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Response surface optimization of osmotic dehydration process for aonla slices

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Abstract Response surface methodology was used to investigate the effect of sugar concentration (50–70° Brix), solution temperature (30–60°C), solution to fruit ratio (4:1–8:1) and immersion time (60–180 min) on the water loss, solute gain, rehydration ratio, vitamin-C loss, colour change and sensory overall acceptability of Indian gooseberry (aonla) slices. The optimum process parameters obtained by computer generated response surfaces, canonical analysis and contour plot interpretation were: sugar concentration, 59° Brix solution temperature 51°C, solution to fruit ratio 4:1 and immersion time of 60 min.

Keywords Aonla · Indian gooseberry · Dehydration · Optimization · Osmosis · Response surface methodology

Introduction

Indian gooseberry or aonla (*Phyllanthus emblica* L.) is an important fruit, which is highly valued among indigenous medicines. Aonla fruits are a natural source of vitamin-C and work better than synthetic ascorbic acid in the cure of deficiency diseases. The storability after harvesting is limited due to its high perishable nature (Kumar and Nath 1993). The other methods of extending shelf life are cold storage, sun drying and hot air drying or processing to murabba, pickle, juice syrup, squash and dehydrated powder (Kalra 1988). Among the processes, dehydration offers many advantages, such as reduced weight, inexpensive packaging, dry shelf stability and negligible deterioration in quality due to enzymatic changes. Open sun drying/solar drying has been used to some extent and has the limitations of high solar radiations (Bhatia et al. 1959, Sethi 1986, Verma and Gupta 1996).

Osmotic dehydration is a process of partial removal of water by soaking foods, mostly fruits and vegetables, in hypertonic solutions (Shi and Maguer 2002). The driving force for the diffusion of water from plant tissue into solution is difference between osmotic pressures of hypertonic solution and plant tissue. The diffusion of water is accompanied by simultaneous counter diffusion of solutes from solution into tissue (Lazarides et al. 1995). Leakage of natural solutes from plant tissue occurs because the cell membranes of plant tissue responsible for osmotic transport is not perfectly selective but this flow is negligible, although it may be important for the organoleptic and nutritional properties of the product (Heng et al. 1990, Mizrahi et al. 2001, Sahoo et al. 2007, Singh et al. 2008). The food which has been osmotically dehydrated, can be further processed by freezing, freeze drying vacuum drying and air drying (Nanjundaswamy et al. 1978). Sugar, glucose, fructose, corn syrup and sodium chloride are the common osmotic agents and out of this sodium chloride solution is commonly used for vegetables and sucrose solution for fruits. Only limited efforts have so far been made to process aonla into dehydrated product (Palodkar et al. 2003). An expanding interest currently exists for osmo-convective dehydrated aonla in the domestic and world markets. No attempt has been made to optimize the osmotic process parameters for osmo-convectively dehydrated product of aonla. The purpose of the present work was to study the effect of osmotic process parameters on quality responses and also to optimize these parameters for developing an efficient osmo-convective dehydration system to obtain higher quality finished product.

Materials and methods

Experimental design: The Box- Behnken design of 4 variables and 3 levels each with 3-center point combination was

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used (Box and Behnken 1960). This design was selected as it fulfills most of the requirements needed for optimization of the pretreatment (osmotic dehydration) process prior to convective drying. In this design X_1, X_2, X_3, X_4 are the coded variables, which are related to un-coded variables using the following relation

$$X_i = 2\ (\xi_i - \bar{\xi}_i)/d_i \tag{1}$$

where, ξ_i is variable value in actual units of the ith observation, ξ_i is the mean of highest and lowest variable value of ξ_i. and d_i is the difference between the highest and lowest variable value of ξ_i.

The independent process variables were sugar concentration (C) (50–70 °Brix sugar), osmotic solution temperature (T) (30–60°C), solution to fruit ratio (STFR) (4:1–8:1) and immersion time (t) (60–180 min). A second order Box-Behnken design was conducted to work out the range of osmotic process variables for osmo-convective dehydration of aonla slices.

