Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2020; SP6: 328-331

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International Web-Conference
On
New Trends in Agriculture, Environmental & Biological Sciences for Inclusive Development
(21-22 June, 2020)

Modelling and Optimization of process parameters for osmo-sonication drying of sand pear fruits

Swati Sharma, Devina Vaidya, Manisha Kaushal, Anil Gupta and Faruk Ansari

Abstract
In this study, Response Surface Methodology (RSM) was used to optimize osmo-sonicated drying of sand pear fruits. Processing parameters viz. cube size of fruit pieces; osmotic solution concentration and sonication time during drying are considered most important for determining the drying kinetics and quality of final product. Henceforth, the present study was investigated, for this, osmo-sonication of sand pear was carried out in sucrose solution of 50, 60 and 70 °B with cube size of 1, 3 and 5 cm^3 and sonication time of 15, 30 and 45 min. The influence of all these process parameters on response variables i.e. solids gain and water loss were observed. Results showed that maximum water loss and solid gain obtained at optimal conditions of 30 min osmo-sonicated treatment at 60°B and cube size of 3 cm^3 sand pear fruits. The study concluded that application of sonication improved the product quality through 30-40 per cent reduction in dehydration time.

Keywords: Response Surface Methodology (RSM), Sand pear, Osmo-sonication, solids gain, water loss

Introduction
Himachal Pradesh is predominately a horticulture state of India especially known for pome fruits. Sand pear (*Pyrus pyrifolia*) is one among major pome fruits of Himachal Pradesh that belongs to Rosaceae family. It is grown in temperate and subtropical environment due to its broad adaptability to environmental conditions. In India, it is grown in semi-temperate regions of states of Himachal Pradesh, Punjab, Haryana, Utter Pradesh and North East region. Sand pear also known as *Pathernakh* is a variety of pear that is known so, because of its hard texture. The fruits of Sand pear are mostly like by consumers owing to its crispness, sweetness, fragrance and unique flavour. It has grit cells that improve its eating quality (Baniwal and Singh, 2017) [2]. The annual production of sand pear in Himachal Pradesh is 25,214 MT from an area of 7220 ha respectively (NHB, 2019) [9]. The fruits of Sand pear have high nutritional and functional value as it provides 11.90 g of carbohydrates, 52 kcal of energy per 100 g of edible portion and also a rich source of minerals, vitamin C and fiber (FDA, 2016) [3]. In addition to this, they also posses higher amount of water content (more than 80 %) and make them perishable (Orsat *et al.*, 2006) [10]. Owing to their perishable nature, fruit losses are considerably high and in India, these losses are estimated more than 25 percent because of poor processing infrastructure. These losses can be overcome by employing various preservation methods. Drying is most commonly used method to preserve or to increase shelf life of foods. The quality of dried products is dependent to on drying methods and conditions. Osmotic dehydration prior to drying has a protective effect on the structure of the dried material, making it more acceptable for consumption. This reduces the loss of fresh fruit flavor, increases the sugar content and removes some acids, making osmotically concentrated products more acceptable (Ispir and Togrul., 2008 [7]; Sharma *et al.,* 2020) [11]. With the advantages it has some disadvantages and inconveniences too (Jackson and Mohamed, 1971) [8] such as low mass trasnsfer rate, long osmotic drying time, increase risk of microbial contamination and un-desirable reduction in acidity level that reduces the overall acceptability of some products (Yadav and Singh, 2014) [12].

However, mass transfer rates during dehydration also depend on concentration of the osmotic medium, size and geometry of the sample (Ispir and Togrul., 2008) [7]. This can be overcome with the use of combined drying techniques that have recently gained increasing interest in the advancement of drying technology (Sharma *et al.*, 2020) [11]. Using sonication with osmosis and cabinet or tray drying, increases the mass transfer of osmotic treatment. The reason is that ultrasonic waves cause 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]. The sonication also causes cavitation in a liquid medium that generates bubbles in the liquid that can explosively collapse and generate localized pressure and temperature (Fernandes *et al.*, 2011) [4].This ultimately decrease the drying time, total energy consumption and effective even at ambient temperatures, therefore heat damage to texture, colour and flavour can be minimized. Henceforth, the aim of current study is to optimize the processing variables to maximize the overall acceptability of the product by using RSM (Response Surface Methodology).

