Process optimization for osmo-dehydrated carambola (*Averrhoa carambola L*) slices and its storage studies

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Abstract An osmotic-dehydration process protocol for Carambola (*Averrhoacarambola L.*), an exotic star shaped tropical fruit, was developed. The process was optimized using Response Surface Methodology (RSM) following Central Composite Rotatable Design (CCRD). The experimental variables selected for the optimization were soak solution concentration (°Brix), soaking temperature (°C) and soaking time (min) with 6 experiments at central point. The effect of process variables was studied on solid gain and water loss during osmotic dehydration process. The data obtained were analyzed employing multiple regression technique to generate suitable mathematical models. Quadratic models were found to fit well (R^2 , 95.58 - 98.64 %) in describing the effect of variables on the responses studied. The optimized levels of the process variables were achieved at 70°Brix, 48 °C and 144 min for soak solution concentration, soaking temperature and soaking time, respectively. The predicted and experimental results at optimized levels of variables showed high correlation. The osmo-dehydrated product prepared at optimized conditions showed a shelf-life of 10, 8 and 6 months at 5 °C, ambient (30±2 °C) and 37 °C, respectively.

Keywords Carambola · Osmosis · Dehydration · Solid gain · Water loss · Optimization

Introduction

Carambola, popularly known as star fruit, is widely grown in the tropics in several countries including oriental and Latin American countries. Carambola is a juicy fruit with predominantly yellow greenish in appearance with a succulent pulp. The fruit is available as sweet and sour varieties (Prati et al. 2002). Both the cultivars are as such suitable for value addition. However the sweet variety is preferred due to better sensory attributes in terms of flavour and texture. Abdullah et al. (2006) gave a comprehensive discrimination and classification of fresh-cut star fruits using automated machine vision system. The fruit poses postharvest problems due to the high degree of perishability and appearance of chilling injury at low temperature below 10 °C (Perez-Tello et al. 2001) resulting in shortest shelf life under refrigerated storage. Therefore, the fruits need to be subjected to value addition either by primary or secondary process. Value added products from star fruit are preferred for a number of reasons including the appetizing flavour attributes with fine balance of brix/acid coupled with an attractive yellow colour. The characteristic flavour components were subjected to extensive studies and as such 56 components were isolated and characterized and the major components were found to be butyl acetate, ethyl decanoate and hexadecanoic acid (Pino et al. 2000). The fruit is a rich source of natural antioxidants (Murcia et al. 2001) besides being a rich source of functional fiber with significant hypoglycemic effects (Chau et al. 2004). Considerable work had also been carried out on the reduction of oxalic acid content by precipitation techniques involving ultra filtration and vacuum concentration (Wang et al. 1998). The pretreatment to the juice was found essential to

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minimize the formation of kidney stones a common problem associated with the product with high concentration of oxalic acid. Value added products from carambola include low calorie jam (Abdullah and Cheng 2001) with partial substitution of sugar with artificial sweeteners and texturizing agents. Many ready-to-serve beverages are available making use of carambola extracts (Soyad 1999; Abdullah Liew et al. 2007) besides cordials (Yusof and Lee 1997). Minimally processed carambola (Weller et al. 1997; Teixeira Gustavo et al. 2008) and dehydrated products based on foam mat dehydration of star fruit puree (Abd-Karim and Chee-Wai 1999) were the other value added products. Mauro et al. (2005) and Ruiz-Lopez et al. (2011) described the drying kinetics during osmotic dehydration of carambola fruits and influence of calcium infusion and soak temperature were investigated. However, the reports on osmo-dehydration of carambola fruit slices were few. Therefore, the present study was taken up with the objectives of process optimization of process variables for osmotic process and also the physico-chemical evaluation of the osmo-dehydrated product during storage.

