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EVALUATION OF MASS TRANSFER DURING OSMO-CONVECTIVE DRYING OF *BENINCASA HISPIDA* CUBES IN SALT SOLUTION USING REGRESSIONAL-DESIRABILITY METHOD

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ABSTRACT

Regressional-desirability approach in Box-Behnken response surface design was employed in this study to examine and optimize the osmotic dehydration process of *Benincasa hispida* cubes by impregnating in salt solution as an osmotic agent. The effect of independent parameters such as, concentration of solution (1-5%), sample to solution ratio (1:5-1:15 g/ml), temperature of osmotic solution (30-50°C) and time of immersion (30-180 min) on the weight reduction (WR), solid gain (SG), water loss (WL), rehydration ratio (RR) and shrinkage (SH) were studied. Second order polynomial mathematical models were developed for the responses and all the independent process variables have considerable consequence on the responses. The optimal dehydration process condition was found by regressional-desirability method and were: osmotic solution concentration of 2.73%, sample to solution ratio of 1:14 g/ml, osmotic solution temperature of 50°C and osmotic dehydration time of 179 minutes with the mass transfer and quality properties such as weight reduction of 24.59%, solid gain of 7.69%, water loss of 32.28%, rehydration ratio 11.43%, shrinkage 8.58% and overall acceptability 8.19. The optimized samples were subjected to convective drying in cabinet tray dryer at different drying air temperatures (40, 50 and 60°C). The results indicated that the osmotic pre-treatment of the samples using salt solution was better in terms of water removal and reduction in the processing time when combined with convective drying process. Also, the quality of the final product was found to be good for the osmo-convective dried product using salt solution.

Keywords: *Benincasa hispida,* Osmotic dehydration, Mass transfer, Desirability method, Model, Convective drying

INTRODUCTION

Plant-based food materials are very essential in supplying nutrition and maintaining the health and wellness of human beings. They are considered as the suppliers of important sources such as vitamins, minerals, flavour to human diet. Their varied aroma and structure make the diet more appetizing and palatable with pleasing taste. The nutritional value of the fruits and vegetables in human diet is comprehended by the dietary fibre which comprises of celluloses, hemicelluloses, pectic substances and lignin.

The fruits and vegetables constitute about 80 percent of moisture which forces them to be highly perishable in nature. Because of this high moisture level, they cannot be stored at ordinary conditions for a long period which leads to heavy losses of the product due to poor handing, insufficient cold storage facilities and transportation apart from the water loss and decay losses (**Jayaraman & Gupta 2006; Kaya *et al*,. 2007**). Since the fruits and vegetables are highly perishable commodity, spoilage of them occurs in larger quantities. They are sold at much cheaper rates at the time of glut period and the farmers become the victims of severe monetary losses. Hence, enhancing the shelf life of these fruits and vegetables not only prevents the wastage but also makes it available even during off season at reasonable price (**Singh *et al.*, 2007**).

In Southeast Asia, *Benincasa hispida* (Ash gourd) is considered as one of the most popular vegetable because of its economic importance, nutritive value and biological activities (**Sathishsekar & Subramanian, 2005; Budrat & Shotipruk, 2008**). The major constituent of *B. hispida* is moisture and it also contains petite quantities of protein, carbohydrates, fat and fibre, minimal amount of phosphorous, calcium, iron, riboflavin, thiamine, niacin and Vitamin C (**Randhawa *et al.*, 1983**). It is also reported that *B. hispida* contains low level of sodium and high level of potassium with low calorific value along with many amino acids (**Gopalan *et al.*, 2004**). It has numerous medicinal values and can be used as diet food for **diabetics, curing peptic ulcer and acts as blood coagulant. The vegetable is regarded f**or the preparation of various food materials of culinary nature and for making variety of products by value addition. Because of its high moisture content and perishability, a large quantity of the produce is spoiled and renders financial loss to the producer. Hence, preservation of this vegetable by adopting suitable preservation technique has become necessary for the prevention of huge spoilage.

Osmotic dehydration process is one of the promising pre-treatment techniques and has received considerable attention now-a- days. This method can be conveniently coupled with other drying methods as it reduces the initial water content which subsequently shortens the total processing time, reduction in energy consumption and food quality enhancement (**Torreggiani, 1993; Karathanos *et al.*, 1995; Jayaraman & DasGupta, 2007**). Apart from these advantages, the process also retains natural colour, volatile aromas and inhibits enzymatic browning during the ensuing air drying process (**Pokharkar *et al.*, 1998**). Osmotic dehydration process is basically a non-thermal process where the dehydration from the sample occurs through impregnation process and it has the ability of minimizing the negative changes of fresh food constituents due to the pressure difference between hypertonic and hypotonic materials. In this process, water from the hypotonic material is leached out and solute is transferred from hypertonic solution to hypotonic material (**Rastogi *et al.*, 2002; Shi *et al.*, 2009;** Samborska ***et al.*, 2019**).

