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Osmotic drying out of Coconut Slices in salt solution: Optimization of process parameters using response surface methodology

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Abstract: In this study the Response Surface Methodology was used to determine the optimum concentration of salt solution, temperature and processing time for the osmotic dehydration of coconut slices. Osmotic dehydration of coconut slices was conducted over the range of salt concentration (6.59 to 23.40 % w/w), temperature (26.59 to 43.41 °C) and processing time (0.32 to 3.68 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 percentage of WR, SG and WL were developed .A constant solvent to sample ratio of 5:1 (w/w) was used. Analysis of the regression coefficients showed that salt concentration with temperature and temperature with processing time for WR and WL and salt concentration with processing time for SG were the most important factor that affected the osmotic dehydration of coconut slices as they exerted a highly significant influence ($p<0.05$) on all the dependent variables. Optimum conditions for maximum percentage of weight reduction, water loss and minimum solid gain was found at 16.27 % w/w salt concentration, 34.74 °C and 2.01 hours. At these conditions, Weight Reduction (WR), Solid Gain (SG) and Water Loss (WL) were 14.38 %, 1.77 % & 16.16 % respectively.

Key words: Osmotic drying, Coconut Slices, response surface methodology, process parameters.

1. 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 [1]. Osmotic dehydration has received greater attention in recent years as an effective method for preservation of fruits and vegetables. Being a simple process, it facilitates processing of tropical fruits and vegetables such as banana, sapota, pineapple, mango, and leafy vegetables etc. with retention of initial fruit and vegetables characteristics viz., colour, aroma and nutritional compounds [2]. Osmosis is the movement of water molecules through a selectively-permeable membrane down a water potential gradient. More specifically, it is the movement of water across a selectively- permeable membrane from an area of high water potential (low solute concentration) to an area of low water potential (high solute concentration [3].

Osmotic treatment is actually a combination of dehydration and impregnation processes, which can modifies the negative effects of fresh food components. Osmotic dehydration is the process of partial removal of water by contacting the fruits and vegetables in a hypertonic solution. During the osmotic dehydration, two major simultaneous counter current flows occur. Water present inside the tissues flows out into the osmotic solution and simultaneously solutes in the osmotic solution enter the tissues of fruits and vegetables due to the difference in osmotic pressures gradient [4]. In addition ,other substances such as vitamins, organic acids, saccharides and mineral salts were leached from the cells of fruit and vegrtables into osmotic solution, but these amounts are considered to be quantitatively negligible. Although, this flow has no considerable amount in the mass exchange, it can influence the final nutritive values and organolepic properties of food [5]. Osmotic dehydration has recently received increasing attention as a potential pretreatment to conventional drying and freezing processes for improving the quality of fruit. It is a slow process suggesting the need for enhancing mass transfer without affecting the food quality negatively. Pretreatment such as blanching, freezing, high pressure, high intensity pulsed electric field and ultrasound have been reported to enhance mass transfers [6]. The texture and stability of pigments during dehydration and storage was improved and sugar to acid ratio was also increased during osmotic dehydration [7]. 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. 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 [8]. Any pre treatment such as blanching or freezing prior to osmotic water removal was detrimental to the product quality. Dipping in 1 percent citric acid solution prior to drying or osmotic dehydration was used to prevent enzymatic browning of fruits. Immersion of product in alkaline or acid solutions of oleate esters prior to drying of fruits affected the prevention of discoloration [9].

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 effect of sucrose and glycerol mixtures in the osmotic solution on mass transfer of mandarin was studied. Peeled mandarin samples were immersed in osmotic solution prepared from various ratios of sucrose solution (60%) to glycerol solution (60%), specifically, 9:1, 8:2, 7:3, 6:4 and 5:5 w/w. It was found that the highest water loss was obtained when the osmotic solution of 5:5 was used. This is because of glycerol having a lower molecular weight than sucrose. Increasing the amount of glycerol increased the osmotic pressure gradient and thereby increased the water loss. Additionally, an increase in solid gain was observed when the sucrose/glycerol ratio was decreased to 5:5.

This indicated that a decrease in the Molecular size of the solute could enhance the solid gain. In fact, mass transfer of the solute depends on the effective diffusion coefficient that can be affected by the radius of molecules.(10)..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 [11]. The mass transfer during osmotic dehydration of watermelon slabs was studied. The process was carried out at three different sucrose concentrations (40oBrix, 50oBrix and 60oBrix). Water loss and solid gain increased with the osmotic solution concentration increase. Watermelon slabs immersed into 60oBrix sucrose solution showed higher water loss and solid gain compared to those immersed in 40oBrix and50oBrix solutions[12]. During osmotic dehydration of mango and pineapple increase in osmotic duration resulted in increase in weight loss, but the rate of which occurs decreases[13]. 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 [14].There are numerous studies on osmotic dehydration of fruits and vegetables [15-17].

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 [18]. 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., [19-23]. 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 (salt solution), temperature and processing time were found out for maximum water loss, weight reduction and minimum solid gain.

2. Materials and Methods

The commercial grade salt was purchased from local super market. The salt was mixed with required quantity of distilled water to prepare desired osmotic solution salt concentration. The concentration of salt solution was measured by refractometer. The mature coconut was purchased in a local market on the basis 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 washed coconut slices were undergoing pre-treatment followed by osmotic dehydration.

2.1. Experimental design and statistical analysis

The experimental design was carried out by using a central composite design in response surface methodology consisting of five levels and three factors for the three responses. The response and the independent variables are correlated by using a quadratic model. 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 salt concentration , temperature and processing time respectively. The independent variables were salt concentration (6.59 to 23.40 % w/w), temperature (26.59 to 43.41 °C) and processing time (0.32 to 3.68 hours).Twenty runs of the experiment were carried out according to response surface methodology and applied in Design Expert 8.0.7.1 to obtain analysis of variance (ANOVA) for response surface quadratic model for the osmotic dehydration of coconut slices by using salt solution.

