International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 7 (2015) pp. 17357-17374

http://www.ripublication.com

Osmotic Dehydration of Coconut Slices In Hypertonic Sugar Solution: Optimization of Process Variable Using RSM

G. Kamalanathan* and Dr. RM. Meyyappan

Department of Chemical Engineering, Annamalai university,
Annamalai nagar,
Tamil nadu,India, 608002.
Email id: suthakamal15@yahoo.com

Abstract

In this study osmotic dehydration of coconut slices was performed to determine the weight reduction (WR), solid gain (SG) and Water loss (WL) over the range of concentration of sugar solution(43.18 to 76.82 % w/w), temperature (26.59 to 43.41 °C) and processing time (1.32 to 4.68 hours). A statistical tool of the Central Composite design has been used to design the experimental run and optimization. The quadratic regression equation describing the effects of these factors on WL, SG and WR were developed. Analysis of the regression coefficients showed that concentration of sugar solution with temperature and temperature with processing time for WR ,the concentration of with processing time for SG and concentration of sugar solution with temperature and temperature with processing time for WL were the most important factor that affects the osmotic dehydration of coconut slices .Optimum conditions for maximum percentage of weight reduction (20.852%),minimum percentage of solid gain (2.267%) and maximum percentage of water loss (23.119%) was found to be concentration of (61.189 % w/w), temperature (34.915 °C) and processing time (3.084 hours).

Keywords: Hypertonic sugar solution, Temperature, Processing time, Weight reduction, Solid gain, Water loss

Introduction

Coconut scientifically named as *Coco nucifera L.* is one of the important crops in the tropical and sub-tropical regions. The coconut palm is cultivated in more than 90 tropical countries and it represents an important income source. Indonesia, Philippines and India are the major producers and account for about 75% of world production. India holds third rank in the production of coconut with total production of coconut of 10,824,100 tonnes (FAOSTAT, 2013). Even though India is a leading producer of coconut, the cultivation is not uniformly distributed. Coconut is cultivated mainly in the coastal tracts of South India. The use of coconut in Indian culinary remains invariable throughout the country. Coconuts are transported either as whole coconut or after removal of husk to balance the demand and the availability of coconut. Various disadvantages associated during transportation are desiccation of kernel, germination, damages due to stress, crack development, susceptibility to various diseases and pest attack. High transportation cost also affects the price of the coconut and minimize the use of coconut in Indian culinary. To overcome these disadvantages, the coconut slices are dehydrated to intermediate moisture content. This can be achieved by a process called osmotic dehydration.

Osmotic dehydration is the process of contacting the fruits and vegetables in a hypertonic solution for partial removal of moisture. During the osmotic dehydration, two major simultaneous counter current flows occur. Water entrapped in the tissues flows out into the solution and simultaneously solutes in the hypertonic solution enter the fruit or vegetable tissues due to the difference in osmotic pressures (P. S. Madamba, 2003).In addition, other solutes present in the cells can be leached in to the osmotic solution, but these amounts are considered to be quantitatively negligible (Lerici,C.R.et al .,1985.). Osmotic dehydration is a pre-treatment for many processes such as drying, freeze drying, vacuum drying etc. It is used to enhance the nutritional, sensorial and functional properties of food without changing its integrity (D. Torrengiani, 1993). The texture and stability of pigments during dehydration and storage was improved and sugar to acid ratio was also increased during osmotic dehydration (A. L. Raoult-Wack, 1994). The osmotic dehydration is considered to be an energy efficient method for partial dehydration, since water need not have to undergo a phase change It has been widely used as a pre-treatment step in food drying process since it can reduce the overall the energy requirement for further drying process(Khin, M.M et al , 2006). Another major application of osmotic dehydration is to reduce the water activity of the food material that inhibits the microbial growth. Rehydration ability is superior because shrinkage is reduced by the infusion of solutes preventing the collapse of the biological structure as compared to conventional drying. The influence of the osmotic agents (sucrose and corn syrup solid) on mass transfer during osmotic dehydration of papaya has been studied. It was found that sample dehydrated in sucrose solution had values of solid gain and water loss higher than that obtained from the samples processed in corn syrup solution. The fact is corn syrup solution had visually higher viscosity and molecular weight than sucrose (El-Aouar et al, 2006). Various osmotic agents such as sucrose, glucose, fructose, maltodextrin and sorbitol were used to study the effect of osmotic agent on mass transfer during osmotic dehydration of apricot . They reported that the highest and the lowest water loss were obtained by sucrose and sorbitol solutions, respectively (Ispir, A. and Togrul, T.I. 2009) .The effect of sucrose concentration (45%, 55% and 65%) on mass transfer during osmotic dehydration of apple was studied. The result showed that the increase in sucrose concentration resulted in higher of water loss and solid gain throughout the osmotic period. Solids uptake modifies final product composition (*i.e.* sugar to acid ratio) and taste. The solids uptake blocks the surface layers of the product, posing an additional resistance to mass transfer and lowering the rates of complementary dehydration (Lazarides, H.N et al, 1995). The effect of osmotic temperature on water loss and solid gain of watermelon slabs immersed into sucrose solution (50oBrix) was studied. Water loss and solid gain increased with the solution temperature. Higher water loss and solid gain were observed at 40^{o}C compared to those at 20^{o}C and 30^{o}C (Falade, K.O et al , 2007). The use of highly concentrated viscous sugar solutions creates major problems such as floating of food pieces, hindering the contact between Food material and the osmotic solution, causing a reduction in the mass transfer rates. Thus, to enhance mass transfer, agitation or stirring process can be applied during osmotic dehydration (Moreira, R.et al , .2007).There are numerous studies on osmotic dehydration of fruits and vegetables (Bolin et al, 1983; Rastogi, N. K et al ,2002; Mazza, G., & LeMaguer, M. 1980)

Response Surface Methodology (RSM) is a statistical tool for experimental design and process optimization. It helps us to quantify the relationship between one or more measured response and vital input factors. The major objective is to find the desirable location in the design space. This could be a maximum, a minimum or an area where the response is stable over a range of factors. Response surface and contour plots were generated and the optimization of process variables were carried out by identifying the desirability of process variables with observed and predicted values (Dhingra, D. and Paul, S. 2005). It is used for multivariable optimization studies in several processes such as optimization of fermentation media, process conditions, catalyzed reaction conditions, oxidation, fermentation, bio sorption of metals etc. (Y.C. Chang et al , 2006; E. Kristo et al , 2003; Myers, R.H. and Montgomery, D.C. 1995; Q.K. Beq et al , 2002 ; E.L. Soo et al , 2004). Several works has been carried out on optimization of osmotic dehydration of fruits and vegetables by RSM. No information is available on the statistical modelling of osmotic dehydration of coconut slices. In this study, optimum conditions for concentration of the hypertonic solution (sugar solution), temperature and processing time were found out for maximum water loss, minimum solid gain and maximum weight reduction.