Material and methods

Raw material and osmotic dehydration

Carambola ('Golden variety') fruits with average weight of 35 to 40 g, brix to acid ratio of 6.5–7.0 and greenish yellow in colour (maturity level at FAMA No. 1, Abdullah et al. 2006) were harvested from the orchards in Assam, India. Fruits with mechanical damages and visual infection were removed during grading. The graded fruits were washed thoroughly with chlorinated water (100 ppm available Cl_2). The surface moisture was removed by placing the fruits in the stream of air. The fruits were sliced manually using a stainless steel knife and thickness of the slices were maintained at 1 cm. The slices were soaked in sucrose solutions (1:2 w/v) of different concentrations at varying temperature and time durations (Table 1) and the solution was stirred in

between at different time intervals. The samples were removed after specific time of osmotic dewatering and put in hot air oven maintained at 60 °C with hot air velocity of 3 m/s for further dehydration till final moisture content of samples reached to 14–15 %.

Experimental design and process optimization

The sugar based osmotic process was optimized using Central Composite Rotatable Design (CCRD) taking 3 variables at 5 levels each with 6 experiments at central point (Mullen and Ennis 1979). The independent variables selected for the study were concentration of soak sucrose solution (°Brix), soaking temperature (°C) and soaking time (min) (Table 1). A total number of 20 experiments were carried out as per the statistical design (Table 2). The effects of the variables were studied on solid gain and waterloss of the slices during osmotic process. The variables were standardized for ease in computation and to reduce their relative effect on the responses. For the analysis of experimental design by the response surface methodology (RSM), it was assumed that n -mathematical functions, f_k (where, $k=1, 2, \dots, n$), Y_k in terms of m independent factors X_i (where, $i=1, 2, \dots, m$) existed for each response variable.

$$Y_k = f_k(X_1, X_2, \dots, X_m)$$

The function was assumed to be approximated by following second-order polynomial equation.

$$Y_k = \beta_{k0} + \sum_{i=1}^3 \beta_{kii} X_i + \sum_{i=1}^3 \beta_{kii} X_i^2 + \sum_{i=1, j=i+1}^3 \beta_{kij} X_i X_j$$

Where, β_{k0} is the value of the fitted response at the centre point of the design, i.e. point (0,0) and β_{ki} , β_{kii} and β_{kij} are the linear, quadratic and interactive regression terms, respectively.

The data obtained were regressed using multiple regression technique. The coefficients of second-order polynomial models obtained after multiple regressions of the responses show the effect of a particular variable on the response. The adequacy of the model was tested using F-ratio, coefficient of correlation (R^2) and lack of fit test. The models were considered adequate when the calculated F-ratio was more than the table F-value, R^2 value was more than 80 % and lack of fit test (LoF) was insignificant.

Optimization of fitted polynomials for the response variables was carried out through nonlinear mathematical optimization method using Design Expert software (Version 7.1, Statease, Minneapolis, MN, USA). Surface plots were generated from the fitted quadratic polynomial regression equations in order to visualize the

Table 1 Coded and uncoded levels of variables

Independent variables	Coded and uncoded levels of variables				
	-1.68	-1	0	1	+1.68
Soak solution concentration (°Brix), X_1	43.18	50	60	70	76.82
Soaking temperature (°C), X_2	33.18	40	50	60	66.82
Soaking time (min), X_3	19.09	60	120	180	220.91

Table 2 Response surface design showing number of experiments at different levels of variables along with corresponding response values

