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ORIGINAL ARTICLE

Optimization of process parameters for ultrasound-assisted osmotic dehydration of pineapple slices using response surface methodology

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Abstract

The effect of ultrasound-assisted osmotic dehydration (USOD) on dehydration kinetics viz., water loss (WL), solid gain (SG), and osmotic dewatering rate (ODR) was investigated using response surface methodology, in order to optimize process parameters. Pineapple slices were subjected to USOD at three different osmotic solution concentrations (50, 60, and 70°B), sonication time (20, 30, and 40 min), and temperatures (10, 20, and 30°C) using two types of osmotic agents (glucose and fructose) in an ultrasonic bath (ultrasound frequency of 33 ± 3 kHz and ultrasound power of 250 W). Box–Behnken design was used as experimental design, consisting of three factors with three levels, and a categoric factor with two levels, totaling 34 data points. Results of ANOVA and regression analysis conducted showed significant effects on responses and model's best fit to the experimental data. Results revealed that USOD treatment led to higher water loss and osmotic dewatering rate compared to osmotic dehydration (OD). The optimized values that would give maximum WL, ODR, and minimum SG were osmotic solution concentration of 50°B, sonication time of 26.6 min, temperature of 30°C, and using fructose as osmotic agent. This resulted in values of 0.266 g water/g, 0.049 g solid/g, and 0.730 g/min for water loss, solid gain, and osmotic dewatering rate, respectively.

Practical applications

USOD is a non-thermal process and could be a novel technology in food processing and preservation. Application of ultrasonic waves during osmotic dehydration enhanced the water loss and dewatering rate, due to the synergistic effect of osmotic pressure gradient and generation of microscopic channels caused by cavitation (ultrasonic effect). USOD can remove upto 26.6% of water from the fresh pineapples in 26.6 min of sonication time, using fructose as osmotic agent at 50°B and temperature of 30°C therefore, maybe considered as a promising method for the production of partially dried product.

1 | INTRODUCTION

Native to South America, pineapple (*Ananas comosus*) is one of the commercially important fruit crops of India (Joy & Anjana, 2015). Pineapple is an excellent source of calcium, potassium, fiber, and Vitamin C. It is also a good source of Vitamin B1, Vitamin B6, copper, and dietary fiber (Joy, 2010). India ranks sixth in the production of pineapple 1.79 MT spanning an area of 1.07 lakh ha (NHB, 2020).

Part of the production does not meet the minimal standard for export and excess is lost after harvesting as they are highly perishable hence cannot be stored for long periods nor can be stored frozen. Processing of pineapple employing suitable technologies can deliver shelf stable product with fresh-like quality. In order to commercialize excess production and to preserve the fruit in conjunction with minimal processing, pineapples could be dried after peeling, coring, and slicing keeping in view the retention of its most important quality characteristics.

Traditional food preservation techniques such as freezing, blanching, pasteurization, sterilization, canning, drying, and dehydration rely on heating and cooling operations. Conventional drying using convective (hot air) is the ancient and commonly used method to extend the shelf life of the products, as well as economical compared to other methods, but it adversely affects the product quality, reducing its value. The high temperature and long process time induce a series of chemical and biochemical conversions resulting in the change of color, taste, aroma, and nutrient properties. Also, excessive shrinkage makes the product unappealing. Drying is one of the most energy expensive unit operations apart from associated environmental concerns such as greenhouse gas emissions and depletion of fossil fuels. Therefore, alternative ways of treatment processes are to be sought to produce high-quality dried pineapple slices at possibly minimum capital and operating cost.

Osmotic dehydration is one of the promising methods of predrying treatment to reduce the water content of foods (Lenart & Lewicki, 1988). It is a non-thermal process, carried out by immersion of produce in a hypertonic solution which results in partial moisture removal from the produce. The diffusion of water is assisted by simultaneous counter diffusion of solutes from the osmotic solution in to the tissue. The rate of diffusion depends upon factors such as concentration gradient, temperature, and type of solute used. Quality improvement is not only connected to water removal without thermal stress but also the impregnation of solute. At optimal process variables, the natural flavor and color of the fruit products are better retained (Marcotte & Le Maguer, 1992).

The osmotic process is usually very slow (especially at ambient temperatures) owing to its diffusional characteristic and confined by equilibrium state. To accelerate the mass transfer in the osmotic dehydration process, and thereby increase its efficiency, these processes are increasingly aided by power ultrasound process associated with drying procedures. The introduction of ultrasound technology assists the time-consuming osmotic or conventional hot air dehydration processes and produces dried product of better quality.

