Optimization of process variables for osmo-freeze drying of strawberry slices using response surface methodology

Vishal Kumar*, Pranay Kumar, Ashish Kumar

(College of Agricultural Engineering, Dr.Rajendra Prasad Central Agricultural University, Pusa, Bihar, India,- 848125)

Abstract: The production of high-quality osmo freeze-dried strawberry slices was studied by response surface methodology. The osmotic treatment and experiment were conducted using Box-Bohnken design. The low and high levels of the process variables were 40% (w/w) and 60% (w/w) for sucrose concentration of osmotic solution; Two and 4 mm for slice thickness and -10^{o}C and -30^{o}C for operating temperatures in freeze dryer. Responses studied comprised Final moisture content, colour index, water activity, rehydration ratio and overall acceptability. It was found that effects of all the process variables were significant on all responses. Optimum conditions (desirability = 0.692) obtained by numerical optimization were 51% sucrose concentration; Two mm slice thickness and -22^{o}C operating temperatures to achieve maximum rehydration ratio &organoleptic score and lower final moisture content, colour variation and water activity. Corresponding to the optimum conditions, the predicted value was 5.55% for final moisture content, colour index 68.9, water activity 0.40, rehydration ratio 3.27 and overall acceptability 6.31.

Keywords: osmotic, freeze, rehydration, hardness, colour, water activity

Citation: Kumar, V., P. Kumar, and A. Kumar. 2020. Optimization of process variables for osmo-freeze drying of strawberry slices using response surface methodology. Agricultural Engineering International: CIGR Journal, 22(3):179-189.

1 Introduction

Strawberry *Fragaria vesca* (Linn.) belongs to the family *Rosaceae* which is a widely grown hybrid species cultivated worldwide for its fruit. It is an attractive, luscious, tasty and nutritious fruit with a distinct and pleasant aroma, and delicate flavor; rich in Vitamin C and iron. Strawberries are of great interest among fruits because they have one of the highest antioxidant activities related to the high content in vitamin C and phenolic compounds, mainly anthocyanin (Wills and Kim, 1995; Carle et al., 2001; Oszmiański et al., 2009; Van Buggenhout et al., 2009; Bardonaba et al., 2010; and Kawanobu et al., 2010) .

Strawberries are very sensitive to chemical and microbial deterioration during post-harvest storage and handling, therefore, they have a rather limited shelf life in a fresh form (Duxbury, 1992). Fresh consumption of strawberry is the best way to get all its sensory, nutritional and functional properties. However, the seasonal production and/or the short shelf life; associated to its high water content, limits their availability. In this sense, strawberries can be processed by freezing and/or dehydration methods and consumed in many other forms such as juice, jam, jelly or dried fruit. The preservation of biological products by reducing their water content can be achieved by several dehydration techniques (Ghio et al., 2000; Erle and Schubert, 2001; Agnelli and Mascheroni, 2002).

In recent years, a variety of drying methods have been tried and much attention has focused on the quality of the

Received date: 2019-01-16 **Accepted date:** 2020-03-29

***Corresponding author: Vishal Kumar,** Department of Processing and Food Engineering, College of Agricultural Engineering, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, India. Email: vishal.cae@gmail.com. Tel: 91-8709635031.

products obtained by these methods (Jena and Das, 2005; Matuska et al., 2006). Some studies have been carried out into the production of conventionally air dried berry fruits such as strawberries (Alvarez et al., 1995), blueberries (Lim and Tang., 1995) or mulberries (Maskan and Gögüs, 1998) which leads to elaborate freeze-drying technology (Bonazzi et al., 1996). Lyophilization produces excellent quality products, both foodstuff and pharmaceuticals, due to the moderate temperatures at which the process takes place, contributing to the formation of highly porous solids that retain aroma, color, and flavor (Ratti, 2001; Bubnovich et al., 2011; Ceballos et al., 2012; Marques et al., 2009; Kowalska et al., 2008; Shukla, 2015; and Kunal et al., 2016). There is a need to modify the freeze-drying method so as to limit its adverse influence, especially on fragile and delicate structures.

Investigations made in recent years have proved that application of osmotic dehydration to fruit and vegetable pre-treatment yields very good results in decreasing water content in the products, and significantly increases dry mater content (Kowalska et al., 2008; Diana and Walter, 2006). Osmotic treatment has been used mainly as pre-treatment to some conventional processes such as freezing, vacuum drying, and air drying, in order to improve final quality of products, reduce energy costs, or even to develop new products (Hammami, C., and F. Rene. 1997; Escriche et al., 2000; Sereno and Hubiner, 2001; Gabriela et al., 2004; Fabiano et al., 2005; Blanda et al., 2008; and Ramya, 2017).

The aim of this study was to investigate influence of osmo-freeze dried strawberries on the chosen physical properties of the product. Various conditions of osmotic dehydration were taken into account. An attempt was made to define pre-treatment conditions before freeze-drying of strawberries which could affect rehydration and water vapour sorption of dried fruit.

2 Materials and methods

2.1 Samples preparation

The strawberries (*Fragaria Var. Camarosa*) were purchased from a popular local market of Pusa, Samastipur, Bihar, India. They were transported to the laboratory and stored at 5 ºC for 24 h. Strawberries were selected, cleaned and washed with potable water; they were subsequently cut with a hand knife into slices of three variable thicknesses of 2, 3 and 4 mm. The slices were gently blotted with absorbent paper prior to osmotic dehydration for determination of initial weight of each sample.