Materials and Methods

The mature coconut of 10 month after flowering was used for osmotic dehydration. The average moisture content of coconut was found to be 55.02 ± 2.12% on wet basis. The kernel portion of the coconut was taken for the experimental studies. The coconut slices of 5 mm thickness and 20 mm length were prepared by slicing the kernel. The coconut slices were washed in clean water to get rid of residual husk particles. The commercially available sugar was used to prepare osmotic solution, which was purchased from a local super market. The osmotic solution is prepared by mixing the sugar with required amount of distilled water. The concentration of sugar solution was measured by using refractometer.

Experimental design and statistical analysis

In RSM a Central Composite Design was used for the experimental design. A quadratic model was used for correlating the responses and the independent variables. The independent variables were concentration of sugar solution (43.18 to 76.82 % w/w), temperature (26.59 to 43.41 °C) and processing time (1.32 to 4.68 hours). A second degree polynomial equation below describes the relation between the independent and dependent Variables.

$$\text{Response} = \alpha_0 + \beta_1 A + \beta_2 B + \beta_3 C + \beta_{12} AB + \beta_{13} AC + \beta_{23} BC + \beta_{11} A^2 + \beta_{22} B^2 + \beta_{33} C^2. \quad (1)$$

Where the responses are WR, SG and WL, the α_0 , β_i are adjustable constants and A, B, C are Concentration of sugar solution, temperature and processing time respectively.

Twenty experiments were carried out according to response surface methodology and analysis of variance (ANOVA) for response surface quadratic model for the osmotic dehydration of coconut slices was obtained by using Design Expert 8.0.7.1.

Experimental Procedure:

The osmotic dehydration process was done in a 500 ml Erlenmeyer flask, which was kept in a thermostatically controlled water bath shaker. Coconut kernel was cut into slices (100 g), blanched at 90 ^{0}c for 2 minutes and the samples were submerged in a 2% citric acid for 2 minutes to increase the shelf life of the coconut slices and then the samples were weighed and placed into the flask containing sugar solution of varying concentrations (43.18 to 76.82 % w/w). A constant solution to sample ratio of 5:1(w/w) was used. The flask was placed in the water bath at a constant temperature. After every run, the coconut slices were taken out and then gently blotted with adsorbent paper and weighed. The average moisture and dry matter content of the samples were determined by drying in hot air oven at 105 °C for 24 hours. In each of the experiments fresh osmotic solution was used. All the experiments were done in triplicate and the average value was taken for calculations. For each experiment the agitation speed of 200 rpm was used and maintained constant. Weight reduction (WR), solid gain (SG) and water loss (WL) data were obtained, according to the expressions

$$WR = ((M_i - M)/M_i) \quad (2)$$

$$SG = ((m_t - m_i)/ M_i) \quad (3)$$

$$WL = WR + SG \quad (4)$$

where M_i - initial mass of sample (g), M_t - mass of sample after dehydration (g), m_i - initial mass of the solids in sample (g), m_t - mass of the solids in sample after dehydration (g).

Results and Discussions

In order to obtain the optimum conditions, a CCD design in RSM was developed, the range and levels of independent variables was presented in Table (1) with the runs of the experiment in a random form and the values of the response variables obtained in each run.

The experimental values and predicted values for weight reduction (WR), solid gain (SG) and water loss (WL) under different treatment conditions were presented in Table (2). The regression coefficients for the second order polynomial equations and results for the linear, quadratic and interaction terms were presented in Table (3), (4) &(5). The statistical analysis indicates that the proposed model was adequate, possessing no significant lack of fit and with very satisfactory values of the R^2 for all the responses. The R^2 values for percentage of weight reduction, solid gain and water loss were 0.9883, 0.9774 and 0.9803 respectively. The closer the value of R^2 to the unity, the better the empirical model fits the actual data. The smaller the value of R^2 the less relevant the dependent variables in the model have to explain the behaviour variation. The probability (p) values of all regression models were less than 0.050 depicted highly significant. In this study the Model F value for WR, SG and WL were 93.89, 47.98 and 55.36 implies the Model is significant and lack of fit F value for WR, SG and WL were 3.58, 3.32 and 3.21 implies the Lack of Fit is not significant.non –significant lack of fit is good.

Effects of Sugar Concentration, Temperature and Processing Time on Percentage of Weight Reduction:

The effect of independent variable such as concentration of sugar solution, temperature and processing time on percentage of weight reduction were reported in Fig (1), (2) & (3) .The coefficient of the second order polynomials indicates the effects of independent variable on percentage of weight reduction table (3). In this case A, B, C, AB, BC, A^2, B^2, C^2 are significant model terms. The Predicted R-Squared of 0.9269 is in reasonable agreement with the Adjusted R-Squared of 0.9778. Percentage of weight reduction was positively related to the linear effect of concentration of aqueous sugar solution ($p<0.0001$), temperature ($p <0.050$) and processing time ($p<0.0001$) and negatively related to the quadratic effect of concentration of sugar solution ($p<0.0001$), temperature ($p<0.0001$) and processing time ($p<0.0001$). Interaction effects of concentration of sugar solution with temperature ($p <0.050$) and temperature with processing time on percentage of weight reduction were highly significant ($p <0.050$).