Ultrasound is a series of sound waves with frequencies above the range of human hearing, 18 kHz (Mason, 1998). Low-frequency power ultrasound (frequencies range between 20 kHz and 1 MHz) instigates physical, chemical, or mechanical changes on the products or processes where it is applied. Ultrasonic waves cause cavitation in a liquid medium, a phenomenon where small bubbles or voids are formed, grow, and collapse due to pressure fluctuation which results in micro-agitation. The micro-agitation enhances the mass transfer rate by the reduction of solid diffusion boundary layer thickness leading to increased mass transfer coefficients. In a solid medium, the traveling ultrasound produces rapid alternative compressions and expansions resulting in a "sponge effect" in the solid where it helps the liquid to flow out of the solid, interchanging with the entry of fluid from outside (Cárcel et al., 2007). Ultrasonic waves induce "Cavitation" phenomenon which allows removal of moisture bound to solid material (Fernandes et al., 2009).

Some recently published studies have shown that ultrasound-assisted osmotic dehydration (USOD) results in higher water loss apart from other advantages mentioned. Studies on osmotic dehydration, ultrasound, and ultrasound-assisted osmotic dehydration have shown that different fruits respond differently to the application of these drying pretreatments and consequently influence the convective drying that follows till the product achieves safe lower level moisture contents. Toward this, it is hypothesized that USOD would increase the osmotic pressure, generating microscopic channels leading to enhanced water diffusion coefficient and dewatering rate. This study optimizes the process parameters for USOD of pineapple slices in terms of maximum water loss, osmotic dewatering rate, and minimum solid gain.

2 | MATERIALS AND METHODS

2.1 | Raw materials

Fresh ripe pineapples (*Ananas comosus*) (Figure 1a) of Mauritius variety procured from the local market in Kuttipuram, Kerala, India, were used for the study. The level of ripeness of the fresh fruit chosen was as homogenous as possible with a total soluble solid content (TSS) of 13 ± 2°B (Brix) (Digital Refractometer) and moisture content 82 ± 4% wet basis (wb) (Infrared moisture meter, SHI-AM Technologies). All the chemicals used for the experiments were analytical grade procured from Sisco Research Laboratories (Taloja, Maharashtra, India).

2.2 | Sample preparation

The pineapples were washed, peeled, and cored using a stainless steel (SS) corer (Figure 1b). Due to the fact that the amount of nutrients could vary from one end of the pieces to the other (Ramallo & Mascheroni, 2012), the end portions of ~2 cm were discarded. Pineapple rings (Figure 1c) were then sliced to get 5 mm thick slices which were then cut radially to get sliced pineapple (Figure 1d) of average width 8 mm measured using a digital Vernier caliper with a least count of 0.01 mm.

2.3 | USOD pretreatment

The prepared pineapple slices were immersed in two different osmotic solutions and subjected to ultrasonic waves for 20, 30, and

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FIGURE 1 (a) Pineapple (b) SS Pineapple corer (c) Pineapple rings (d) Pineapple pieces

40 min and at three different temperatures of 10, 20, and 30°C. The osmotic solutions were prepared by mixing glucose and fructose with distilled water separately, to give concentrations of 50, 60, and 70°B. The levels of independent variables were taken based on a thorough review of the literature and preliminary studies conducted.

The ultrasonic bath is 3/4th (i.e., 7.5 L) filled with distilled water. The pineapple slices were immersed in the osmotic solution in 1000 ml Erlenmeyer beakers and placed in the bath at 4:1 solution to fruit ratio (weight basis). This ratio was selected based on previous works that have shown that at this solution to fruit ratio the dilution of the osmotic solution due to the exchange of water and solute between sample and solution was negligible (Gheybi et al., 2013). To determine the effect of ultrasound, a control experiment was run with optimized parameters without ultrasonication and at ambient temperature. Also, to study the influence of USOD on solute diffusion into the product, solid gain was determined.

After USOD treatments, the dehydrated samples were drained and blotted with absorbent paper to remove the excess solution. The weight and moisture content of the samples were used to calculate Water Loss (WL), Solid Gain (SG), and Osmotic Dewatering Rate (ODR), according to the following equations:

$$\mathrm{WL} = \frac{w_i\, M_i - w_f\, M_f}{w_i} \tag{1}$$

$$\mathrm{SG} = \frac{w_f\left[1 - M_f\right] - w_i\left[1 - M_i\right]}{w_i} \tag{2}$$

$$\mathrm{ODR} = \frac{dm}{dt} \tag{3}$$

where w_i and w_f are the initial and final weight (g) of the samples, respectively; M_i and M_f are the initial and final moisture contents of the samples on wb (g water/g); dm is the change of sample mass, and dt is the time taken in change of mass.

