STUDY TO OPTIMIZE THE OSMOTIC DEHYDRATION PARAMETERS OF APPLE CUBES

Rajni Kamboj[1], Manav Bandhu Bera[2], Vikas Nanda[3]

[1] *Department of Food Technology, CDL State Institute of Engineering and Technology, Panniwala Mota, Sirsa, Haryana (India)*

[2,3]*Department of Food Engineering and Technology, SLIET, Longowal Sangrur, Punjab (India)*

ABSTRACT

A specific technique used to produce high quality product of fruit being immersed in hypertonic solution of high osmotic pressure for a specified time and temperature. To optimize the process conditions response surface methodology was used. Independent process variables for osmotic dehydration of apple were temperature (45-65 °C), process time (10-540 min.), solution to fruit ratio (1:1 to 3:1) and concentration of sucrose into honey (100:5-100:15) by response surface methodology. Responses of water loss and solute gain were fitted to polynomials, with multiple coefficients of correlation (R^2) 0.99. The fitted functions were optimized for maximum water loss and solute gain to obtain a good quality product. The low and high levels of temperature 45 and 65 °C, concentration of sucrose into honey 5 and 15 w/w, solution to fruit ratio 1:1 and 3:1 w/w and process time 10 and 540 minutes respectively. The optimum conditions for osmotic dehydration concentration of sucrose, temperature, time and solution to fruit ratio were 100:13, 60 °C, 420 minutes and 2:1 respectively.

Keywords: apple, honey, osmotic dehydration, response surface methodology and sucrose.

I. INTRODUCTION

Osmotic dehydration is a preservation technique to give high quality products which involves partial removing water without change of phase [1]. Whereas, water removal by high temperatures and long dehydration times may cause loss of nutrients and also affect sensory characteristics (flavor, color, texture, and other properties) of the product [2]. By osmotic dehydration product obtained is of good quality and energy consumption also reduced [3]. In osmotic dehydration, the kind of osmotic agent and its concentration strongly affected the kinetics of water removal, the solute gain and the equilibrium moisture content [4]. In osmotic dehydration fruits immersed in sucrose whereas vegetables are immersed in sodium chloride, solutions of high osmotic pressure [5], which involves three types of cross current mass transfer (1) water outflow, from the product to the osmotic medium due to concentration gradient between them. (2) a solid transfer, from the osmotic solution to the product. (3) a leaching out of the products natural solids (sugars, organic acids, minerals, vitamins, etc.), which is quantitatively minor compared with the first two types of transfer, but necessary relating to the composition of the final product.

Apple is the main temperate fruit and is fourth among the most widely produced fruits in the world after banana, orange and grape. Apple is rich in phyto-nutrients which are vital for optimal health, reduces the risk of colon cancer, prostate cancer and lung cancer. The antioxidants present in the apple have a number of health benefits and disease prevention properties. Apple contains good quantity of fiber, iron, vitamin C, beta-carotene and B-complex vitamins such as riboflavin, thiamin and pyridoxine. Apples also carry a small amount of minerals like potassium, phosphorus and calcium. Response surface methodology (RSM) has practical usefulness in optimization. It has been widely used in industries for product development and upgrading of product [1, 6]. Experimental design technique used to observe and find out the valuable type of method that entails one or more response variables that are affected by various factors or independent variables [7].

The objective of this work was to study the effect of concentration of osmotic agents (sucrose and honey), temperature of solution, time of immersion and solution to fruit ratio (STFR) on water loss and solute gain during osmotic dehydration through response surface methodology (RSM).

II. MATERIAL AND METHODS

2.1 Raw Material

Experiments were conducted to study the effect of different osmotic agents, temperature of solution, time of immersion and osmotic agent concentration on water loss and solute gain during osmotic dehydration of apple pieces. Apples used for the testing were obtained from the market of Sirsa, Haryana. Apples thoroughly washed with water to remove debris and peeled manually. These were cut into pieces of uniform size of (10×10 mm) with 10 mm thickness. Blanching of samples was done in hot water to inactivate enzymes. Then pieces were removed from the water and their surface blotted with tissue paper. Osmosis of the sample was done and initial moisture content was determined.