Sample preparation: Fresh Indian gooseberry (aonla) (*Phyllanthus emblica*) fruits of variety 'Francis' were procured from new orchard of the University. The fruits were sorted for uniform size, colour and physical damage, washed with fresh water and wiped with muslin cloth. As the aonla fruit waxy skin represents a high resistance to mass transfer, mechanical treatment was given to aonla with sharp stainless steel knife resulting sheet shape aonla slices of 2 mm thickness. The initial moisture content of aonla slices was 87.8% (wb).

Osmotic agent concentrations: Sugar was purchased from local market. The osmotic solutions of different concentrations (50, 60 and 70 °Brix) were prepared by dissolving required amounts of sugar in distilled water using magnetic stirrer. Concentrations were checked by HRN-18 hand refractrometer.

Osmotic dehydration: For each experiment, known weight of aonla slices (150–160 g) were put in the stainless steel containers having calculated volume (as per STFR) of osmotic solutions of different concentrations pre set at the desired temperature by water bath. During experimentation, it was assumed that the amount of solid leaching out of aonla slices during osmosis was negligible (Biswal and Bozorgmehr 1992, Lazarides et al. 1995). At the specified times the aonla slices were removed from the osmotic solutions and rinsed with water to remove surplus solvent adhering to the surfaces. These osmotically dehydrated aonla slices were then spread on the absorbent paper to remove free water present on the surface. A proportion of pretreated aonla slices (5–8 g) were used for determination of dry matter by oven method (AOAC 2000). The remaining part of each sample was dried to final moisture content of 10 % (wet basis) using hot air drier preset at 60°C air temperature. The dried samples were cooled in desiccators containing silica gel for half an hour, packed in HDPE (100 gauge) bags and kept at ambient condition (28°C, 60% RH) for analysis.

Measurement of water loss and solute gain: The mass transfer parameters i.e water loss (WL) and solute gain (SG) reflecting as one of the quality attributes of aonla were calculated by the equations given by Ozen et al. (2002) and Singh et al. (2007):

$$\%\,\mathrm{WL} = \text{water loss/100g fresh fruit}$$
$$= \frac{(W_0\text{-}W_t) + (S_t\text{-}S_0)}{W_0} \times 100 \tag{2}$$

$$\%\,\mathrm{SG} = \text{Solute gain/100g fresh fruit}$$
$$= \frac{(S_t - S_0)}{W_0} \times 100 \tag{3}$$

where, W_0 is the initial weight of fruit (g), W_t is the weight of fruit after osmotic dehydration at time t (g), S_0 is the initial dry matter of fruit (g) and S_t is the dry matter of fruit after osmotic dehydration at time t (g).

Rehydration ratio: Due to low porous structure of whole aonla fruit its reconstitution time was standardized by taking various sets of time like 5, 10, 15, 20, 25, and 30 min and temperature (95°C) i.e. maximum temperature attained by boiling water and found 20 min rehydration time was adequate for all shapes of dried samples maintaining texture of the rehydrated product (Ranganna 1986). Rehydration ratio (RR) was evaluated by soaking known weight (5–10 g) of sample in sufficient volume of water in a glass beaker (~30 times the weight of aonla slices) at 95°C for 20 min. After soaking, the excess water was removed with the help of filter paper and samples were weighed. To minimize the leaching losses, water bath was used for maintaining the set temperature.

$$\mathrm{RR} = \frac{W_r}{W_d} \tag{4}$$

where, W_r is the drained weight of rehydrated sample (g) and W_d is the weight of dried sample used for rehydration (g)

Colour change: The colour of fresh and rehydrated sample was measured by using Miniscan XE plus Hunter Lab Colourimeter (USA), Model 45/0-L. The colour of the fresh and rehydrated aonla was measured in terms of 'L', 'a' and 'b' value after making a paste of the sample. Before measuring the colour, the colourimeter was calibrated using white or black plates provided. For determination of colour, the sample was completely filled in Petri dish so that no light was allowed to pass during the measuring process. The 'L', 'a' and 'b' values were recorded at D 65/10° and were compared with the standard values of fresh aonla. Hunter colour change (HCC) was measured by the equation given by Gnanasekharan et al. (1992).

$$HCC = \sqrt{[(L-L_0)^2 + (a-a_0)^2 + (b-b_0)^2]} \quad (5)$$

where, L_0, a_0 and b_0 represent the respective readings of fresh sample.

