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Optimization of process parameters for hybrid drying of apple

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Abstract

The processing parameters viz. thickness of fruit slices, osmotic solution concentration and temperature during dehydration are considered most important for determining the drying kinetics and quality of final product. Hence, the present study was designed with the objective to optimize the processing conditions of hybrid drying involved ultrasound, osmotic followed by convective dehydration of apple. Data for the optimization were analyzed by using Response Surface Methodology. The experimental design involved sucrose concentration (30-70°B), thickness of apple rings (3.00–5.00 mm) and ultrasonicated time (0-60 min) and the response variables were solids gain and water loss. Results showed that maximum water loss and solid gain obtained at optimal conditions of 30 min ultrasonicated osmotic treatment at 50°B and thickness of 4.5 mm apple rings. The study concluded that application of ultrasound improved the product quality through 30-40 per cent reduction in dehydration time.

Keywords: Drying kinetics, hybrid drying, response surface methodology (RSM), solids gain, water loss

Introduction

Apple is most important horticultural crop in the world and constitute the greater part of the fruit production. In India, annual production of apple is 2521 (000 MT) from an area of 277 (000 hectare) during the year 2017-18 respectively and it is also a major pome fruit of Himachal Pradesh and belong to Rosaceae family. The consumption of apple is increasing in the world, mostly in the form of fresh fruit, juice and dried apples (Rodriguez *et al.*, 2014) [11]. But fruits have a very short shelf-life due to their high water content (more than 80 per cent) (Orsat *et al.*, 2006) [9]. Owing to their perishable nature, fruit losses are considerably high. These looses can be overcome by employing various preservation methods. Drying/dehydration is one of the oldest and widely used method of food preservation. Dehydration by hot-air is probably the most common and effective preservation method, used to make a food product with long shelf-life. Drying adds new values to food by limiting the spoilage and reducing the mass of the product (Witrowa-Rajchert *et al.*, 2006) [14], thereby it remains an area of continous interest for food research. Although the preservation of fruits through drying dates back many centuries and is based on sun and solar drying techniques but the poor quality such as loss of colour (Chua *et al.*, 2001) [3], change of texture, chemical changes affecting flavour and nutrients, shrinkage (Mayor and Sereno, 2004) [8] and product contamination leads to the search for alternate or innovative drying technologies (Bezyma and Kutovoy, 2005) [2]. The alternative methods of drying include osmotic, cabinet or tray, ultrasonication, freeze, vacuum, Ohmic, microwave and hybrid drying methods (George *et al.*, 2004) [6]. Osmotic dehydration has received greater attention as an effective method for preservation of fruits. Being a simple process, it facilitates processing of fruits with retention of initial fruit characteristics viz., colour, aroma and nutritional compounds (Pokharkar and Prasad, 1998) [10]. With the advantages it has some disadvantages and inconveniences too (Jackson and Mohamed, 1971) [7] such as long osmotic drying time, increase risk of microbial contamination and reduction in acidity level that reduces the overall acceptability of some products (Yadav and Singh, 2014) [15]. This can be overcome with the use of combination of drying techniques that have recently gained increasing interest in the advancement of drying technology. Henceforth, Hybrid drying is becoming familiar now a day since the hybrid technology receives the benefits of individual process. Introducing ultrasonication technique with osmosis and cabinet drying increases the mass transfer behavior of product. The reason is that power ultrasound when applied, ultrasonic waves travel through the solid medium causing a rapid series of alternative compressions and expansions, in a similar way to a sponge when it is squeezed and released repeatedly (sponge effect) (Fuente-Blanco *et al.*, 2006) [5]. This ultimately decreases the drying time, total energy consumption and reduces the product thermal damage since lower temperature used allows the retention of nutrients. So, the purpose of this study is to investigate the optimization of the processing variables to maximize the overall acceptability of the product by using RSM (Response Surface Methodology).

Materials and Methods

The fruits of apple (*Golden delicious*) harvested at optimum maturity were procured from the local market of Solan Himachal Pradesh. Sugar and packaging material were purchased from the local market. Fruits were collected randomly and brought to the laboratory for carrying out the present study. Apples slices were cut in the form of rings (varying thickness from 3 to 5 mm), after removing core with a corer and a knife. The measured average moisture content of the prepared apple rings was 85.90 per cent on a wet basis.

Osmotic dehydration and drying procedure

The osmotic dehydration was carried out using a ultrasonicated-osmotic dehydration setup. Apple rings of selected thickness (3-5 mm) were weighed and dip in sucrose solution at a selected concentration (30–70^0B) in glass beaker under ultrasonicator for different ultrasonicated treatment times (0–60 min). For each experiment, the ratio of solution/sample was kept 4:1 (w/w) and temperature of 50^0C was maintained using water bath.