Osmotic dehydration of various fruits and vegetables has been studied by many researchers. But very few attempts have been made to study the osmo-convective drying of *B. hispida* (**Sudhir *et al.*, 2009; Thankitsunthorn *et al.*, 2009; Alam *et al.*, 2010; Prajapati *et al.*, 2011; Jie Chen *et al.*, 2013; Sarveshkumar *et al.*, 2015**). In this current research work, the effect of independent parameters such as osmotic solution concentration (salt), sample to solution ratio, osmotic solution temperature and osmotic time on the responses such as weight reduction, solid gain, water loss and quality features (rehydration ratio, shrinkage and overall acceptability) of *B. hispida* cubes in salt solution during osmo-convective drying process were investigated by applying four factors three levels BBD using regressional desirability method.

MATERIALS AND METHODS

Raw Material

Fresh *B. hispida* (Ash gourd) was purchased in a local market near Coimbatore, TamilNadu, India. The vegetable was selected based on uniform size, shape and maturity. They were cleaned in tap water in order to eliminate the extraneous matter remaining over the surface. With the help of sharp stainless steel knife, the samples were peeled off manually and then cut into cubes (10 mm x 10 mm x 10 mm). The raw materials were kept in refrigerated condition prior to experimental analysis. The initial quantity of moisture present in the sample was estimated by using hot air oven method **(AOAC, 2000)** and it was found to be 94% (wb).

Preparation of Osmotic Solution

Food grade salt was procured from a market situated at Coimbatore, TamilNadu, India and was used as the osmotic agent. Osmotic solution was prepared by dissolving required quantity of salt (1, 3 and 5% w/w) in distilled water. Stirring was performed with a ladle to dissolve the osmotic agent completely.

Osmotic Dehydration Experiment

A known weight of sample was immersed in the Erlenmeyer flasks containing required quantity of osmotic solution with different concentrations and kept at various temperature conditions ranging from 30 to 50°C in a water bath with temperature control. During the conduction of experiments, the Erlenmeyer flasks were covered with a plastic cover with the purpose of eliminating the evaporation of osmotic solution. The experiments were carried out at various concentrations of osmotic solution (1-5% w/w), sample to solution ratio (1:5-1:15 g/ml), temperatures (30-50°C) and osmotic time for immersion (30-180 minutes). The samples were taken off from the hypertonic osmotic solution at specified time interval and weights were measured after wiping the adhered solution with filter paper. Triplicate experiments were performed in all experimental conditions, mean value was estimated, and used to determine the mass transfer properties (water loss, solid gain and weight reduction) (**Tiroutchelvame *et al.*, 2015**).

Experimental Design

RSM is one of the easy and effective statistical modeling tool used for designing experiments, collection of experimental data, investigating the interaction and influence of the effects of each process variable on the responses and develop an equation which could describe the outcome of the independent variables on the responses. RSM will also establish relationships among the process variables and correspond to the common effect of all process (independent) variables in any dependent variable (**Prakashmaran *et al.*, 2012; Bialik *et al.*, 2018**). Box-Behnken Design (BBD) with three levels, four factors was applied in the work to design the experiments. Independent process variables selected for the optimization of the osmotic dehydration were: concentration of osmotic solution (X_1), sample to solution ratio (X_2), osmotic temperature (X_3) and osmotic dehydration time (X_4). Coding of each independent process variables at three level (+1, 0 and -1) was carried out as per the equation mentioned below:

$$x_i = \frac{x_i - x_{cp}}{\Delta x_i} \quad i = 1, 2, 3.......k \tag{1}$$

where x_i, value of an independent variable (dimensionless); x_i, real value of an independent variable; x_{cp}, real value of an independent variable at the centre point; and Δx_i, step change of real value of the variable *i* corresponding to a variation of a unit for the dimensionless value of the variable *i*. The experimental design of the process is furnished in Table 1.

Performance evaluation of osmotic dehydration process was completed by evaluating the responses (Y), which are dependent on the process independent factors ($x_1, x_2..., x_k$) and the association among responses and input process independent factors is ascribed by the equation,

$$Y = f\left(x_1, x_2........x_k\right) + e \tag{2}$$

Where, "*f*" is the real response function and the format of which is unknown and "*e*" describes the differentiation error.

Quadratic model was utilized in this study to develop mathematical model for responses and the generalized form of the model mentioned below

$$Y = \beta_0 + \sum_{j=1}^{k} \beta_j x_j + \sum_{j=1}^{k} \beta_{jj} x_j^2 + \sum_{i} \sum_{<j=2}^{k} \beta_{ij} x_i x_j + e_i \tag{3}$$

where, Y is the response; x_i and x_j are variables (*i and j range from* 1 to *k*); β_0 is the model intercept coefficient; β_j, β_{jj} and β_{ij} are interaction coefficients of linear, quadratic and the second-order terms, respectively; *k* is the number of independent parameters (k= 4 in this study); and e_i is the error.

Statistical analysis of observed data was performed using Statease design expert software (Statease Inc., Minneapolis, USA) and analysis of variance (ANOVA) tables were derived for each response in order to identify the significance of the independent variables over the responses. Response surface graphs (3D) were plotted from the developed mathematical models and were used to evaluate the influence of independent process variables on the dependent response variables.