Run	Soak solution concentration (°Brix)	Soaking temperature (°C)	Soaking time (min)	Water loss (g/100 g)	Solid gain (g/100 g)
1	76.82	50.00	120.00	30.34±0.02	40.02±0.03
2	70.00	60.00	180.00	29.69±0.03	52.16±0.01
3	70.00	40.00	60.00	23.97±0.02	38.61±0.02
4	50.00	60.00	180.00	23.64±0.04	36.15±0.04
5	60.00	50.00	19.09	18.88±0.03	40.88±0.02
6	50.00	40.00	180.00	22.09±0.04	34.52±0.01
7	50.00	60.00	60.00	10.85±0.01	25.78±0.03
8	60.00	50.00	120.00	20.19±0.02	40.69±0.05
9	60.00	33.18	120.00	21.66±0.03	36.93±0.03
10	50.00	40.00	60.00	8.92±0.02	32.48±0.01
11	60.00	66.82	120.00	30.24±0.04	48.02±0.02
12	60.00	50.00	220.91	30.91±0.05	43.93±0.03
13	43.18	50.00	120.00	8.23±0.02	23.49±0.02
14	70.00	60.00	60.00	35.25±0.06	47.48±0.04
15	60.00	50.00	120.00	21.22±0.04	42.44±0.02
16	70.00	40.00	180.00	24.72±0.03	43.08±0.02
17	60.00	50.00	120.00	20.21±0.01	40.66±0.01
18	60.00	50.00	120.00	20.16±0.01	40.67±0.03
19	60.00	50.00	120.00	20.17±0.02	40.70±0.05
20	60.00	50.00	120.00	20.18±0.03	40.68±0.02

relationship among the variables and responses and to obtain the numerical solution for optimum conditions for variables at desired response levels. The mapping of the fitted response was achieved using the software. The contour plots for the models were plotted as a function of the two variables, while keeping the other one at optimum levels. Optimization was carried out keeping the level of variables in the experimental range (Table 1), whereas values for solid gain and water loss were maximized to arrive at optimum conditions. The result showing highest desirability was selected and considered for further storage investigations.

Shelf-life studies

Twenty kilograms of carambola fruits were used for the preparation of osmo-dehydrated carambola slices at optimal levels experimental variables, i.e. soak sucrose solution concentration, soaking temperature and soaking time, obtained after regression analysis. The osmo-dehydrated slices (50 g) were packed in polypropylene pouches (75 µ thickness) followed by secondary packaging in paper-aluminumfoil-polyethylene laminated pouches. The samples were kept at three different temperatures, i.e. low (5 °C), ambient temperature (30±2 °C) and high (37 °C) in

preset temperature cabinets for storage evaluation for a period of 10 months. Samples were drawn after every 2 month interval and analyzed for different physico-chemical parameters.

Physico-chemical analysis

Analysis of Moisture content, total sugar, reducing sugar, ascorbic acid, carotenoids, acidity, non enzymatic browning were carried out using standard procedure as described in AOAC (1990). Brix was measured by using hand refractometer (M/s Atago, Tokyo, Japan) and pH of the sample was measured using a pH meter (Century, model CP 931, Bangalore, India). Water activity of the osmo-dried carambola slices were measured using a water activity meter (Aqua Lab, Model 3TE, Decagon Devices Inc., Pullman, Washington, USA). All the measurements were conducted at 25 °C.

Solid gain and water loss

During osmotic dehydration water loss and solute gain both take place simultaneously. Weight of sample undergoes reduction due to water loss and at same time weight increases due to solute gain. The water loss

and solute gain were measured using following equations as described by Chauhan et al. (2011):

$$\text{Weight reduction}(W_R) = (W_0 - W_t)$$

$$\text{Solid gain after osmotic dehydration for time } t(\text{SG}) = (S_t - S_0)$$

$$\text{Water loss} = \text{Weight reduction} + \text{Solid gain}$$

$$\text{Water loss (g/100g)} = \frac{(W_0 - W_t) - (S_t - S_0) \times 100}{W_0} \quad (1)$$

$$\text{Solid gain (g/100g)} = \frac{(S_t - S_0) \times 100}{W_0} \quad (2)$$

Where, W_0 is initial weight of sample (g), W_t is weight of slices after osmotic dehydration for any time t (g), S_0 is initial weight of solids (dry matter) in slices (g), S_t is weight of solids (dry matter) in slices after osmotic dehydration for time t (g).