2.4 | Experimental design

Response Surface Methodology (RSM) was applied to the experimental data to determine the optimal process parameters, assess the interaction between them, and provide data for a predictive regression model. Among the several designs used to apply RSM, the Box–Behnken design, an independent quadratic design was selected since the safe operating limits for the process are known. Central composite designs have axial points outside the cube, which is beyond the safe operating zone. The Box–Behnken design does not contain treatment combinations at which all the factors are simultaneously at their lowest or highest levels. Hence, these designs are useful in eliminating the experiments performed at extreme conditions, which would lead to unsatisfactory results.

A Box–Behnken design with three numeric factors at three levels and a categoric factor with two levels (Table 1) were used to analyze the responses and then characterize the optimal condition for the USOD process. Osmotic solution concentration (°B), sonication time (min), and temperature (°C) were the three independent variables, and type of osmotic agents (glucose and fructose) was the categoric factor. Thirty-four points were given by the design (Appendix A).

A total of around 12–15 pineapples were used for the experiments. For each trial, 125 g of pineapple slices was immersed in 500 ml of osmotic solution taken in a beaker, sealed using aluminum foil, and then placed in the ultrasonic bath with a chiller.

2.5 | Optimization

Response surface methodology (RSM) was applied on experimental data using Design-Expert software version 12.0.3.0. The polynomial model of the linear regression method with 12 coefficients gave the relationships between the independent variables (*A*, *B*, and *C*) and response (*Y*).

$$Y = b_o + b_1A + b_2B + b_3C + b_4D + b_{11}A^2 + b_{22}B^2 + b_{33}C^2 + b_{44}D^2 + b_{12}AB + b_{13}AC + b_{23}BC + b_{24}BD. \quad (4)$$

where, *Y* is the response calculated by the respective model (WL, SG, and ODR); A is the osmotic solution concentration; °B, B is sonication time, min; C is temperature; °C and D are type of osmotic solution; b_0 is the intercept; b_1, b_2, b_3, and b_4 are linear coefficients; b_{11}, b_{22}, b_{33}, and b_{44} are quadratic coefficients; and b_{12}, b_{13}, b_{23}, and b_{24} are interaction coefficients.

3 | RESULTS AND DISCUSSION

The quadratic model explores the impact of all variables and their interactions on dependent variables. The lack of fit was checked for all the responses corresponding to the variation of experimental data. ANOVA and regression analysis was conducted to analyze the significant effects on responses and model's best fit to the experimental data (Table 2).

TABLE 1 Independent variables and its coded and actual values

Independent variables	Units	Code levels −1	0	+1
Osmotic solution concentration (A)	**°brix**	**50**	**60**	**70**
Immersion time (B)	min	20	30	40
Temperature (C)	°C	10	20	30
Categoric factor				
Type of osmotic solution (D)	a. Glucose (G) b. Fructose (F)			

3.1 | Water loss

The effect of osmotic solution concentration, sonication time, and temperature on water loss (WL) is represented in Figure 2a–c). The polynomial regression model representing the interaction between the independent variables is represented by the following equation:

$$WL\left(g\frac{\text{water}}{g}\right) = 0.2708 - 0.039A + 0.019B + 0.014C + 0.02AB - 0.05AC + 0.09BC - 0.054A^2 - 0.0369B^2. \quad (5)$$

where, A = osmotic solution concentration, °B; *B* = sonication time, min; *C* = temperature, °C; *D* = type of osmotic solution.

It may be revealed from the equation (Equation 5) that the linear term of osmotic solution concentration, sonication time, and temperature had a significant ($p < .05$) effect on WL. The coefficient values showed that WL is highly influenced by sonication time, followed by temperature and further followed by solution concentration. Figure 2a shows that the WL increased with an increase in solution concentration upto 60°B and with further increase in solution concentration, WL showed no significant change. This may be due to the fact that the viscosity of the solution increases with an increase in concentration and beyond particular solution viscosity; the transmission of ultrasonic waves was hindered causing the US effects to be insignificant (Fernandes & Rodrigues, 2008).

It could be seen from Equation (5), Figure 2b,c that the coefficient estimate of the interaction of solution concentration and sonication time, and sonication time and temperature, respectively, had a positive effect on WL and this inferred that the increase in one variable with an increase in other resulted in increase of WL. It could be seen that the WL increased upto 30 min of sonication time and with further sonication WL showed no significant change. This could be due to the saturation of microchannels by solids and the osmotic pressure equilibrium attained (Kek et al., 2013).