2.2. Experimental procedure:

The fresh mature coconut slices of 100 g were used for osmotic dehydration. The coconut slices samples were initially subjected to pre treatment by blanching and immersing in citric acid solution followed by osmotic dehydration process. The osmotic dehydration process was conducted in a 500 ml Erlenmeyer flask, which was kept in a thermostatically controlled water bath shaker. Coconut kernel was cut into slices, blanched at 90 0c for 2 minutes for tissue permeability and to deactivate the enzyme activity, submerged in 2% citric acid solution for 2 minutes to improve the shelf life of the coconut slices, weighed and then placed into the flask containing salt solution of varying concentrations (6.59 to 23.40 % 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 5 hours. In each of the experiments fresh osmotic salt 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. Percentage of 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).

3. Results and Discussions:

The effect of process parameters (independent variables) on percentage of weight reduction (WR), solid gain (SG) and water loss (WL) of osmotic dehydration of coconut slices by using salt solution was studied. The experimental results were analysed statistically by RSM to obtain an empirical model for the best response. Mathematical expressions of second order polynomial coefficients for the response equation (5), (6) & (7) were determined using design expert 8.0.7.1.

Weight reduction = 14.17194 +1.08556 * Salt +0.36366 * Temperature + 0.96026*Time - 0.30087 * Salt * Temperature -0.11762 *Salt * Time - 0.40262 * Temperature*Time - 0.97883 * Salt^2- 0.56959 * Temperature^2 - 0.94153 * Time^2 (5)

Solid gain = 1.69695 + 0.29826 * Salt + 0.24160 * Temperature + 0.46308 * Time +1.37500E-003 * Salt * Temperature + 0.095875 * Salt * Time + 0.016125 * Temperature * Time + 0.16125 * Salt^2 + 0.097927 * Temperature^2 + 0.20965 * Time^2 (6)

Water loss = 15.86888+1.38382 * Salt+0.60526 * Temperature +1.42334* Time -0.29950 * Salt * Temperature - 0.021750 * Salt *Time - 0.38650 * Temperature * Time - 0.81726*Salt^2 - 0.47166 * Temperature^2 – 0.73188 * Time^2 (7)

The results were analysed by using analysis of variance (ANOVA) and are given in table (3), (4) & (5). In this work the model F value of 69.26, 55.02 and 63.60 for WR, SG and WL implies that the models are significant. The smaller the magnitude of P, more significant is the corresponding coefficient. From the ANOVA table, it was found that the linear effect of WR, SG, &WL is more significant for osmotic dehydration of coconut slices by using salt solution .Also the interactive effect of salt concentration with temperature and temperature with processing time for WR, WL and concentration of salt solution with processing time for SG implies significant for osmotic dehydration of coconut slices .In RSM a CCD design was developed in order to obtain optimum conditions. The range and levels of independent variables was presented in table (1). The 20 runs of the experiment in a random form and the values of the response variables obtained in each run, along with predicted values were presented in table (2). The R^2 values for weight reduction, solid gain and water loss were 0.9842, 0.9802 and 0.9828 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 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 probability (p) values of all regression models were less than 0.050 indicates that the model terms are significant.

Table-1: Range of independent variables used for the osmotic dehydration of coconut slices

Factors	**Variable**	**Unit**	**Range and levels**				
			-1.68	**-1**	**0**	**1**	**+1.68**
A	Salt concentration	%(w/w)	6.59	10	15	20	23.40
B	Temperature	(^{o}c)	26.59	30	35	40	43.41
C	Processing time	(hrs)	0.32	1	2	3	3.68

Percentage of Weight reduction

Table 2: Experimental conditions and observed response values of CCD

Run order	**Salt 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	-1	1	1	11.813	2.632	14.445	11.9362	2.4913	14.4276
2	0	0	0	14.011	1.634	15.645	14.1719	1.6969	15.8689
3	0	0	-1.68179	9.382	1.432	10.814	9.8939	1.5111	11.4051
4	0	1.68179	0	13.01	2.295	15.305	13.1725	2.3802	15.5527
5	-1	-1	-1	8.622	1.412	10.034	8.4514	1.2765	9.7279
6	1	1	-1	12.549	2.234	14.783	12.3903	2.1322	14.5226
7	0	0	0	14.301	1.747	16.048	14.1719	1.6969	15.8689
8	1	1	1	13.328	3.243	16.571	13.2704	3.2824	16.5528
9	0	0	1.68179	13.313	3.012	16.325	13.1239	3.0687	16.1926
10	0	-1.68179	0	11.789	1.517	13.306	11.9493	1.5676	13.5169
11	-1	1	-1	10.951	1.743	12.694	10.5857	1.7247	12.3104
12	1	-1	-1	11.811	1.634	13.445	11.4595	1.6785	13.1381
13	0	0	0	14.001	1.633	15.634	14.1719	1.6969	15.8689

14	1	-1	1	13.813	2.842	16.655	13.9500	2.7642	16.7142
15	0	0	0	14.381	1.773	16.154	14.1719	1.6969	15.8689
16	0	0	0	14.002	1.635	15.637	14.1719	1.6969	15.8689
17	1.68179	0	0	13.083	2.645	15.728	13.2291	2.6555	15.8846
18	-1.68179	0	0	9.401	1.527	10.928	9.5777	1.6523	11.2300
19	-1	-1	1	11.482	1.973	13.455	11.4124	1.9787	13.3911
20	0	0	0	14.391	1.783	16.174	14.1719	1.6969	15.8689