2.2 Osmotic pretreatment

Three sugar concentrations (40%, 50% and 60% w/w) and one salt concentration (5% w/w) were mixed to obtain different osmotic solutions for strawberry sample. These concentrations were selected as being representative of osmotic ranges recommended in various published research (Lenart and Flink, 1984a, 1984b; Lerici et al., 1985; Lenart, 1996; Singh et al., 1999; and Kumar et al., 2012). Salt was used because it retards oxidative non-enzymatic browning (Lenart and Gródecka, 1989). The effect of salt and sugar were chosen from the viewpoint of organoleptic characteristics. Potassium Metabisulphide, 0.1% by mass was added to increase storage/shelf life of product under adverse temperature conditions (Ruiz et al., 2005). The osmotic solution was used at room temperature ($30^oC±2^oC$). An experimental group consisting of strawberry samples was immersed in the osmotic solutions for 6 h. The osmotic dehydration was carried out in separate 250 mL Erlenmeyer flasks to avoid interference between the samples and runs. The osmotic solution to fruit ratio was maintained at 5:1 (weight basis). The experiment was performed with constant mechanical agitation (150 rpm) in a rotary shaker (Tecnal model TE-420), which homogenized the osmotic solution avoiding formation of local concentration gradients. After removal from the solution, the dehydrated samples from each group were drained and blotted with absorbent paper to remove excess solution (Lenart, 1996; Montserrat and Wet, 2003; Moraga et al., 2004; Piotrowski et al., 2004; Ruiz et al., 2005; Ciurzynska and Lenart, 2006; Diana and Walter, 2006; and Janowicz et al., 2007). The selected osmotically dehydrated strawberries samples as per Box-Behnken design were further dried at three independent temperatures -10°C, -20°C and -30°C in a freeze-dryer using contact heating under the pressure of 63 Pa and, safety pressure 103 Pa (Kasper and Friess, 2011). The samples were put on a sieve platform in the freeze dryer. For each time intervals of 1 hour duration, the samples were taken out one by one without replacement and their final weight measured using an electronic balance (sensitivity: 0.0001/0.1G) until equilibrium was reached.

2.3 Experimental plan and analysis of factor effects

Optimization of freeze drying process variables was carried out by applying Box-Behnken design and response surface methodology. This methodology is widely used for bioprocess optimization. RSM was known to be useful in parameter interaction studies which allowed building models and selecting optimum working ranges. The osmotically dehydrated freeze dried samples of strawberry slices were dried in the freeze dryer at three drying temperatures namely -10°C, -20°C and -30°C in accordance with experiments suggested by Behnken design. Dependent variables measured were basically the quality assessment parameters which include: final moisture content (*M*) using method described by Kumar et al. (2014); colour index (*L*) using Hunters colour LAB, water activity (a_w) using water activity meter; rehydration ratio (R_R) and overall acceptability (O_A) using method described by Ranganna (1986) in terms of sensory scores of osmo-freeze dried strawberry samples as discussed below:

Table 1 Independent variables used in the optimization.

Independent variable	Coded value		
	-1	0	1
A = sucrose concentration in osmotic solution (%, w/w)	40	50	60
B= thickness of strawberry samples (mm)	2	3	4
C = operating temperature of freeze dryer (°C)	-10	-20	-30

I. Moisture content: The total dry materials or the initial moisture content of sample was determined in accordance with AOAC (1990) method. Moisture content at different stages was determined by drying the samples in the hot air oven at 102°C± 2°C for 24 hours.

$$MC = \frac{W_m}{W_m + W_d} \times 100 \quad (1)$$

Where: W_d is the Bone dry weight (g), W_m is the Moisture evaporated (g).

Colour: The changes in colour of osmo-freeze dried strawberry samples were analyzed using Hunters colour LAB. Three Hunter parameters, namely, *L* (lightness), *a* (redness/greenness), and *b* (yellowness/blueness) were measured and total colour index was calculated by formula (Kumar et al., 2014):

$$L = \sqrt{\ } L^2 + a^2 + b^2 \quad (2)$$

$$L = \sqrt{L^2 + a^2 + b^2} \quad (3)$$

II. Rehydration ratio: The capacity of freeze-dried strawberries to rehydrate was measured by weighing about 1 g of freeze-dried product after soaking in distilled water (50°C) for different times. The rehydration coefficient (CR%) was defined as the ratio of the amount of water taken up over the total amount of water removed by freeze-drying. The maximum rehydration coefficient is obtained when soaking the product in warm water does not change its weight significantly (Ranganna, 1986).

III. Organoleptic evaluation: Consumer acceptance test was conducted using nine-point hedonic scale (Krokida et al., 2001) by a trained panellist who evaluated the product for overall acceptability (Ranganna, 1986). The samples scoring an overall quality of seven or above were considered acceptable and those receiving six or below six were considered unacceptable.

2.4 Analysis of data

The data were analyzed using Design Expert 8 (Stat-Ease, Minneapolis, MN, USA) to obtain mathematical models. RSM has been used with Box Behnken Design to optimize ohmic heating process variables. Regression analysis and analysis of variance (ANOVA) were conducted for fitting the model represented by Equation 4 to the experimental data and examine the statistical significance of the model terms.

$$Y = a_o + \sum_{i=1}^{n=3} a_i X_j + \sum_{i=1}^{n=3} \sum_{j=1}^{n=3} a_{ij} X_i X_j \quad (4)$$

Where: Y, a_0, X_i and X_j, a_i, and a_{ij} are the predicted responses of the dependent variable, second-order reaction constant, independent variables, linear regression coefficient, and regression coefficient of interactions between two independent variables, respectively.

