3.9 to 22.3 per cent.

Fig. 3 shows the effect of brine concentration on water loss and salt gain. It can be seen that water loss (WL) increased rapidly initially, but the rate of increment was gradually reduced and increment in water loss was not much beyond the 15 per cent concentration. However, salt gain (SG) increased linearly with increase in salt concentration.

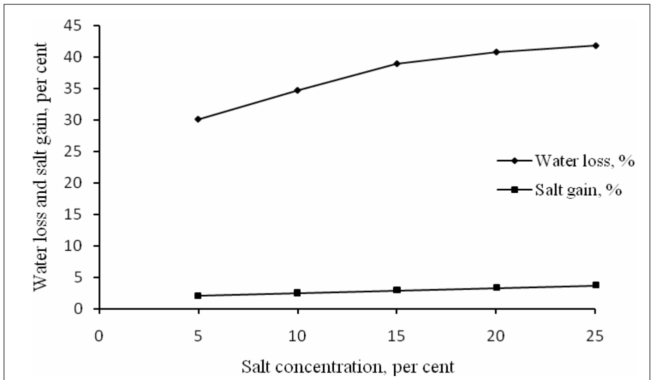

Fig. 3: Effect of salt concentration on water loss and salt gain (Temp.=45°C; brine to sample ratio = 5:1 and duration =60 min)

Although, the salt gain in samples increased with increase in initial concentration of brine, but beyond 15 per cent of brine concentration without much advantage of water loss. Therefore, it can be inferred from Table 3 and Fig. 3 that the product was much saltiness at higher concentration of brine solution without much advantage of water loss. For this reason it was felt necessary to optimize the salt concentration for better results. The mass transport for water loss (WL) and salt gain (SG) were statistically analyzed and co-related with brine concentration (C) as follows:

$$WL = C^3 - 4.500\,C^2 + 1.625\,C + 22.997 \quad R^2 = 0.99 \qquad \text{....... (9)}$$

$$SG = 0.400\,C + 1.351 \quad R^2 = 0.99 \qquad \text{......(10)}$$

Brine temperature :

The effect of brine temperature on water loss and salt gain for 60 min of osmotic dehydration was studied with salt concentration at 15 per cent and salt to sample ratio as five. The results of the study are presented in Table 4. It can be seen that with increase in brine temperature from 25 to 65°C, the mass reduction and water loss also increased from 31.77 to 41.71 and 34.12 to 44.65 per cent, respectively, however, the salt gain increased from 2.35 to 3.09 per cent up to 45°C temperature and decreased thereafter to 2.94 per cent.

It is also found that water loss increased linearly with increase in brine temperature (T), while salt gain increased up

Table 3: Effect of salt concentration on mass transport data for mushroom samples (R' = 5:1, T = 45°C and θ = 60 min)

Salt concentration (%)	Initial mass (g)	Final mass (g)	FMC (% wb)	Mass reduction (%)	Water loss (%)	Salt gain (%)	Concentration of brine after osmotic dehydration (%)
5	50.15	36.09	80.39	28.04	30.16	2.12	3.9
10	50.19	34.03	78.53	32.20	34.76	2.57	8.2
15	50.04	32.01	76.59	36.03	39.02	2.99	13.1
20	50.07	31.29	75.43	37.51	40.87	3.36	16.9
25	50.32	31.12	74.59	38.16	41.88	3.72	22.3

Table 4: Effect of brine temperature on mass transport data for mushroom samples (C= 15%, R = 5:1, and θ = 60 min)

Temperature (°C)	Initial mass (g)	Final mass (g)	FMC (% wb)	Mass reduction (%)	Water loss (%)	Salt gain (%)	Concentration of brine after osmotic dehydration (%)
25	50.05	34.15	80.95	31.77	34.12	2.35	11.1
35	50.07	32.02	79.01	36.05	38.82	2.77	11.9
45	50.18	30.61	77.48	39.00	42.09	3.09	12.3
55	50.27	29.95	77.13	40.42	43.40	2.98	12.8
65	50.25	29.29	76.69	41.71	44.65	2.94	13.7

to 45°C and then decreased at higher temperatures (Fig. 4). Increase in water loss and decrease in salt gain at higher temperatures may be due to the fact that at higher temperatures, the cell permeability increased and influenced the rate of osmosis. Salt having a larger ionic radius cannot diffuse as easily as water through the cell membrane and thus, the osmotic equilibrium is achieved primarily by the flow of water from the cells. Similar trends were also reported by Pokharkar *et al.* (1994); Jain *et al.* (2011) and Pisalkar *et al.* (2008).

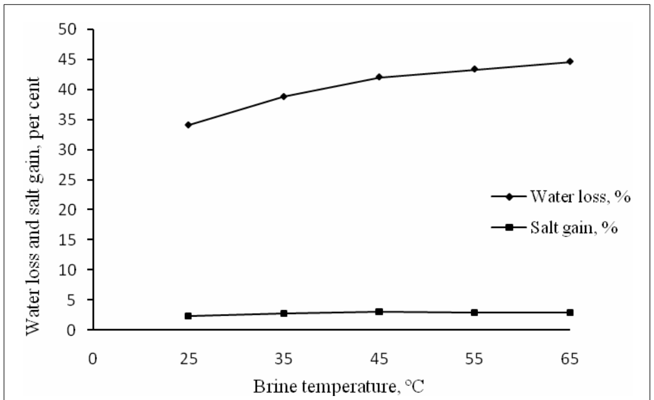

Fig. 4: Effect of brine temperature on water loss and salt gain (Conc.=15%, brine to sample ratio = 5:1 and duration =60 min)