3.1. Effects of independent variable on percentage of Weight reduction:

The effects of independent variable on percentage of weight reduction were reported in Figures (1), (2) & (3). The ANOVA for percentage of weight reduction table (3) indicates that, The Lack of Fit F-value of 3.94 implies the Lack of Fit is not significant. Non-significant lack of fit is good. The Predicted R-Squared of 0.8980 is in reasonable agreement with the Adjusted R-Squared of 0.9700. In this case A, B, C, AB, BC, A^2, B^2, C^2 are significant model terms .The coefficient of second order polynomial indicates the effects of independent variables on percentage of Weight reduction. The linear effect of salt concentration ($p<0.0001$), temperature ($p<0.050$) and processing time ($p<0.0001$) were shows positive relationship with percentage of weight reduction and negatively related to the quadratic effect of salt concentration ($p<0.0001$), temperature ($p<0.0001$) and processing time ($p<0.0001$). Interaction effects of salt concentration with temperature ($p <0.050$) and temperature with processing time ($p<0.050$) on percentage of weight reduction were highly significant .In the Fig (1) & (3), it implies that the percentage of weight reduction was increased with increase in salt concentration with temperature and temperature with processing time from 6.59 % to 16.27 % salt concentration , 26.59 ^{0} C to 34.74 ^{0} C temperature and 0.32 to 2.01 hrs processing time. The maximum percentage of weight reduction 14.38 % was obtained at salt concentration of 16.27 % w/w, temperature of 34.74^{0}c and processing time of 2.01 hours of osmotic dehydration. Whereas this effect does not appear above these conditions, since it may be due to the solids in osmotic solution accumulate intermediately in the capillaries of the coconut tissues and slightly slow down the movement of water transfer rate between coconut slices and osmotic solution. At lower concentration of salt solution and temperature, it facilitates the movement of water transfer from coconut slices to the osmotic solution and thereby the percentage of weight reduction was increased. While at higher concentration of salt solution and temperature it promotes higher water loss at the same time it promotes higher solid gain (24). Which accumulate intermediately at the sub surface layer of the coconut slices and slightly resist the movement of water transfer rate between coconut slices and osmotic salt solution and these effect contributes to reduce the mass transfer rate simultaneously in high concentrated osmotic salt solution with temperature and temperature and processing time and affect on percentage of weight reduction at above condition 16.27 % salt concentration , 34.74 ^{0} c temperature and 2.01 hrs processing time .

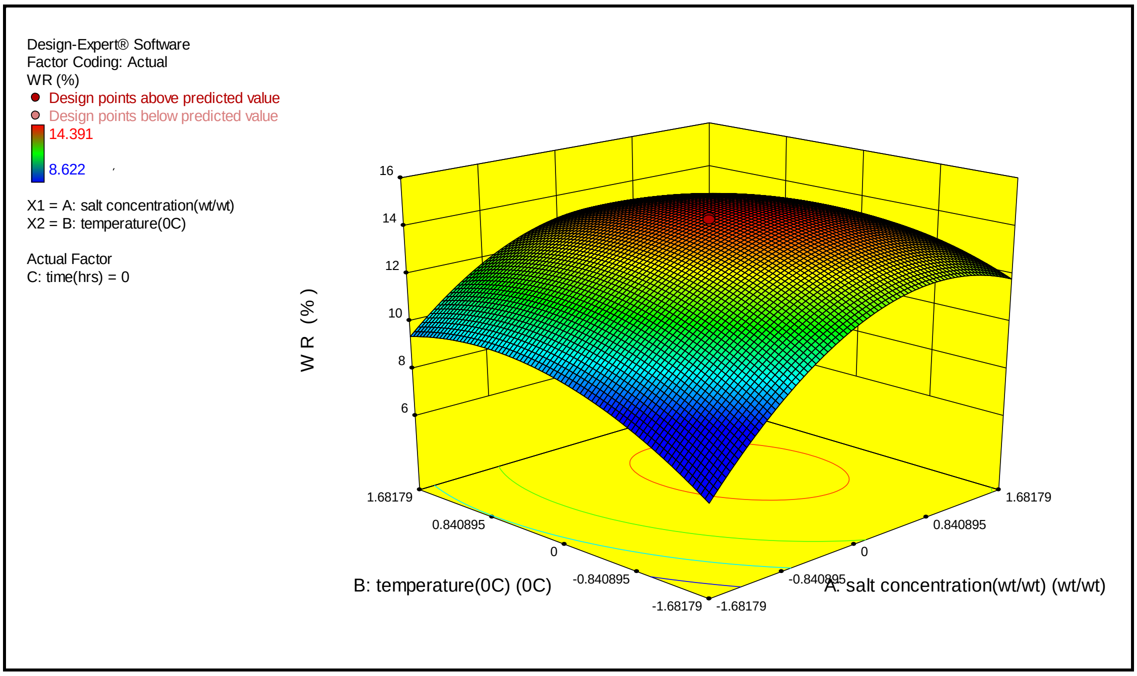

Figure 1 :3D plot of the combined effect of the salt concentration and temperature on percentage of weight reduction