Determination of Mass Transfer Properties

During osmotic dehydration process, both water loss and solid gain take place simultaneously. The reduction in mass is ascribed by the loss of water from the sample and raise in the mass of the sample is due to solute gain from the osmotic solution. The properties of osmotic dehydration process were estimated by dependent variables such as weight reduction (WR), solid gain (SG) and water loss (WL) and were calculated using following equations **(Tiroutchelvame *et al.*, 2015)**:

$$WR(\%) = \frac{W_0 - W_t}{W_0} \times 100 \tag{4}$$

$$SG(\%) = \frac{S_t - S_0}{W_0} \times 100 \tag{5}$$

$$WL(\%) = \frac{W_0 S_0 - W_t S_t}{W_0} \times 100 \tag{6}$$

where, W_0 is the initial weight of sample (g), W_t is the weight of sample for any time 't' after osmotic dehydration (g), S_0 is the initial dry weight of sample (g), and S_t is dry weight of sample for any time 't' after osmotic dehydration (g).

Quality Characteristics of the Osmotically-Dehydrated Samples

Rehydration ratio

Rehydration ratio is the difference between the initial weight of the dehydrated and rehydrated sample. The rehydration ratio of osmotically dehydrated samples was estimated by immersing known amount of osmotically dehydrated samples in water (50 ml) and kept at normal room temperature until the constant weight was attained **(Mazza, 1983)**. The rehydration ratio was computed from the equation mentioned below.

$$RR(\%) = \frac{\text{Weight of rehydrated sample(g)}}{\text{Weight of dehydrated sample(g)}} \times 100 \tag{7}$$

Shrinkage

Shrinkage (SH) of the dehydrated sample was determined by using the following equation,

$$SH(\%) = \left(1 - \frac{V_i}{V_0}\right) \times 100 \tag{8}$$

where, V_i is volume of water displaced by dehydrated sample and V_0 is volume of water displaced by fresh sample (**Lozano *et al.*, 1980**).

Evaluation of overall acceptability

The overall acceptability of osmo-dehydrated samples at optimized condition was evaluated by hedonic scale (9-point), from like extremely (9) to dislike extremely (1) (**Resurreccion, 1998**). The acceptability was performed with a team of panel members and appraised the texture, odour, colour and taste of the samples. From the individual scores of the panelists, the average value of overall acceptability was computed.

Optimization of osmotic dehydration process parameters

In the present study, numerical optimization method using Derringer's desired function methodology was adopted to optimize the osmotic dehydration process conditions. To exploit and convert the responses into dimensionless desirability (d_i) value, the following equation was used,

$$d_i = \frac{Y_i - Y_{min}}{Y_{max} - Y_{min}} \tag{9}$$

where, Y_i is the value of the obtained response, Y_{min} is the minimum value of the obtained response and Y_{max} is the maximum value of the obtained response.
The overall value of desirability function (D) was attained with the help of the following equation

$$D = (d_1^{n_1} \times d_2^{n_2} \times d_3^{n_3} \times .... \times d_k^{n_k})^{1/k} \quad (10)$$

where, d_i is the individual desirability value of the individual response, k is the no. of considered responses, and n_1 is the weight of each response. A weight factor of 1 was chosen for all individual desirability in this work. The "importance" of a goal can be changed in relation to the other goals. It can range from 1 (least importance) to 5 (most important). The default is for all goals to be equally important in a setting of 3.

Convective Drying

Convective drying method using tray drier was performed for the optimized osmotically dehydrated sample. The samples were weighed and spread uniformly in perforated aluminum trays as a single layer and dried at different levels of temperatures (40, 50 and 60°C) and at constant air velocity of 1.5 m/s in a tray drier. The reduction in weight of osmotically treated samples was noted at an interval of 30 minutes and continued until the constant weight was obtained. Similar experiments were performed for each temperature. Triplicate experiments were carried out at different temperatures and average value was calculated to evaluate the drying characteristics of the samples.

Drying characteristics of osmo-convective samples

Moisture content

The moisture content (MC) of the sample at any time 't' was calculated by using the initial quantity of moisture present in the dried and bone dry weight of the sample and the following formula was utilized to calculate the moisture content.

$$MC = \frac{M_t - M_d}{M_i} \times 100 \quad (11)$$

where, M_i is the mass of sample before drying, M_d is mass of sample after drying and M_t is the mass of sample at any time't'.

Moisture ratio

The moisture ratio was calculated by transforming the MC of sample at any drying time (t) and it was calculated by the method described by **Hosain *et al.* (2014)**.

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (12)$$

where, MR is the moisture ratio (dimensionless); M_t is the moisture content at any time 't' (kg water/kg dry matter); M_e is the equilibrium moisture content (i,e. the constant value of moisture level that was attained during drying) (kg water/kg dry matter) and M_0 is the initial moisture content (kg water/kg dry matter).

RESULTS AND DISCUSSION

Mass transfer properties of ash gourd during osmotic dehydration

Effects of process variables on weight reduction

The effect of independent parameters such as osmotic solution concentration, sample to solution ratio, osmotic solution temperature and osmotic time on the responses such as weight reduction, solid gain, water loss and quality features (rehydration ratio, shrinkage and overall acceptability) of *B. hispida* cubes during osmotic dehydration process were investigated by applying four factors three levels BBD. The experimental design of the process and the responses is furnished in Table 1.

