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Effect of ultrasound-assisted osmotic dehydration pretreatment on drying of pineapple core

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Abstract

This research aimed to evaluate the effects of ultrasound-assisted osmotic dehydration (UAOD) on the drying of pineapple core slices. This study compared conventional osmotic dehydration (OD) utilizing sucrose as the osmotic agent, at varying volumes of 10, 30, and 50 mL, as well as immersion times of 2, 31, and 60 mins. The OD process served as a control with no sonication treatment. Response variables including water loss, solid gain, hardness change, and stickiness change were measured. The optimal osmotic pretreatment conditions were determined after assessing the effect of sucrose solution volume and immersion time on response variables. The effect of the osmotic pretreatment conditions on the drying time and water diffusivity was also evaluated. The results showed that water loss increased with treatment time, while solid gain and texture exhibited a decline. The optimal conditions identified were a sucrose solution volume of 50 mL with a 2-min immersion time for OD and 37.76 mins for UOAD. Results indicated that UAOD significantly decreased drying time by 23% and allowed moisture content to reach as low as 15%, while OD could not reach moisture content below 30% without sonication. These findings suggested that UAOD can improve both the quality and drying efficiency in pineapple processing, while also positioning pineapple core as a valuable food product and improving energy efficiency in the pineapple processing industry.

1. Introduction

Pineapple is the third-most important tropical fruit crop, following mango and banana, grown widely in tropical and subtropical regions (Carlier *et al.*, 2007). Among the various pineapple-based products, canned pineapple plays a significant role, with only 5% of the total supply being consumed locally, while the remaining 95% is exported (Lun *et al.*, 2014). Unripe pineapple is commonly used in the canning industry due to its firmer texture, which minimizes damage during processing steps such as cutting, sorting, filling, syrup addition, and pasteurization.

The canning process of pineapples generates substantial amounts of waste, with approximately 35% of the fruit consisting of peel, crown, core, and trimmings (Siti Roha *et al.*, 2013). While this waste is often repurposed as animal feed or disposed of in landfills, there is considerable potential for transforming pineapple waste, particularly the core, into a viable human food product. Prakongpan *et al.* (2006) showed that cellulose and dietary fibre extracted from pineapple core could be processed into purified pineapple core powder, which successfully served as a food enrichment in oil reduction cake-type doughnut, increased cake volume, and improved the texture of the beef burger. Studies conducted by Omotoyinbo and Sanni (2017) and Sriwatanapongse *et al.* (2000) on locally produced pineapple in Nigeria and Thailand discovered the extraction of bromelain from pineapple core, indicating potential uses for this underutilized resource.

Osmotic dehydration, a technique that combines dewatering and impregnation, serves as a pretreatment for air-drying. This method involves removing water from the cell while dissolving it in a hypertonic solution typically containing distilled water and food-grade salt or sugar (Escriche *et al.*, 2006). According to Fernandes and Rodrigues (2008), ultrasound technology can enhance this process by increasing water activity and improving energy utilization, thus reducing drying time. The sponge effect of compression and expansion causes sound waves to penetrate the medium, generate high force, maintain the moisture inside, and accelerate water

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removal (Fuente-Blanco *et al*., 2006).

To our knowledge, the application of ultrasound-assisted osmotic dehydration specifically to pineapple core has not been investigated. This study aimed to evaluate the effects of immersion time and sucrose solution volume on the drying of pineapple core during ultrasound-assisted osmotic dehydration.

2. Materials and methods

2.1 Sample preparation

Unripe Moris pineapples, with an average weight of 2.3±0.2 kg each, were purchased from a local market in Johor, Malaysia. After cleaning under running water, the pineapples were peeled and de-cored. A cylindrical core weighing between 3.5-4.5 g, with a diameter of 3.0 cm and a length of 0.5 cm, was obtained using a pineapple core slicer. The samples were kept refrigerated at 6°C until further processing to maintain their freshness (Hong *et al*., 2013).