2.2 Osmotic Dehydration

Sucrose and honey were used as the osmotic agents. Osmotic solution was prepared by dissolving sucrose in to honey, beneath the conditions as given in the experimental design (Table1). Slices of apple were submerged in the osmotic solution of sucrose into honey concentration (100:5, 100:10 and 100:15) in 500 ml beakers and placed inside a water bath at temperature (45, 55 and 65 ^{o}C), solution to fruit ratio (1:1, 2:1 and 3:1) and immersion time (10, 275 and 540 minutes). After each time of osmosis, samples were removed from the osmotic solution, removal of excess of solution at the surface by absorbent paper and weighted on an electronic balance. Osmosed samples were then used for determination of moisture.

The initial and final moisture content of sample was determined by using hot air oven method recommended by Ranganna [8] for fruits and vegetables.

$$\text{Moisture Content}\ (\%) = \frac{(M_1 - M_2)}{M_1} * 100 \qquad (1)$$

where M_1= Weight of sample (gm), M_2 = Weight of dried sample (gm)

$$WL_t = \frac{(W_0 - W_t) + (S_t - S_0)}{W_0} * 100 \qquad (2)$$

where WL_t= Water loss g/100g fresh sample, M_0 = Weight of initial moisture (gm), M= Weight of final moisture (gm) and W= Initial weight of sample.

$$SG_t = \frac{(S_t - S_0)}{W} * 100 \qquad (3)$$

where SG_t= Solute gain g/100g fresh sample, S_t = Weight of final solid (gm), S_0 = Weight of initial solid (gm), and W = Initial wt of sample (g)

2.3 Experimental Design and Statistical Analysis

Different statistical tools, as Response Surface Methodology (RSM), are used by several instigators to study process variables [9, 10]. Response surface methodology (RSM) was used to optimize and evaluate main effects, interaction effects and quadratic effects of the process conditions on water loss and solutes gain. A face centered rotatable design was used for designing the experiments for osmotic dehydration of apple pieces with four variables and five levels. The independent variables were temperature (45-65 ^{O}C), concentration of sucrose into honey (5-15% w/w) and time (10-540 min). The solution to fruit ratio was kept 1:1, 2:1 and 3:1 (w⁄w) (Table 1). The experiments were conducted in three replications.

In the equation (4) the mathematical function Ψ, exists for the response variable Y (water loss and solute gain) and four independent variables [11], (temperature, concentration, time and STFR):

$$\mathbf{Y= \Psi= (T,C,t,S)=\beta_0 + \beta_1 T + \beta_2 C + \beta_3 t + \beta_4 S + \beta_{11} T^2 + \beta_{22} C^2 + \beta_{33} t^2 + \beta_{44} S^2 + \beta_{12} T.C + \beta_{13}\, T.t + \beta_{14} T.S+ \beta_{23} C.t+ \beta_{34} t.S+ \beta_{24} C.S} \qquad \mathbf{(4)}$$

To observe the significant effect of various process variables on the various responses, analysis of the experimental data was carried out. The regression coefficient helps to compare the comparative contribution of every independent variable in the prediction of the dependent variable. Regression coefficients, analysis of variance, test of lack of fit and the generation of three-dimensional graphs, superimposition of contour plots, and optimization of process variables were calculated using Design– Export version 10.0.0 (Trail version; Statease Inc., Minneapolis, MN,USA).

III. RESULTS AND DISCUSSION

3.1 Diagnostic checking of fitted models and response surfaces

The results of second-order response surface model in the form of analysis of variance (ANOVA) are for water loss and solute gain given in Tables 3. The results indicated that the fitted quadratic models were highly significant (R^2 > 0.90)