The adequacies of the models were determined using model analysis, lack-of-fit test, and R^2 (coefficient of determination) analysis as outlined by Rustom et al. (1991), Lee et al. (2000), and Weng et al. (2001). The lack-of-fit is a measure of the failure of a model to represent data in the experimental domain at which points were not included in the regression and variations in the models cannot be accounted by random error (Montgomery, 1984). If there is a significant lack of fit as indicated by a low probability value, the response predictor is discarded. The R^2 (coefficient of determination) is defined as the ratio of the explained variation to the total variation and is a measure of the degree of fit (Haber and Runyon, 1977). Coefficient of variation (CV) indicates the relative dispersion of the experimental points from the model prediction. Response surfaces were generated and numerical optimization was also performed by Design Expert software.

2.5 Optimization technique

Numerical optimization technique of Design Expert was used for simultaneous optimization of the multiple responses. The desired goals for each factor and response were chosen. The possible goals were maximize, minimize, target, within range, none (for responses only). All the independents factors were kept within the experimental range while the responses were either maximized or minimized (Table 2). In order to search a solution for multiple responses, the goals were combined into an overall composite function, *D(x)*, called the desirability function (Myers and Montgomery, 2002) which is defined as:

$$D(x) = [d_1 X d_2 X d_3 X \ldots\ldots d_n]^{1/n} \qquad (5)$$

$$D(x) = [d_1 d_2 d_3 \ldots d_n]^{1/n} \qquad (6)$$

Where d_1, d_2, . . . ,d_n are responses and n is the total number of responses in the measure. The function *D(x)* reflects the desirable ranges for each response (*di*). Desirability is an objective function that ranges from zero (least desirable) outside of the limits to one (most desirable) at the goal. The numerical optimization finds a point that maximizes the desirability function. The goal-seeking begins at a random starting point and proceeds up the steepest slope to a maximum. There may be two or more maximums because of curvature in the response surfaces and their combination into the desirability function. By starting from several points in the design space, chances improve for finding the best local maximum.

In order to optimize the process conditions, Maximize rehydration ratio & organoleptic score. 2. Minimize final moisture content, colour variation and water activity,

Table 2 Optimum values of process parameters and responses

Constraints Name	Goal	Lower Limit	Upper limit	Importance
A = sucrose concentration (%, w/w)	is in range	-1	1	3
B= thickness (mm)	is in range	-1	1	3
C = operating temperature (°C)	is in range	-1	1	3
M	minimize	5.04	6.76	3
L	minimize	60.32	75.76	3
A_w	minimize	0.344	0.552	3
R_R	maximize	2.7	4.24	3
O_a	maximize	4.341	7.852	4

3 Results and discussion

It was seen that the total dry materials in strawberry was 10.14 g for 100 g of raw sample, thus the initial moisture content in sample was 89.86% (w.b.). The strawberries were pretreated osmotically as recommended by Kumar et al. (2012).

The experimental data of various responses are presented in Table 3. The estimated regression coefficients of the quadratic polynomial models (Equation 1 for various responses and the corresponding R^2 and CV values are given in Table Analysis of variance indicated that the models are highly significant at $p \leq 0.05$ for all the responses. The lack of fit did not result in a significant F-value in case of final *M*, *L*, a_w, R_R and O_a indicating that the models are sufficiently accurate for predicting these responses supported by low value of PRESS and CV and high values of both R^2 and adj-R^2 (≥ 0.80). Acceptable PRESS (less than 40), CV (less than 10%), R^2 (more than 0.8) and adequacy precision values indicate that the model is sufficient to predict the response (Rustom et. al, 1991).

As a general rule, the coefficient of variation should not be greater than 10%. In this case, the coefficients of variation for all the responses were less than 7% (Table 3). A Model F-value of 3.912, 5.2932, 5.9122, 2.5566 and 6.2501 for M, L, a_w, R_R and O_a respectively implies that the model is significant. The Fisher F-test with a very low probability value (P model ≥ F at 0.05) demonstrates a very high significance for the regression model. The goodness of fit of the model is checked by the determination coefficient (R^2). The coefficient of determination (R^2) was calculated to be 0.816, 0.836, 0.961, 0.884 and 0.867 for final M, L, water activity (A_w), rehydration ratio (R_R) and overall acceptability (O_a) respectively.

To visualize the combined effect of the two factors on the response, the response surface and contour plots were generated for each of the models in the function of two independent variables, while keeping the remaining independent variable at the central value (Figure 1).

Table 3 Box Behnken design matrix with calculated values of response (dependent) variables

Run	Coded Level			Independent Variables			Dependent Variables				
	X_1	X_2	X_3	Sc	H	T	M	L	A_w	R_R	O_a
1	0	1	-1	50	4	-10	6.66	68.45	0.416	3.12	6.092
2	0	1	1	50	4	-30	6.43	67.32	0.411	3.08	6.067
3	0	-1	-1	50	2	-10	5.28	62.23	0.369	4.20	7.852
4	0	-1	1	50	2	-30	5.04	60.32	0.344	4.24	7.490
5	1	0	-1	60	3	-10	5.89	66.83	0.434	3.04	6.203
6	1	0	1	60	3	-30	5.06	70.91	0.399	4.08	7.470
7	-1	0	-1	40	3	-10	6.76	75.76	0.552	2.72	4.523
8	-1	0	1	40	3	-30	6.34	72.67	0.501	2.70	4.341
9	1	1	0	60	4	-20	6.52	68.64	0.419	3.34	6.070
10	1	-1	0	60	2	-20	5.12	65.96	0.378	4.18	7.544
11	-1	1	0	40	4	-20	6.25	70.60	0.481	3.16	5.220
12	-1	-1	0	40	2	-20	6.58	67.93	0.487	3.26	5.456
13	0	0	0	50	3	-20	5.44	66.67	0.403	3.80	5.558
14	0	0	0	50	3	-20	5.57	66.54	0.411	3.76	5.523
15	0	0	0	50	3	-20	5.50	65.85	0.402	3.72	5.641
16	0	0	0	50	3	-20	5.42	65.54	0.395	3.70	5.670
17	0	0	0	50	3	-20	5.62	66.53	0.414	3.75	5.623