2.2 Experimental design

The response surface methodology was used to estimate the main effects of process variables on water loss (WL), solid gain (SG), thickness, and stickiness during osmotic dehydration (OD) and ultrasound-assisted osmotic dehydration (UAOD) of pineapple core. A second-order Central Composite Design (CCD) in the form of a Face-Centred was utilized, with immersion time and volume of sucrose solution as the two factors, which varied over five levels. The variables were set at low, medium, and high, corresponding to times of 2, 31, and 60 mins, and volumes of 10, 30, and 50 mL, respectively. The design consists of 13 experimental runs with 5 centre points, and each experiment was carried out twice (Changrue *et al*., 2008).

2.3 Ultrasound-assisted osmotic dehydration

An osmotic solution was prepared by mixing distilled water and refined sugar in a 1:1 weight ratio. Pineapple core samples were weighed and immersed in the osmotic solution at room temperature (25°C). The immersion steps were conducted again for other samples using an ultrasonic bath, which involved applying ultrasound to facilitate the osmotic process. After that, samples were taken out of the solution at various intervals of time. Any excess solution on the pineapple core samples was then removed with absorbent paper (Shamaei *et al*., 2012).

2.4 Physicochemical properties analysis

2.4.1 Weight

The samples were weighed using a weighing scale both before and after the treatment. All readings were recorded in triplicate.

2.4.2 Moisture content

A total of 5 g of each sample were weighed after being crushed in a mortar. Each sample was spread equally on a pan and then placed inside a moisture analyzer that was set to 140°C under a controlled high-heat condition (Zzaman and Yang, 2013). Each sample was subjected to this procedure three times, and the corresponding data were recorded.

2.4.3 Water loss and solid gain

The effectiveness of both conventional osmotic and ultrasound-assisted osmotic dehydration was determined by calculating water loss (WL) and soluble solids gain (SG) using Equations 1 and 2, respectively (Kek *et al*., 2013).

$$WL = \frac{\left(w_i(x_i) - w_f(x_f)\right)}{w_i} \times 100 \quad (1)$$

$$SG = \frac{w_f(1-x_f) - w_i(1-x_i)}{w_i} \times 100 \quad (2)$$

where w_i is the initial fruit mass (g) before pretreatment; w_f is the final fruit mass (g) after pretreatment; x_i is the initial fruit moisture content on a wet basis (g water = g total fruit mass) before pretreatment; x_f is the final fruit moisture content on a wet basis (g water = g total fruit mass) after pretreatment.

2.4.4 Hardness and stickiness

The differences in hardness (Δhardness) and stickiness (Δstickiness) of pineapple core samples before and after treatment were assessed using a texture analyzer puncture test (Thompson *et al*., 1982). A 2-mm diameter stainless cylindrical puncture probe and a double compression test were used to determine the hardness and stickiness of the sample. The testing parameters included a pre-test speed of 10 mm/s, a test speed of 1 mm/s, a post-test speed of 10 mm/s, a penetrating distance of 5 mm into the fruit, and a trigger force of 5 g. The measurement was repeated three times, and the data were recorded.

2.5 Optimization

Multiple regression analysis was used to analyse mathematical models for each response variable. A quadratic model was employed, incorporating linear, squared, and interaction terms. Analysis of variance (ANOVA) was used to identify the significant terms within each model, and the F-statistics was applied to assess their significance (Eren and Kaymak-Ertekin, 2007). Residual analyses were performed following model fitting to validate the assumptions underlying ANOVA, including the examination of diagnostic plots and the calculation of case statistics. The statistical software was used to fit response surfaces and optimize the OD and UAOD processes.

The OD process was optimized using criteria such as maximum water loss ranging from 12.434 to 72.527, minimum solid gain ranging from 10.204 to 77.811, acceptable range change in hardness ranging from -8.086 to -19.490, and acceptable range change in stickiness ranging from -12.605 to -2.238. In the UAOD, optimal points were determined based on maximum water loss ranging from 34.415 to 175.503, minimum solid gain ranging from 33.774 to 179.948, acceptable range change in hardness ranging from -426.677 to 6.284, and acceptable range change in stickiness ranging from -33.15 to -6.185.