Table 1 Box-Behnken design matrix and observed values of responses for *B. hispida* cubes in salt solution

	Independent Variables				**Dependent Variables**				
	Conc. (%)	**SS Ratio** (g/ml)	**Temp** (°C)	**Time (min)**	**WR(%)**	**SG(%)**	**WL(%)**	**RR(%)**	**SH(%)**
Run	X_1	X_2	X_3	X_4	Y_1	Y_2	Y_3	Y_4	Y_5
1	3	1:10	50	180	29.63	16.47	46.1	17.37	13.47
2	3	1:5	50	105	23.99	10.81	34.8	11.74	8.78
3	1	1:10	50	105	27.38	14.18	41.56	15.13	11.60
4	3	1:10	40	105	35.80	22.06	57.86	22.98	18.14
5	3	1:10	50	30	27.39	14.21	41.6	15.14	11.61
6	3	1:5	40	180	23.41	10.21	33.62	11.15	8.28
7	3	1:15	30	105	10.28	0.72	11	3.13	1.60
8	1	1:15	40	105	18.28	5.13	23.41	6.02	4.01
9	3	1:15	40	180	19.85	0.58	20.43	7.59	5.32
10	1	1:10	40	30	21.08	8.48	29.56	8.25	5.87
11	1	1:5	40	105	18.85	5.71	24.56	6.60	4.49
12	5	1:15	40	105	23.83	10.08	33.91	9.94	7.28
13	5	1:10	30	105	27.15	14.01	41.16	14.90	11.41
14	3	1:10	40	105	35.80	22.05	57.85	22.98	18.14
15	3	1:10	30	30	23.24	10.05	33.29	10.98	8.15
16	3	1:5	40	30	22.79	9.57	32.36	10.52	7.76
17	5	1:10	50	105	31.86	18.58	50.44	20.80	16.33
18	3	1:10	40	105	35.25	22.6	57.85	22.98	18.14
19	1	1:10	40	180	20.49	7.29	27.78	8.24	5.86
20	3	1:15	50	105	27.38	14.2	41.58	15.13	11.60
21	1	1:10	30	105	12.60	2.3	14.9	3.17	1.63
22	5	1:10	40	30	28.89	15.69	44.58	16.64	12.86
23	3	1:10	40	105	35.24	22.04	57.28	22.98	18.14
24	3	1:5	30	105	22.91	9.71	32.62	10.65	7.87
25	5	1:10	40	180	29.81	16.65	46.46	17.56	13.63
26	3	1:15	40	30	22.69	9.13	31.82	11.80	8.25
27	5	1:5	40	105	28.51	15.29	43.8	16.24	12.53
28	3	1:10	40	105	35.21	22.02	57.23	22.98	18.14
29	3	1:10	30	180	19.81	6.65	26.46	7.55	5.28

The changes that occurred in weight reduction due to the effect of process variables during the impregnation of *B. hispida* cubes in salt solution are indicated in Figure 1. It was clearly perceived from the figure that progress in concentration, sample to solution ratio, temperature and time for immersion caused an improvement in weight reduction up to a maximum level and then slowed down even with the increase of the process parameters.
During the osmotic dehydration of *B. hispida* cubes, the highest weight reduction occurred at 110 minutes at a temperature range of 30 to 45°C. The corresponding concentration of salt solution was found to be 4.5% (sample to solution ratio 1:11). The 3D plots showed a declining trend after this maximum limit. The enhancement in weight reduction of the samples up to the maximum limit might be due to the development of high osmotic potential between the solution and the semi-permeable membrane of the plant tissue (**Lenart & Flink, 1984**). The increase in weight reduction might also be due to the reason that the molecular weight of the solute might have strongly influenced an increase in the driving force which affected the rate of weight reduction till the attainment of equilibrium level (**Lerci *et al.*, 1985; Panagiotou, 1999**). As the dehydration process progressed, the osmotic stress might have caused some damages in the

structure of the samples which could have compressed the surface layers and thereby created confrontation for water transport phenomena (**Singh *et al.*, 2007; Tiroutchelvame *et al*., 2019)**.