3.2 | Solid gain

The effect of osmotic solution concentration, sonication time, and temperature on solid gain (SG) is depicted in Figure 3a–c). The polynomial regression model representing the interaction between the independent variables is represented by the following equation:

$$SG\left(g\frac{\text{solid}}{g}\right) = 0.10861 - 0.0114A + 0.007B + 0.004C - 0.005D - 0.009AB + 0.004BC - 0.0531A^2 - 0.012B^2 - 0.0118C^2. \quad (6)$$

It may be revealed from the equation (Equation 6) that the linear terms of solution concentration, time, and temperature showed a significant ($p < .05$) effect on solid gain. The coefficient estimate of the linear term of solution concentration had a negative effect on solid gain, revealing that SG increased when solution concentration was increased from 50 to 60°B but further found to decrease with an

TABLE 2 Analysis of variance and regression analysis for water loss, solid gain and osmotic dewatering rate

		Water loss			Solid gain			Osmotic dewatering rate		
Source	df	coefficient	Sum of squares	*p*-value	coefficient	Sum of squares	*p*-value	coefficient	Sum of squares	*p*-value
Model	13	0.2708	0.0798	<.0001*	0.1086	0.0335	<.0001*	0.6112	0.2983	<.0001*
A: Concentration(°B)	1	−0.0391	0.0244	<.0001*	−0.0115	0.0021	<.0001*	−0.0896	0.1284	<.0001*
B: Time	1	0.0191	0.0059	<.0001*	0.0079	0.0010	<.0001*	0.0055	0.0005	.4102
C: Temperature (°C)	1	0.0142	0.0032	<.0001*	0.0047	0.004	<.0001*	0.0161	0.0042	.0231*
D: Type of solution	1	0.0071	0.0017	<.0001*	−0.0058	0.0011	<.0001*	0.0296	0.0298	<.0001*
AB	1	0.0204	0.0033	<.0001*	−0.0099	0.0008	<.0001*	−0.0271	0.0059	.0083*
AC	1	−0.0058	0.0003	.0114*	−0.0019	0.0008	.1605	−0.0778	0.0484	<.0001*
BC	1	0.0099	0.0008	.0001*	0.0049	0.0002	.0012*	0.0233	0.0044	.0205*
BD	1	0.0009	0.0000	.5556	0.0019	0.0001	.0464*	0.0006	5.063E-06	.9325
A2	1	−0.0548	0.0253	<.0001*	−0.0531	0.0238	<.0001*	−0.0516	0.0224	<.0001*
B2	1	−0.0369	0.0115	<.0001*	−0.0122	0.0012	<.0001*	−0.0753	0.0477	<.0001*
C2	1	−0.0085	0.0006	.0004*	−0.0118	0.0012	<.0001*	−0.0116	0.0011	.2145
Residual	20	—	0.0007	—	—	0.0003	—	—	0.0137	
Lack of fit	12	—	0.0005	.1265	—	0.0001	.6908	—	0.0106	.1332
Pure error	8	—	0.0002	—	—	0.0001	—	—	0.0032	
Total	33	—	0.0804	—	—	0.0337	—	—	0.3120	
R^2	—	0.9915	—	—	0.9921		—	0.9560	—	
Adj R^2	—	0.9860	—	—	0.9870			0.9273	—	

*Significant at $p < .05$.