3.1.1 Water loss

The magnitude of P values from Table 3 revealed that all linear terms of process variables have significant effect at 5% level of significance ($P < 0.05$) on water loss during osmotic dehydration. In quadratic terms of the process variables time and STFR have significant effect on water loss. Further, interaction of temperature and time, temperature and STFR, conc and STFR has significant effect on water loss. The model F-value is 238.45, which implies the model is significant. The relative magnitude of β values (Table 3) indicates the maximum positive effect of time (β =19.67) followed by concentration (β = 2.34), STFR (β = 2.08) and osmotic solution temperature (β = 1.58) on water loss. The quadratic and interaction terms of all the process parameters have least effect on water loss as compared to the linear terms of process variables. Figure 1(a) depicts the increased water loss with increase in temperature and time up to certain level and same trend have been found in figure 1(d) and (e). This might be because of the fact that the increase in temperature decreases the viscosity of the osmotic solution and thus reduces the external resistance to mass transfer at product surface to facilitate the outflow of water through cellular membrane [12]. The increase in water loss with osmotic solution concentration is mainly because of the increase in the osmotic pressure gradient [13]. A similar variation in water loss with temperature and concentration has also been observed in Fig. 1(b) and with increase in STFR and temperature and concentration and STFR in figure 1(c) and (d) respectively water loss increased up to certain level and then remains constant.

3.1.2. Solute gain

Table 3 indicates that all linear terms of process variables have significant effect ($P < 0.05$) on solute gain. Further, quadratic effect of temperature and time and interaction of 'temperature and time' have significant effect on solute gain during osmotic dehydration ($P < 0.05$). The model F-value 220.97 implies the model is significant. The magnitude β values indicates the maximum positive effect of temperature ($\beta = 6.56$) followed by concentration of sucrose into honey ($\beta = 1.14$), time ($\beta = 0.35$) and STFR ($\beta = 0.27$) on solute gain. Figure 2(a) depicts that solute gain increased with increase in temperature and time may be because of high diffusion rates of solute which decreases viscosity of the osmotic solution [14]. Figure 2(b) and (c) indicated that with increase in temperature and concentration, solute gain increased due to high concentration difference between the beetroot and osmotic solution [15]. Figure 2 (d) and (e) revealed that solute gain enhanced with time and concentration and STFR and time but where time interact with other process variable solute gain remains constant after some time.

The increase in water loss and solute gain with time, temperature, concentration of sucrose into honey and STFR may also be because of agitation given during osmotic dehydration process which reduces the mass transfer resistance between the surface of beetroot and osmotic solution [16].

3.2 Optimization of osmotic dehydration process

To optimize the process conditions for osmotic dehydration process by numerical optimization technique, equal importance of '4' was given to all the four process parameters (viz. temperature, time, concentration of sucrose into honey and STFR). However, based on their relative contribution to quality of final product, the importance given to different responses was given to maximum water loss and minimum solute gain. The optimum conditions for time, temperature, concentration of sucrose into honey and STFR were 420 min., 60 ^oC, 13% (w/w) and 2 (w/w), respectively to get water loss 65.75 g/100g fresh sample and solute gain 15.59 g/100g fresh sample. The optimum processing conditions were experimentally verified twice and proven to be adequately reproducible with ±0.1% deviation.

IV. CONCLUSION

Response surface methodology was effective in optimizing process parameters for the osmotic dehydration of apple the process time 330 to 420 min., temperature 55- 60^oC, concentration of sucrose into honey 8 to13% (w/w) and STFR 2-3 (w/w). The regression equations obtained in this study can be used for optimum conditions for desired responses within the range of conditions applied in this study. Optimum solution by numerical optimization obtained was time 420 min, temperature 60 ^oC, concentration of sucrose into honey 13% (w/w) and STFR 2 (w/w) to get water loss 65.75 g/100g fresh sample and solute gain 15.59 g/100g fresh sample.

V. ACKNOWLEDGEMENT

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Table 1: The levels of different process variables in coded and un-coded form for the osmotic dehydration of apple

Independent Variables	**Coded Levels**		
	-1	0	1
Temperature (A, ^{o}C)	45	55	65
Time (B, Minutes)	10	275	540
Concentration of sucrose (C, %)	5	10	15
Solution to Fruit Ratio (D, w/w)	1	2	3

Table 2 Experimental data for water loss (WL) and solute gain (SG) under different treatment conditions of temperature (T), time (t), concentration of sucrose into honey (C) and solution to fruit ratio (STFR)