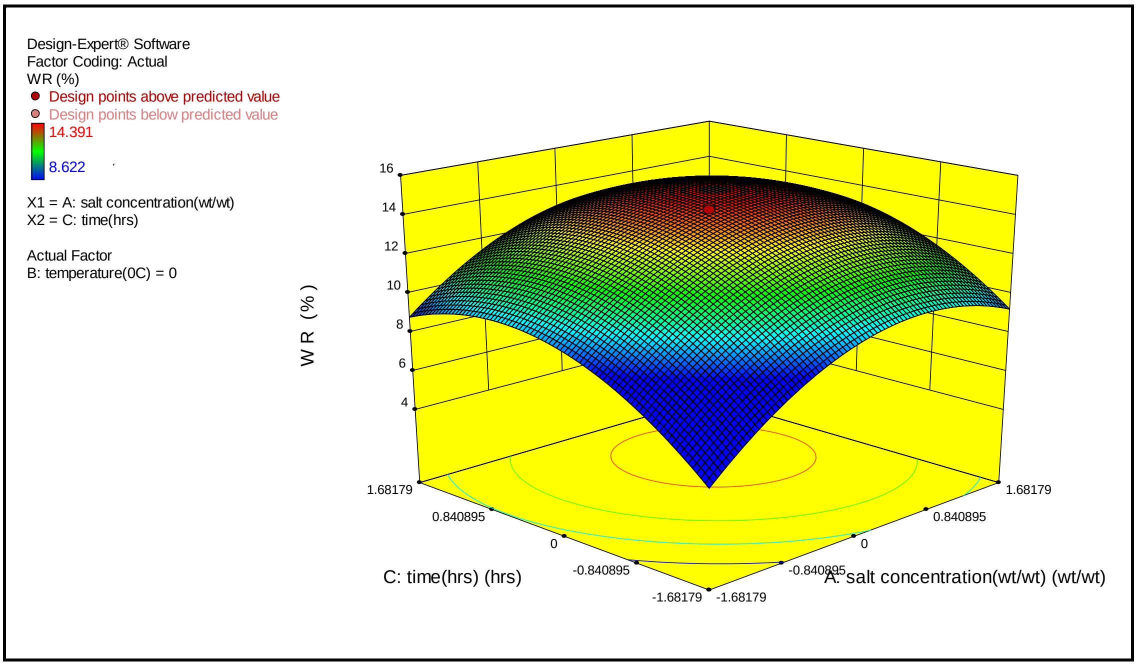

Figure 2: 3D plot of the combined effect of the salt concentration and time on percentage of weight reduction

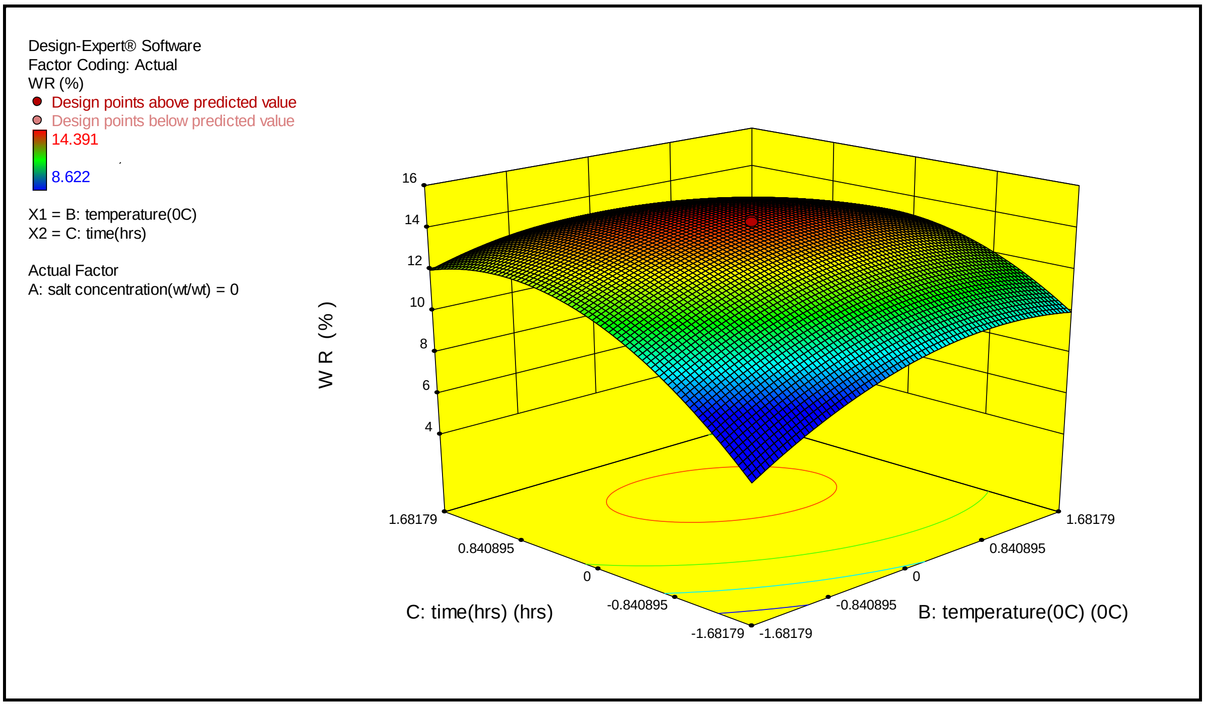

Figure 3: 3D plot of the combined effect of the temperature and time on percentage of weight reduction Percentage of Solid gain

Table: 3 Analysis of variance (ANOVA) for Response Surface Quadratic Model for the Osmotic dehydration of coconut slices – Percentage of Weight reduction

Source	**Coefficient Estimate**	**Sum of squares**	**df**	**Mean square**	**F value**	**p-value prob>F**
Model		59.11	9	6.57	69.26	<0.0001 significant
Intercept	14.17					
A-salt concentration % (w/w)	1.09	16.09	1	16.09	169.72	<0.0001
B-temperature (^{0}c)	0.36	1.81	1	1.81	19.05	0.0014
C-time (hrs)	0.96	12.59	1	12.59	132.80	<0.0001
AB	-0.30	0.72	1	0.72	7.64	0.0200
AC	-0.12	0.11	1	0.11	1.17	0.3053
BC	-0.40	1.30	1	1.30	13.68	0.0041
A^2	-0.98	13.81	1	13.81	145.61	<0.0001
B^2	-0.57	4.68	1	4.68	49.30	<0.0001
C^2	-0.94	12.78	1	12.78	134.72	<0.0001
Residual		0.95	10	0.095		
Lack of Fit		0.76	5	0.15	3.94	0.0792 Not significant
Pure Error		0.19	5	0.038		
Cor Total		60.06	19			