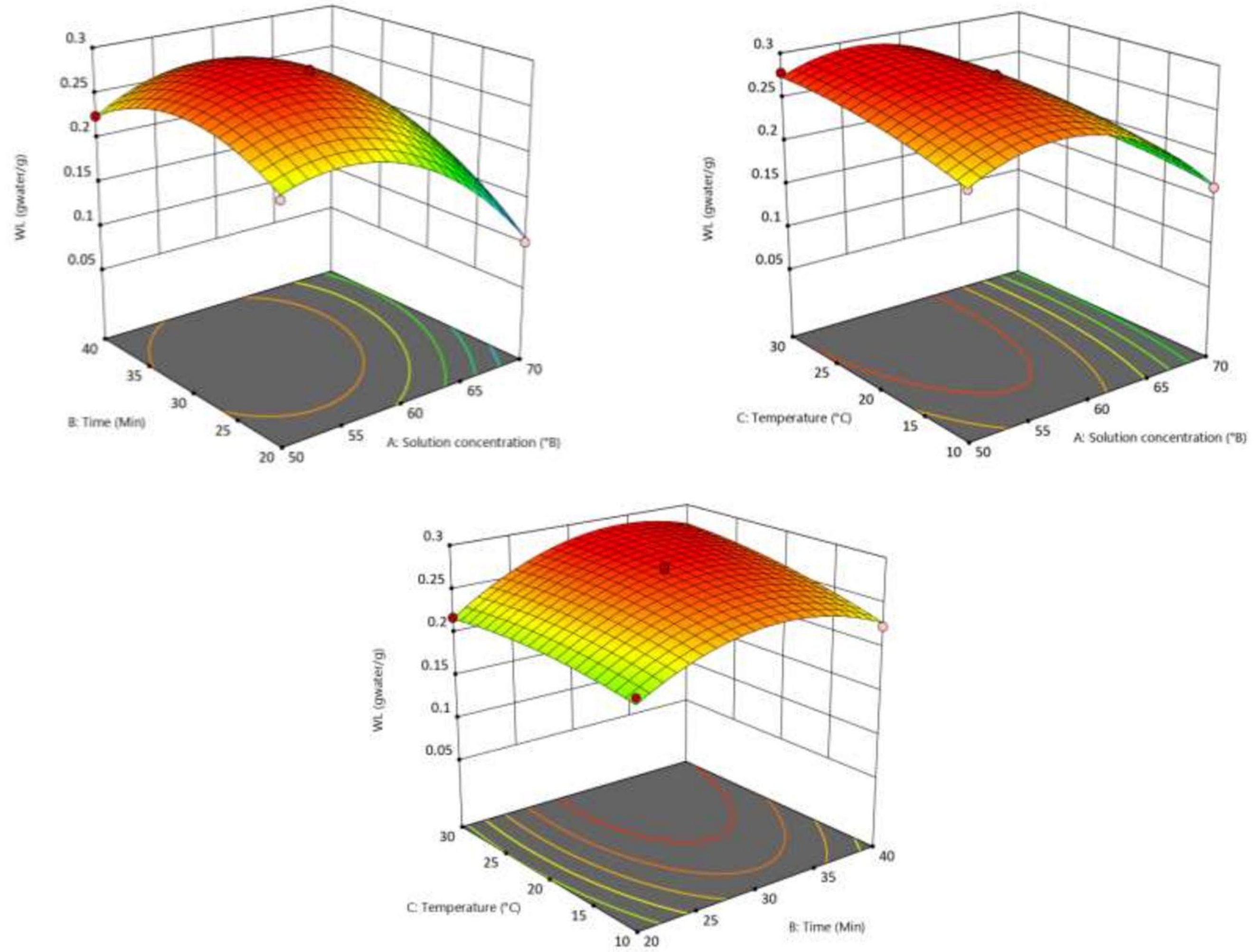

FIGURE 2 Response surface plot of WL as affected by (a) solution concentration and time (b) solution concentration and temperature (c) temperature and time

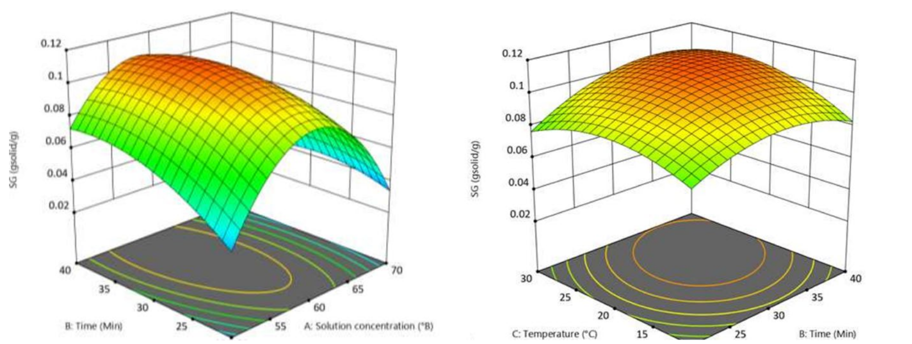

FIGURE 3 Response surface plot of SG affected by (a) solution concentration and time (b) temperature and time

increase in solution concentration. This may be due to fact that the osmotic pressure attained equilibrium and further increase in concentration would not increase the SG and the higher concentration of solution would saturate the microscopic channels (Oladejo, 2020).

Figure 3a shows the interaction between solution concentration and time. The interaction between solution concentration and time was significant ($p < .05$) and the coefficient estimate of the interaction had a negative effect on the solid gain which implied that the increase in one variable with a decrease in other brought about the same response on solid gain. The mass transfer tends to increase with the increase in concentration, but the fast saturation of the sample surface with sugars resulted in a net decrease in the soluble solids and water mass transfer coefficient, at high concentrations of osmotic solution (Fernandes et al., 2019). Figure 3b shows the interaction of time and temperature on solid gain. The coefficient estimate of the interaction was positive on solid gain.