Table 4 Regression coefficients of the second-order polynomial model for the response variables (in coded units)

Factor	Coefficient				
	M	L	A_w	R_R	O_a
Constant	5.356	66.734	0.399	3.784	6.494
A –Sucrose content	-0.131	-1.741	0.020	0.166	0.586
B - Thickness	0.173	1.648	-0.019	0.391	-0.396
C – Operating temperature	-0.471	-2.799	-0.047	0.343	0.448
AB	-0.013	1.318	0.008	0.022	0.015
AC	0.065	2.035	0.018	-0.130	-0.241
BC	-0.268	-2.618	-0.035	0.215	0.573
F - value	3.972	5.282	5.912	2.554	1.256
Std. Dev.	0.962	0.317	2.241	0.027	0.370
R^2	0.816	0.836	0.961	0.884	0.867
CV%	5.978	5.592	3.317	6.375	3.521
PRESS	6.364	9.092	7.197	0.065	4.435

3.1 Final moisture content

The Model F-value of 3.972 implies the model is significant and there is only 4.12% chance that a "Model F-Value" this large could occur due to noise. The overall variation in final M was between 5.04 and 6.76. The regression equation describing the effect of the process variables on M in terms of actual levels of the variables are given as:

$$M = 5.365 - 0.131A + 0.1725B - 0.471C - 0.0125C - 0.0125AB = 0.065AC - 0.268BC \quad (7)$$

It can be observed from ANOVA (Table 5) that sucrose concentration (A) and thickness of strawberry samples (B) and operating temperature of freeze dryer (C) are significant variables affecting the M at p ≤ 0.05. Thickness of strawberry samples (B) was the main factor affecting M as revealed by corresponding regression coefficient and F value.

The magnitude of p and F values in Table 5 indicates that linear terms of sucrose concentration (A), thickness of strawberry samples (B) and operating temperature of freeze dryer (C) had significant effect on M. The interactive terms and quadratic terms had non-significant effect on final *M* during freeze drying.

The relative magnitude of coefficients indicates the negative contribution of all process variables except linear effect of B and interactive effect of A and C. The operating temperature (C) having lowest F-value, had least effect on M and therefore was kept fixed along to generate response surface diagram between A and B (Figure 1a). The figure clearly indicates increased final *M* changes with the rise in A and B. Increase in thickness (B) will increase M while increase in sucrose content will decrease it (Ruiz et al., 2005; Janowicz et al., 2007; Agudelo et al., 2012; and Horn et al., 2018).

3.2 Colour index

The overall variation in *L* was from 60.32 to 75.76. The minimum *L* was 60.32 observed at combination of sucrose concentration (A) -50% w/w, thickness of strawberry samples (B) -2 mm and operating temperature of freeze dryer (C) -30°C. However, the maximum *L* (T) 75.76°C was observed at combination of sucrose concentration (A) -40% w/w, thickness of strawberry samples (B)-3 mm and operating temperature of freeze dryer (C) -10°C.

The Model F-value of 5.293 implies the model is significant and there is only 1.06% chance that a "Model F-Value" this large could occur due to noise. The magnitude of p and F values in Table 45 indicate that all linear had significant effect on attained *L* of freeze dried strawberry slices. The interactive terms and quadratic terms had non-significant effect on *L* except BC.

The regression model for T relating the process variables are given as:

$$L = 66.573 - 1.741A + 1.647B - 2.798C + 1.317AB + 2.035AC - 2.617BC \qquad (8)$$

The negative signs of coefficient values of linear terms A, B, and C indicate that, with increase in sucrose concentration and operating temperature, there will be an decrease in *L* (Agnelli and Mascheroni, 2002; Agnieszka and Andrze, 2009; Horn et al., 2018; and Holzwarth et al., 2012). The operating temperature (C) having lowest F-value, had least effect on M and therefore was kept fixed along to generate response surface diagram between A and B (Figure 1b). The figure clearly indicates an increased attained *L* with the decrease in variables A and C. The freeze dried samples processed at higher sucrose concentration osmotic solution and having higher thickness had lower *L*. However, increased thickness of the samples will decrease the value of *L*.

Table 5 ANOVA for different models

Source	df	*M*		*L*		a_w	
		F Value	*p*-value	F Value	*p*-value	F Value	*p*-value
Model	9	3.972	0.0412*	5.2932	0.0106*	5.9122	0.0144*
A –Sucrose content	1	2.363	0.01681*	4.8282	0.0427*	4.4251	0.0735*
B - Thickness	1	17.636	0.0040*	12.4731	0.0054*	24.135	0.0017*
C – Operating temperature	1	1.368	0.02804*	4.3223	0.0643*	3.9963	0.0857ns
AB	1	0.006	0.9394ns	1.3821	0.2670ns	0.3281	0.5847ns
AC	1	0.168	0.6943ns	3.2973	0.0994ns	1.7699	0.2251ns
BC	1	2.841	0.1357na	5.4552	0.0416*	6.6920	0.0361ns
Residual	7						
Lack of Fit	3	4.864	0.0803ns	0.212126	0.9539ns	4.3464	0.0948ns
Pure Error	4						
Cor Total	16						

Note: * significant difference (p<0.05); ns –non significant difference.