Sensory evaluation of dried aonla slices: Organoleptic quality of dried aonla slices was determined with the help of 20 semi trained consumer panel using a 9-point Hedonic scale. The aspects considered were colour, appearance, taste, flavour and overall acceptability (OA). OA was evaluated as an average of colour, appearance, taste and flavour. The average scores of all the 20 panelists were computed for different characteristics.

The vitamin-C content in fresh and dried samples was determined by the 2,6- dichlorophenolindophenol xylene extraction method (AACC 1969).

Optimization of process parameters: Response surface methodology (RSM) was applied to the experimental data using the package, Design-Expert version 7.1.1 (Statease Inc, Minneapolis, USA, Trial version). The same software was used for the generation of response surface plots, superimposition of contour plots and optimization of process variables (Dhingra and Paul 2005). The response surface and contour plots were generated for different interactions for any 2 independent variables, while holding the value of other 2 variables as constant (at the central value). Such 3-dimensional surfaces could give accurate geometrical representation and provide useful information about the behaviour of the system within the experimental design (Cox and Cochran 1964, Montgomery 2004). The optimization of osmotic dehydration process aimed at finding the levels of independent variables viz. C, T, STFR and t, which could give maximum possible WL, RR and OA; and lowest SG, HCC and vitamin-C loss (VCL). Desirability, a mathematical method was used for selecting the optimum process values. For several responses and factors, all goals get combined into one desirability function. The numerical optimization finds a point that maximizes the desirability function.

Results and discussion

The value of various responses at different experimental combinations for coded variables is given in Table 1. A wide variation in all the responses was observed for different experimental combinations i.e. 32.0 to 49.2% for WL, 4.8 to 18.9% for SG, 2.3 to 3.1 for RR, 2.3 to 15.2 for HCC, 68.4 to 91.1 % for vitamin-C loss and 72.0 to 89.9 % for OA. Maximum consumer acceptance was for the sample pretreated at experimental condition of 60 °Brix, 45°C, 4:1 and 60 min immersion time.

The data was analyzed employing multiple regression technique to develop a response surface model. A linear model and a second order model with and without interaction terms were tested for their adequacies to describe the response surface and R^2 values were calculated. A second order polynomial of the following form was fitted to the data of all the responses and results are given in Table 2.

$$y_k = \beta_0 + \sum_{i=1}^{n} \beta_i x_i + \sum_{i=1}^{n} \beta_{ii} x_i^2 + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \beta_{ij} x_i x_j \quad (6)$$

where, β_i, β_{ii}, β_{ij} are constant coefficient and χ_i χ_j are coded independent variables.

All 6 models were tested for their adequacy using ANOVA technique. *F*-values for the lack of fit were non-significant ($p < 0.01$) thereby confirming the validity of the models. Analysis of experimental values for responses revealed that WL, SG, RR, HCC, VCL and OA could be treated with 0.864, 0.925, 0.921, 0.875, 0.889 and 0.896 coefficient of determination, respectively.

Table 2 shows that the combined effect of all process variables was significant at linear and quadratic level ($p<0.01$) for all the responses. At interaction level except HCC all other factors were significant ($p<0.01$). Further statistical analysis for overall effect of process variables on all responses was performed. In simple terms, the values obtained give factor wise analysis of variance i.e. the contribution of each independent variable to the total sum of squares are separated. The results revealed the higher influence of C, T and t in comparison to STFR irrespective of the responses. The concentration showed most significant effect on WL; T has most significant effect on OA; t showed significantly higher effect on all the responses ($p<0.01$). The maximum effect of t was for RR (Table 3).

Full second order model of the form was fitted to data and regression coefficients were computed the results of which are reported in Table 4. The sign and magnitude of coefficients indicate the effect of variable on the response. Negative sign of the coefficient means decrease in response when the level of the variable is increased while positive sign indicates increase in the response. Significant interaction suggests that the level of one of the interactive variable can be increased while the other decreased for constant value of the response (Montgomery 2004).