Figure 4 represents the contour plot of SG as affected by time and temperature. It could be seen that the solid gain increased as time and temperature were increased until equilibrium is attained.

3.3 | Osmotic dewatering rate

The effect of osmotic solution concentration, sonication time, and temperature on osmotic dewatering rate (ODR) is shown in Figure 4a,b. The polynomial regression model representing the interaction between the independent variables is represented by the following equation:

$$\begin{aligned}\text{ODR (g/min)} &= 0.61116 - 0.0895A + 0.0161C \\ &+ 0.0296D - 0.0271AB + 0.023BC - 0.0515A^2 - 0.075B^2.\end{aligned} \quad (7)$$

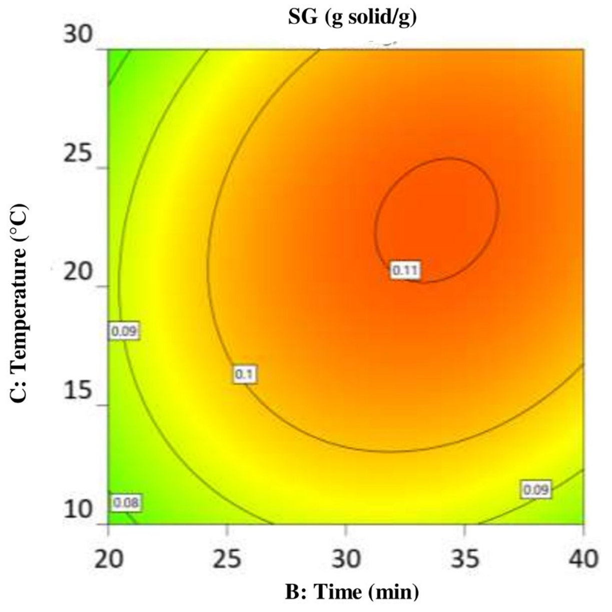

FIGURE 4 Contour plot of SG as affected by time and temperature

The linear terms of solution concentration and temperature showed a significant ($p < .05$) effect on ODR. Figure 5a shows the interaction effect of sonication time and temperature on ODR and the coefficient estimate (Equation 7) of these showed a positive effect. This implied that the combined effect of time and temperature influenced the cavitation as well as reduction of the laminar boundary sublayer. These aspects lead to an increase in water diffusivity (Mierzwa & Kowalski, 2016). Figure 5b shows the interaction between solution concentration and time and the coefficient estimate (Equation 7) showed a negative effect on ODR. This is due to the saturation of microscopic channels and increased solution viscosity as concentration increased.

3.4 | Osmotic agents

Both the osmotic agents used were monosaccharides having low molecular weight than sucrose and therefore, have more profound effect on water activity depression compared to polysaccharides. The values of ODR are presented in Appendix B. It was found that the ODR for osmotic solution of fructose ranged from 0.3912 to 0.75 and that of glucose ranged from 0.3354 to 0.708 g/min. Osmotic solution using fructose gave the higher values of ODR. This was in accord with Dash et al. (2019) on studying the effect of high pressure-assisted osmotic dehydration of ginger slices. The effective moisture diffusivity values for fructose and glucose at 40°C and 0.1 MPa were found to be 0.362×10^{-9} and 0.322×10^{-9} $m^2\ s^{-1}$, respectively.

3.5 | Optimization

The optimization of the process parameters of the USOD process was carried out using Design Expert (Version 12.0.3.0) software, based

FIGURE 5 Response surface plot of ODR affected by (a) time and temperature (b) solution concentration and time

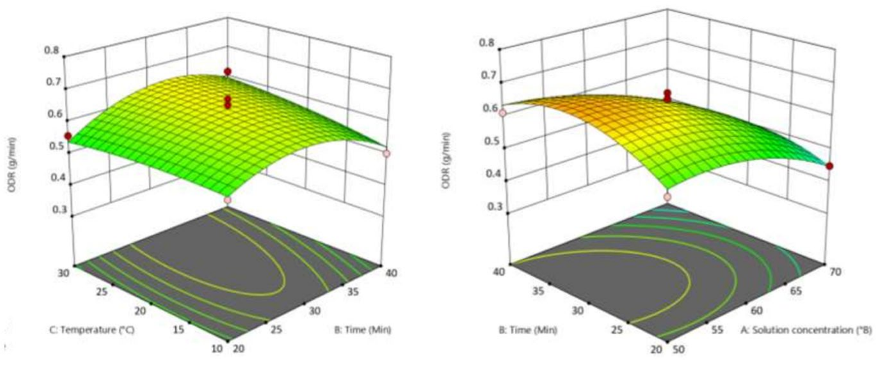

TABLE 3 Optimum value obtained from desirability analysis

Sl no	Response	Units	Desirability	Optimal level	Low level	High level
1	Water loss	g water/g	Maximize	0.266	0.092	0.283
2	Solid gain	g solid/g	Minimize	0.049	0.02	0.119
3	Osmotic dewatering rate	g/min	Maximize	0.730	0.3354	0.75