3.3 Water activity

The "Model F-value" of 5.91 implies the model is significant. There is a 1.44% chance that a "Model F-value" this large could occur due to noise. The second order polynomial multiple regression equation for explaining the effect of variation process variables on water activity (A_w) is as follows:

$$a_w = 0.309 - -0.0201A - 0.019B + 0.047C + 0.008AB + 0.018AC - 0.035BC \quad (9)$$

Table 5 reveals that sucrose concentration (A) and thickness of strawberry samples (B) with high F-values, had significant effect on water activity (a_w) at 5% level of significance while the operating temperature of freeze dryer (C) effect was non-significant. Operating temperature of freeze dryer (C) having lowest F-value, had less effect on water activity (Aw) and therefore was kept fixed along to generate response surface diagram between A and B (Figure 1c).

Figure 1c reveals that the combined effect of sucrose concentration (A) and thickness of strawberry samples (B) had significant effect on water activity (A_w) of the freeze dried sample. As the sucrose concentration (A) increases and thickness of strawberry samples (B) decreases, the water activity (a_w) increases. The peak value of water activity (a_w) 0.352 was observed at combination of sucrose concentration (A) 40% w/w, thickness of strawberry samples (B)- 3 mm and operating temperature of freeze dryer (C) -10^{o}C (Mosquera et al. (2012).

3.4 Rehydration ratio

The rehydration ration of all the rehydrated samples ranged between 2.7 to 4.24 which depict that the rehydrated product could very well be utilized for substituting the fresh product in off-season. These findings are in conformity with those of Lewicki, (1997), Singh et al. (1999), Krokida et al. (2001).

The Model F-value of 2.55 implies the model is significant and there is only 11.46% chance that a "Model F-Value" this large could occur due to noise.. The regression equation describing the effect of the process variables on M in terms of actual levels of the variables are given as:

$$R_R = 3.784 + 0.1665A + 0.391B + 0.345C + 0.023AB - 0.13AC + 0.215BC \quad (10)$$

It can be observed from ANOVA (Table 4) that all variables had significant effect on RR at p ≤ 0.05. Thickness of strawberry samples (B)) was the main factor affecting M, as revealed by corresponding regression coefficient and F value. The interactive terms and quadratic terms had non-significant effect on RR for freeze dried samples except A^2.

The relative magnitude of coefficients (Table 6) indicates the positive contribution of all process variables except interactive effect of A and C. The operating temperature (C) having lowest F-value, had least effect on RR and therefore was kept fixed along to generate response surface diagram between A and B (Figure 1d). Figure 1 clearly indicates increased R_R increases with the rise A and B (Lenart and Lewicki, 1988; Lewicki, 1998; Lenart, 1996; Tzee et al., 2006; Agnieszka and Andrze, 2009; Marques et al., 2009; and Savo et al., 2012).

Table 6 ANOVA for different models

		R_R		O_a	
Source	df	F Value	*p*-value	F Value	*p*-value
Model	9	2.5566	0.01146*	6.2501	0.0393*
A –Sucrose content	1	6.840	0.0346*	2.9675	0.0128*
B - Thickness	1	8.9257	0.0203*	1.3583	0.0282*
C – Operating temperature	1	1.6116	0.02448*	1.7313	0.2297ns
AB	1	0.014	0.9067ns	0.0091	0.9764ns
AC	1	0.4927	0.5054ns	0.2500	0.6324ns
BC	1	1.3476	0.2837ns	1.4193	0.2723ns
A^2	1	1.7787	0.02241*	2.4302	0.1629ns
B^2	1	0.4852	0.5085ns	0.1233	0.7358ns
C^2	1	1.1461	0.3199ns	0.8834	0.3785ns
Residual	7				
Lack of Fit	3	0.3579	0.7875ns	0.4666	0.7213ns
Pure Error	4				
Cor Total	16				

Note: * significant difference (p<0.05); ns –non significant difference

3.5 Overall acceptability

The Model F-value of 6.25 implies the model is significant. There is only a 3.06% chance that a "Model F-Value" this large could occur due to noise. The overall variation in overall acceptability (O_A) was from 4.341 to 7.852. While a sensory panel detected the firmer texture of the osmo-freeze dried product, the overall acceptability was satisfactory and comparable for all treatments. The regression equation relating the sensory score to the actual levels of the process variables is

$$O_a = 6.494 + 0.585\,A - 0.396\,B + 0.447\,C + 0.015\,A\,B - 0.241\,A\,C + 0.573\,B\,C \quad (11)$$

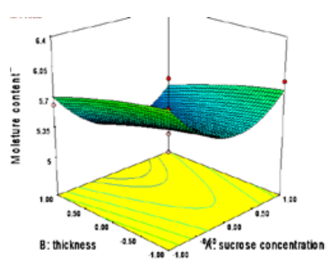
The sucrose concentration (A) and thickness of strawberry samples (B) had significant effect on *Oa* while operating temperature of freeze dryer (C) had non-significant effect at $p \leq 0.05$ (Table 6). All the interaction terms and quadratic term of A, B and C had non-significant effects on overall acceptability of the rehydrated product. The relative magnitude of coefficients indicates the maximum negative contribution of B and quadratic effect of A and C. The operating temperature of freeze dryer (C) having lowest F-value, had less effect on overall acceptability (O_A) and therefore was kept fixed along to generate response surface diagram between A and B.

Figure 1e reveals that the combined effect sucrose concentration (A) and thickness of strawberry samples (B) had significantly on overall acceptability (O_A) of the sample. As the thickness of strawberry samples (B) decreased and sucrose content increased, the overall acceptability (O_A) increased. It is well established that osmotic dehydration coupled with freeze drying at higher temperatures helped in attainment of highly accepted products which is associated with higher colour, texture, and thus overall acceptability (O_A) (Rustom et al 1991; Skrede, 1996; Savo et al., 2012).