3.2. Effect of independent variable on percentage of solid gain:

Table-4Analysis of variance (ANOVA) for Response Surface Quadratic Model for the Osmotic dehydration of coconut slices – Percentage of Solid gain

Source	**Coefficient Estimate**	**Sum of squares**	**df**	**Mean square**	**F value**	**p-value prob>F**
Model		6.00	9	0.67	55.02	<0.0001 significant
Intercept	1.70					
A-salt concentration % (w/w)	0.30	1.21	1	1.21	100.29	<0.0001
B-temperature (^{0}c)	0.24	0.80	1	0.80	65.80	<0.0001
C-time (hrs)	0.46	2.93	1	2.93	241.76	<0.0001
AB	1.375E-003	1.513E-005	1	1.513E-005	249E-003	0.9725
AC	0.096	0.074	1	0.074	6.07	0.0335
BC	0.016	2.080E-003	1	2.080E-003	0.17	0.6873
A^2	0.16	0.38	1	0.38	31.05	0.0002
B^2	0.098	0.14	1	0.14	11.41	0.0070
C^2	0.21	0.63	1	0.63	52.29	<0.0001
Residual		0.12	10	0.012		
Lack of Fit		0.094	5	0.019	3.41	0.1024 Not significant
Pure Error		0.027	5	5.499E-003		
Cor Total		6.12	19			

The table 4 shows the analysis of variance for effect of independent variable on percentage of solid gain. In this case A, B, C, AC, A^2, B^2, C^2 are significant model terms . The lack of fit F Value of 3.41 shows the lack of fit is not significant. The Predicted R-Squared of 0.8687 is in reasonable agreement with the Adjusted R-Squared of 0.9624. The coefficient of second order polynomial shows the effects of independent variables on percentage of solid gain. The effects of the independent variable on the percentage of solid gain were shown in figures (4), (5) & (6). The second order polynomial coefficient shows the positive sign towards the linear effect of salt concentration, temperature and processing time with P value ($P < 0.0001$, $P <0.0001$ and $P<0.050$) and also towards the quadratic effect of salt concentration, temperature and processing time with P value ($P <0.050$, $P <0.050$ and $P < 0.0001$) . The Interactive effects of salt concentration with processing time on percentage of solid gain were highly significant with P value ($P <0.050$) .During osmotic dehydration, simultaneous counter-current flow occurs. Solid diffuses from the osmotic salt solution to the coconut slices and water diffuses out from the coconut slice to the osmotic salt solution. In figure (5), it was clearly depicted that the minimum percentage of solid gain was attained with salt concentration and processing time from 6.59 % to 16.27 % and 0.32 hrs to 2.01 hrs. During osmotic dehydration large solid gain uptake will occur at higher concentration of salt solution, temperature and processing time. Solid uptake modifies the final product composition and taste. The solids uptake blocks the surface layers of the product,, posing an additional resistance to mass transfer and lowering the rate of complementary osmotic dehydration (11) .The minimum solid gain of 1.77 % was attained at salt concentration (16.27 % w/w), temperature (34.74 °C) and processing time (2.01 hours). Whereas this effect was did not appear above this conditions, the salt has low molecular weight, which induces more solid gain in coconut slices naturally. At higher concentration of salt solution and processing time ,it promotes more solids uptake into the coconut slices .

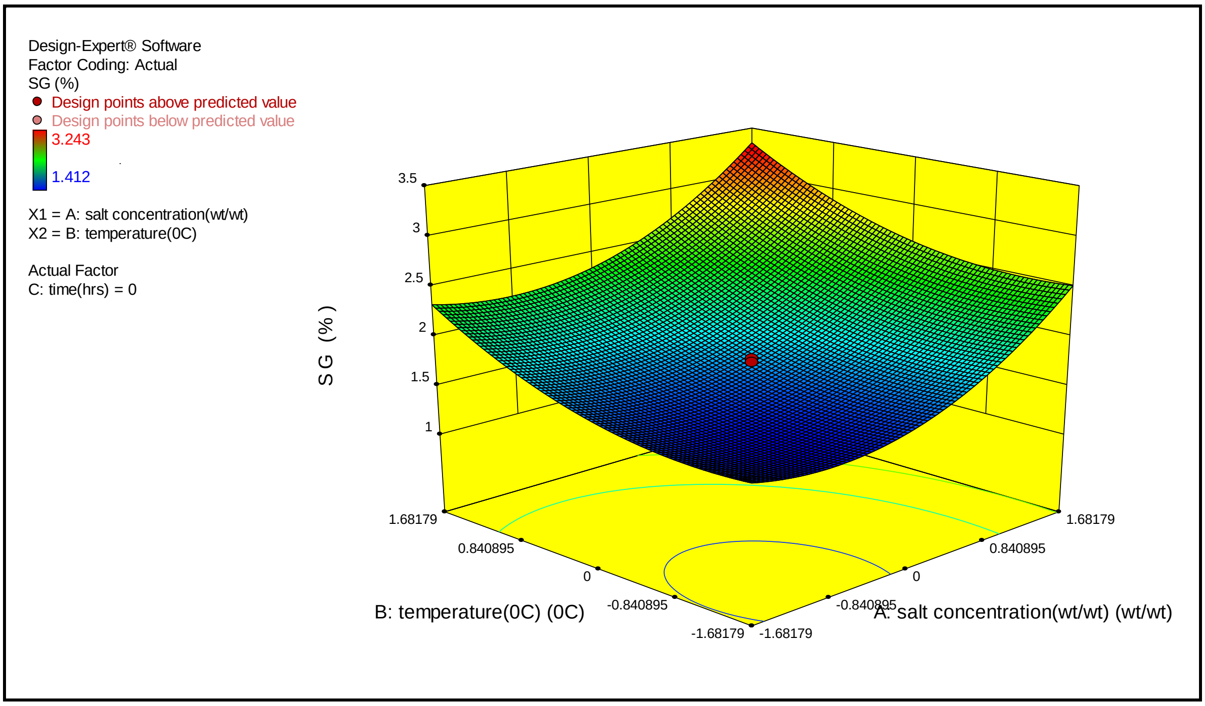

Figure 4: 3D plot of the combined effect of the salt concentration and temperature on percentage of solid gain