2.6 Drying of the osmotic pretreated pineapple core

After pretreatment, the optimized sample was air-dried at a temperature of 70°C in a forced circulation air-drying oven. The sample was weighed at 20-min intervals during the drying process to determine the moisture content, and this weighing continued until the moisture content reached a stable level of 30% (Shamaei *et al*., 2012). The water effective diffusivity of the samples during the air-drying process was calculated from the recorded moisture content over time. The effective diffusivity was computed using Equation 3 (Green and Perry, 2008).

$$\frac{dH}{dt} = \frac{2\pi}{\sigma^2} DHH_{eq} \tag{3}$$

where D is the effective water diffusivity (m^2/s), H is the moisture content, H_{eq} is the equilibrium moisture content, t is the time (s), and σ thickness of the sample (m).

3. Results and discussion

3.1 Model fitting

Table 1 presents the significant changes in water loss (%), sugar gain (%), hardness (g), and stickiness (g) in response to variations in the independent variables (X_1 and X_2). The coefficients for individual factors (X_1 and X_2) show the effects of each variable independently, while the coefficients for interactions (X_1X_2) and squared terms (X_1^2 and X_2^2) represent the interaction between the two factors and their non-linear effects. Positive values indicate synergistic effects, whereas negative values imply antagonistic effects.

The F-ratio value in the ANOVA reflects the ratio of the model mean square to the error mean square. According to Krishna *et al.* (2013), higher F-value indicate a greater likelihood that the variance attributed to the model is significantly larger than random error. The reported F-values for water loss, sugar gain, ∆hardness, and ∆stickiness for UAOD are 164.7, 162.83, 3759.72, and 21.66, respectively. In comparison, the F-values for OD are notably lower, at 92.96, 87.45, 4.04 and 4.44. For each of the model coefficients, the p-value was utilised to determine its significance. The significance of each model coefficient was evaluated using p-values, with smaller p-values indicating greater significance (Ravikumar *et al*., 2005).

Chauhan and Gupta (2004) claimed that an R^2 value more than 75% is appropriate for model fitting, whereas Koocheki *et al.* (2009) suggested that R^2 values should not be less than 80% for good model fitting. In this study, the UAOD models showed R^2 values ranging from 93.93% to 99.96%, with adjusted R^2 values between 89.59% and 99.94%. These results indicate that the proposed model effectively optimizes the UAOD of pineapple core when the four dependent variables are mathematically combined. Furthermore, Zaibunnisa *et al.* (2009) observed that the fit of the empirical model to the experimental data improves as R^2 approaches unity.

Table 1. Second-order quadratic models were developed for the response variables.

Ultrasound-assisted osmotic dehydration (UAOD)	
Response Variables	Second-order quadratic model
Water loss	$70.23 + 56.29X_1 + 9.17X_2 + 17.53X^2{}_1 + 10.48X^2{}_2 + 12.62X_1X_2$
Sugar gain	$71.67 + 55.10X_1 + 8.81X_2 + 15.36X^2{}_1 + 8.52X^2{}_2 + 11.64X_1X_2$
∆Hardness	$-70.70 - 161.66X_1 + 47.28X_2 - 97.97X^2{}_1 - 1.49X^2{}_2 + 48.59X_1X_2$
∆Stickiness	$-10.50 - 8.74X_1 - 1.72X_2 - 6.28X^2{}_1 - 2.03X^2{}_2 - 3.35X_1X_2$
Osmotic dehydration	
Response Variables	Second-order quadratic model
Water loss	$52.25 + 20.80X_1 + 4.67X_2 - 17.96X^2{}_1 + 20.95X^2{}_2 - 4.48X_1X_2$
Sugar gain	$53.46 + 20.53X_1 + 4.00X_2 - 17.54X^2{}_1 + 16.79X^2{}_2 - 4.84X_1X_2$
∆Hardness	$-6.78 + 0.29X_1 + 1.14X_2 + 3.50X^2{}_1 - 0.98X^2{}_2 + 0.76X_1X_2$
∆Stickiness	$-8.01 + 1.33X_1 - 1.07X_2 - 0.24X^2{}_1 + 2.85X^2{}_2 + 3.12X_1X_2$

3.2 Effect of process variables on responses

3.2.1 Water loss

Figure 1 illustrates the surface plot of water loss during OD and UAOD. The UAOD resulted in a significantly higher percentage of water loss compared to OD. The maximum water loss for the OD samples was 77.811% after 31 mins of immersion in 50ml of sucrose solution. In contrast, the UAOD samples demonstrated 179.948% water loss after 60 mins of immersion in 50ml of sucrose solution.