T (^{O}C)	**t (min.)**	**C (%)**	**STFR (w/w)**	**WL**	**SG**
45	540	5	3	58.23	16.31
65	275	10	2	57.22	16.13
55	275	5	2	54.57	14.14
55	275	10	2	55.67	15.25
55	275	15	2	56.75	15.87
55	275	10	2	55.67	15.25
65	540	15	1	66.95	20.54
55	10	10	2	23.43	5.44
45	10	15	3	24.99	6.03
45	540	5	1	50.01	15.22
65	10	15	3	22.82	6.57
65	10	5	3	19.32	4.04
55	275	10	3	52.83	16.02
65	540	5	3	60.83	16.48
45	540	15	1	57.78	18.00
55	275	10	2	55.67	15.25
45	540	15	3	61.02	19.33
45	10	5	3	22.11	4.13
65	540	15	3	64.84	18.69
65	10	15	1	20.64	5.22
65	10	5	1	18.95	3.99
55	275	10	1	43.56	16.25
45	10	15	1	21.01	4.12

55	275	10	2	55.67	15.25
65	540	5	1	58.30	16.84
55	275	10	2	55.67	15.25
55	275	10	2	55.67	15.25
45	10	5	1	12.30	2.57
55	540	10	2	61.73	18.87
45	275	10	2	54.00	16.43

Table 3 Regression coefficients for osmotic dehydration of apple cubes

Source	**Water Loss**					**Solute Gain**				
	df	**β**	**Sum of squares**	**F-value**	**P-level**	**df**	**β**	**Sum of squares**	**F-value**	**P-level**
Intercept	14	54.97	8800.77	238.45	< 0.0001	14	15.62	943.13	220.97	< 0.0001
Linear										
A	1	1.58	44.79	16.99	0.0009	1	0.35	2.23	7.32	0.0163
B	1	19.67	6966.52	2642.54	< 0.0001	1	6.56	775.43	2543.53	< 0.0001
C	1	2.34	98.86	37.49	< 0.0001	1	1.14	23.71	77.77	< 0.0001
D	1	2.08	78.03	29.60	< 0.0001	1	0.27	1.32	4.32	0.0552
Quardratic										
A^2	1	1.34	4.62	1.75	0.2053*	1	0.27	0.19	0.63	0.4381*
B^2	1	-11.69	354.31	134.40	< 0.0001	1	-3.85	38.46	126.15	< 0.0001
C^2	1	1.38	4.95	1.87	0.1907*	1	-1.00	2.60	8.52	0.0106
D^2	1	-6.08	95.68	36.29	< 0.0001	1	0.12	0.04	0.14	0.7137*
Cross-Product										
AB	1	1.41	31.80	12.06	0.0034	1	0.04	0.03	0.11	0.7459*
AC	1	-0.27	1.15	0.43	0.5182*	1	0.02	0.01	0.04	0.8528*
AD	1	-1.39	31.05	11.77	0.0037	1	-0.41	2.79	9.17	0.0085
BC	1	0.40	2.57	0.97	0.3386*	1	0.28	1.26	4.14	0.0599
BD	1	-0.28	1.24	0.47	0.5024*	1	-0.29	1.37	4.48	0.0513
CD	1	-0.85	11.61	4.40	0.0531	1	0.02	0.01	0.03	0.8605*
Residual	15	-	95.68	-	-	15	-	4.57	-	-
Lack of Fit	10	-	39.54	-	-	10	-	4.57	-	-
Pure Error	5	-	0	-	-	5	-	0	-	-
R^2	-	**0.99**	-	-	-	-	**0.99**	-	-	-
Adj R^2	-	0.99	-	-	-	-	0.99	-	-	-