Effect of variables on all quality parameters is presented in Fig. 1. WL decreased with increase in T but increased with increase in C whereas, it showed initial decrease followed by increase with t. The maximum value of WL was observed for combination of lower temperature and STFR. Among the process variables studied C witnessed maximum affect on WL (Table 3). It was also affected by the interaction of concentration and temperature as shown in Table 4. It can be seen that WL was significantly affected by C and T individually followed by C: T and t: t interaction ($p < 0.01$) whereas, lower effect of STFR: STFR interaction was observed ($p < 0.1$).

SG increased with increase in t whereas, maximum SG was observed for experimental combinations of higher T lower C and *vice versa*. Moreover, SG was highly affected by T followed by C (Table 3). It can be seen from Table 4

Table 1 Experimental data for the four-factor three level response surface analyses

Coded process variables				Un-coded process variables				Responses					
X_1	X_2	X_3	X_4	C, °Brix	T, °C	STFR	T, min	WL (Y1)	SG (Y2)	RR (Y3)	HCC (Y4)	VCL (Y5)	OA (Y6)
-1	-1	0	0	50	30	6	120	45.0	11.1	3.0	15.2	86.0	72.0
1	-1	0	0	70	30	6	120	40.0	18.9	2.8	13.9	85.5	72.7
-1	1	0	0	50	60	6	120	32.0	18.2	2.8	8.8	79.7	80.0
1	1	0	0	70	60	6	120	49.2	12.1	2.7	2.3	78.5	89.8
0	0	-1	-1	60	45	4	60	43.1	4.8	3.1	3.4	76.5	89.9
0	0	1	-1	60	45	8	60	42.8	6.3	2.8	3.6	74.9	84.3
0	0	-1	1	60	45	4	180	48.7	10.6	2.6	3.6	80.5	88.9
0	0	1	1	60	45	8	180	48.9	11.9	2.5	4.2	89.0	85.7
0	0	0	0	60	45	6	120	41.1	10.2	2.6	14.0	73.3	79.5
-1	0	0	-1	50	45	6	60	43.8	11.0	2.9	6.7	75.1	78.0
1	0	0	-1	70	45	6	60	47.5	12.3	2.8	3.2	68.4	81.0
-1	0	0	1	50	45	6	180	40.1	14.6	2.7	10.1	81.3	78.9
1	0	0	1	70	45	6	180	48.9	14.2	2.3	4.8	87.0	86.6
0	-1	-1	0	60	30	4	120	48.4	12.5	2.8	8.7	91.1	73.4
0	1	-1	0	60	60	4	120	37.8	5.3	2.7	4.6	82.4	88.9
0	-1	1	0	60	30	8	120	45.5	10.2	2.7	12.1	87.0	75.0
0	1	1	0	60	60	8	120	38.7	12.6	2.7	8.0	80.3	81.9
0	0	0	0	60	45	6	120	39.1	8.4	2.6	12.7	74.4	79.9
-1	0	-1	0	50	45	4	120	41.2	11.9	3.0	15.0	87.3	73.4
1	0	-1	0	70	45	4	120	48.4	9.3	2.7	7.6	88.3	80.3
-1	0	1	0	50	45	8	120	42.4	11.7	2.8	10.9	78.1	76.2
1	0	1	0	70	45	8	120	43.9	10.3	2.7	7.9	80.0	81.9
0	-1	0	-1	60	30	6	60	45.4	11.4	2.8	3.2	75.6	80.3
0	1	0	-1	60	60	6	60	43.7	9.1	2.7	3.0	71.5	89.8
0	-1	0	1	60	30	6	180	47.6	11.4	2.6	4.3	83.5	85.2
0	1	0	1	60	60	6	180	44.4	16.6	2.3	4.1	83.0	86.6
0	0	0	0	60	45	6	120	40.2	9.7	2.6	12.2	72.3	81.6