The lowest water loss percentages for both OD and UAOD were recorded at 2 mins of immersion in 30ml of sucrose solution, with OD showing 10.204% and UAOD at 33.774%. The enhanced water loss in UAOD is consistent with expectations, as the application of ultrasonic frequency is known to facilitate vacuum impregnation, which accelerates the expulsion of external water. This process allows the osmotic solution to induce compositional changes through hydrodynamic mechanisms.

The inflow of osmotic solutions is influenced by the expansion or compression of internal gas within the capillary pores (Fito *et al*., 2001). Although vacuum impregnation also happens in OD samples, the application of ultrasonic frequency during UAOD significantly enhances the solid-liquid mass transfer process (Barman and Badwaik, 2017). The ultrasonic treatment promotes the formation of microscopic channels, which serve as more efficient pathways for water diffusion to the surface of the fruit. This increase in water diffusivity aligns with the findings of Fernandes *et al*. (2009), who noted that ultrasound generates microscopic channels that facilitate water movement.

Fernandes *et al.* (2009) used microscopic imaging to verify the formation of micro-channels, which showed elongation and flattening of fruit cells in specific regions because of ultrasonic treatment. The development of these microscopic channels results from reduced adhesion between cells, which increases intercellular spaces, as well as the rupture of cell walls when immersed in the osmotic solution. These structural changes enhance water loss and improve the overall efficiency of the osmotic dehydration process.

3.2.2 Sugar gain

Figure 2 shows the surface plot of sugar gain achieved through UAOD and OD, where the sugar gain from UAOD was significantly higher than that from OD. The highest sugar gain for both pretreatment methods were recorded after immersing the pineapple core samples for 60 mins in 50 mL of sucrose solution. UAOD achieved 175.503%, whereas OD reached 72.527%. Conversely, the lowest sugar gain was observed when the samples were immersed in 30 mL volume of sucrose solution for 30 mins, with UAOD yielding 175.503% and OD only 12.434%.

The enhanced sugar gain observed with UAOD can be attributed to the mechanisms described by Rastogi *et al*. (2002), which include cavitation, rectified diffusion and acoustic steaming. Cavitation involves the formation

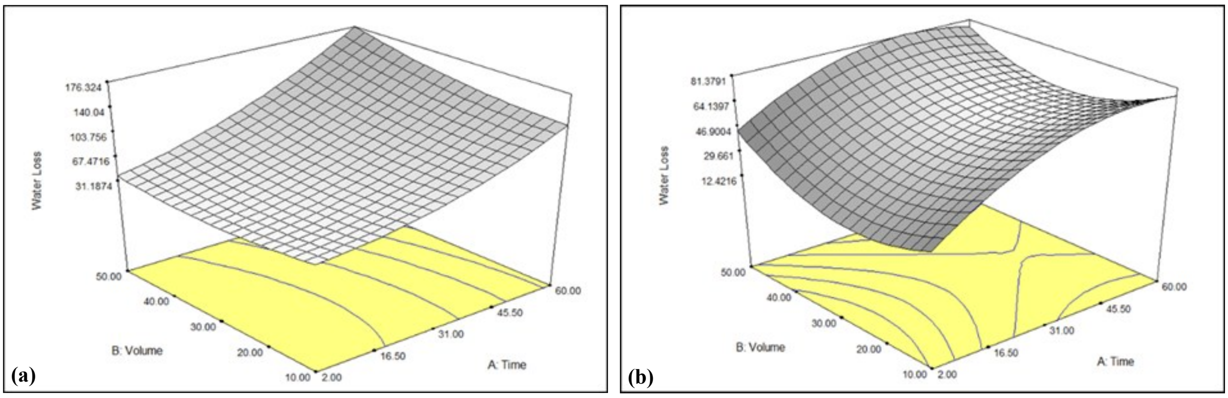

Figure 1. Surface plot of water loss by (a) UAOD and (b) OD.