CIE colour values

Surface colour of the samples were recorded using a colour meter (Mini Scan XE Plus, Model 45/0-S, Hunter Associates Laboratory, Inc., Reston, VA, USA) as reflected in CIELAB ($L^*a^*b^*$) colour space. All the measurements were referenced to the CIE (Commission Internationale de l'Eclairage) using the standard illuminant D65 and 10° observer and the equipment was calibrated using a white and black standard ceramic tiles. The osmo-dried carambola slices were converted in to fine powder and mixed thoroughly and uniform sample mix was taken for color analysis.

Total phenolics

Total phenolics as mg gallic acid equivalents per 100 ml of juice were estimated colorimetrically in methanolic extracts using Folin-Ciocalteu reagent as per the method described by Singleton and Rosi (1965). 10 ml of sample was taken and diluted to 100 ml with water. To 5 ml of this aliquot, 1 ml of Folin-Ciocalteu reagent was added. After 6 min, 10 ml of Na_2CO_3 (7 g/100 g) was added and volume was made up to 25 ml with distilled water followed by incubation at room temperature for 90 min. The absorbance was

read at 750 nm using distilled water as blank using a spectrophotometer (Shimadzu 1609, Tokyo, Japan).

Total flavonoids

Total flavonoids were estimated using the method described by Zhishen et al. (1999). 10 ml of sample was diluted with distilled water and volume was made up to 100 ml. 5 ml of this aliquot was taken and 0.3 ml of NaNO_2 (5 g/100 g) was added, kept for 5 min followed by addition of 0.3 ml of AlCl_3 (10 g/100 g). The reaction mixture was kept again for 6 min followed by addition of 2 ml sodium hydroxide (1N). The volume was made up to 10 ml with distilled water and absorbance was read at 510 nm using distilled water as blank. Total flavonoids content was reported as mg catechin equivalents per 100 ml sample on fresh weight basis.

Total antioxidant potential

The total antioxidant potential in terms ferric reducing antioxidant power (FRAP) was carried out by using methanolic extracts of the osmo-dehydrated products (Benzie and Szento 1999).

Texture analysis

The osmo-dehydrated products using different humectants were subjected to shear vale analysis using a Texture analyzer (TAHiD Stable Microsystem, UK) loaded with texture expert software (Version 1.22, Stable Microsystem, UK). The shear force was measured by cutting the slices (7 mm thickness) in the centre using WarnerBratzler blade at a test speed of 0.5 mm.s^{-1} . The pre and post cut speed were set 1 and 5 mm.s^{-1} respectively.

Sensory evaluation

The overall sensory score was obtained on a nine point hedonic scale using ten semi-trained panelists. A hedonic score of 9 stands for extreme liking and 1 for extreme dislike (Larmond 1977). The panelist remained constant during the entire study.

Statistical analysis

The data obtained from storage study were subjected to analysis of variance (ANOVA) using completely randomized design (CRD) and least significant difference (LSD) at $p < 0.05$ using Statistica 7 software (Statsoft, Tulsa, USA). Three replicates were recorded for each experiment and average of the same has been reported.

Results and discussion

Effect of variables on water loss

Moisture comes out from the tissues during osmotic process as a result causing dehydration of the product. The water loss ranged from 8.23 to 35.25 g/100 g among different experimental combinations (Table 2). The soak solution concentration used during osmotic process caused significant ($p < 0.01$) loss in moisture the effect being more pronounced that soaking temperature and soaking time. The effects of all the three variables were found to be on positive side indication increase in water loss with increase in the level of variables as shown in response surface and perturbation graphs (Fig. 1). The study shows that with increase in the soak medium concentration, soaking temperature and soaking time increased the water loss from the carambola tissues during osmotic dehydration process. Increase in soak medium (sucrose) concentration caused higher trans-membrane differences in osmotic pressure leading to increased water loss from the fruit tissues. Similarly, at higher temperature the water loss is more due to increased permeability of the cell membranes. A quadratic model was found to fit well in describing the effect of variables on water loss:

$$Y_{\text{Waterloss}} = -30.34 + 3.32X_1 - 2.03X_2 - 0.03X_3 \\ - 0.03X_1^2 + 3.24X_2^2 + 8.34X_3^2 + 0.03X_1X_2 \\ - 6.78X_1X_3 + 1.78X_2X_3$$