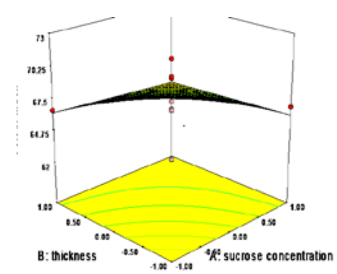
Table 7 indicates that 3 best solutions were obtained at different desirability for the various combinations of independent variables and the results of the responses. The highest desirability value (nearest to the response goal), which is 0.624 (solution 1), was selected as the optimum conditions for osmo-freeze drying of strawberry slices.

Table 7 Solution for optimum condition

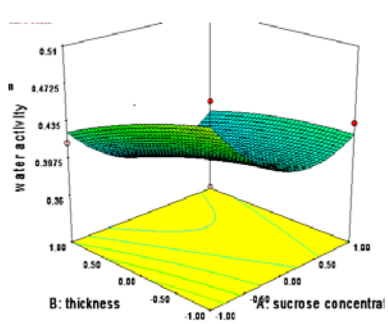
Solutions Number	Coded			*M*	*L*	*Aw*	R_R	O_A	Desirability
	Sucrose conc.	Thickness	Temperature						
1	0.101	-1.000	0.008	5.489	68.912	0.410	3.280	6.311	0.624
2	0.104	-1.000	-0.002	5.491	68.903	0.410	3.279	6.314	0.624
3	0.091	-1.000	0.016	5.488	68.942	0.410	3.280	6.306	0.624



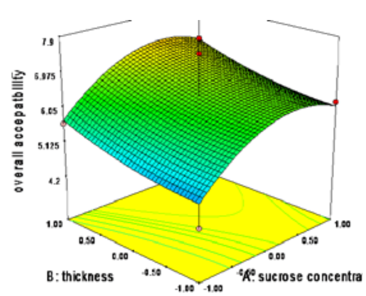
(a) Effect of A and B on M



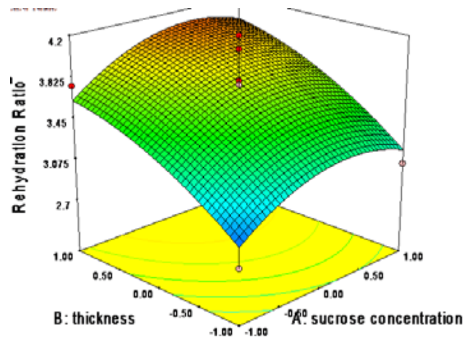
(b) Effect of A and B on L



(c) Effect of A and B on Aw



(d) Effect of A and B on RR



(e) Effect of A and B on Oa

Figure 1 Response surface plots showing effects of process variables

4 Conclusions

It has been shown that the composition of the osmotic solution plays a decisive role in terms of the modifications achieved in the treated material. The use of ternary sucrose-salt aqueous solutions has proven to be very effective in water removal from strawberry slices and the beneficial effects of osmotic treatment on freeze dried strawberry slices have also been proved. Overall osmotic dehydration permits to reduce the moisture content at a low energy intake. It does not represent a saving in total drying time but can permit a significant energy saving per kg of water removed. Optimum conditions obtained by numerical optimization were 51% sucrose concentration.; 2 mm slice thickness and -22°C operating temperature to achieve maximum rehydration ratio &organoleptic score and lower final moisture content, colour variation and water activity.

References

Agnelli, M. E., and R. H. Mascheroni. 2002. Quality evaluation of foodstuffs frozen in a cryomechanical freezer. *Journal of Food Engineering*, 52(3): 257-263.

Agnieszka, C., and L. Andrze. 2009. Rehydration and sorption properties of osmotically pretreated freeze-dried strawberries. *Journal of Food Engineering*, 97(2): 267-274.

Agudelo-Laverde, L. M., C. Schebor, and M. P. Buera. 2012. Water content effect on the chromatic attributes of dehydrated strawberries during storage, as evaluated by image analysis. *LWT-Food Science and Technology*, 52(2): 157-162.

Alvarez, C. A., R. Aguerre, R. Gomez, S. Vidales, S. M. Alzamora, and L. N. Gerschenson. 1995. Air dehydration of strawberries: effects of blanching and osmotic pretreatments on the kinetics of moisture transport. *Journal of Food Engineering*, 25(2): 167-178.

AOAC. 1990. *Official Methods of Analysis*. Washinton DC: Association of Official Analytical Chemists.

Bardonaba, J. G., and L. A. Terry. 2010. Manipulating the taste-related composition of strawberry fruits (Fragaria×ananassa) from different cultivars using deficit irrigation. *Food Chemistry*, 122(4): 1020-1026.

Blanda, G., L. Cerretani, A. Bendini, A. Cardinali, A. Scarpellini, and G. Lercker. 2008. Effect of vacuum impregnation on the phenolic content of Granny Smith and Stark delicious frozen apple cvv. *European Food Research and Technology*, 226(5): 1229-1237.

Bonazzi, C., E. Dumulin, A. L. Roult-Wack, Z. Berk, J. J. Bimbenet, F. Coustois, G. Trystram, and J. F. Vasseur. 1996. Food drying and dewatering. *Drying Technology*, 14(9): 2135-2170.

Bubnovich, V., A. Reyes, E. Quijada, and A. Mahn. 2011. Numerical simulation of lyophilization of carrot slices at atmospheric pressure in a fluidized bed. *Journal of Food Engineering*, 109(4): 659-667.

Carle, R., P. Borzych, P. Dubb, H. Siliha, and O. Maier. 2001. A new process for firmer canned cherries and strawberries. *Food Australia*, 53(8): 343-348.