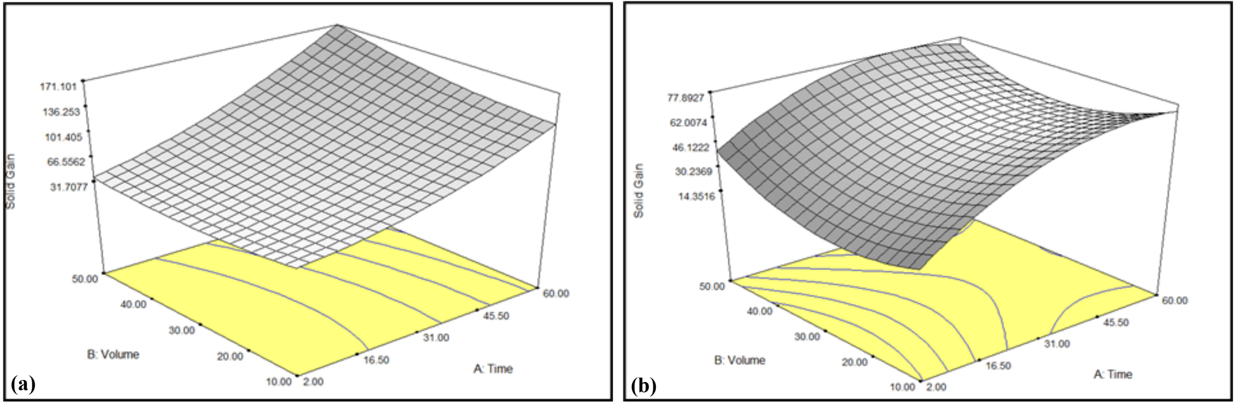

Figure 2. Surface plot of sugar gain by (a) UAOD and (b) OD.

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and collapse of small bubbles due to pressure fluctuations during ultrasonic application. This process, coupled with rectified diffusion, allows high-intensity acoustic energy to propagate through the fruit tissue, leading to rapid compressions and rarefactions that facilitate mass transfer.

Further supporting evidence comes from photomicrograph of pineapple tissue structures, as reported by Fernandes *et al*. (2009). These images reveal significant changes in fruit tissue subjected to ultrasonic treatment compared to those treated solely with osmotic dehydration. The early application of ultrasonic frequency promotes the formation of microchannels within the fruit tissue, which improves the mass transfer of both water and sugar. Sugar gain increased considerably during the immersion time from 2 to 31 mins, corresponding with the formation of these microchannels and the breakdown of cell walls. This reduction in tissue resistance allows for a more efficient flow of large molecules, such as sucrose. The formation of large microchannels in the fruit tissue explains the decreased resistance to molecular flow, thereby facilitating a higher sugar gain and greater water loss under UAOD conditions.

3.2.3 Hardness

Hardness is a critical parameter for evaluating the texture of fruits and other foods. The textural properties of food samples are relying on the behavior of the cellular matrix, the soluble solids within the tissues, interactions with water, and the mechanical properties of the food. Numerous studies have established that ultrasound pretreatment significantly affects these textural properties across various fruits. For example, Brncic *et al*. (2010) reported that applying ultrasound as a pretreatment method on apple slices resulted in decreased hardness as ultrasonic amplitudes and intensities increased. Deng and Zhao (2008) found that apples subjected to UAOD exhibited softer textures compared to those treated by vacuum or agitation, with a 22% reduction in hardness. Duan *et al*. (2008) observed low hardness and high springiness in sea cucumbers, which contributed to the beneficial effects of ultrasound on chewiness.