In osmotic dehydration increase in osmotic solution concentration resulted in corresponding increases in water loss to equilibrium level and drying rate. If increased osmotic solution concentration lead to increased weight reduction (Conway J et al ,1983). In the Fig (1, 3), it implies that at lowest level , the Percentage of weight reduction increases with increase in concentration of sugar solution with temperature and temperature with processing time due to increase in osmotic pressure gradient between osmotic sugar solution and cellular solution in the coconut slices. It is well recognised that diffusion is a temperature dependent phenomenon. At higher process temperature that seems to promote faster water loss and better water transfer characteristics on the surface due to lower viscosity of the osmotic sugar solution. At highest level, the Percentage of weight reduction slightly decreases with concentration of sugar solution with temperature and temperature with processing time due to higher uptake of solute which forms a dense solute barrier layer at the surface of the coconut slices. At higher process temperature and concentration of sugar solution, the swelling and plasticising of cell membranes will occur and favour the cell membrane permeability to sugar molecules (Lazarides HN ,1994). Even though it promote faster water loss and better water transfer characteristics and it also improved the cell membrane permeability to sugar molecules which forms a dense solute barrier layer at the surface of the coconut slices hence the weight reduction rate was slightly decreased . The maximum percentage of weight reduction of 20.852% was obtained at concentration of sugar solution (61.189% w/w), temperature (34.915^0c) and processing time (3.084 hours) of osmotic solution. Whereas these effects does not appear above these conditions, since it may be due to the accumulation of solute at the subsurface layers of the coconut slices.

Effect of Sugar Concentration, Temperature and Processing Time on Percentage of Solid Gain:

The Figures (4), (5) & (6) show the effect of independent variables on the percentage of solid gain. In Table (4), A, B, C, AC, A^2, B^2, C^2 are significant model terms. The Predicted R-Squared of 0.8602 is in reasonable agreement with the Adjusted R-Squared of 0.9570. The coefficient of second order polynomial indicates that the percentage of solid gain was positively related to the linear effect of concentration of sugar solution ($p<0.0001$), temperature ($p<0.050$) and processing time ($p<0.0001$) and quadratic effect of concentration of sugar solution, temperature and processing time of p value less than 0.050. Interaction effects of concentration of sugar solution with processing time on percentage of solid gain were highly significant ($p<0.050$).During osmotic dehydration, simultaneous counter-current flow occurs. Solute from the osmotic solution diffused in to the coconut slices and moisture diffused out from the coconut slice to the osmotic sugar solution. In the figure (5)**,** it was clearly shows that, the percentage of solid gain was increased with increase in concentration of sugar solution and processing time. When the concentration of sugar solution was increased, it also increased the rate of diffusion of solute into the coconut slices. This may be due to the highly different in concentration between the coconut slices and osmotic sugar solution which increased the rate of diffusion of solute into the coconut slices with processing time and moreover the membrane swelling and plasticizing also contribute for more uptake of solute into the coconut slices at higher temperature and concentration of sugar solution. In osmotic dehydration , the solid uptake modifies final product composition and taste.

The solute uptake blocks the surface layers of the product, posing an additional resistance to mass transfer and lowering the rates of complementary dehydration (Matuska et al , 2006). In recent years, the minimizing the solid gain and maximizing the water loss and to maintain the quality characteristics of the final product has attracted extensive research interest. The minimum percentage of solid gain of 2.267 % was attained at concentration of sugar solution (61.189 % w/w), temperature (34.915 °C) and processing time (3.084 hours). Whereas this effect was did not appear above this conditions. Due to the highly difference in concentration between coconut slices and osmotic sugar solution which increases the diffusion of solute into the coconut slices with processing time (Azoubel, P.M. and Murr, F.E.X. 2004).

Effect of Sugar Concentration, Temperature and Processing Time on Percentage of Water Loss:

The effects of independent variables on percentage water loss were shown in figures (7), (8) & (9). It was clearly depicted in table (5) that the percentage water of loss was positively related to the linear effect of concentration of sugar solution ($p < 0.0001$), temperature ($p <0.050$) and processing time ($p < 0.0001$). The percentage of water loss showed a negative relationship with quadratic effects of concentration of sugar solution ($p<0.0001$), temperature ($p <0.050$) and processing time ($p<0.0001$). In this case A, B, C, AB, BC, A^2, B^2, C^2 are significant model terms. The Predicted R-Squared of 0.8793 is in reasonable agreement with the Adjusted R-Squared of 0.9626. The interaction effect between concentration of sugar solution with temperature ($p <0.050$) and Temperature with processing time ($p <0.050$) towards the percentage of water loss were highly significant. In the figure (7) & (9), it was clearly shown that, the percentage of water loss was increased with increase in concentration of sugar solution with temperature and temperature and processing time. At highest level of concentration of sugar solution, the percentage of water loss decreases slightly with temperature and temperature and processing time. The maximum percentage of water loss of 23.119% was obtained at concentration of sugar solution (61.189 % w/w), temperature (34.915°C) and processing time (3.084 hours). This effect could not be seen above optimum conditions, this could be the effect of solute accumulated in the intermediate layers of the coconut slices.

At higher level of concentration of sugar solution and temperature, the membrane swelling and plasticizing effect favours the movement of solute into the coconut slices which affects the mass transfer rate simultaneously. Due to the accumulation of solute at the subsurface layer of the coconut slices. It disturbs the mass transfer between moisture entrapped in the coconut tissues flows out into the solution and solutes in the hypertonic osmotic sugar solution enter in to the coconut slices and mass transfer rate was slightly decreased and therefore the percentage of water loss was decreased in high concentration of sugar solution with temperature and temperature with processing time. A case hardening effect could be responsible for the percentage of water loss decreased at the highest level of concentration of sugar solution with temperature and temperature with processing time (Giraldo, G et al, 2003). Therefore it slightly hinders the water transfer rate between coconut slices and the osmotic sugar solution.

The experimental results were analysed statistically by RSM to obtain an empirical model for the best response. Mathematical expressions to the response with independent variables are shown below.