Air-Drying Method

Air-drying was done in a specially designed food dehydrator at 60^0C. After ultrasonicated osmotic drying pretreatment, the samples were taken out from the ultrasonicator, drained and blotted with absorbent paper to remove the excess solution. These pretreated test samples were then subjected to air-drying until reaching a moisture content of 18 per cent (wb). In order to determine the endpoint, the weight of test samples during drying was continuously monitored by attaching the drying tray to an electronic balance. After drying, products were cooled and packed in low-density polyethylene bags for measuring product quality attributes. Test samples without ultrasound treatment also were similarly dried to get osmotically air-dried (OAD) samples.

Optimization of process parameters of drying through Response Surface Methodology (RSM)

The central composite design (CCD) was selected for the study as it drastically reduces the number of experiments when more than two variables are involved. CCD was used to design the experiments without any blocking comprising three independent variables (A: Thickness (mm), B: Sucrose concentration (°B) and C: Ultrasonication time). The ranges for different independent variables were selected based on pre-trials as shown in Table 1. Different combinations of variables were formulated, as per the RSM model design. The polynomial model was used to analyze the responses such as solid gain and water loss comprising of 15 experimental runs (Table 2).

$y = X_0 - X\ _1A\ _1 - X_2B_2 - X_3C_3 - X\ 11A^2 11 - X_{22}B^2_{22} - X33C^2 33 - X_{12}A\ B_{12} - X_{13}A\ C_{13} - X_{23}B\ C_{23}$ -------(1)

From the equation y was response variable, X_0 was intercept, X_1, X_2 and X_3 were linear coefficients, X_{11}, X_{22} and X_{33} were quadratic coefficients, X_{12}, X_{13} and X_{23} were interaction coefficients and A, B, C, A^2, B^2, C^2 and AB, AC and BC were the levels of independent variables (Thickness, Sucrose concentration and Ultrasonication time).

Table 1: Coded values of independent variables used for experimental design

Independent variable		Coded value		
		-1	**0**	**+1**
Real value	Thickness (mm) (A)	3	4	5
	Substrate concentration (^{0}B) (B)	30	50	70
	Ultrasonication time (min) (C)	0	30	60

Mass Transfer Determination

The samples were prepared following the central composite rotatable design; then the process kinetic variables of WL and SG rates of the samples were calculated as described by Singh *et al.* (2007) [13] and Falade *et al.* (2007) [4] by using

$$WL\% = \frac{(M0 - m0) - (Mt - mt)}{M0} X100\% \text{ ------(2)}$$

$$SG\% = \frac{mt - m0}{M0} X100\%$$

where $M0$ and $m0$ are the initial mass weights of the apple samples and the dry solid mass in the samples (g), respectively; Mt and mt are the mass weights of the samples and the dry solids (g) in the samples after the osmotic dehydration time t.

Results and Discussions

Fitting the model

Response Surface Methodology (RSM) is widely used as a statistical technique in process optimization and product quality amelioration in a short time period and minimum experiences. The experiment results are shown in Tables 2. The second-order polynomial response surface model was fitted to each of the response variables (Y), and the sum of squares of the sequential models was analyzed. These analyses indicated that adding terms up to quadratic significantly improved the model (data not given). In order to determine the significant effects of process variables on each response, an analysis of variance was the approach used, and the results are shown in figures. The ANOVA results indicated that lack of fit was not significant ($P > .05$) for any of the responses which meant that all models were adequate for describing the influence of process variables on the responses. The coefficient of determination, R^2, was found to be higher than 0.95 for all the responses. Moreover, the fact that the coefficient of variation (CV) was less than 5 per cent indicated that the variation in the mean value was low; therefore, the response models were satisfactorily.

Effect of process variables on solid gain and water loss rates

The relationship between the independent variables (thickness of rings, sucrose concentration and ultrasonicated treatment time) and solid gain is mentioned in the equation (3).