In this study, UAOD resulted in lower hardness values compared to OD (Figure 3). Variations in immersion time and sucrose solution volume did not yield significant differences across trials. The application of ultrasound likely disrupted the cell walls and enhanced water transfer from the cells, resulting in a softer texture (Gabaldón-Leyva *et al*., 2007). The cavitation effects during ultrasound treatment induced compressive and expansive stresses on the solid surface of UAOD samples, weakening the internal structure and creating pores and intercellular spaces that contributed to increased porosity, which is known to correlate with reduced texture hardness (Ozuna *et al*., 2014).

Kek *et al.* (2013) found a significant decrease in hardness in UAOD guava samples compared to untreated ones. Loss of turgor pressure, which is caused by protoplast shrinkage and detachment from the cell wall, also contributed to the softening of texture (Nowacka *et al*., 2017). This study confirmed that UAOD samples became progressively softer with increased immersion time and sucrose solution volume, reflecting the relationship between texture changes and porosity. Increased porosity is caused by water loss, sugar gain, immersion time, moisture content and microstructural changes during the osmotic process (Shamaei *et al*., 2012).

The effect of the processing parameters on the hardness OD samples showed a significant influence only from the square of the sucrose solution volume, with a p-value of 0.0059. This suggests that increasing the sucrose solution volume positively impacts the hardness of pineapple core samples, but only when the volume is doubled. Other variables that had p-values more than 0.05 (0.6503, 0.1027, 0.3083 and 0.3427, respectively) and did not show statistical significance included immersion time, volume of sucrose solution, the square of immersion time and the interaction between

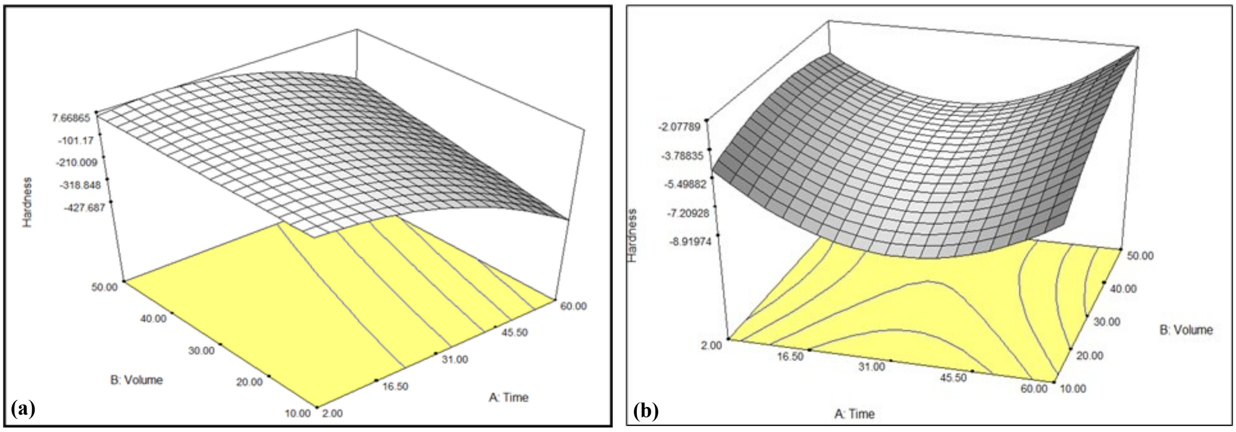

Figure 3. Surface plot of ΔHardness by (a) UAOD and (b) OD.

immersion time and volume of sucrose solution.

These findings indicate that while OD alone does not significantly improve the hardness of pineapple core samples, ultrasonic treatment may reduce hardness, especially with increased frequency and temperature. However, merely increasing the volume of sucrose solution did not alter the texture, which remained hard and undesirable, similar to that of fresh samples.

3.2.4 Stickiness

Figure 4 displays the surface plot of ΔStickiness in relation to UAOD and OD. At a shorter immersion time of 2 mins, the Δstickiness values between the two methods were statistically insignificant. However, more pronounced differences were observed at longer immersion times, indicating that time plays a critical role in the effectiveness of these treatments.