Percentage of Weight reduction = 20.72889 +0.76283*Concentration of Sugar Solution +0.27606*Temperature + 0.71490* Process Time - 0.35837*Concentration of Sugar Solution*Temperature -0.15012*Concentration of Sugar Solution* Process

Time + 0.41512*Temperature*Process Time – 1.14042*Concentration of Sugar Solution ^{2}- 0.58464*Temperature^2 - 0.92122* Process Time^2 _______________ (5)

Percentage of Solid gain = 2.18155 + 0.40246*Concentration of Sugar solution + 0.20433*Temperature + 0.42134* Process Time +0.075125*Concentration of Sugar Solution*Temperature +0.13963*Concentration of Sugar Solution*Process Time - 0.022625*Temperature*Process Time + 0.16823*Concentration of Sugar Solution ^{2} +0.10654*Temperature^2+0.24036*Process Time^2 _______________ (6)
Percentage of Water loss = 22.91044+1.16529*Concentration of Sugar Solution +0.48039*Temperature +1.13624*Process Time -0.28325*Concentration of Sugar Solution *Temperature - 0.010500*Concentration of Sugar solution *Process Time - 0.43775*Temperature*Process Time – 0.97219*Concentration of Sugar Solution^2 - 0.47810*Temperature^2 – 0.68086* Process Time^2 _________________ (7)

Table 1: Range of Independent Variables Used For The Osmotic Dehydration of Coconut Slices

Factors	Variable	Unit	Range and levels				
			-1.68179	-1	0	1	+1.68179
A	Sugar concentration	%(w/w)	43.18	50	60	70	76.82
B	Temperature	(^{o}c)	26.59	30	35	40	43.41
C	Processing time	(hrs)	1.32	2	3	4	4.68

Table 2: Experimental conditions and observed response values of CCD

Run order	Sugar con %(w/w)	Temp (0c)	Processing time (Hrs)	WR (%) Experimental values	SG (%) Experimental values	WL (%) Experimental values	WR (%) Predicted values	SG (%) Predicted values	WL (%) Predicted values
1	0	0	0	20.882	2.262	23.144	20.728	2.181	22.910
2	1.68179	0	0	18.422	3.148	21.570	18.786	3.334	22.120
3	-1	-1	-1	15.421	1.881	17.302	15.405	1.860	17.265
4	0	0	0	20.851	2.232	23.083	20.728	2.181	22.910
5	0	-1.68179	0	18.388	2.051	20.439	18.611	2.139	20.750
6	0	1.68179	0	19.409	2.794	22.203	19.539	2.826	22.366
7	0	0	0	20.654	2.121	22.775	20.728	2.181	22.910
8	-1	1	1	18.412	2.611	21.023	18.404	2.682	21.086

9	0	0	0	20.902	2.286	23.188	20.728	2.181	22.910
10	1	1	-1	18.748	2.943	21.691	18.613	2.840	21.453
11	0	0	-1.68179	16.781	2.011	18.792	16.921	2.152	`19.073
12	0	0	0	20.621	2.112	22.733	20.728	2.181	22.910
13	0	0	0	20.524	2.097	22.621	20.728	2.181	22.910
14	1	-1	-1	18.190	2.393	20.583	17.947	2.236	20.183
15	1	-1	1	20.112	3.461	23.573	19.907	3.403	23.310
16	-1	-1	1	18.081	2.452	20.533	17.965	2.469	20.434
17	-1.68179	0	0	16.231	2.046	18.277	16.220	1.980	18.200
18	-1	1	-1	17.550	2.192	19.742	17.504	2.164	19.668
19	0	0	1.68179	19.112	3.591	22.703	19.325	3.570	22.895
20	1	1	1	19.147	3.982	23.129	18.912	3.916	22.829

Table 3: Analysis of variance (ANOVA) for the Osmotic dehydration of coconut slices using hypertonic sugar solution – WEIGHT REDUCTION

source	Coefficient Estimate	Sum of squares	df	Mean square	F value	p-value prob>F
Model		49.13	9	5.46	93.89	<0.0001 significant
Intercept	20.73					
A-sugar concentration (w/w)	0.76	7.95	1	7.95	136.69	<0.0001
B-temperature (^{0}c)	0.28	1.04	1	1.04	17.90	0.0017
C-time (hrs)	0.71	6.98	1	6.98	120.05	<0.0001
AB	-0.36	1.03	1	1.03	17.67	0.0018
AC	-0.15	0.18	1	0.18	3.10	0.1087
BC	-0.42	1.38	1	1.38	23.71	0.0007
A^2	-1.14	18.74	1	18.74	322.37	<0.0001
B^2	-0.58	4.93	1	4.93	84.72	<0.0001
C^2	-0.92	12.23	1	12.23	210.36	<0.0001
Residual		0.58	10	0.058		
Lack of Fit		0.45	5	0.091	3.58	0.0939 Not significant
Pure Error		0.13	5	0.025		
Cor Total		49.71	19			

Table 4: Analysis of variance (ANOVA) for the Osmotic dehydration of coconut slices using hypertonic sugar solution – SOLID GAIN

source	Coefficient Estimate	Sum of squares	df	Mean square	F value	p-value prob>F
Model		6.62	9	0.74	47.98	<0.0001 significant
Intercept	2.18					
A-sugar concentration (w/w)	0.40	2.21	1	2.21	144.32	<0.0001
B-temperature (^{0}c)	0.20	0.57	1	0.57	37.20	0.0001
C-time (hrs)	0.42	2.42	1	2.42	158.18	<0.0001
AB	0.075	0.045	1	0.045	2.95	0.1169
AC	0.14	0.16	1	0.16	10.18	0.0097
BC	-0.023	4.095E-003	1	4.095E-003	0.27	0.6165
A^2	0.17	0.41	1	0.41	26.61	0.0004
B^2	0.11	0.16	1	0.16	10.67	0.0085
C^2	0.24	0.83	1	0.83	54.32	<0.0001
Residual		0.15	10	0.015		
Lack of Fit		0.12	5	0.024	3.32	0.1071 Not significant
Pure Error		0.036	5	7.102E-003		
Cor Total		6.77	19			