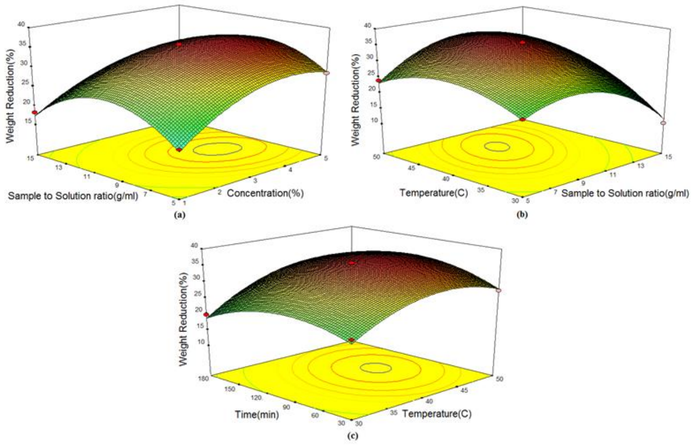

Figure 1 Effect of process variables on weight reduction of *B. hispida* cubes

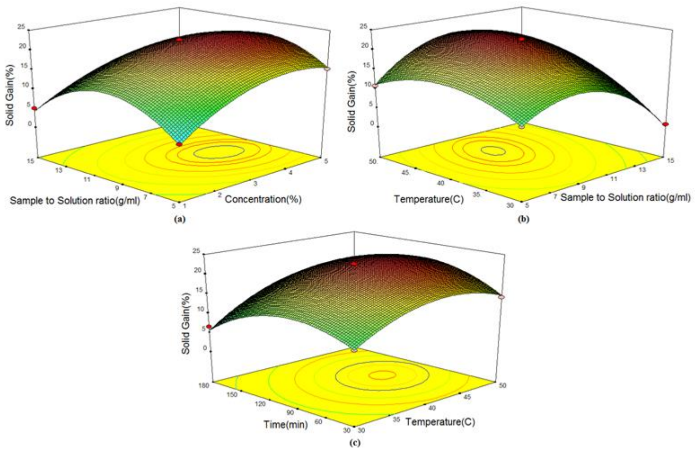

Figure 2 Effect of process variables on solid gain of *B. hispida* cubes

Effects of process variables on solid gain

The rate of solid gain in *B. hispida* cubes treated with salt under various process conditions are pictorially depicted in Figure 2. The higher level of solid gain was attained at 4.7% concentration, 1:11.5 sample to solution ratio, 45°C and 110 minutes. This revealed a positive relationship between process parameters and the observed responses. The trend of the plots approached equilibrium and then showed a declining trend. It can be seen that the solid gain was increasing with respect to sample to solution ratio, temperature of osmotic solution and duration of osmosis. It may be due to the collapse of the cell membrane at higher temperatures and transfer of solutes with increase in the volume of the solution. This is in confirmation with the research findings of other researchers (**Hawkes & Flink, 1978; Conway *et al*., 1983; Nieuwenhuizen *et al*., 2004; Rodriguez *et al.*, 2019**). The figure also indicated that the solid gain was affected by a slightly greater temperature or by increasing the volume of the solution. This affirms that solid gain can be enhanced either by increasing the salt solution temperature or concentration of solution or sample to solution ratio (**Videv *et al.*, 1990; Pokharkar & Prasad, 1998**).

The increase in the level of process parameters beyond the equilibrium level exhibited a negative trend because the viscosity of the osmotic solution might have decreased at higher temperatures. It is also attributed due to the prolonged osmotic time of contact between the solution and the cellular structure of the vegetable beyond the equilibrium level has filled the pore spaces of the tissues and unavailability of pores for the solids to penetrate inside (**Barat *et al.*, 2001; Singh *et al.*, 2007**).

Effects of process variables on water loss

The effect of process variables on water loss is illustrated in figure 3 a 3D contour plots and it was apparent that the independent variables had a visible effect on the dependent process parameters. From the figure, it can be observed that the water loss increased with the increase in concentration of solute, sample to solution ratio, temperature and osmotic dehydration time. Maximum water loss was obtained for 4.5% solution concentration, 1:11.5 sample to solution ratio, 42°C temperature and 115 minutes time. This is in confirmation with the results obtained by the other researchers.

The water loss was found to increase gradually due to the osmotic effect with the increase in the level of the osmotic solution concentration up to a solute concentration of 4.5%. This indicated that a slight incremental variation in the concentration of the osmotic solution increase the water loss. It is reported that higher concentration of the solution increase the osmotic pressure which obviously resulted in the increase of driving force that is needed for the moisture migration (**Lenart & Flink, 1984; Rastogi & Raghavarao, 1997; Barat *et al.*, 2001**). However, further increase in solute concentration beyond maximum level indicated a negative trend which can be visualized by the convex shape of the curve. The reduction in water loss might be due to the solids gained by the samples and the concentration equilibrium attained between the samples and the solution through the semi-permeable membrane (**Rahman & Lamb, 1990**).

Apart from the concentration of the solution, the water loss was also affected by the sample to solution ratio, temperature of the osmotic solution and duration of osmosis. The increase in water loss could be due to the changes in semi-permeability of the cell membrane in the sample which allowed more water to seep out in a shorter period (**Conway *et al*., 1983; Kar & Gupta, 2003**). Besides, at elevated temperatures, the viscosity of the solution also decreased and it caused setting of convection currents in the solution and in turn eliminated local dilution and favoured osmosis (**Sodhi *et al.*, 2006; Dermesonlouoglou & Giannakourou, 2018**).

From the figure 3, it could be seen that the osmotic solution temperature induced higher water loss from the sample. The increase in water loss up to a solution temperature of 44°C may be due to the fact that higher temperatures make the samples to swell and plasticize the cell membrane and enable the membrane to favour permeability for water to escape out of the product and increased the water transfer attributes on the surface of the product (**Contreras & Smyral, 1981; Saputra, 2001**). The decreasing trend might be due to the reason that at a higher temperature of the solution beyond the acceptable limit might have affected the semi-permeability of the cell walls by disrupting the cell walls of the sample tissue and thereby reduced the water loss (**Yao & Le Maguer, 1996; Park *et al.*, 2002**).