df is degree of freedom, β is coefficients

*Non-significant at 5% level

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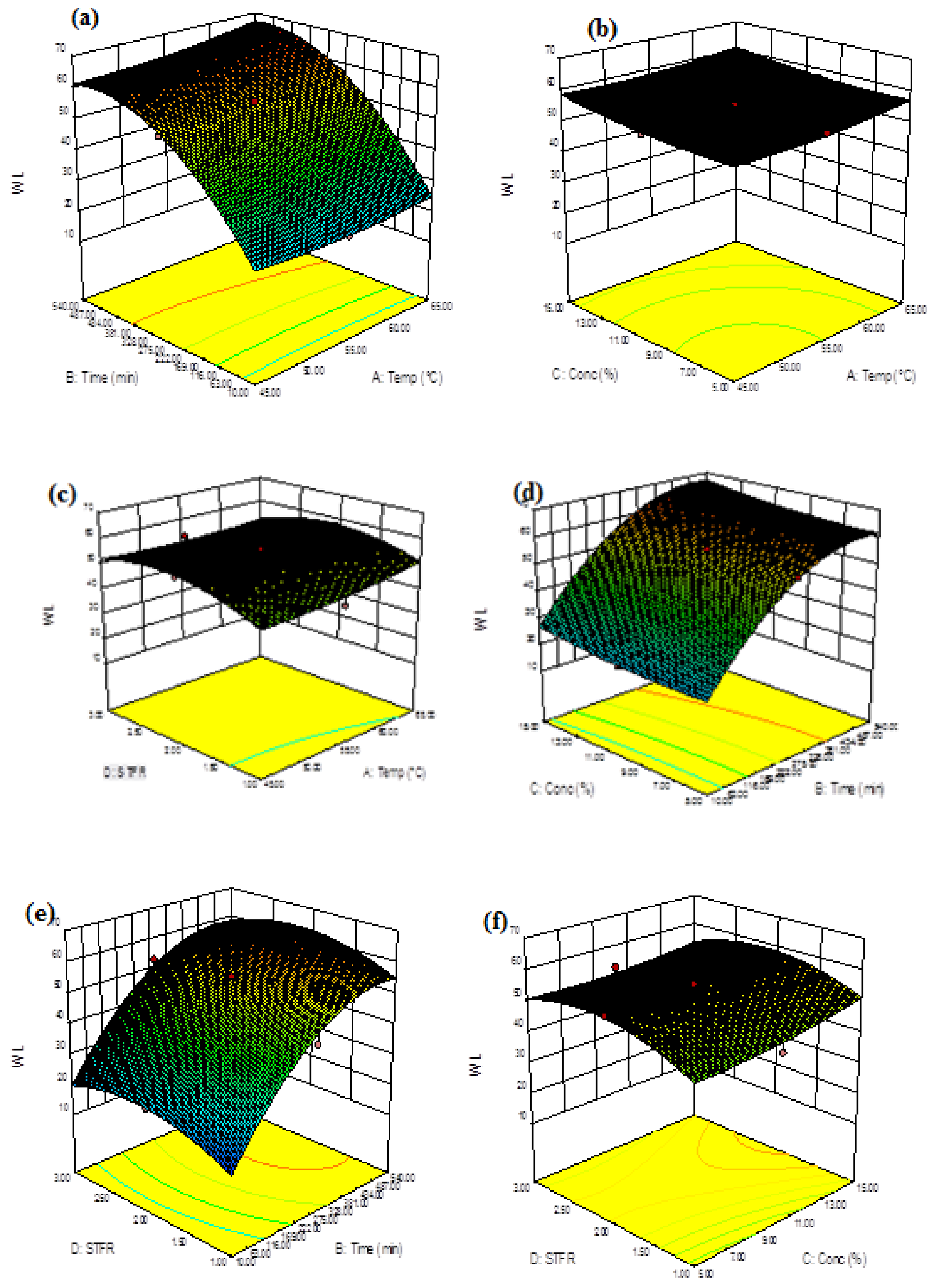

Fig. 1 Influence of process variables on water loss (a) temperature and time at concentration of sucrose into honey 10% and STFR 2% (b) temperature and sucrose concentration at process time 275 minute and STFR 2% (c) temperature and STFR at process time 275 minute and sucrose concentration 10% (d) time and sucrose concentration at temperature 45 °C and STFR 2% (e) time and STFR at temperature 55 °C and concentration 10% (f) concentration of sucrose into honey and STFR at temperature 55 °C and time 275 minute.