Table 5: Analysis of variance (ANOVA) for the Osmotic dehydration of coconut slices using hypertonic sugar solution – WATER LOSS

source	Coefficient Estimate	Sum of squares	df	Mean square	F value	p-value prob>F
Model		61.68	9	6.85	55.36	<0.0001 significant
Intercept	22.91					
A-sugar concentration (w/w)	1.17	18.54	1	18.54	149.81	<0.0001
B-temperature (^{0}c)	0.48	3.15	1	3.15	25.46	0.0005
C-time (hrs)	1.14	17.63	1	17.63	142.43	<0.0001

AB	-0.28	0.64	1	0.64	5.19	0.0460
AC	-0.010	8.820E-003	1	8.820E-003	7.125 E-003	0.9344
BC	-0.44	1.53	1	1.53	12.38	0.0055
A^2	-0.97	13.62	1	13.62	110.03	<0.0001
B^2	-0.48	3.29	1	3.29	26.61	0.0004
C^2	-0.68	6.68	1	6.68	53.97	<0.0001
Residual		1.24	10	0.12		
Lack of Fit		0.94	5	0.19	3.21	0.1130 Not significant
Pure Error		0.29	5	0.059		
Cor Total		62.92	19			

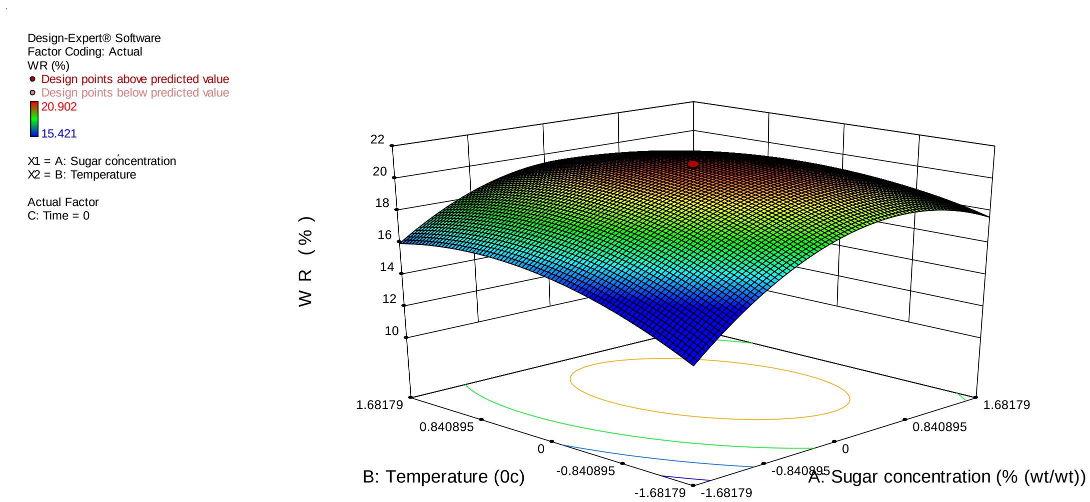

Figure 1: 3D plot of the combined effect of the sugar concentration and temperature on percentage of weight reduction

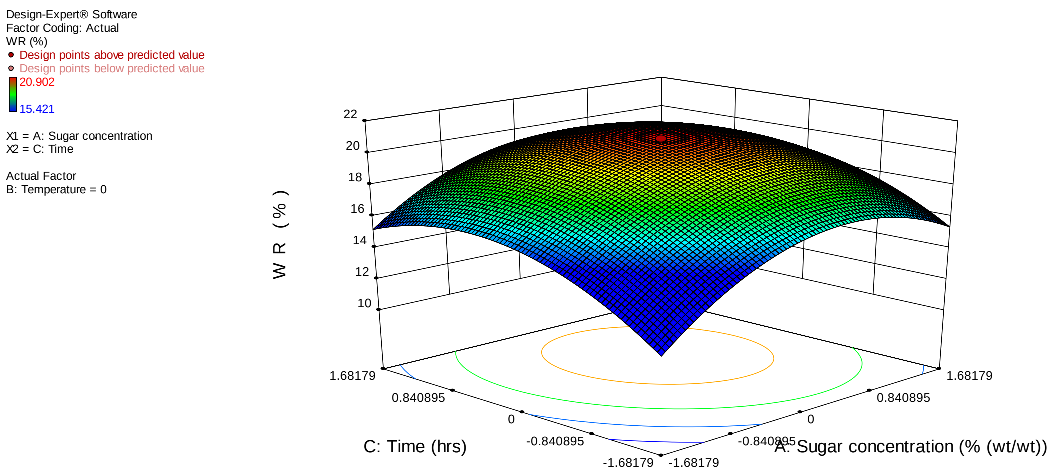

Figure 2: 3D plot of the combined effect of the sugar concentration and processing time on percentage of weight reduction

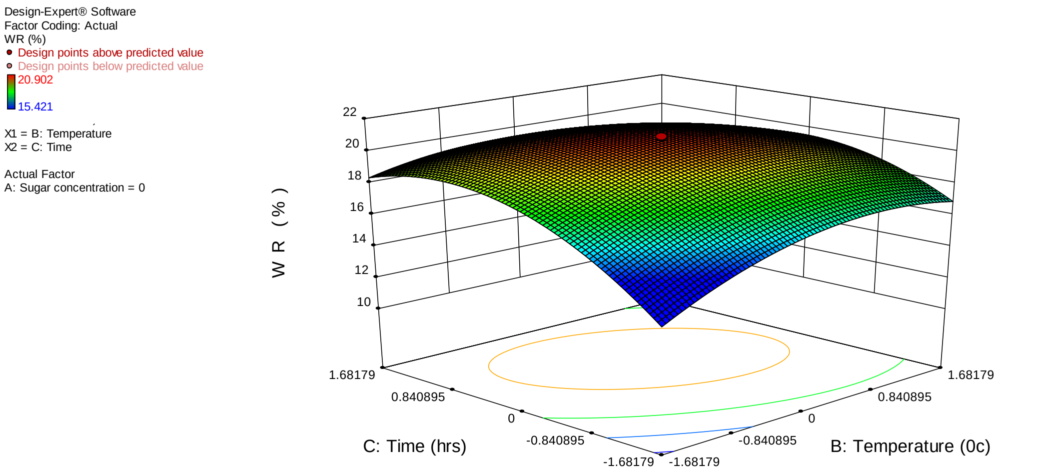

Figure 3: 3D plot of the combined effect of the temperature and processing time on percentage of weight reduction