Table 2: Mass transfer behaviour of ultrasonicated osmo-drying of apple rings

Runs	Variables			Responses	
	Thickness (mm) (A)	Sucrose Concentration (^{0}B)(B)	US Time (C) (min)	Solid gain (%)	Water loss (%)
T_1	4.50	16.36	30.00	4.00	6.00
T_2	1.98	50.00	30.00	22.00	45.00
T_3	4.50	50.00	30.00	25.00	55.00
T_4	4.50	50.00	30.00	28.00	58.00
T_5	6.00	70.00	0.00	0.00	0.00
T_6	3.00	30.00	0.00	0.00	0.00
T_7	4.50	50.00	-20.45	0.00	0.00
T_8	7.02	50.00	30.00	22.00	54.00
T_9	3.00	70.00	0.00	0.00	0.00
T_{10}	4.50	50.00	80.45	27.00	56.00
T_{11}	6.00	30.00	0.00	0.00	0.00
T_{12}	6.00	30.00	60.00	26.00	40.00
T_{13}	3.00	70.00	60.00	25.00	54.00
T_{14}	6.00	70.00	60.00	22.00	55.00
T_{15}	3.00	30.00	60.00	27.00	42.00

SG (%)=24.45-0.29A-0.66B+10.56C-0.79A2-7.48B2-3.83C2-0.25AB-0.50AC-0.75 BC..eq-(3)
R^2=0.9712
WL (%) = 53.12+1.04A+2.61B+20.55C-1.92A2-16.38B2-9.66C2+0.38AB-0.13AC+3.37BC..eq-(4)

R^2=0.9754
The value of the determination coefficient (R^2) indicated that the model as fitted explained 97.12 and 0.9754 per cent of variability in solid gain (SG) and water loss (WL) respectively. Solid gain (SG) (%) and water loss (WL) (%) were significantly affected by increase in thickness, sucrose concentration and ultrasonicated treatment time (Fig1 and Fig 2).

From the derived equation (3 & 4) it was observed that the thickness of apple rings (A) and sucrose concentration (B) had negative linear and quadratic effect on the solid gain (SG) while ultrasonicated treatment time had positive linear and negative quadratic effect. The interaction of the thickness, sucrose concentration and ultrasonicated treatment time had negative effect on the solid gain of apple rings. The increase in the solid gain with increase in sucrose concentration may be due to increasing osmosis pressure gradient (Shamaei *et al.* 2012) [12]. In case of water loss, thickness of apple rings (A), sucrose concentration (B) and ultrasonicated treatment time had positive linear and negative quadratic effect while interactions among thickness of apple rings (A) - sucrose concentration (B) and sucrose concentration (B)-ultrasonicated treatment time (C) had positive effect whereas interactions among thickness of apple rings (A)-ultrasonicated treatment time (C) had negative effect.

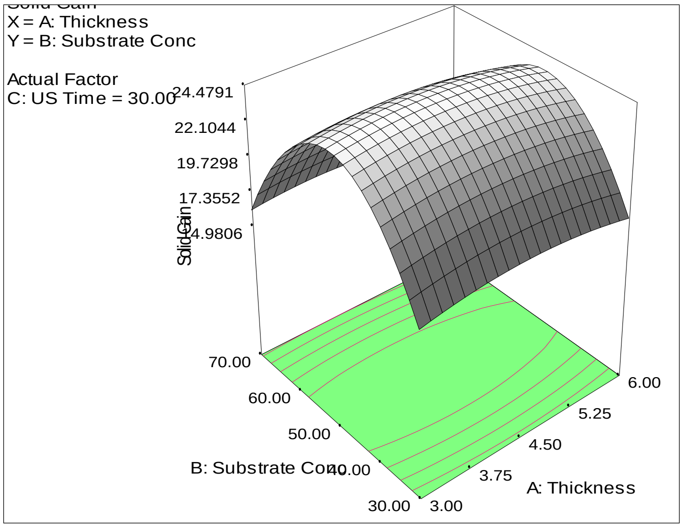

Fig 1: Effect of process variables on SG (%)

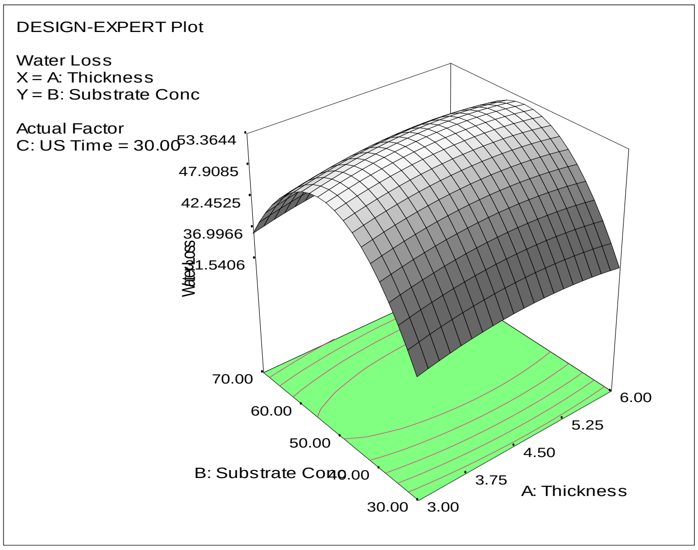

Fig 2: Effect of process variables on WL (%) Optimization

The result obtained from the RSM plot presented in Table 3 indicated the dependence of combination of independent variables (thickness of rings, sucrose concentration and ultrasonicated treatment time) on the mass transfer behavior during ultrasonicated osmo-drying of apple rings.