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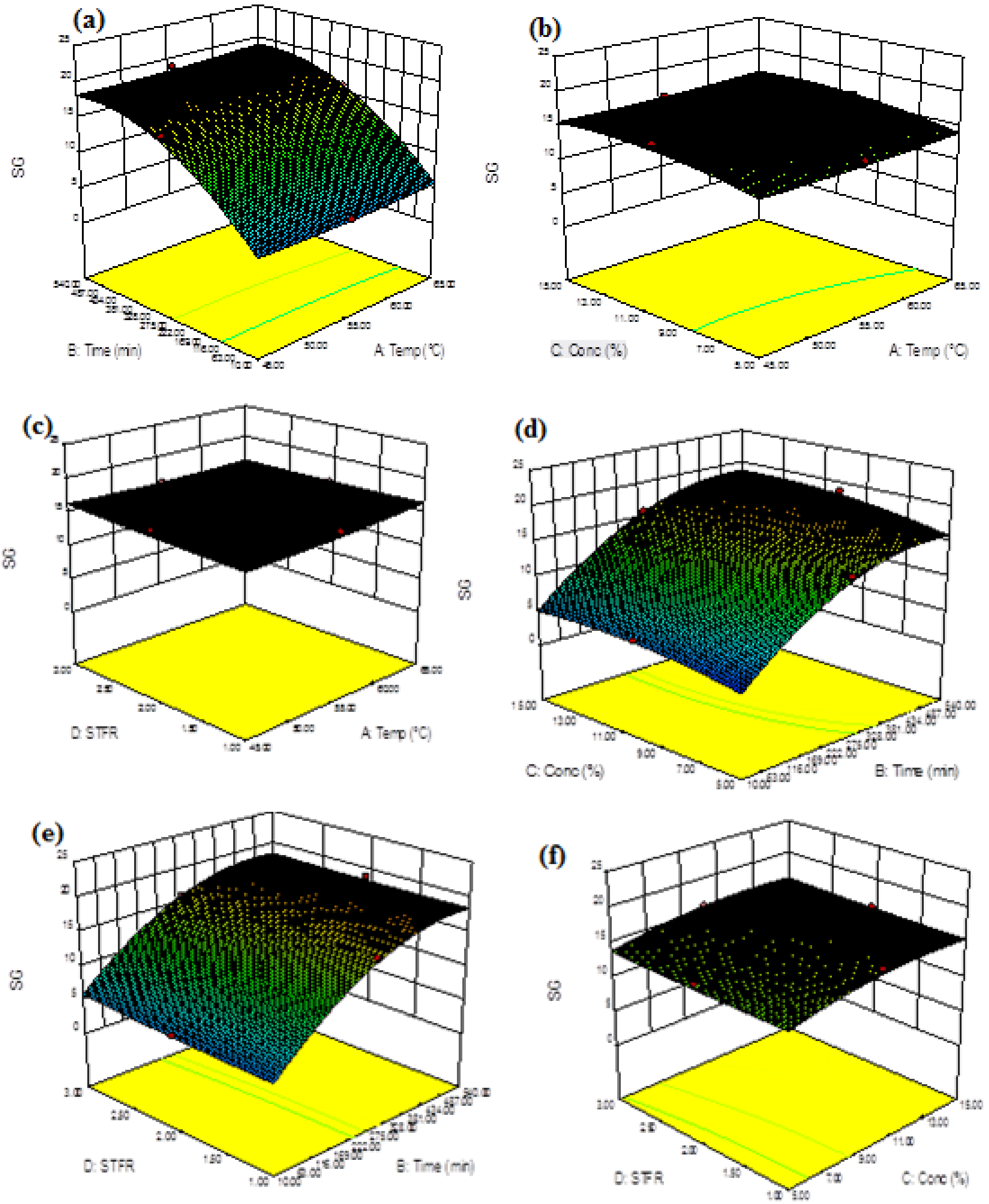

Fig. 2 Influence of process variables on solute gain (a) temperature and time at concentration of sucrose into honey 10% and STFR 2% (b) temperature and sucrose concentration at process time 275 minute and STFR 2% (c) temperature and STFR at process time 275 minute and sucrose concentration 10% (d) time and sucrose conc. at temperature 45 ^{o}C and STFR 2% (e) time and STFR at temperature 55 ^{o}C and concentration 10% (f) concentration of sucrose into honey and STFR at temperature 55 ^{o}C and time 275 minute.