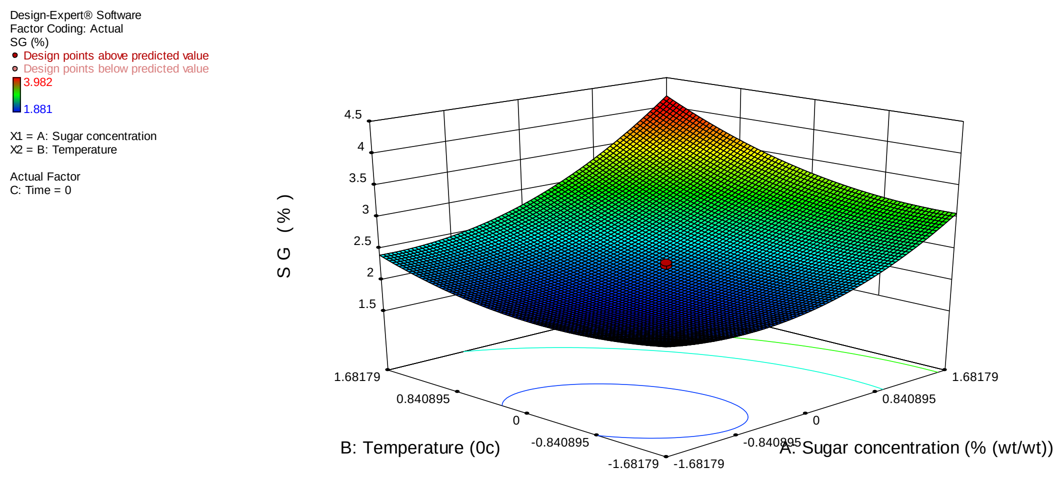

Figure 4: 3D plot of the combined effect of the sugar concentration and temperature on percentage of solid gain

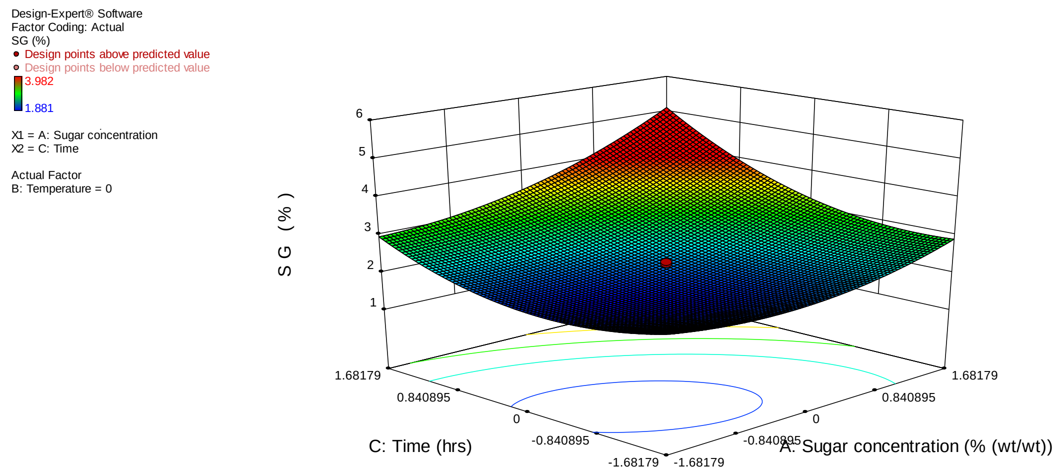

Figure 5: 3D plot of the combined effect of the sugar concentration and processing time on percentage of solid gain

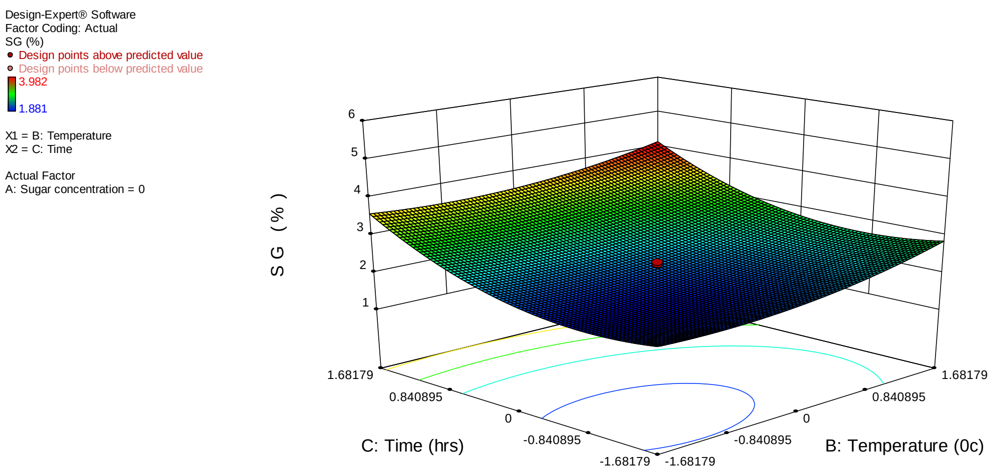

Figure 6: 3D plot of the combined effect of the temperature and processing time on percentage of solid gain