on desirability analysis. Desirability ranges from 0 to 1, indicating lowest to highest desirability, respectively (Maran et al., 2013). The process variables such as solution concentration, sonication time, and temperature were set at range. The dependent variables, water loss and osmotic dewatering rate, were set at maximum, while solid gain was set at minimum.

From desirability analysis, it could be revealed that the optimum operation conditions for the USOD process were solution concentration of 50°B, sonication time of 26.6 min, temperature of 30°C, and fructose as osmotic agent. The water loss, solid gain, and osmotic dewatering rate at this optimum operating conditions recorded were 0.266 g water/g, 0.049 g solid/g, and 0.730 g/min, respectively (Table 3), at desirability level of 0.847.

For rigorous comparison of the effect of ultrasound treatment on osmotic dehydration, experiments were carried out on osmotic dehydration of pineapple slices at the optimized process conditions of 50°B osmotic solution concentration for 30 min at ambient temperature, with fructose as the osmotic agent. The experiments were done in triplicate and the mean value was reported.

The results revealed that the USOD pretreatment resulted in enhanced water loss of 0.266 g water/g and osmotic dewatering rate of 0.730 g/min as compared to osmotic dehydration (OD) which recorded a water loss of 0.099 g water/g, and osmotic dewatering rate of 0.665 g/min at same solution concentration and treatment time of 30 min. Thus, the results affirm that the USOD process would accelerate the process of OD, which is in accordance with Xu et al. (2014) during their studies on the influence of USOD on quality characteristics of radish (*Raphanus sativus L.*) cylinders and Nowacka and Wędzik (2016) for their studies on the effect of USOD on microstructure, color, and carotene content in carrot tissue. The ultrasound pretreatment enhances the moisture expulsion from the samples into the solution by synergistic effects of osmotic pressure and acoustic cavitation. The porous tissue structure with thin cell walls offers resistance to both internal and external mass transport which is overcome by ultrasonic effects such as sponge effect (alternate compression and expansion of the solid materials) and the generation of microscopic channels in the cell structure (Garcia-Noguera et al., 2010).

The solid gain of the USOD pretreated samples ranged from 0.02 to 0.119 g solid/g and that of OD sample was 0.0071 g solid/g; this is due to the creation of microscopic channels within the cell membrane by ultrasound effect and the counter-current flow of the osmotic solution has caused impregnation of the solutes into pineapple slices. This is in accordance with Kek et al. (2013). For the USOD effect on guava slices, ultrasonic waves may cause a breakdown in the biomaterial structure, coherence loss, or may even cause cell disruption. Therefore, the solute can penetrate more easily causing higher solute uptake.

4 | CONCLUSION

The ultrasound-assisted osmotic dehydration increased water transport through the pineapple cells through the generation of microscopic channels due to ultrasound cavitation. The results showed that the optimum operation conditions for the USOD process were solution concentration of 50°B, sonication time of 26.6 min, temperature of 30°C, and fructose as osmotic agent. The water loss (WL), solid gain (SG), and osmotic dewatering rate (ODR) at this optimum operating condition recorded were 0.266 g water/g, 0.049 g solid/g, and 0.730 g/min, respectively, at desirability level of 0.847. The process parameters showed a significant effect on WL, SG, and ODR. WL increased with an increase in solution concentration upto 60°B and sonication time upto 30 min. SG increased when solution concentration was increased from 50 to 60°B and with an increase in time and temperature. ODR increased upto 60°B solution concentration, and with an increase in temperature.

CONFLICT OF INTEREST

The authors have declared no conflict of interest to this article.

AUTHOR CONTRIBUTIONS

Meena N.: Conceptualization; data curation; formal analysis; methodology; writing – original draft; writing – review and editing. **Prince M.V.:** Conceptualization; funding acquisition; investigation; methodology; project administration; resources; supervision; visualization; writing – review and editing. **Sreeja R.:** Resources; writing – review and editing.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in Meena et al. (2022).