The pineapple core samples treated with OD displayed relatively insignificant variations among themselves compared to those treated with ultrasonic frequencies. This discrepancy can be attributed to the textural changes influenced by several factors, including sample porosity. The porosity of the samples is affected by water loss, specific gravity, immersion time in the osmotic solution, moisture content and changes in microstructure during the osmotic process. As the concentration of the osmotic solution and temperature increase during the UAOD process, both water loss and specific gravity tend to rise as well.

While solid uptake alone may not fully account for the porosities of samples, it does enhance the viscosity of the texture matrix, thereby mitigating texture degradation. Treatments involving sucrose during the osmotic process have been shown to preserve texture, allowing the samples to maintain characteristics similar to fresh fruit (Shamaei *et al*., 2011). The introduction of ultrasonic frequency during the treatment resulted in a notable softening of the pineapple core samples. This softening effect is attributed to the ultrasound-induced creation of fractures and microchannels within the tissue, which effectively reduces the required force for processing.

3.3 Optimization

Optimization is a crucial process that involves identifying the best conditions for various factors and their corresponding response values. It serves as an efficient tool for conducting processes, modifying existing methods, and designing new products. By determining the best treatment conditions, optimization facilitates the achievement of desired minimum or maximum output values.

In this study, the main objective of optimization was to determine the optimal values of variables related to water loss, sugar gain, hardness and stickiness using both UAOD and OD methods. The optimization process often incorporates constraints that make the findings more applicable to real-world scenarios. When the optimization model is based on empirical data, the high and low levels of process parameters established during experimental design act as explicit constraints that prevent extrapolation (Fu *et al*., 2007).

The pretreatment conditions for UAOD and OD applied on pineapple core samples are considered optimal when the variables such as water loss, sugar gain, hardness and stickiness, attain their respective maximum, minimum and targeted range values. To facilitate the optimization, contour plots were generated, illustrating the relationships between immersion time and sucrose solution volume for both UAOD and OD methods. This analysis identified an optimal zone, where each point within it corresponds to a specific combination of immersion time and sucrose solution volume that maximizes, minimizes and or maintains desired values for water loss, sugar gain, hardness and stickiness.

Table 2 shows the optimal conditions identified for the UAOD and OD methods. For UAOD, the ideal immersion time was found to be 37.78 mins with a sucrose solution volume of 50ml. In contrast, the OD

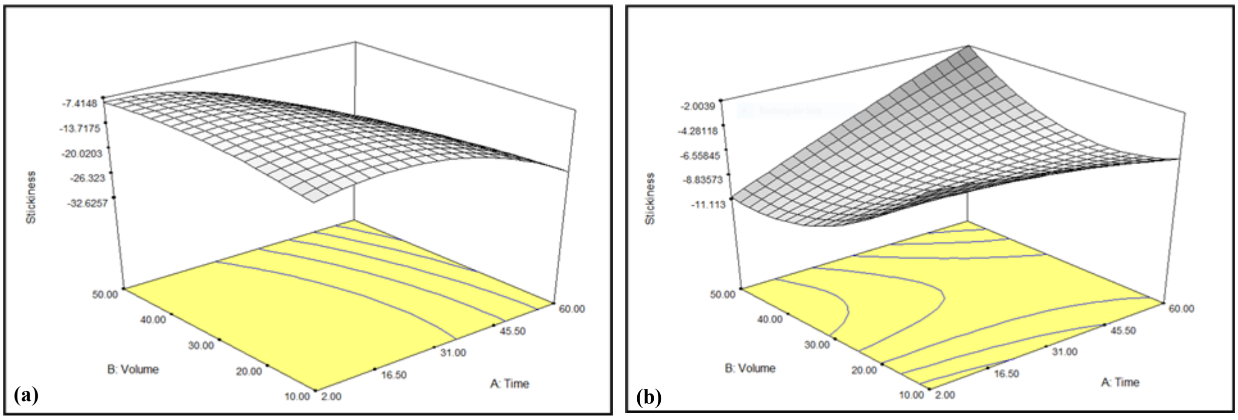

Figure 4. Surface plot of ΔStickiness by (a) UAOD and (b) OD.

method achieved optimal results with just 2 mins of immersion time, and also using 50 mL of sucrose solution. To validate these predicted values, additional experiments were conducted, and the findings showed no significant differences, with the error margin remained below 10% between predicted and experimental values. This finding confirms that the optimal process conditions derived from this study can be reliably applied to the ultrasound-assisted osmotic dehydration of pineapple core.