C: Sugar concentration, T: Temperature, STFR: Solution to fruit ratio, t: Immersion time, WL: Water loss, SG: Solute gain, RR: Rehydration ratio, HCC: Hunter colour change, VCL: Vitamin C loss, OA: Overall acceptability

Table 2 Analysis of variance of process variables as linear, quadratic and interactive terms on response variables

Source	df	Sum of squares					
		WL, %	SG,%	RR	HCC	VCL,%	OA,%
Model	14	399.947**	265.187**	0.843**	411.186**	842.146**	724.716**
Linear	4	164.148**	56.306**	0.682**	126.193**	439.440**	394.604**
Quadratic	4	115.791**	98.388**	0.129**	306.17**	446.736**	185.092**
Cross product	6	142.984**	86.384**	0.038**	12.520	69.176**	62.533**
Residual							
Lack of fit	10	60.789	19.607	0.071	57.077	102.039	81.969
Pure error	2	2.040	1.760	0.001	1.619	2.317	2.411
Total error	12	62.829	21.368	0.072	58.696	104.356	84.380
Coeff deter (R^2)		0.864	0.925	0.921	0.875	0.889	0.896

Significant ** $p \leq 0.01$; WL: Water loss, SG: Solute gain, RR: Rehydration ratio, HCC: Hunter colour change, VCL: Vitamin C loss, OA: Overall acceptability