The variables used in the study affected the water loss on linear, quadratic and interactive levels. The R^2 value of 95.58 g/100 g shows the fitness of the quadratic model used to describe the effect of variables on water loss. Water loss of similar magnitude was also observed in melon and mango (Mujica-Paz et al. 2003). Moreira and Sereno (2003) predicted volumetric shrinkage of apple cylinders treated by osmotic solutions by measuring the change in moisture content or the net mass loss due to treatment and suggested linear correlation between moisture content and soak solution concentration. Barat et al. (2001) was of the opinion that changes in mass during osmotic process are directly correlated with soak solution concentration. The type of sugar used during osmotic process also affects the water loss during osmotic dehydration, the high molecular weight sugars causing higher water loss. Sucrose has also been considered as the better osmotic medium than glucose or fructose for osmo-dehydration

of carambola slices favoring higher water loss to solid gain ratios (Ruiz-Lopez et al. 2011). The present study also reflected similar results favoring sucrose as a good osmotic medium for getting higher water loss during the development of osmo-dehydrated carambola slices.

Effect of variables on solid gain

The variables used in this study i.e. soak solution concentration, soaking temperature and soaking time affected the solid gain significantly at linear, quadratic and interactive levels, the effect of all the variable being at positive side indicating that increase in the concentration of soak solution, soaking temperature or soaking time will cause increase in the solid gain in the carambola slices during osmotic process which is depicted in the response surface and perturbation graphs as show similar results Fig. 1. The solid gain varied from 23.49 to 52.16 g/100 g among different experimental combinations (Table 2). The effect of soak solution concentration affected the solid gain significantly at higher level as compared to soaking temperature and time, respectively. Increase in concentration of soaking medium as well as soaking temperature and time lead to increased movements of sucrose molecules through the cell membranes causing more solid gain. Following quadratic model was found to fit well in describing the effect of variables on solid gain:

$$Y_{\text{Solidgain}} = 40.14 - 0.48X_1 - 1.78X_2 + 0.18X_3 - 2.16X_1^2 \\ + 3.98X_2^2 - 9.13X_3^2 + 0.03X_1X_2 - 1.41X_1X_3 \\ - 9.75X_2X_3$$

A R^2 value of 98.64 % showed adequacy of fitted model in describing the effect of variables on solid gain during osmotic dehydration of carambola slices. Corzo and Gomez (2004) also reported similar results during osmotic dehydration of cantaloupe. Solute gain was found to be controlled by diffusion inside the material while water loss was found to be governed by mixed internal-external flow during osmotic dehydration of apple slices in sucrose solutions (Moreira and Sereno 2003). Ruiz-Lopez et al. (2011) also reported higher water loss to solid gain ratio in the case of osmo-dehydrated carambola slices prepared using sucrose solutions. Solid gain is due to the diffusion of sugar molecules into the tissues during osmotic process and the type of sugar used during osmotic process affects the solid gain, the low molecular weight sugars causing higher solid gain (Chauhan et al. 2011).