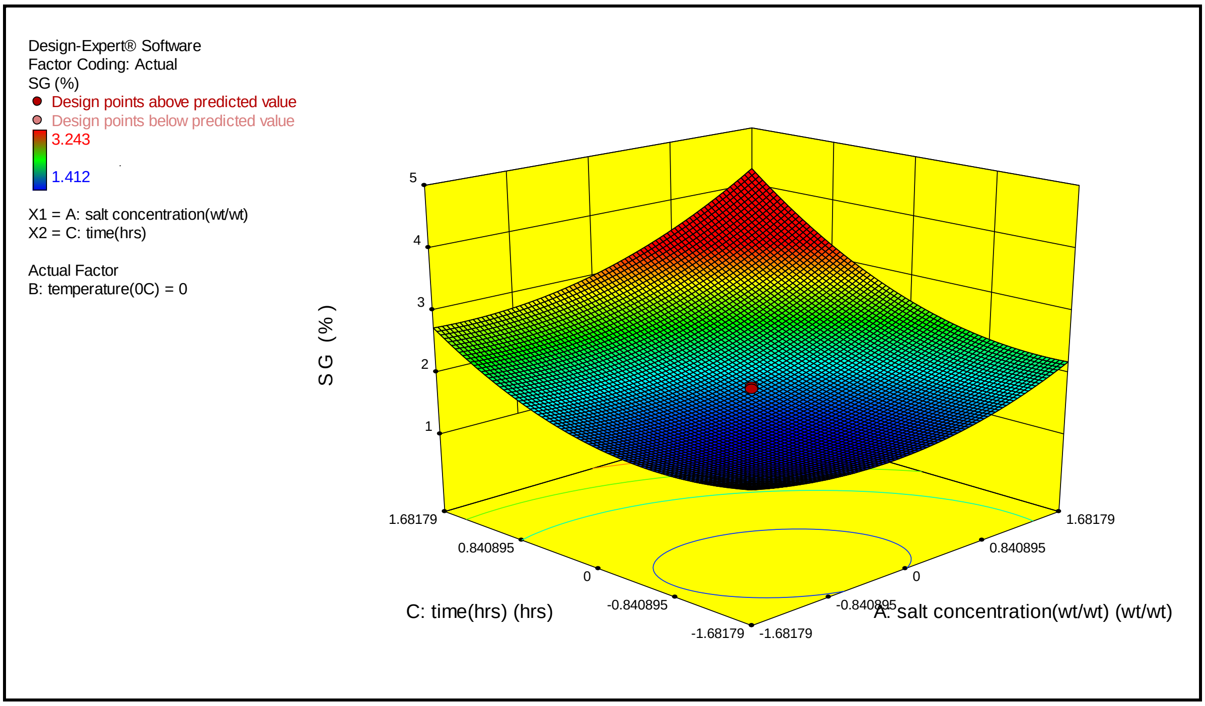

Figure 5: 3D plot of the combined effect of the salt concentration and time on percentage of solid gain

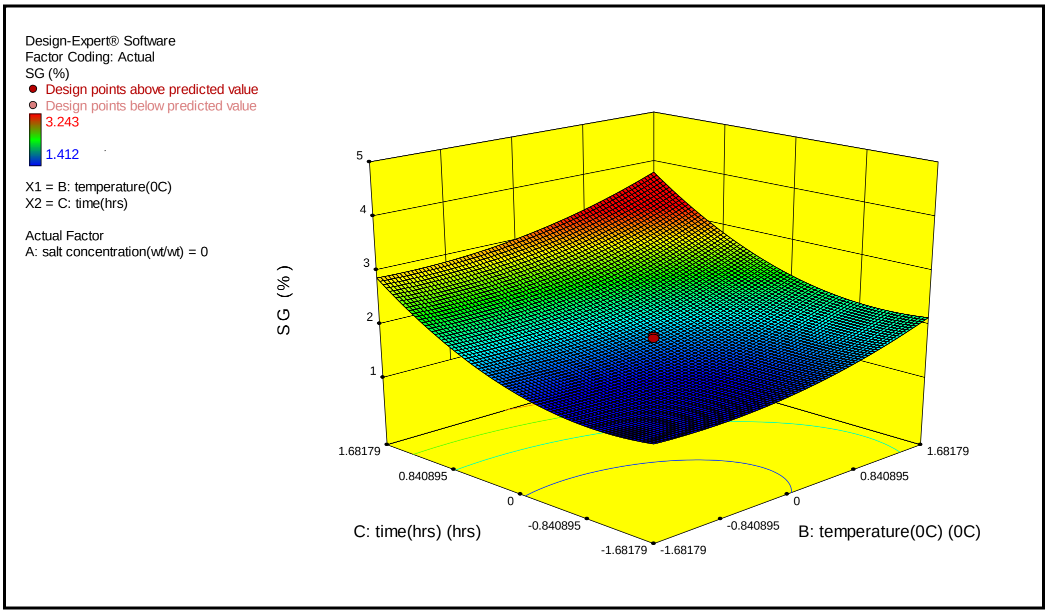

Figure 6: 3D plot of the combined effect of the temperature and time on percentage of solid gain

Percentage of Water loss

3.3. Effect of salt concentration, temperature and processing time on Water loss:

Table-5 Analysis of variance (ANOVA) for Response Surface Quadratic Model for the Osmotic dehydration of coconut slices – Percentage of Water loss