Materials and Methods

The fruits of Sand pear harvested at optimum maturity were procured from the local market of Solan, Himachal Pradesh. Sugar was purchased from the local market. Fruits were collected randomly and brought to the laboratory for carrying out the present study. Sand pear was cut in the form of cubes (varying size 1, 3 and 5 cm^3). The measured average moisture content of the prepared cubes was 84.95 per cent on a wet basis. The drying process was carried out using an osmo-sonicated setup. Sand pear cubes of size from 1-5 cm^3 were weighed and dip in sucrose solution of concentration (50, 60 and 70 ^{0}B) in glass beaker under sonicator for different sonicated treatment times (15, 30 and 45 min). For each experiment, the ratio of solution/sample was kept 4:1 (w/w) and temperature of 50 ^{0}C was maintained using water bath. Air-drying was done in a specially designed food dehydrator at 60 ^{0}C. After osmo-sonicated drying pretreatment, the samples were taken out from the sonicator, 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 control samples.

Optimization of process parameters

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.

$$y = X_0 - X_1A_1 - X_2B_2 - X_3C_3 - X11A^211 - X_{22}B^2{}_{22} - X33C^233 - X_{12}AB_{12} - X_{13}A\,C_{13} - X_{23}B\,C_{23} \quad (1)$$

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 (Cube size, Sucrose concentration and Sonication time).

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

Independent variable		Coded value		
		-1	0	+1
Real value	Cube size (cm^3) (A)	1	3	5
	Substrate concentration (^{0}B) (B)	50	60	70
	Sonication time (min) (C)	15	30	45

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 Sharma *et al.*, (2020) [11] by using

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

$$\text{SG\%} = \frac{mt - m0}{M0} X100\% \quad (3)$$

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

Response surface methodology (RSM) was used to estimate the main effects of osmo-sonication drying process on water loss (WL) and solid gain (SG) in sand pear fruits. A centered composite design was used with cube size (1-5 cm^3), osmotic solution concentration (50-70 °B), and sonication time (15-45 minutes) being the independent process variables. The RSM was applied to the experimental data using a commercial statistical package, Design-Expert version 6.01 (Stat ease Inc., Minneapolis, USA).

Table 2: Experimental design for all responses for optimization of process of osmo-sonication drying of sand pear cubes

Runs	Variables			Responses	
	Cube size (cm^3) (A)	Sucrose Concentration (^{0}B) (B)	US Time (min) (C)	Solid gain (%)	Water loss (%)
T_1	3.00	60.00	30.00	16.00	46.12
T_2	3.00	43.18	30.00	6.00	21.04
T_3	5.00	70.00	15.00	12.00	37.18
T_4	1.00	50.00	15.00	14.00	30.94
T_5	1.00	70.00	15.00	17.00	35.89
T_6	1.00	50.00	45.00	15.00	31.34
T_7	1.00	70.00	45.00	20.00	40.19
T_8	5.00	50.00	45.00	15.00	43.53
T_9	3.00	76.82	30.00	22.00	45.39
T_{10}	5.00	70.00	45.00	20.00	46.09
T_{11}	-0.36	60.00	30.00	0.00	0.00
T_{12}	6.36	60.00	30.00	14.00	43.00
T_{13}	3.00	60.00	4.77	4.10	14.10
T_{14}	5.00	50.00	15.00	5.43	28.43
T_{15}	3.00	60.00	55.23	13.09	44.09

Diagnostics checking of fitted Model

Regression analysis for different models indicated that the fitted quadratic models accounted for more than 95 per cent of the variation in the experimental data, were found to be more significant. Multiple regression equation was generated relating water loss and solid gain to coded levels of the variables.

Models were developed as follows:

$$\text{Water Loss} = +45.80 +6.53A+4.84B+5.80C-6.62A^2-2.48B^2-3.94C^2-0.31AB+2.41AC-0.29BC \quad (4)$$

$R\text{-Squared}=0.9240$

$$\text{Solid Gain} =+15.83+0.70A +3.43B +2.72C-2.07A^2 +0.41B^2-1.54C^2+0.50AB+1.75AC+0.00\,BC \quad (5)$$

$R\text{-Squared}=0.9353$

The experimental values for water loss and solid gain under different treatment conditions are presented in Table 2. Regression equations describing the effect of osmo-sonication drying variables on the water loss (WL) and solid gain (SG) of sand pear cubes are given in equation (4) and (5). During the experiment high correlation coefficients (i.e. R^2) were obtained for both responses indicating good fit of experimental data to Equation.