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APPENDIX A

Coded factors					Decoded factors			
Treatment run	A	B	C	D	Osmotic solution concentration (°B)	Immersion time (min)	Temperature (°C)	Type of osmotic solution
1	0	0	0	G	60	30	20	Glucose
2	0	+1	+1	F	60	40	30	Fructose
3	−1	0	−1	F	50	30	10	Fructose
4	+1	0	+1	F	70	30	30	Fructose
5	+1	+1	0	F	70	40	20	Fructose
6	0	0	0	F	60	30	20	Fructose
7	+1	−1	0	F	70	20	20	Fructose
8	−1	0	−1	G	50	30	10	Glucose
9	−1	+1	0	F	50	40	20	Fructose
10	0	0	0	G	60	30	20	Glucose
11	−1	−1	0	F	50	20	20	Fructose
12	0	−1	+1	G	60	20	30	Glucose
13	0	0	0	F	60	30	20	Fructose
14	+1	0	−1	G	70	30	10	Glucose
15	−1	0	+1	F	50	30	30	Fructose
16	+1	0	−1	F	70	30	10	Fructose
17	−1	0	−1	G	50	30	30	Glucose
18	0	−1	+1	F	60	20	30	Fructose
19	0	0	0	F	60	30	20	Fructose
20	0	−1	−1	G	60	20	10	Glucose
21	+1	+1	0	G	70	40	20	Glucose
22	0	0	0	F	60	30	20	Fructose
23	0	0	0	G	60	30	20	Glucose
24	0	0	0	G	60	30	20	Glucose
25	−1	−1	0	G	50	20	20	Glucose
26	0	−1	−1	F	60	20	10	Fructose
27	−1	+1	0	G	50	40	20	Glucose
28	0	+1	−1	F	60	40	10	Fructose
29	0	+1	+1	G	60	40	30	Glucose
30	+1	−1	0	G	70	20	20	Glucose
31	0	0	0	G	60	30	20	Glucose
32	+1	0	+1	G	70	30	30	Glucose
33	0	0	0	F	60	30	20	Fructose
34	0	+1	−1	G	60	40	10	Glucose

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APPENDIX B

Run	A: Osmotic solution concentration (°B)	B: Sonication time (min)	C: Temperature (°C)	D: Type of osmotic solution	Water Loss (WL) (g water/g)	Solid gain (SG) (gsolid/g)	Osmotic dewatering rate (ODR) (g/min)
1	**60**	**30**	**20**	**Glucose**	**0.266**	**0.116**	**0.5928**
2	60	40	30	Fructose	0.271	0.1002	0.618
3	50	30	10	Fructose	0.232	0.039	0.6036
4	70	30	30	Fructose	0.184	0.033	0.3912
5	70	40	20	Fructose	0.195	0.023	0.42
6	60	30	20	Fructose	0.282	0.1009	0.6534
7	70	20	20	Fructose	0.102	0.024	0.4494
8	50	30	10	Glucose	0.219	0.051	0.5508
9	50	40	20	Fructose	0.225	0.072	0.612
10	60	30	20	Glucose	0.269	0.119	0.6012
11	50	20	20	Fructose	0.22	0.0345	0.5478
12	60	20	30	Glucose	0.208	0.084	0.51
13	60	30	20	Fructose	0.276	0.1005	0.6366
14	70	30	10	Glucose	0.148	0.04	0.4956
15	50	30	30	Fructose	0.278	0.058	0.75
16	70	30	10	Fructose	0.165	0.02	0.5496
17	50	30	30	Glucose	0.262	0.064	0.708
18	60	20	30	Fructose	0.218	0.067	0.558
19	60	30	20	Fructose	0.279	0.1006	0.6396
20	60	20	10	Glucose	0.203	0.088	0.4764
21	70	40	20	Glucose	0.176	0.033	0.366
22	60	30	20	Fructose	0.283	0.111	0.672
23	60	30	20	Glucose	0.258	0.111	0.5568
24	60	30	20	Glucose	0.259	0.113	0.546
25	50	20	20	Glucose	0.207	0.0429	0.495
26	60	20	10	Fructose	0.215	0.069	0.5484
27	50	40	20	Glucose	0.216	0.078	0.579
28	60	40	10	Fructose	0.224	0.078	0.5022
29	60	40	30	Glucose	0.252	0.1007	0.5478
30	70	20	20	Glucose	0.092	0.039	0.4056
31	60	30	20	Glucose	0.263	0.114	0.579
32	70	30	30	Glucose	0.172	0.044	0.3354
33	60	30	20	Fructose	0.273	0.1001	0.6342
34	60	40	10	Glucose	0.212	0.09	0.4338