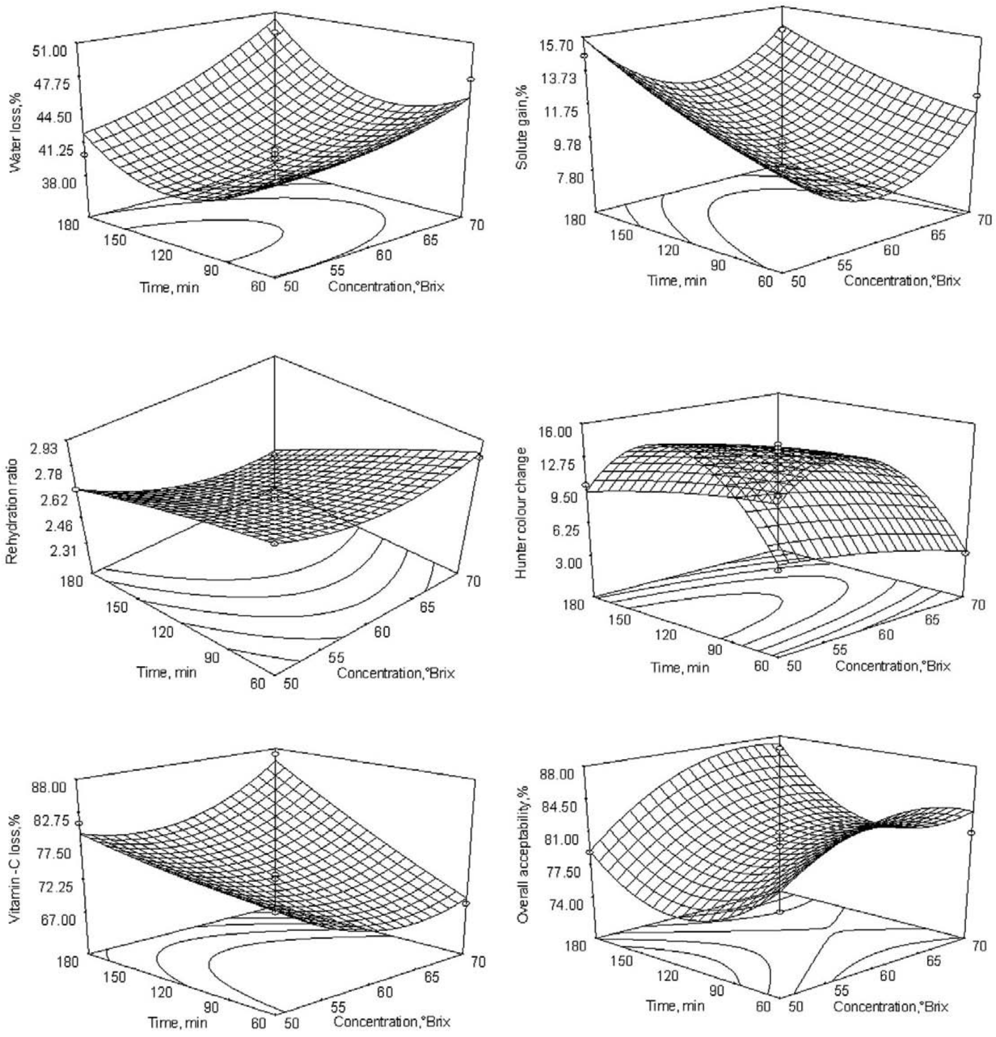

Fig. 1 Response surface plots for different quality parameters during osmotic dehydration of aonla slices in sugar solution at stationary point of temperature=45°C and Solution to fruit ratio =6

Table 3 Analysis of variance for the overall effect of the process variables on the six responses

		Sum of squares					
Process variables	df	Water loss, %	Solute gain, %	Rehydration ratio	Hunter colour change	Vitamin- C loss, %	Overall acceptability, %
C	5	238.748**	102.042**	0.181**	73.729**	123.002**	169.572**
T	5	186.425**	115.587**	0.088**	99.414**	234.049**	340.642**
STFR	5	37.734**	44.450**	0.130**	35.296**	276.052**	30.168*
t	5	103.0**	65.382**	0.489**	248.965**	391.426**	164.380**

Significant ** $p \leq 0.01$, * $p \leq 0.05$; C: Sugar concentration, T: Temperature, STFR: Solution to fruit ratio, t: Immersion time

that SG was significantly affected by t ($p<0.01$) and STFR ($p<0.1$) individually followed by interaction of C and T; quadratic terms of C and T ($p<0.01$) and STFR ($p<0.05$).

RR decreased with the increase in all the process variables. The reason for this decrease may be the blocking of pores at higher level of process variables. The t showed maximum influence on RR when compared to other process variables (Table 3). It is clear from Table 4 that individually C, T, t ($p < 0.0 1$) and STFR ($p < 0.05$) significantly affected RR. However, the interaction terms had non-significant effect on RR.

The HCC increased with increase in STFR and t and decreased with increase in C and T. The minimum HCC was observed for higher T range and minimum and maximum t studied (Fig. 1). The t significantly affected HCC in comparison to other process variables (Table 3). HCC was significantly affected by C and T individually followed by t: t interaction ($p <0.01$). Moreover, the quadratic terms of STFR and T also affected the HCC significantly ($p <0.05$). However, the interaction terms had non-significant effect on HCC.