The coefficient of determination for water loss and solid gain (R^2= 0.9240 and R^2= 0.9353, respectively) are quite high for response surfaces. 3D and 2D surfaces were generated using regression equations, as shown in figure 1 and 2. The figure 1 and 2 shows the variation of water loss and solid gain as a function of size and osmotic solution concentration, size and sonication time and osmotic solution concentration and sonication time respectively. The water loss increased gradually with the sucrose solution over the entire osmo-sonication drying process (Fig 1).

Conditions for Optimum Responses

Models were useful in indicating the direction in which to change variables in order to maximize water loss and solid gain. Therefore the multiple regression equation was solved for the maximum water loss and solid gain. The coded values for the optimum responses were first decoded into actual values as per the equations were transformed into actual variables by solving the algebraic equation as described in experimental design. The response surfaces are obtained by selecting two variables and the third variable has the value that lead to the optimum response in the equations y_1 and y_2. The surfaces are presented in Figs 1 and 2.

Diagnostic checking of fitted model and surface plots for water loss

The effect of various process parameters on water loss are indicated in Figs 1. The water loss varied from 14.10 to 46.12 g/100g with change in process parameters. Sucrose concentration and sonication time had most significant effects in sand pear cubes. Fig 1 shows that water loss increased with increase in cube size and also increased with increase in sonication time then starts decreasing (Fig 1). Results were in agreement with Alam *et al.*, (2010) [1] that showed positive effect of sugar syrup concentration and osmotic time on water loss of aonla fruit.

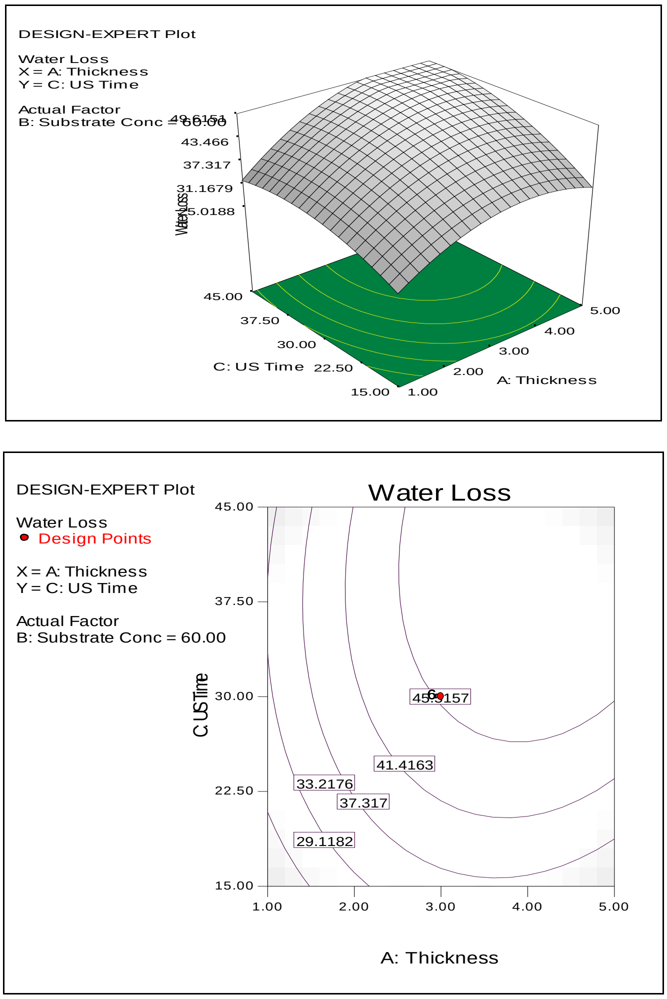

Fig 1: Water loss during osmo-sonication drying of sand pear cubes as function of sonication time and thickness (size) of cube

Diagnostic checking of fitted model and surface plots for solid gain

The effect of various process parameters on solid gain are indicated in Fig 2. The solid gain varied from 4.10 to 22.00 g/100g with change in process parameters. Substrate concentration and sonication time had most significant effect on solid gain in sand pear cubes. Solid gain increased with increase in substrate concentration and slightly increased initially with increase in sonication time and then started decreasing as shown in Fig 2. Similar findings were reported by Sharma *et al.*, (2020) [11] in apple rings. Moreover, Garcia-Noguera *et al.*, (2010) [6] also gave parallel results on osmotic dehydration with ultrasonication on strawberry fruit, those presented that solid gain values tended to increase as the sucrose concentration and ultrasonicated treatment time increased upto specific level.