Source	Coefficient Estimate	Sum of squares	df	Mean square	F value	p-value prob>F
Model		78.14	9	8.68	63.60	<0.0001 significant
Intercept	15.87					
A-salt concentration % (w/w)	1.38	26.15	1	26.15	191.58	<0.0001
B-temperature (^{0}c)	0.61	5.00	1	5.00	36.65	0.0001
C-time (hrs)	1.42	27.67	1	27.67	202.68	<0.0001
AB	-0.30	0.72	1	0.72	5.26	0.0448
AC	-0.022	3.784E-003	1	3.784E-003	0.028	0.8711
BC	-0.39	1.20	1	1.20	8.75	0.0143
A^2	-0.82	9.63	1	9.63	70.51	<0.0001
B^2	-0.47	3.21	1	3.21	23.49	0.0007
C^2	-0.73	7.72	1	7.72	56.55	<0.0001
Residual		1.37	10	0.14		
Lack of Fit		1.00	5	0.20	2.75	0.1460 Not significant
Pure Error		0.36	5	0.073		
Cor Total		79.51	19			

The effect of the independent variables such as salt concentration, temperature and processing time on the percentage of water loss were shown in fig (7), (8) & (9). In the ANOVA table (5), The Lack of Fit F-value of 2.75 implies the Lack of Fit is not significant. In this case A, B, C, AB, BC, A^2, B^2, C^2 are significant model terms. The second order polynomial coefficient show positive coefficient values towards the linear effect of salt concentration ($p < 0.0001$), temperature ($p<0.0001$) and processing time ($p <0.050$). The percentage of water loss showed a negative coefficient values towards the quadratic effects of salt concentration ($p<0.0001$), temperature ($p <0.050$) and processing time ($p<0.0001$). The interaction effect between salt concentration with temperature ($P<0.050$) and temperature and processing time ($p <0.050$) towards the percentage of water loss was highly significant. The Predicted R-Squared of 0.8980 is in reasonable agreement with the Adjusted R-Squared of 0.9674. In the figure (8), it was clearly implies that at lowest level of salt concentration, the percentage of water loss increased with temperature and temperature with processing time. At highest level of salt concentration, the percentage of water loss decreased at a slower rate with temperature and temperature with processing time. The maximum water loss of 16.16% was obtained at salt concentration (16.27 % w/w), temperature (34.74 °C) and processing time (2.01 hours).

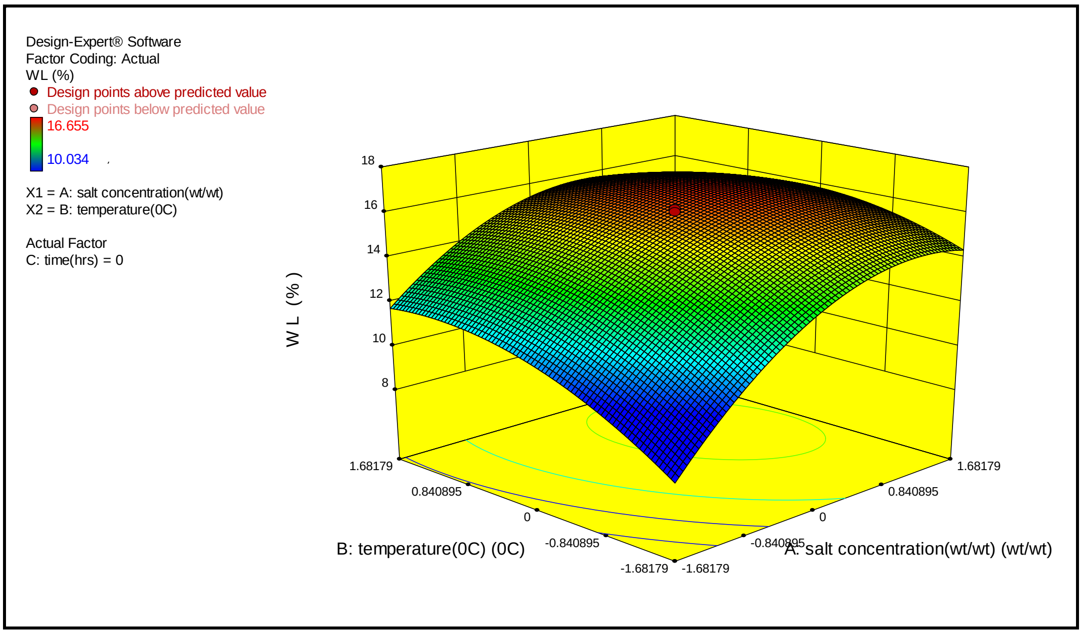

Figure 7: 3D plot of the combined effect of the salt concentration and temperature on percentage of water loss