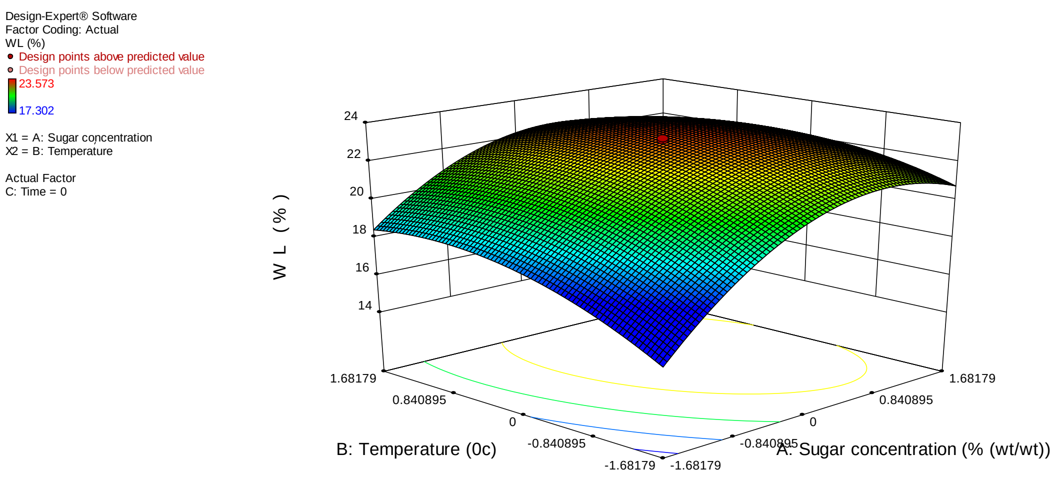

Figure 7: 3D plot of the combined effect of the sugar concentration and temperature on percentage of water loss

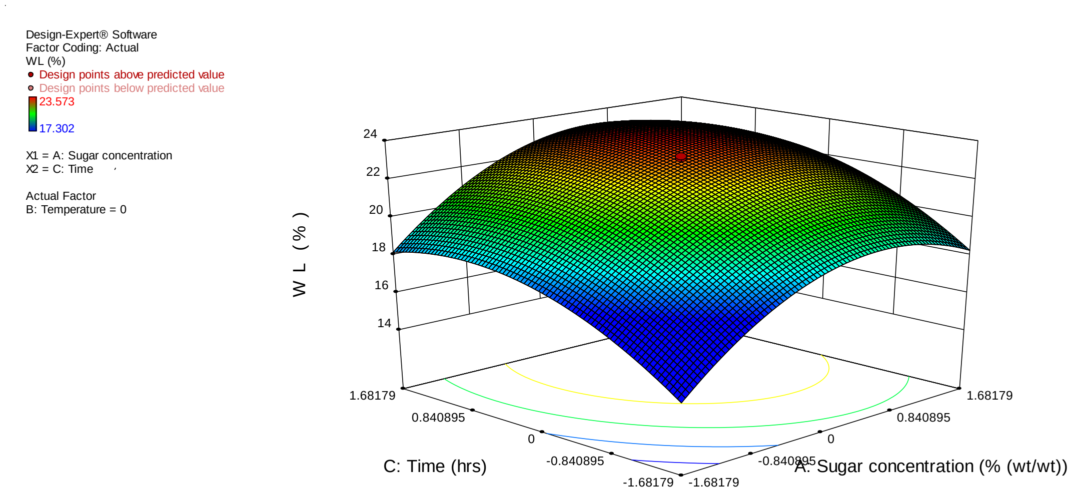

Figure 8: 3D plot of the combined effect of the sugar concentration and processing time on percentage of water loss

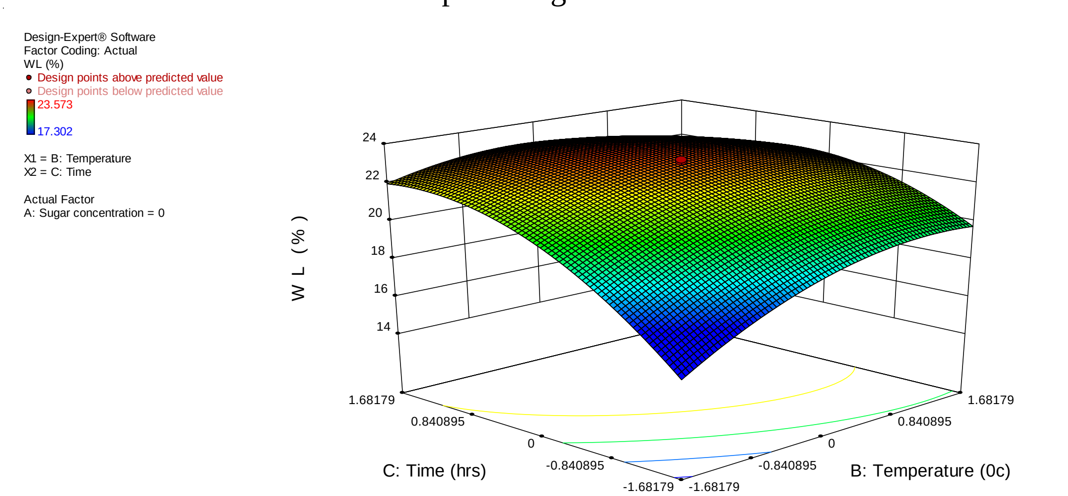

Figure 9: 3D plot of the combined effect of the temperature and processing time on percentage of water loss

Optimization:

Optimum condition for osmotic dehydration of coconut slices was determined to obtain maximum percentage of weight reduction, minimum percentage of solid gain and maximum percentage of water loss. Second order polynomial models obtained in this study were utilized for each response in order to determine the specified optimum conditions. The sequential quadratic programming in MATLAB 7 is used to solve the second-degree polynomial regression equation (5),(6) & (7). Optimization was done with the criteria such as to Maximizes percentage of Weight reduction, water loss and to minimize percentage of Solid gain. Optimum conditions for maximum percentage of weight reduction, water loss and minimum percentage of solid gain was found at 61.189 % w/w concentration of sugar solution , Temperature 34.915 °C and Processing time 3.084 hours. At these conditions percentage of Weight Reduction (WR), Solid Gain (SG) and Water Loss (WL) were 20.852, 2.267 and 23.119 % respectively.