The water loss (WL) and salt gain (SG) in mushroom samples were co-related with brine temperature (T) as follows:

$$WL = -0.633\ T^2 + 7.629\ T + 21.49 \quad ......(11)$$

$$R^2 = 0.99$$

$$SG = -0.096\ T^2 + 0.911\ T + 0.919 \quad ......(12)$$

$$R^2 = 0.96$$

Levels of input parameters :

Based on the results of preliminary investigations on water loss and salt gain (Table 1 to 4), the ranges of input parameters were fixed for further experimentation of optimization as shown in Table 5. Among these, the brine to sample ratio was taken as constant at 5:1 level, which was also suggested by various researchers for various fruits and vegetables (Kar and Gupta, 2001; Pokharkar and Prasad, 2002; Pisalkar *et al*., 2008; Borkar *et al*., 2011). However, the ranges of the other parameters namely, brine temperature; salt concentration and duration of osmosis were selected and optimized on the basis of salt gain. The optimum salt gain was decided on the basis of consumer's taste panel.

Table 5 : Process parameters selected for further investigations

Process parameters	Levels
Brine temperature	35, 45 and 55°C
Brine concentration	10, 15 and 20%
Duration of osmosis	30, 45 and 60 min

Conclusion :

It was concluded that by increasing the value of process variables, the response (water loss and salt gain) was increasing, but the rate of increase was found to be decreased at later stage. The upper level of the input variables (brine temperature, salt concentration and duration of osmosis and brine to sample ratio) was decided at that point from which there was negligible change (increase) in response (water loss and salt gain). The lower and middle level of the input variables were chosen logically on the similar lines as described by earlier researchers (Pokharkar, 1994; Jain, 2007; Borkar *et al*., 2011).

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■ REFERENCES

Borkar, P.A., Verma, R.C., Jain, S.K. and Sharma, G.P. (2011). Osmo-convective dehydration of Aloe-vera. Ph.D. Thesis, CTAE, Maharana Pratap University of Agriculture and Technology, Udaipur, RAJASTHAN (INDIA).

Giri, S.K. and Prasad, S. (2007). Drying kinetics and rehydration characteristics of microwave-vacuum and convective hot-air dried mushrooms. *J.Food Engg.,* **78**: 512-521.

Jain, S.K., Verma, R.C., Murdia, L.K., Jain, H.K. and Sharma, G.P. (2011). Optimization of process parameters for osmotic dehydration of papaya cubes. *J. Food Sci. Technol.,* **48**(2): 211-217.

Jain, S.K. (2007). Studies on osmotic and air drying of papaya. Ph.D. Thesis, CTAE, Maharana Pratap University of Agriculture and Technology, Udaipur, RAJASTHAN (INDIA).

Jayaraman, K.S. and Gupta, D.K. (1992). Dehydration of fruit and vegetables-recent development in principles and techniques. *Drying Technol.,* **10**: 1-50.

Kaleemullah, S., Kailappan, R. and Varadharaju, N. (2002). Studies an osmoticair drying characteristics of papaya cubes. *J. Food Sci. & Technol.,***39**(1):82-84.

Kar, A. and Gupta, D.K. (2001). Osmotic dehydration characteristics of button mushroom. *J.Food Sci.& Technol.,* **40**(1): 23-27.

Lal Kaushal, B.B. and Sharma, K.D. (1995). Postharvest technology of mushroom. *Adv. Hort.,* **13**: 553-565.

Lenart, A. and Flink, J.M. (1984). Osmotic concentration of potato. II Spatial distribution of the osmotic effect. *J. Food Technol.,* **19**:65-89.

Pisalkar, P., Jain, N.K. and Jain, S.K. (2008). Convective and osmo-convective drying of aloe vera gel. M. Tech. Thesis, CTAE, Maharana Pratap University of Agriculture and Technology, Udaipur, RAJASTHAN (INDIA).

Pokharkar, S.M. (1994). Studies on osmotic concentration and air drying of Pineapple slices. Ph.D.Thesis, Indian Institute of Technology, Kharagpur, W.B. (INDIA).

Pokharkar, S. M., Prasad, S. and Das, H. (1997). A model for osmotic concentration of banana slices. *J.Food Sci.& Technol.,* **34**(4): 230-232.

Pokharkar, S.M. and Prasad, S. (2002). Air drying behaviour of osmotically dehydrated pineapple. *J. Food Sci. Technol*, **39**:384–387.

Poongkodi, G. K. and D, Sakthisekaran. (1995). Nutrient content of the mushrooms. *Madras Agric. J.,* **82**(9): 555-556.

Ranganna, S. (2000). *Handbook of analysis and quality control for fruits and vegetable products*. Tata McGraw Hill Publishing Co. Ltd., NEW DELHI, INDIA.

Sethi, V., Sahani, C.K., Sharma, K.D. and Sen, N. (1999). Osmotic dehydration of tropical temperate fruits- A review. *Indian Food Packer,* Jan- Feb. pp. 34-38.

Shahabuddin, M., Hawlader, M.N.A. and Rahman, M.S. (1990). Evaluation of drying characteristics of pine apple in the production of pineapple powder. *J. Food Proc.& Preservation,* **14**:375-391.

Silveira, E.T.F., Rahman, M.S. and Buckle, K.A. (1996). Osmotic dehydration of pineapple: kinetics and product quality. *Food Res. Internat.,* **29**(3-4):227-233.

Shukla, B.D. and Singh, S.P. (2007). Osmo-convective drying of cauliflower Mushroom and Greenpea. *J. Food Engg.,* **80**:741-747.

Torringa, E., Esveld, E., Scheewe, (I), Van. Den. Berg. R. and Barlets, P. (2001). Osmotic dehydration as a pre-treatment before combined microwave hot air drying of mushrooms. *J.Food Engg.*, **43**(2): 185-189.

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