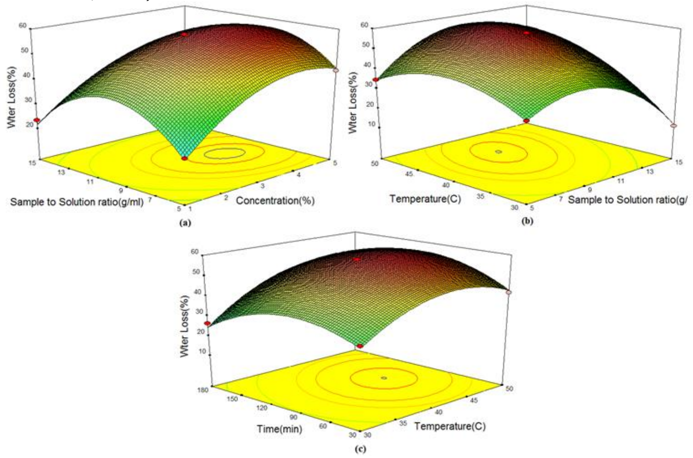

Figure 3 Effect of process variables on water loss of *B. hispida* cubes

Quality characteristics of *B. hispida* during osmotic dehydration

Effects of process variables on rehydration ratio

Rehydration ratio is an important indicator to measure the water absorption by dehydrated product. The changes in rehydration ratio for the different process variables are presented in Table 1. The effects of independent variables (salt concentration, sample to solution ratio, solution temperature and osmotic dehydration time) on rehydration ratio are represented in response surface plots (Figure 4). From the figure it is visualized that the rehydration ratio generally increased with the increase of the process variables. However, after the central points of the processing parameters, the rehydration ratio was found to reduce which is exhibited by a slight convex trend of the response surface plot. Maximum value of rehydration ratio was obtained at 4.7% solution concentration, 1:12 sample to solution ratio, 44°C temperature and 110 minutes of immersion time.

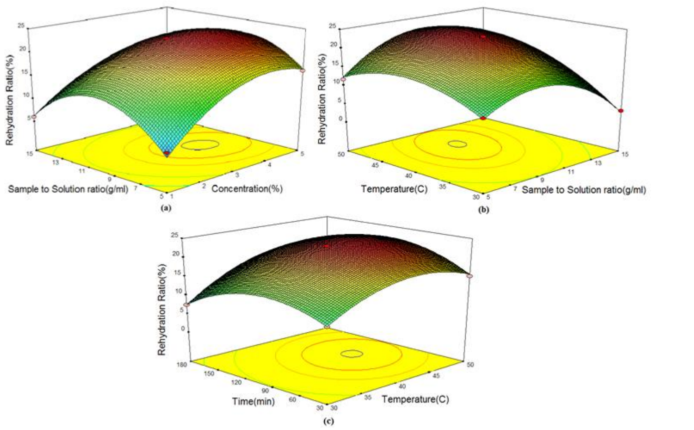

Figure 4 Effect of process variables on rehydration ratio of *B. hispida* cubes

The increase in process variables upto the central point resulted in increased rehydration ratio which might be due to the loosening of the cell structure with more permeability for water. This might have augmented the intrusion of water thereby increasing the rehydration ratio during the initial stages (**Prothon *et al.*, 2001**). The reduction in rehydration ratio might be due to the coating over the surface of cytoplasm of the samples by sugar and salt molecules which resulted in the formation of a dense superficial layer that could have actually diminished the absorption of water (**Nsonzi & Ramaswamy, 1998**).

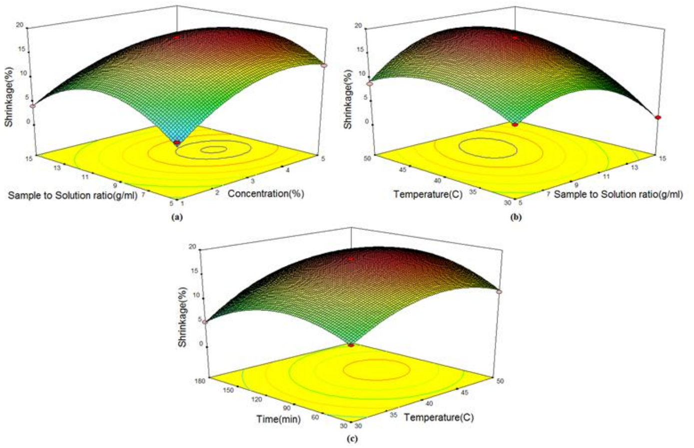

Figure 5 Effect of process variables on shrinkage of *B. hispida* cubes

Effects of process variables on shrinkage

The effect of process parameters on the shrinkage of *B. hispida* cubes during the osmotic dehydration process is presented in Table 1. The effects are also represented in figure 5 as 3D and contour plots. The shrinkage of the samples increased gradually with the raise in the values of process parameters till the reach of maximum values. A maximum value of shrinkage was obtained at 4.5% solution concentration, 1:12 sample to solution ratio, 43℃ temperature and 110 minutes of immersion time. During the initial stages of osmotic dehydration process more quantity of water was removed from the sample and this continued till equilibrium level was achieved. Also, the stresses developed in osmotic dehydration could have played a major role in water removal. This might be the possible reason for the increase in shrinkage during initial stages (**Demirel & Turhan, 2003**). The decrease in the shrinkage may be due to the fact that the solid gain might have occupied the pore spaces of the sample pieces and prevented the further shrinking of the material (**Mayor *et al.*, 2011**).