Fig. 1 Response surface and perturbation graphs showing effect of variables on water loss and solid gain

Table 3 Changes in some physicochemical attributes during storage of osmo-dehydrated carambola slices

Storage condition and time		Moisture (g/100 g)	Acidity (g/100 g Citric acid)	pH	Sugar (g/100 g)		Ascorbic acid (mg/100 g)
					RS	TS	
Initial		14.8±0.21 ^a	0.36±0.02 ^a	4.8±0.10 ^a	10.6±0.01 ^a	81.1±0.05 ^a	20.3±0.22 ^a
2 m	5 °C	14.8±0.21 ^a	0.36±0.02 ^a	4.8±0.10 ^a	10.7±0.11 ^a	81.1±0.04 ^a	20.0±0.13 ^a
	RT	14.8±0.22 ^a	0.36±0.03 ^a	4.8±0.10 ^a	10.8±0.23 ^a	81.1±0.04 ^a	18.3±0.11 ^b
	37 °C	14.8±0.23 ^a	0.37±0.01 ^a	4.8±0.10 ^a	10.9±0.22 ^b	80.9±0.02 ^b	19.9±0.12 ^a
4 m	5 °C	14.8±0.22 ^a	0.37±0.02 ^a	4.8±0.11 ^a	10.7±0.14 ^a	81.0±0.04 ^a	18.3±0.50 ^b
	RT	14.8±0.23 ^a	0.37±0.04 ^a	4.8±0.12 ^a	10.8±0.13 ^a	81.0±0.06 ^c	17.3±0.62 ^b
	37 °C	14.9±0.12 ^b	0.38±0.02 ^a	4.8±0.12 ^a	10.9±0.11 ^b	81.1±0.07 ^c	16.2±0.05 ^c
6 m	5 °C	14.9±0.11 ^b	0.37±0.05 ^a	4.8±0.11 ^a	10.8±0.14 ^a	80.9±0.04 ^b	16.1±0.46 ^c
	RT	14.9±0.11 ^b	0.38±0.01 ^a	4.8±0.12 ^a	10.9±0.20 ^b	80.9±0.06 ^c	15.4±0.18 ^d
	37 °C	14.9±0.22 ^c	0.39±0.01 ^b	4.8±0.18 ^a	11.0±0.10 ^b	80.8±0.03 ^b	14.8±0.32 ^e
8 m	5 °C	14.9±0.13 ^b	0.38±0.01 ^a	4.8±0.14 ^a	10.9±0.14 ^b	80.9±0.02 ^c	15.2±0.15 ^d
	RT	14.9±0.26 ^c	0.38±0.01 ^a	4.8±0.16 ^a	10.9±0.12 ^b	80.9±0.12 ^d	14.4±0.42 ^e
	37 °C	14.9±0.24 ^c	0.39±0.02 ^b	4.8±0.20 ^a	11.1±0.31 ^c	80.9±0.16 ^d	13.6±0.52 ^f
10 m	5 °C	14.9±0.18 ^b	0.39±0.03 ^b	4.8±0.16 ^a	10.9±0.12 ^b	80.9±0.02 ^c	14.8±0.52 ^e
	RT	14.9±0.22 ^c	0.39±0.04 ^b	4.8±0.20 ^a	11.0±0.21 ^c	80.9±0.12 ^d	14.3±0.42 ^e
	37 °C	15.0±0.12 ^c	0.40±0.01 ^b	4.8±0.41 ^a	11.1±0.13 ^c	80.9±0.03 ^c	13.2±0.62 ^f

*RS Reducing sugar; TS Total sugars; RT Room temperature. Values in each column with different superscripts differ significantly ($p<0.05$)

Optimization of process variables

The independent variables used in the study were optimized using keeping the water loss at maximum and

solid gain at minimum levels. The optimized conditions for the variables were arrived at 70°Brix, 48 °C and 144 min for soak solution concentration, soaking temperature and soaking time, respectively showing a

Table 4 Changes in some physicochemical and sensory attributes during storage of osmo-dehydrated carambola slices