Optimization of the processing parameters to maximize overall acceptability of product

Design expert software was used to optimize the processing parameters like cube size, sugar concentration and sonication time to maximize overall acceptability of product. The software uses second order model to optimize the responses. Table 3 showed constrains used for the optimization of processing parameters and Table 4 represented the optimized conditions given by design expert.

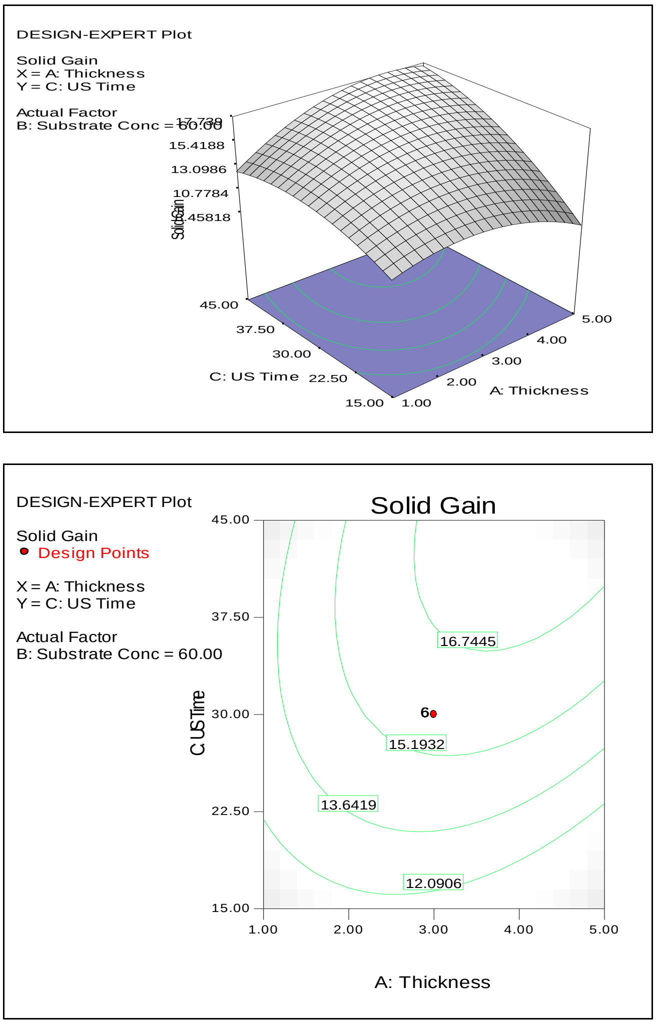

Fig. 2: Solid gain during osmo-sonication drying of sand pear cubes as function of sonication time and thickness (size) of cube

Table 3: Constraints selected in the range for optimization

Factors and responses	Goal	Operating conditions	
		Lower limit	Upper limit
Thickness or size of cube (cm^3) (A)	In range	1.00	5.00
Sucrose concentration (^{0}B) (B)	In range	50.00	70.00
Ultrasonication treatment time (min) (C)	In range	15.00	45.00
Solid gain (%)	Target	0.00	22.00
Water loss (%)	Target	0.00	46.12

Table 4: Optimized level (in the range) and predicted optimum values

Factors and responses	Optimum value	Responses	Optimum conditions	
			Experimented value	Predicted value
Thickness or size of cube (cm^3) (A)	3.00	Solid gain (%)	16.00	15.82
Sucrose concentration (^{0}B) (B)	60.00	Water loss (%)	46.12	45.80
Ultrasonication treatment time (min) (C)	30.00			

Conclusion
Response surface methodology was found effective in identifying the optimum processing conditions for osmo-sonicated drying of sand pear cubes. The process parameters such as cube size of 3 cm^3, sucrose concentration of 60 ^{0}B and sonicated time of 30 min were optimized through Response Surface Methodology (RSM) and these optimized condition reduced the original water content of sand pear cubes by about 18.00 per cent. Therefore, osmo-sonication of sand pear could effectively decrease the solid gain while increase the water loss, this ultimately increase the acceptability of end product and could be used as an effective pretreatment prior to conventional drying or freeze drying as it reduces total drying time with maintaining the natural end product quality by preserving nutritional, sensory and functional properties of the product.

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