Organoleptic evaluation of the samples

The overall acceptability data of the *B. hispida* cubes treated in salt solutions at optimized conditions were found by organoleptic evaluation. From the results the maximum acceptability was observed for the samples was 8.19. The increase in acceptability for the samples treated with salt solution might be due to the intrusion and formation of coating over the surface by the solutes which improved the taste and colour (**Suresh kumar & Sagar, 2009**).

Model development

Box-Behnken Design (BBD) was applied in the design of experiments to study the effect of process variables on the response function. The experimental conditions for the osmotic dehydration of *B. hispida* and salt as the osmotic agent and their corresponding mass transfer and responses are presented in Table 1. Performance of the process was evaluated by analyzing the responses (Y), which depends on the input factors X_1, X_2, X_3 and X_4. A second order polynomial mathematical equation was used to fit the experimental data obtained from BBD. The purpose was to construct empirical models to articulate the association between independent process variables and the responses. The final empirical models obtained in the form of coded factors are given in Table 2.

Table 2 Models developed with coded dependent variables for *B. hispida* cubes

Response	Developed Model
WR	$35.46+4.18X_1-1.37X_2+4.26X_3-1.34X_1X_2-2.48X_1X_3+4.26X_2X_3$ $-0.73X_2X_4+1.59X_3X_4-7.64X_1^2-8.13X_2^2-5.64X_3^2-6.12X_4^2$
SG	$21.35+3.83X_1-1.77X_2+3.75X_3-1.18X_1X_2-1.63X_1X_3+3.09X_2X_3$ $-2.30X_2X_4+1.47X_3X_4-4.64X_1^2-8.67X_2^2-4.72X_3^2-5.69X_4^2$
WL	$57.82+8.12X_1-2.89X_2+7.87X_3-2.56X_1X_2-4.45X_1X_3+6.12X_2X_3$ $-3.47X_2X_4+3.43X_3X_4-8.70X_1^2-15.78X_2^2-9.73X_3^2-9.79X_4^2$
RR	$22.98+4.76X_1-1.64X_2+3.62X_3-1.43X_1X_2-1.52X_1X_3+2.43X_2X_3$ $-1.37X_2X_4+1.52X_3X_4-5.47X_1^2-7.74X_2^2-4.97X_3^2-4.78X_4^2$
SH	$18.24+3.78X_1-0.76X_2+3.57X_3-1.26X_1X_2-1.21X_1X_3+2.37X_2X_3$ $-0.76X_2X_4+1.28X_3X_4-3.27X_1^2-5.78X_2^2-3.64X_3^2-4.58X_4^2$

The adequacy and fitness of the model was checked by calculating the coefficient of determination (R^2) and adj-R^2. The coefficient of determination (R^2) gives the proportion of the total variation in the responses predicted by the developed models and R^2 value close to 1 is desirable and a reasonable agreement with adjusted R^2 (adj-R^2) is necessary. The values of R^2 were found to be greater than 0.98 (Table 3), which implied that 98% of experimental data was compatible. The adj-R^2 value corrects the R^2 value for the sample size as well as for the number of terms in the model. The value of adj-R^2 was found to be very nearer to R^2 (Table 3) and it also advocates a high significance of the model. The coefficient of variance (CV %) is the ratio of the standard error of estimate to the average value of the observed response defined by the reproducibility of the model. The CV % values for all responses were found to be very low (Table 3) and apparently point out a very high degree of accuracy and a good reliability of the values obtained from the experiments. Adequate Precision measures the signal to noise ratio and a ratio greater than 4 is desirable. The higher adequate precision values indicated that adequate signals for the models can be used to navigate the design space.

Table 3 ANOVA for the response variables for *B. hispida* cubes

Source	DF	WR	SG	WL	RR	SH
		p value	*p* value	*p* value	*p* value	*p* value
Model	14	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
X_1	1	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
X_2	1	< 0.0001	< 0.0001	< 0.0001	0.0013	0.0005
X_3	1	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
X_4	1	0.3670	0.0242	0.0326	0.2639	0.3189
X_{12}	1	0.0491	0.0465	0.0115	0.0098	0.0061
X_{13}	1	0.0001	0.0039	< 0.0001	0.0069	0.0042
X_{14}	1	0.4418	0.3279	0.2440	0.6326	0.6058
X_{23}	1	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
X_{24}	1	0.0912	0.0007	0.0009	0.0242	0.0346
X_{34}	1	0.0101	0.0183	0.0021	0.0105	0.0065
X_1^2	1	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
X_2^2	1	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
X_3^2	1	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
X_4^2	1	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
R^2		0.990	0.987	0.993	0.988	0.990
Adj-R^2		0.980	0.983	0.987	0.986	0.989
Pre-R^2		0.942	0.924	0.962	0.930	0.940
CV%		3.740	8.630	3.980	7.110	7.240
Adeq.Pre		34.731	29.024	42.470	29.444	31.937

Optimization of the process parameters and responses

The optimal dehydration conditions of *B. hispida* cubes during osmotic dehydration process was evolved by using RSM and desired function methodology, The optimal conditions for the osmotic dehydration of *B. hispida* cubes using salt solution were: osmotic solution concentration of 2.73%, sample to solution ratio of 1:14 g/ml, osmotic solution temperature of 50°C and osmotic dehydration time of 179 minutes with the mass transfer property such as weight reduction of 24.59%, solid gain of 7.69%, water loss of 32.28%, rehydration ratio 11.43% and shrinkage 8.58%. The overall acceptability was found as 8.19.