Storage condition and time		Total Carotenoid (mg/100 g)	Total phenols (mg/100 g)	Total Flavonoids (mg/100 g)	Antioxidant potential (μmole/100 g)	Browning	OAA
Initial		12.4±0.05 ^a	470.3±4.24 ^a	33.2±0.71 ^a	4913±45 ^a	0.03±0.01 ^a	8.0±0.51 ^a
2 m	5 °C	12.4±0.15 ^a	465.4±3.21 ^a	33.1±0.91 ^a	4901±26 ^a	0.04±0.01 ^b	8.0±0.32 ^a
	RT	12.2±0.10 ^a	461.3±2.20 ^b	32.2±0.84 ^a	4873±35 ^a	0.05±0.02 ^c	7.8±0.23 ^a
	37 °C	11.9±0.05 ^b	459.3±2.74 ^b	31.9±0.85 ^a	4831±45 ^b	0.07±0.01 ^d	7.3±0.45 ^a
4 m	5 °C	12.2±0.05 ^a	460.1±1.64 ^b	32.9±0.64 ^a	4896±34 ^a	0.05±0.01 ^b	7.8±0.32 ^a
	RT	12.1±0.04 ^a	458.7±0.64 ^c	31.8±1.15 ^a	4801±52 ^b	0.06±0.01 ^c	7.6±0.52 ^a
	37 °C	11.7±0.12 ^b	450.4±3.21 ^c	31.0±0.56 ^b	4747±56 ^c	0.08±0.02 ^c	6.9±0.23 ^b
6 m	5 °C	12.0±0.04 ^a	459.7±2.83 ^b	32.1±0.94 ^a	4863±11 ^a	0.07±0.01 ^d	7.7±0.14 ^a
	RT	11.9±0.11 ^a	451.8±3.85 ^c	31.5±0.55 ^b	4773±46 ^b	0.09±0.02 ^e	7.0±0.11 ^b
	37 °C	11.9±0.13 ^b	449.1±3.24 ^d	30.6±0.53 ^b	4683±23 ^c	0.12±0.01 ^f	6.9±0.52 ^b
8 m	5 °C	12.0±0.12 ^a	451.4±3.50 ^c	31.9±0.54 ^a	4792±46 ^b	0.09±0.01 ^c	7.5±0.10 ^b
	RT	11.7±0.12 ^b	449.1±2.82 ^d	30.7±0.31 ^b	4691±56 ^c	0.12±0.02 ^f	6.5±0.23 ^b
	37 °C	10.8±0.12 ^c	446.6±3.41 ^e	30.1±0.20 ^c	4601±21 ^d	0.14±0.01 ^g	5.6±0.11 ^c
10 m	5 °C	11.8±0.14 ^b	449.3±4.23 ^c	31.1±0.55 ^b	4713±35 ^c	0.12±0.01 ^f	7.1±0.36 ^b
	RT	11.5±0.02 ^b	443.7±2.30 ^e	30.2±0.54 ^c	4613±16 ^d	0.15±0.01 ^g	5.9±0.42 ^c
	37 °C	10.3±0.04 ^c	441.3±1.20 ^f	29.7±0.35 ^c	4592±38 ^d	0.19±0.01 ^h	5.3±0.23 ^d

* RT Room temperature; OAA overall acceptability. Values in each column with different superscripts differ significantly ($p<0.05$)

Table 5 Color and textural changes during storage of osmo-dehydrated carambola slices