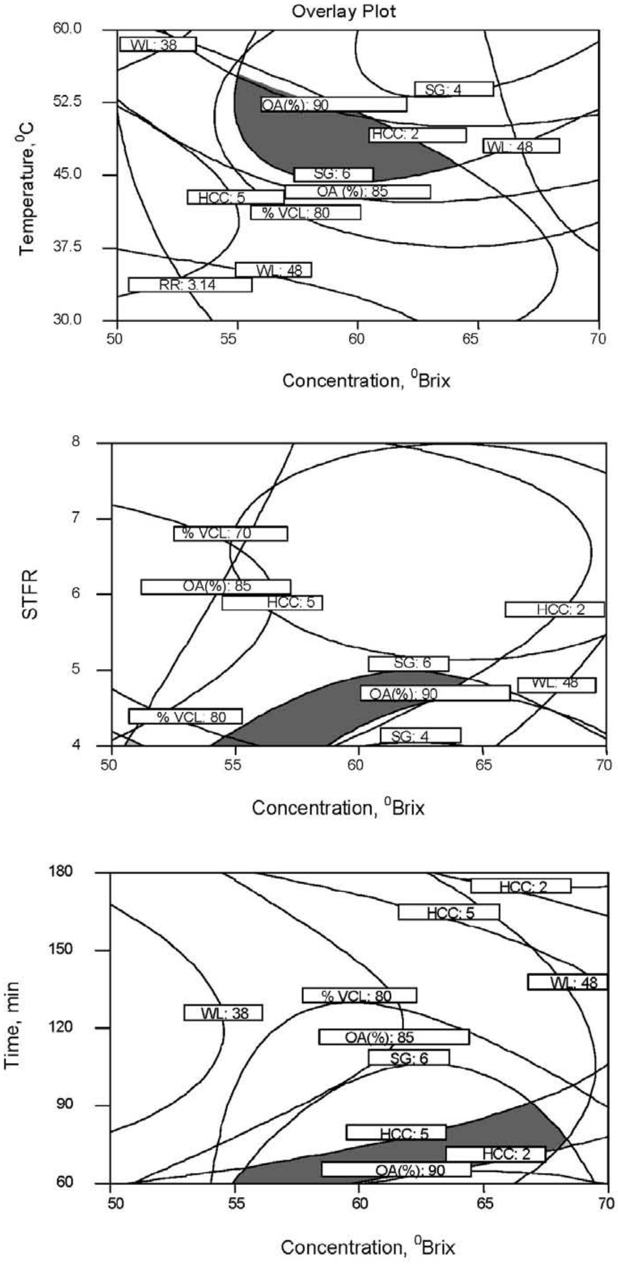

Fig. 2 Overlaid contours of different responses for optimization of osmotic solution temperature, solution to fruit ratio (STFR), sugar concentration during osmotic dehydration process of aonla slices (WL: Water loss, SG: Solute gain, RR: Rehydration ratio, HCC: Hunter colour change, VCL: Vitamin C loss, OA: Overall acceptability)

The vitamin-C loss decreased with increase in all the process variables except t. The minimum vitamin-C loss was observed for T above 35°C, STFR above 5.5 and C above 55 °Brix with the condition that t should be less than 100 min (Fig. 1). The t showed significantly higher effect on VCL in comparison to other process variables (Table 3). From Table 4 it can be seen that vitamin-C loss was significantly affected by T, t individually followed by quadratic terms of C, T and STFR ($p <0.01$). Moreover, the C: t interaction also influenced VCL ($p <0.1$).

The sensory OA of dehydrated product increased with increase in all the process variables except with increase of STFR. The maximum acceptance was noticed for the product osmotically dehydrated under process condition of high T, high C and low STFR with the condition that t should be either less than 90 min or more than 150 min (Fig. 1). The T witnessed significantly higher affect on OA in comparison to other process variables (Table 3). It is clear from Table 4 that individually C, T ($p<0.01$) significantly affected the OA whereas, the interaction terms had non-significant effect on OA. Moreover, the quadratic terms of t ($p<0.01$) and C ($p<0.05$) also significantly affected the OA of the product.

Optimization of osmo-convective dehydration process: Graphical multi-response optimization technique was adopted to determine the workable optimum conditions for the osmotic dehydration of aonla slices. The contour plots for all the responses were superimposed and regions that best satisfied all the constraints were selected as optimum conditions. The main criteria for constraints optimization were maximum possible WL, RR, sensory OA, and lower SG, HCC and VCL (Themelin et al. 1997, Ade-Omowaye et al. 2002). These constraints resulted in “feasible zone” of optimum conditions (shaded area in the superimposed contour plots). Superimosed contour plots having common superimposed area of all the responses for osmo-convective dehydration in sugar solution are presented in Fig. 2. The optimum range of process parameters obtained for osmo-convective dehydration of aonla slices were: 55 to 68 °Brix of osmotic solution C, 44 to 55°C of osmotic solution T, 4:1 to 4.9:1 of STFR and 60 to 91 min of t.