Ceballos, A. M., G. I. Giraldo, and C. E. Orrego. 2012. Effect of freezing rate on quality parameters of freeze dried soursop fruit pulp. *Journal of Food Engineering*, 111(2): 360-365.

Ciurzynska, A., and A. Lenart. 2006. Effect of osmotic dehydration on mechanical properties of freezedried strawberries. *Food Science Technology Quality*, 2(3): 56-67.

Diana, B., and E. L. Walter. 2006. Osmotic Dehydration of Fruits and Vegetable. Available at: www.diana.behsnilian / online e-paper. Accessed 28-09-2019.

Duxbury, D. D. 1992. Strawberries-source of natural flavour and nutrition. *Food Processing*, 53(7): 97.

Erle, U., and H. Schubert. 2001. Combined osmotic and microwave –

vacuum dehydration of apples and strawberries. *Journal of Food Engineering*, 49(2/3): 193-199.

Escriche, I., A. Chiralt, J. Moreno, and J. A. Serra. 2000. Influence of blanching osmotic dehydration treatments on volatile fraction of strawberries. *Journal of Food Science*, 65(7): 1107–1111.

Fabiano, A. N., S. Fernandes, C. P. Odisséia, and L. Edson. 2005. Optimization of osmotic dehydration of papaya followed by air-drying. *Food Research International*, 39(4): 492-498.

Gabriela, A., T. Pompeu, C. Paulo, F. Carneiro, and C. Hilary, 2004. Osmotic dehydration of mango: effects of temperature and process time. *International Sugar Journal*. (7): 70-72.

Ghio, S.; Barresi, A. A. and Roveroa, G. 2000. A comparison of evaporative and conventional freezing prior to freeze-drying of fruits and vegetables. *Food and Bioproducts Processing*, 78(4): 187-192.

Haber, A., and R. Runyon. 1977. General Statistics. **3rd ed**. Addison-Wesley: Reading, MA.

Hammami, C., and F. Rene. 1997. Determination of Freeze-drying Process Variables for Strawberries. *Journal of Food Engineering*, 32(2): 133-154.

Holzwarth, M., S. Korhummel, R. Carle, and D. R. Kammerer. 2012. Evaluation of the effects of different freezing and thawing methods on color, polyphenol and ascorbic acid retention in strawberries (Fragaria×ananassa Duch.). *Food Research International*, 48(1): 241–248.

Horn, J., J. Schanda, and W. Friess. 2018. Impact of fast and conservative freeze-drying on product quality of protein-mannitol-sucrose-glycerol lyophilizates. *European Journal of Pharmaceutics and Biopharmaceutics*, 127(1): 342-354.

Janowicz, M., A. Lenart, and W. Idzikowska. 2007. Sorption properties of osmotically dehydrated and freeze-dried strawberries. *Polish Journal of Food and Nutrition Sciences*, 57(1): 69–76.

Jena, S., and H. Das. 2005. Modeling for moisture variation during osmo-concentration in apple and pineapple. *Journal of Food Engineering*, 66(4): 425-432.

Kasper, J. C., and W. Friess. 2011. The freezing step in lyophilization: Physico-chemical fundamentals, freezing methods and consequences on process performance and quality attributes of biopharmaceuticals. *European Journal of Pharmaceutics and Biopharmaceutics*, 78(2): 248-263.

Kawanobu, S., T. Wajima, K. Zushi, T. Mori, and N. Matsuzoe. 2010. Seasonal variations in the maturation period, anthocyanin content, and ascorbic acid content in strawberry fruits. *Environmental Control in Biology*, 48(4): 175-184.

Kowalska, H., A. Lenart, and D. Leszczyk. 2008. The effect of blanching and freezing on osmotic dehydration of pumpkin. *Journal of Food Engineering*, 86(1): 30-38.

Krokida, M. K., Z. B. Maroulis, and G. D. Saravacos. 2001. Rheological properties of fluid fruit and vegetable puree products: compilation of literature data. *International Journal of Food Properties*, 4(2): 179-200.

Kumar, V., G. Kumar, and P. D. Sharma. 2012. Osmotic dehydration of litchi pulp as a pretreatment for drying processes. *CIGR Journal*, 14 (3): 146-151.

Kumar, V., and D. Rajak, Jha. A. K. Alok, and P. D. Sharma. 2014. Optimization of ohmic heating of fish using response surface methodology. *International Journal of Food Engineering*, 10(3): 481-491.

Kunal, A., M. H. Gaidhani, D. Bhambere, and S. N. Pallavi. 2016. Lyophilization / freeze drying: A review. *World Journal of Pharmaceutical Research*, 4(8): 516-543.

Lee, J., L. Ye, W. O. Landen, and R. R. Eitenmiller. 2000. Optimization of an extraction procedure for the quantification of vitamin E in tomato and broccoli using response surface methodology. *Journal of Food Composition and Analysis*, 13(1): 45-57.

Lenart, A., and J. M. Flink. 1984a. Osmotic concentration of potato - Criteria for end point of osmosis process. *Journal of Food Technology*, 19(6): 45-63.

Lenart, A., and J. M. Flink. 1984b. Osmotic concentration of potato - Spatial distribution of the osmotic effect. *Journal of Food Technology*, 19(6): 65-89.

Lenart, A., and E. Gródecka. 1989. Influence of kind of osmotic substance on the kinetics of convection drying of apples and carrots. *Food Technology Nutrition*, 18(1), 27-35.

Lenart, A. 1996. Osmo-convective drying of fruits and vegetables: technology and application. *Drying Technology*, 14(2): 2-10.

Lenart, A., and P. P. Lewicki. 1988. Energy consumption during osmotic and convective drying of plant tissue. *Acta Alimentaria Polonica*, 14(38): 65-72.