Storage time (m)		L*	a*	b*	Shear force (N)
Initial		44.4±0.22 ^a	2.2±0.05 ^a	21.6±0.21 ^a	49.1±0.21 ^a
2	5 °C	44.0±0.15 ^a	2.3±0.75 ^a	21.1±0.42 ^a	49.0±0.72 ^a
	RT	42.7±0.32 ^b	2.9±0.15 ^a	20.7±0.32 ^a	47.6±0.83 ^a
	37 °C	41.4±0.94 ^c	3.9±0.75 ^c	18.7±0.21 ^b	45.5±0.51 ^b
4	5 °C	43.2±0.82 ^a	2.7±0.10 ^a	20.7±0.40 ^a	47.7±0.35 ^a
	RT	40.0±0.65 ^c	3.4±0.15 ^b	18.9±0.35 ^b	45.1±0.90 ^b
	37 °C	38.6±0.56 ^d	4.6±0.38 ^d	16.8±0.56 ^c	42.0±0.83 ^c
6	5 °C	42.8±0.43 ^b	2.9±0.45 ^b	19.6±0.71 ^b	46.3±0.26 ^b
	RT	37.9±0.51 ^d	4.5±0.52 ^c	16.2±0.32 ^c	41.8±0.54 ^d
	37 °C	34.4±0.66 ^e	5.0±0.15 ^d	13.3±0.72 ^e	37.8±0.26 ^e
8	5 °C	42.1±0.64 ^b	3.3±0.23 ^b	16.8±0.55 ^c	44.0±1.24 ^c
	RT	35.6±0.53 ^e	5.5±0.12 ^e	13.9±0.20 ^d	37.3±0.37 ^e
	37 °C	31.8±0.45 ^f	6.7±0.23 ^f	10.8±0.26 ^e	32.0±0.56 ^f
10	5 °C	41.0±0.72 ^c	3.8±0.82 ^c	14.7±0.81 ^d	41.9±0.55 ^c
	RT	31.4±0.31 ^f	6.6±0.12 ^f	10.4±0.41 ^f	32.6±0.53 ^f
	37 °C	28.5±0.26 ^g	8.1±0.11 ^g	8.0±0.34 ^g	28.8±0.48 ^g

*RT Room temperature. Values in each column with different superscripts differ significantly ($p<0.05$)

desirability value of 0.98. The predicted and experimental results at optimized levels of variables showed high correlation (>98 %).

Storage studies and shelf-life

The osmo-dehydrated product prepared at optimized conditions were kept at 5 °C, ambient (30±2 °C) and 37 °C and evaluated for different physico-chemical parameters. The osmo-dehydrated carambola slices showed varied responses towards different storage temperatures in terms of physicochemical and sensory attributes (Tables 3 and 4). The moisture content, acidity, pH and total sugar content showed minimal changes during storage. However, the effect of storage temperature and period of storage was more pronounced in case of ascorbic acid ($p<0.05$) compared with carotenoids losses. Total Phenolics, flavonoids and also antioxidant potential showed a steady fall and the stability of phenolics was found higher compared with flavonoids. Sample kept at 37 °C showed lower stability in terms of selected parameters and also extent of browning was higher at elevated temperature of storage. The overall acceptability of the product was found to be above the threshold value 6.0 by the end of shelf life of product stored under different temperature (Table 4). The critical parameters were observed to be browning and softening of the product and the maximal changes were observed at 37 °C followed by ambient and low temperature. Abd-Karim and Chee-Wai (1999) attributed higher browning and stability rates of foam mat dried star fruit

puree. The effect of storage temperature was also pronounced ($p<0.05$) on the tristimulus colour coordinates and shear values (Table 5). However, the difference between low and ambient temperature storage compared with samples stored at 37 °C were on the lower side. As such the products showed darkening tendency in terms of L* value, increase in redness in terms of a* value and decrease in yellowness by means of b* values during storage. The osmo-dehydrated product prepared at optimized conditions showed a shelf-life of 10, 8 and 6 months at 5 °C, ambient (30±2 °C) and 37 °C, respectively.

Conclusions

Response surface methodology was successfully employed to optimize the process variables i.e. soaking solution concentration, soaking temperature and soaking time. All the three variables used in the study showed significant effects on the responses i.e. solute gain and water loss and quadratic models were found to fit well in describing the effect of variables on the responses. An optimized condition for the process variables were arrived at 70°Brix, 48 °C and 144 min for soak solution concentration, soaking temperature and soaking time, respectively. The osmo-dehydrated product prepared at optimized conditions was found to be shelf-stable for a period of 10, 8 and 6 months at 5 °C, ambient (30±2 °C) and 37 °C, respectively on the basis of physicochemical and sensory acceptability.

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