Drying characteristics of osmo-pretreated *B. hispida* samples

Moisture content

The moisture loss of convective dried *B. hispida* samples were recorded at an interval of 30 minutes and the observed data was used to calculate the moisture content during drying process. The drying time was 480 minutes for the drying temperature of 40°C whereas it took 360 minutes for 60°C of drying air temperature. It was observed that drying of *B. hispida* cubes primarily occurred in falling rate period and no constant rate period was observed at all drying temperatures(Figure 6).
The depletion of moisture depletion per hour was found to be higher at the initial stages of drying and then decrease with the increase of drying time. It should also be noted that the drying under the falling rate period indicated that the diffusion mass transfer has occurred during the initial stages of drying. Other researchers have also reported similar results for the drying studies (**Yaldiz & Ertekin, 2001; Akpina, 2006; Doymaz *et al.*, 2006**). During later stages of drying process, the moisture has to move from the inner portion of the product to the outer surface and may happen due to liquid diffusion, capillary movement, surface diffusion, gaseous diffusion, or may be related to product shrinkage. Hence, the rate of water removal has decreased during this stage.

Moisture ratio

The moisture content of the convectively dried samples has been converted to moisture ratio which is an important factor for the purpose of describing the various thin layer drying models. The changes in the moisture ratio with time at various temperatures during the drying period for the hot air drying of pretreated *B. hispida* samples are given in figure 7. From the figure, it was observed that the moisture ratio decreased continuously with time and with decrease in the moisture level of the samples. It was also seen that these curves did not indicate constant drying rate period in the drying of ash gourd and only falling rate period existed throughout the whole drying process. This specified that diffusion was the leading physical phenomenon that governed the movement of moisture in the *B. hispida* cubes. The results were in agreement with the observations obtained by other researchers on drying of various vegetables (**Ertekin, 2002; Panchariya *et al.*, 2002; Doymaz, 2009**).

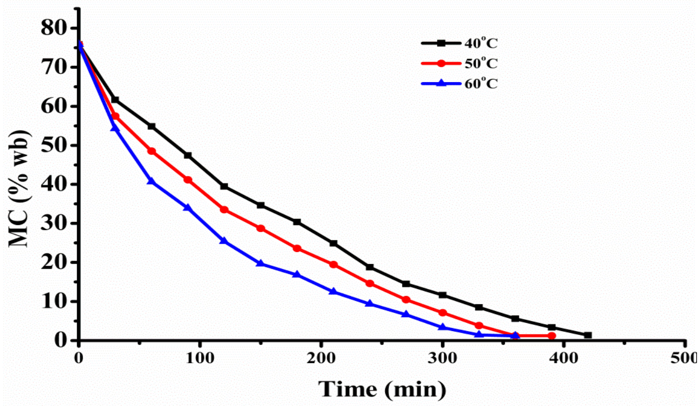

Figure 6 Variation of moisture content during osmo-convective drying of *B. hispida* samples

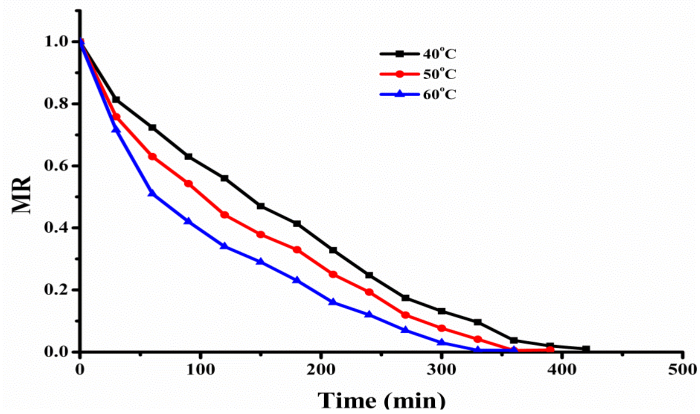

Figure 7 Variation of moisture ratio during osmo-convective drying of *B. hispida* samples

CONCLUSION

Osmotic dehydration combined with convective drying is a promising technology to obtain products of good quality. Experiments were conducted with *B. hispida* cubes immersed in salt solution under various conditions. The optimal dehydration conditions of *B. hispida* cubes during osmotic dehydration process were evolved by using RSM and desired function methodology. The optimal conditions for the osmotic dehydration of *B. hispida* cubes using salt solution were: osmotic solution concentration of 2.73%, sample to solution ratio of 1:14 g/ml, osmotic solution temperature of 50°C and osmotic dehydration time of 179 minutes with the mass transfer property such as weight reduction of 24.6%, solid gain of 7.7%, water loss of 32.3%, rehydration ratio 11.4% , shrinkage 8.6%. and overall acceptability of 8.19. From the results it can be concluded that the weight reduction, solid gain and water loss increased linearly with the increase of independent variables during the initial period and then decreased during the later period. The results indicated that the osmotic pre-treatment of the samples using salt solution was better in terms of water removal and reduction in the processing time when combined with convective drying process and enhanced the quality attributes of the final product. The osmo-convective dried product can be incorporated in powder form for the preparation of several food products.

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