Conclusion

In this study, RSM was used to determine the optimum operating conditions that yield maximum percentage of weight reduction, water loss and solid gain in osmotic dehydration of coconut slices. Analysis of variance has shown that the effects of all the process variables including concentration of sugar solution, temperature and processing time were statistically significant. Second order polynomial models were obtained for predicting percentage of water loss, solid gain and weight reduction. Optimum conditions for maximum percentage of weight reduction, water loss and minimum percentage of solid gain was found at 61.189 % w/w concentration of sugar solution, Temperature 34.915 °C and processing time3.084 hours. At these conditions percentage of Weight Reduction (WR), Solid Gain (SG) and Water Loss (WL) were 20.852, 2.267 and 23.119 respectively.

References

[1] Raoult-Wack, A.L., 1994, "Advances in osmotic dehydration", *Trends in Food Science Technology.*, vol.5, pp. 255–260

[2] Azoubel, P.M., and Murr, F.E.X., 2004. "Mass transfer kinetics of osmotic dehydration of cherry tomato", Journal of Food Engineering., 61, pp. 291-295.

[3] Bolin, H.R., Huxoli, c.c., Jackson, R and NG, K.C., 1983, "Effect of osmotic agent and concentration of food quality", Journal of Food Science., 48, pp. 202-205.

[4] Conway, J., Castaigne, F., Picard, G., and Vovan, X., 1983, "Mass transfer considerations in the osmotic dehydration of apples", Canadian Institute of Food Sci. Technol. J., 16, pp. 25-29.

[5] Dhingra, D., and Paul, S., 2005, "Optimisation of drying conditions of garlic slices", Journal of Food Science and Technology., 42 (4), pp. 348-352.

[6] Torrengiani, D., 1993, "Osmotic dehydration in fruits and vegetable processing"., *Food Research International.*, vol. 26, pp. 59 – 68.

[7] Kristo, E., Biliaderis, C.G., and Tzanetakis, N., 2003, "Modeling of the acidification process and rheological properties of milk fermented with a yogurt starter culture using response surface methodology"., *Food Chemistry.*, vol. 83, pp. 437 – 446.

[8] El-Aouar, A.A., Azoubel, M.P., Barbosa, L.J. and Murr, X.E.F., 2006, " Influence of osmotic agent on the osmotic dehydration of papaya (*Carica papaya* L.)"., Journal of Food Engineering., 75, pp. 267-274.

[9] Soo, E.L., Salieh, A., and Basri, M., 2004, "Response surface methodological study on lipase-catalyzed synthesis of amino acid surfactants"., *Process Biochemistry.*, vol. 39, pp. 1511 – 1518.

[10] Falade, K.O., Igbeka, J.C., and Ayanwuyi, F.A., 2007, "Kinetics of mass transfer and colour changes during osmotic dehydration of watermelon"., Journal of Food Engineering ., 80, pp. 979-985.

[11] FAOSTAT., Production. Crops., Coconut., 2013. http://faostat.fao.org

[12] Giraldo, G., Talens, P., Fito, P., and Chiralt, A., 2003, "Influence of sucrose solution concentration on kinetics and yield during osmotic dehydration of mango"., Journal of Food Engineering ., 58, pp. 33-43.

[13] Ispir, A., and Togrul, T.I., 2009, "Osmotic dehydration of apricot: Kinetics and the effect of process parameters"., Chemical Engineering Research and Design ., 87, pp. 166-180.

[14] Khin, M.M., Zhou, W., and Perera, C., 2006, "A study of mass transfer in osmotic dehydration of coated potato cubes"., Journal of Food Engineering., 77, pp. 84-95.

[15] Lazarides, H.N., Katsanides, E., and Nicolaides, A., 1995, "Mass transfer kinetics during osmotic preconcentration aiming at minimal solid uptake"., Journal of Food Engineering., 25, pp. 151-166.

[16] Lazarides, HN., 1994, "Osmotic pre-concentration: developments and prospects. In:*Minimal processing of foods and process optimisation; an interface"*., Singh RP, Oliveira, F. AR (Eds.)., CRC Press, London,UK.

[17] Lerici, C.R., Pinnavaia, G., Dalla, R.M., and Bartolucci, L., 1985, "Osmotic dehydration of fruits : Influence of osmotic agents on drying behaviour and product quality"., J.Food Sci., 50, pp. 1217-1219.

[18] Matuska, M., Lenart, A., and Lazarides, N.H., 2006, "On the use of edible coatings to monitor osmotic dehydration kinetics for minimal solids uptake"., Journal of Food Engineering ., 72, pp. 85-91.

[19] Mazza, G., & LeMaguer, M., 1980., "Dehydration of onion: some theoretical and practical considerations"., Journal of Food Technology.,15(2), pp. 81–194.

[20] Moreira, R., Chenlo, F., Torres, M.D., and Vazquez, G., 2007, "Effect of stirring in the osmotic dehydration of chestnut using glycerol solutions LWT"., Food Science and Technology., 40, pp. 1507-1514.

[21] Myers, R.H., and Montgomery, D.C., 1995, "Response surface methodology: Process and product optimization using designed experiments"., John Wiley and sons., NewYork.

[22] Madamba, P.S., 2003, "Thin layer drying models for osmotically predried young coconut"., *Drying Technology.*, vol.21, pp. 1759-1780.

[23] Beq, O.K., Saxena, R.K., and Gupta, R., 2002, "Kinetic constants determination for an alkaline protease from *Bacillus mojavensis* using

response surface methodology"., *Biotechnology and Bioengineering.*, vol. 78, pp. 289-295.

[24] Rastogi, N. K., Raghavarao, K. S. M. S., Niranjan, K., and Knorr, D., 2002, "Recent developments in osmotic dehydration: Methods to enhance mass transfer"., Trends in Food Science and Technology.,13(2), pp. 58–69.

[25] Chang, Y.C., Lee, C.L., and Pan, T,M., 2006, "Statistical optimization of media components for the production of Antrodia cinnamomea AC0623 in submerged cultures"., *Applied Microbiology and Biotechnology.*, vol.72, pp. 654-661.