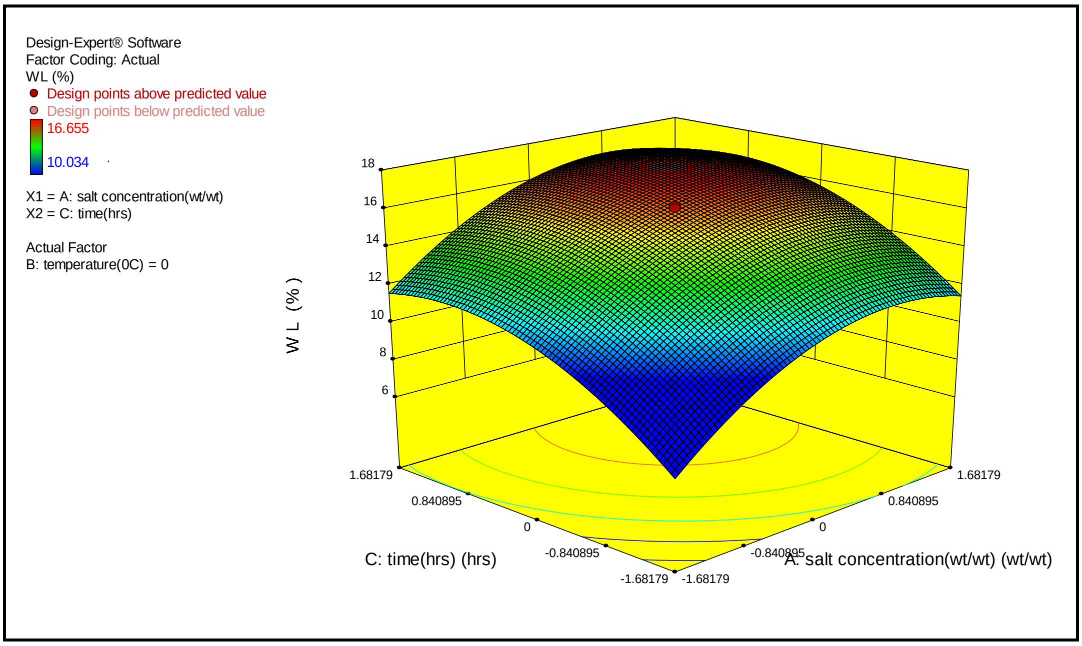

Figure 8: 3D plot of the combined effect of the salt concentration and time on percentage of water loss

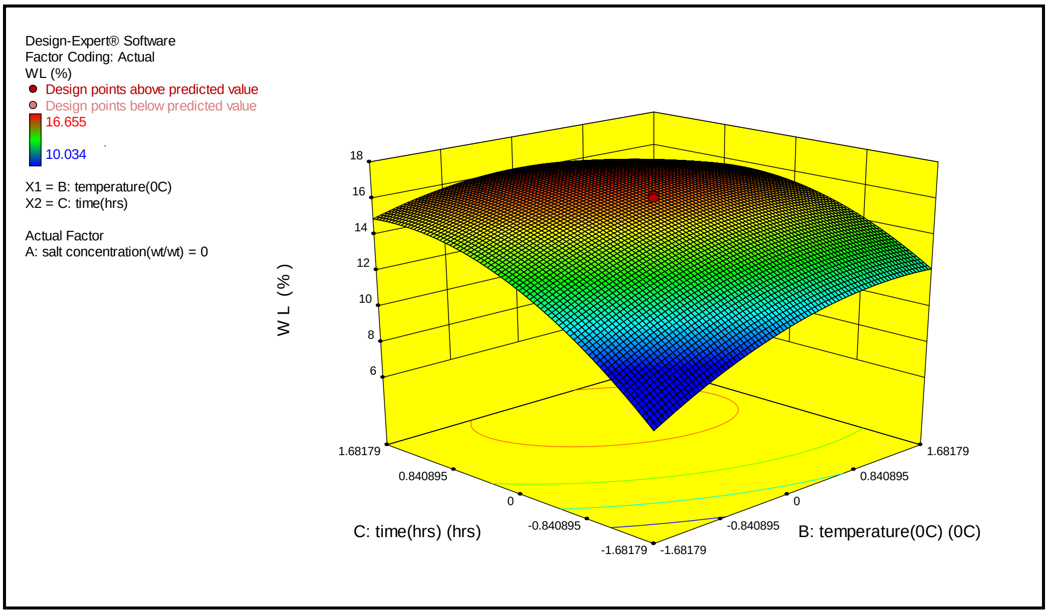

Figure 9:3D plot of the combined effect of the temperature and time on percentage of water loss

The percentage of water loss was increased with increase in salt concentration with temperature and temperature with processing time from6.59% to 16.27%, 26.59 ^{0}C to 34.74 ^{0}C and 0.32 hrs to 2.01 hrs. Above these conditions, the percentage of water loss was decreased at slower rate with salt concentration and temperature and temperature and processing time. This could be the effect of solids accumulate intermediately in the capillaries pores of the coconut tissues. At higher concentration of salt solution with temperature , it facilitates the higher water loss at the same time higher uptake of solid gain also occur due to the membrane swelling and plasticizing effect. These effects improve the permeability of the cell membrane towards solids from osmotic salt solution to the coconut slices (25). Therefore the solids accumulate in the sub layers of the coconut tissues and blocks the surface layers of the coconut slices and posing an additional resistance to mass transfer and lowering the rate of water loss (26) between the coconut slices and osmotic salt solution.

3.4. Optimization:

Optimizing the process parameters to obtain maximum percentage of weight reduction, water loss and minimum solid gain, a Second order polynomial models obtained for the each response in this study were utilized to determine the specified optimum condition of the process parameter .The MATLAB 7 is used to solve the second degree polynomial regression equation 5, 6 and 7. The criteria for the optimization is to maximize the percentage of WR, WL and minimize the SG .The maximum percentage of WR ,WL and minimum SG was found at 16.27 % w/w salt concentration, 34.74 °C temperature and 2.01 hours processing time . At these conditions, the response variable such as percentage of Weight Reduction (WR), Solid Gain (SG) and Water Loss (WL) were 14.38 %, 1.77 % & 16.16 % respectively.

4. Conclusion:

In this study, the RSM was applied to determine the optimum operating conditions to get maximum WR, WL and minimum SG in osmotic dehydration of coconut slices by salt solution. Analysis of variance was determined by using design expert 8.0.1.7. The ANOVA table 3, 4 and 5 shows the proposed second order polynomial model were statistically significant**.** Second order polynomial models were obtained for predicting water loss, solid gain and weight reduction. Optimum conditions for maximum weight reduction, water loss and minimum solid gain was found at 16.27 % w/w salt concentration, 34.74 °C and 2.01 hours. At these conditions, Weight Reduction (WR), Solid Gain (SG) and Water Loss (WL) were 14.38 %, 1.77 % and 16.16 % respectively.

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