Table 3: Optimization of conditions through desirability function

Factors and responses	Goal	Lower limit	Upper limit	Importance	Optimized	Predicated value
Thickness (A)	In range	3.00	6.00	3	4.50	-
Sucrose Concentration (B)	In range	30.00	70.00	3	50.00	-
Ultrasonicated treatment time (C)	In range	0.00	60.00	3	30.00	-
SG	Target	13.40	42.20	3	28.00	24.45
WL	Target	8.72	14.25	3	58.00	53.11

Response surface plots were taken into account in the optimization, considering that the optimal solution arouse from interactions among the different responses. Optimization was performed on the basis of a multiple response method called desirability (Fig3). The score of each dependent variables were transformed into desirability scores that could range from 0.0 for undesirable to 1.0 for very desirable. The overall desirability of the outcomes at different combinations of levels of the predictor variables were computed as the geometric mean of the individual desirability (1.00).

Optimum process conditions for ultrasonicated osmo-drying of apple fruits was shown these criteria, the uncoded optimum process condition for ultrasonicated osmo-drying of apple fruits were thickness 4.5 mm, sucrose concentration 50^{0}B and ultrasonicated treatment time 30 min. The response predicted by the design expert-6 software for these process conditions resulted solid gain 24.45 per cent and water loss 53.11 per cent. The difference between the predicated and actual optimized values were calculated and found below 5.00 per cent which was desirable. The closeness of the actual values of solid gain (28.00 %) and water loss (58.00%) with predicated values of solid gain (24.45 %) and water loss (53.11 %) confirmed the validation of response surface methodology (RSM) model. Similar results i.e. increase in water loss was reported by Barman *et al.* (2017) [1] for carambola slices. The desirability scores for process conditions for ultrasonicated osmo-drying of apple fruits was 1.00 which was in the most acceptable limits. The higher water loss may be due to enhancement of mass transfer by application of ultrasound during dehydration (Yao, 2016) [14]. Thus, it can be concluded that ultrasonic treatment time has a positive effect on osmotic dehydration of apple rings.

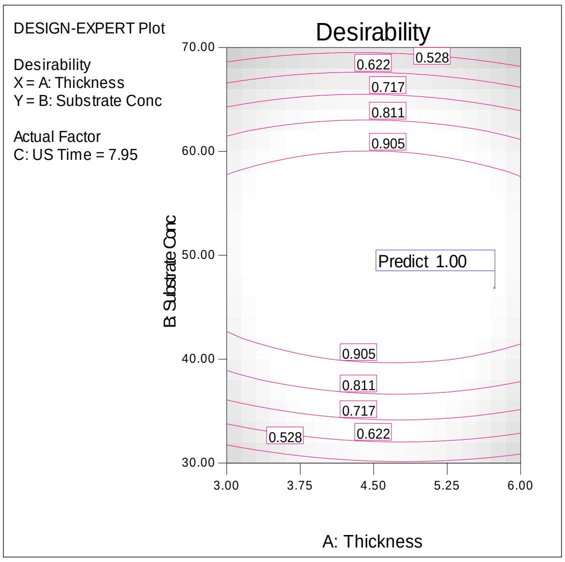

Fig 3: Optimization of process variables through desirability function

Conclusion

The optimization of the ultrasonicated osmotic dehydration conditions for apple rings was examined using the RSM. The optimal conditions comprised ultrasonicated time of 30 min, sucrose concentration at 50^{0}B and thickness of 4.5 mm with a response value of 28.00 and 58.00 per cent for the solid gain (SG) and water loss (WL) rate. The optimal condition was validated and found to be fitted well with the experimental data. Therefore, optimization of ultrasonicated osmotic dehydration of apples was carried out to obtain maximum water loss and minimum solid gain. The findings from this work also show that the use of ultrasound during osmotic dehydration of apples helps to reduce the amount of raw material (sucrose) and time of dehydration needed to achieve the optimized result.

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