Lerici, C. R., G. Pinnavaia, M. Rosa, and L. Bartolucci. 1985. Osmotic dehydration of fruits. Influence of osmotic agents on drying behavior and product quality. *Journal of Food Science*, 50(5): 1217-1226.

Lewicki, P. P. 1997. The applicability of the GAB model to food water sorption isotherms. *International Journals of Food Science and Technology*, 32(6): 553-555.

Lewicki, P. P. 1998. A three parameter equation for food moisture sorption isotherms. *Journal of Food Engineering*, 21(2): 127-144.

Lim, L. T., J. Tang, and J. He. 1995. Moisture sorption characteristics of freeze dried blueberries. *Journal of Food Science*, 60(4): 810-881.

Marques, L. G., M. M. Prado, and J. T. Freire. 2009. Rehydration characteristics of freeze-dried tropical fruits. *LWT - Food Science and Technology*, 42(7): 1232-1237.

Maskan, M., and F. Gögüs. 1998. Sorption isotherms and drying characteristics of mulberry (Morus alba). *Journal of Food Engineering*, 37(4): 437-449.

Matuska, M., A. Lenart, and H. N. Lazarides. 2006. On the use of edible coatings to monitor osmotic dehydration kinetics for minimal solids uptake. *Journal of Food Engineering*, 72(1): 85-91.

Montgomery, D. C. 1984. Design and Analysis of Experiments. **2nd ed**. New York: John Wiley and Sons.

Montserrat, F., and S. Wet. 2003. Effect of osmotic stress on microstructure and mass transfer in onion and strawberry tissue. *Journal of the Science of Food and Agriculture*, 83(9): 951-953.

Moraga, G., N. Martinez-Navarrete, and A. Chiralt. 2004. Water sorption isotherms and glass transition in strawberries: influence of pretreatment. *Journal of Food Engineering*, 62(4): 315-321.

Mosquera, L. H., G. Moraga, and N. Martínez-Navarrete. 2012 .Critical water activity and critical water content of freeze-dried strawberry powder as affected by maltodextrin and arabic gum. Food Research International. 47: 201–206.

Myers, R. and Montgomery, D.C. 2002. Response Surface Methodology; Wiley: New York.

Oszmiański, J., A. Wojdylo, and J. Kolniak. 2009. Effect of L-ascorbic acid, sugar, pectin and freeze–thaw treatment on polyphenol content of frozen strawberries. *Food Science and Technology*, 42(2): 581-586.

Piotrowski, D., A. Lenart, and A. Wardzyn. 2004. Influence of osmotic dehydration on microwave-convective drying of frozen strawberries. *Journal of Food Engineering*, 65(4): 519-525.

Ramya, V., and N. K. Jain. 2017. A Review on osmotic dehydration of fruits and vegetables: an integrated approach. *Journal of Food Process Engineering*, 40(3): 1-22.

Ranganna, M. S. 1986. *Handbook of Analysis and Quality Control for Fruits and Vegetables Products*. New Delhi: McGraw Hill.

Ratti, C. 2001. Hot air and freeze-drying of high-values foods: a review. *Journal of Food Engineering*, 49(4): 311-319.

Ruiz, R. Y., L. A. Caicedo, G. Camacho, and L. M. Clavijo. 2005. Determining the effect of sucrose osmotic solution re-use on the pineapple´s osmotic dehydration Kinetic. *Journal of Chemical Engineering*, 30(45): 03-06.

Rustom, I. Y. S., L. M. H. Lopez, and B. M. Nair. 1991. Optimization of extraction of peanut proteins with water by response surface methodology. *Journal of Food Science*, 56(6): 1660-1663.

Savo, I., M. Dragan, and B. Miladin. 2012. Specificities of fruit freeze drying and product prices. *Economics of Agriculture*, 59(3): 461-471.

Sereno, A. M., and M. D. Hubiner. 2001. Prediction of water activity of osmotic solutions. *Journal of Food Engineering*, 49(2/3): 103-114.

Shukla, F., C. Sharma, and B. Singh. 2004. Studies on the preparation of fruit beverages using whey and butter milk. *Journal of Food Science and Technology Mysore*, 41(1): 102-105.

Shukla, S. 2015. Freeze drying process: A Review. *International Journal of Pharmaceutical Sciences and Research*, 2(12): 3061-3068.

Singh, S., U. S. Shivhare, J. Ahmed, and G. S. V. Raghavan. 1999. Osmotic concentration kinetics and quality of carrot preserve. *Food Research International*, 32(7): 509-514.

Skrede, G. 1996. Effect of freezing on fruits. *Food Science and Technology*, 72(1): 183-245.

Tzee, L. K., M. Farid, and S. K. Nguang. 2006. The mathematical modeling of the rehydration characteristics of fruit. *Journal of Food Engineering*, 72(1): 16-23.

Van Buggenhout, S., D. N. Sila, T. Duvetter, A. Van Loey, and M. Hendrickx. 2009. Pectins in processed fruits and vegetables: Part III — Texture engineering. *Comprehensive Reviews in Food Science and Food Safety*, 8(2): 105-117.

Weng, W., W. Liu, and W. Lin. 2001. Studies on the optimum models of the dairy product Kou Woan Lao using response surface methodology. *Asian–Australasian Journal of Animal Sciences*, 14(10): 1470-1476.

Wills, R. B. H., and G. H. Kim. 1995. Effect of ethylene on postharvest life of strawberries. *Postharvest Biology and Technology*, 6(s3-4): 249-255.

Nomenclature

SD	Standard deviation
ANOVA	Analysis of variance
PRESS	Predicted error sum of squares
OH	Ohmically heated