In order to optimize the process conditions for osmotic dehydration process by numerical optimization,which finds a point that maximizes the desirability function; equal importance of ‘3’ was given to all the 4 process parameters. However, based on their relative contribution to quality of final product, the importance given to different responses was 4, 3, 3, 3, 3 and 5 for WL, SG, RR, HCC, vitamin-C loss and OA, respectively. Maximum importance was given

Table 4 Regression coefficients (uncoded variables) from quadratic model and their significance

Term	Regression coefficient	WL (k=1)	SG (k=2)	RR (k=3)	HCC (k=4)	VCL (k=5)	OA (k=6)
Constant	β_0	207.26	95.92	9.46	-56.16	387.21	-9.58
C	β_1	-2.59798**	-2.73930	-0.14403**	0.19215**	-5.39273	3.0477**
T	β_2	-2.75143**	-0.30191	-0.0204**	1.3781**	-2.3606**	0.07544**
STFR	β_3	-3.70052	0.81457***	-0.52946*	3.70462	-24.24269	1.21012
t	β_4	-0.35996	-0.04233**	0.00340**	0.50316	-0.42075**	-0.36840
C x T	β_{12}	0.03714**	-0.02314**	0.00013	-0.00861	-0.00121	0.01515
C x STFR	β_{13}	-0.07245	0.01533	0.00208	0.05590	0.01234	-0.01406
C x t	β_{14}	0.00207	-0.00074	-0.00009	-0.00075	0.0052***	0.00193
T x STFR	β_{23}	0.03205	0.0806**	0.00008	0.00052	0.01701	-0.07137
T x t	β_{24}	-0.00040	0.00205*	-0.00005	-0.00002	0.00099	-0.00225
STFR x t	β_{34}	0.00111	-0.00046	0.00039	0.00069	0.02107	0.00501
C x C	β_{11}	0.01159	0.03139**	0.00107**	-0.00229	0.03959**	-0.02996*
T x T	β_{22}	0.00260	0.01057**	0.00015	-0.01121*	0.0225**	0.00043
STFR x STFR	β_{33}	0.5204***	-0.41227*	0.02682**	-0.5840*	1.6254**	0.15287
t x t	β_{44}	0.0011**	0.00013	-4.29E-06	-0.00187**	0.0001	0.0014**

Significant *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$; WL, SG, RR, HCC, VCL, OA: see Table 1; C,T, STFR, t: see Table 3

Table 5 Optimum values of process parameters and responses

	Target	Experimental range		Importance	Optimum	Desirability
		Min	Max			
C, °Brix	in range	50	70	3	59	0.848
T, °C	in range	30	60	3	51	
STFR, V/W	in range	4	8	3	4	
t, min	in range	60	180	3	60	
Responses					Predicted	
WL, %	maximize	32.0	49.2	4	44.0	
SG, %	minimize	4.8	18.9	3	4.59	
RR	maximize	2.3	3.1	3	2.98	
HCC	minimize	2.3	15.2	3	2.30	
VCL, %	minimize	68.4	91.1	3	76.8	
OA, %	maximize	72.0	89.9	5	89.9	

*See Tables 1 and 3

to OA, because it includes a number of parameters like appearance, texture, colour, flavour and taste. The optimum operating conditions for C, T, STFR and t was 59 °Brix, 51°C, 4:1 and 60 min, respectively. Corresponding to these values of process variables, the value of WL is 44.0 g water/100 g fresh fruit, SG 4.59 g/100 g fresh fruit, RR 2.98, HCC 2.30, vitamin-C loss 76.8% and OA 89.9% (Table 5). The overall desirability, which ranges from zero outside of the limits to one at the goal, was 0.848. The conditions were experimentally verified with deviation of ± 0.15%.

Conclusion

The RSM was effective in optimizing process parameters for osmotic dehydration of aonla slices in osmotic aqueous solution of sugar having concentration in the range of 50 to 70 °Brix sugar, temperature 30 to 60°C, solution to fruit ratio 4:1 to 8:1 and immersion time 60 to 180 min. The regression equations obtained can be used for optimum conditions for desired responses within the range of conditions applied in this study. Graphical techniques, in connection with RSM, aided in locating optimum operating conditions, which were experimentally verified and proven to be adequately reproducible. Optimum solutions by numerical optimization obtained was 59 °Brix sugar solution concentration, 51°C osmotic solution temperature, 4:1 solution to fruit ratio and 60 min of immersion time to get maximum possible water loss, rehydration ratio and overall acceptability, and lower solute gain, colour change and vitamin-C loss. The model equation for the response variables predicted values under the identified optimum conditions, which were experimentally verified to be in general agreement with the model.

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