Table 2. Optimum value of the responses of UAOD and OD methods.

Parameter	Optimum value
Ultrasound-assisted osmotic dehydration	
Water loss (%)	106.906
Sugar gain (%)	105.403
Δhardness (g)	-56.6041
Δstickiness (g)	-17.4164
Desirability	0.499
Osmotic dehydration	
Water loss (%)	43.905
Sugar gain (%)	40.6676
Δhardness (g)	-4.17056
Δstickiness (g)	-10.9139
Desirability	0.514

3.4 Effect of osmotic pretreatment on the drying of pineapple core

The optimized values for the drying process were validated through the use of a hot air oven for pineapple core samples treated via UAOD and OD. The focus was primarily on the UAOD parameters due to their significant R^2 and p-value, which indicated a stronger statistical relevance. The key factors for the UAOD process were established at 37.78 mins and 50ml.

During the oven drying, moisture content was recorded, and the percentage drop over time for both UAOD and OD pineapple core samples is presented in Figure 5. The curves in Figure 5 illustrate the drying curves for pineapple cores subjected to both UAOD and OD methods. In the initial stages of drying ($t < 60$ min), the UAOD samples exhibited a pronounced deviation in moisture content loss compared to the OD samples, which showed a more gradual drying rate.

Effective water diffusivities for the pineapple cores were calculated based on moisture content values recorded during drying. Figure 6 presents the effective water diffusivity values for both pretreatment methods. The UAOD samples showed effective water diffusivity ranging from a maximum of $448.75\times10^{10}m^2s^{-1}$ to a minimum of $1.66\times10^{10}m^2s^{-1}$ at 200 mins. Conversely, the OD samples demonstrated effective water diffusivities between $706.25\times10^{10}m^2s^{-1}$ and $13.88\times10^{10}m^2s^{-1}$, observed at 20 and 260 mins, respectively. The UAOD samples exhibited an 81.57% increase in effective water diffusivity compared to OD samples following an immersion time of approximately 38 mins in a 50 mL sucrose solution.

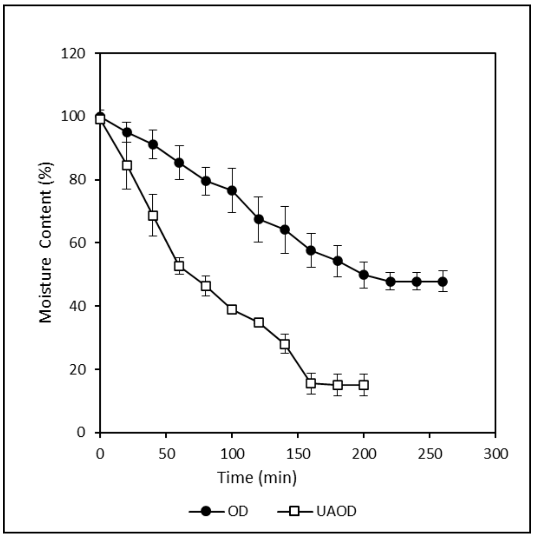

Figure 5. Moisture content loss in optimised UAOD and OD pineapple core samples during oven drying.

The increase in effective water diffusivity can be attributed to the formation of microscopic channels within the intercellular tissue of the fruit (Cárcel *et al*., 2007). These micro-channels facilitate enhanced pathways for liquid and soluble solids to diffuse towards the surface of the fruit, thereby increasing mass transfer, effective diffusivity and drying while decreasing air-drying time (Azoubel *et al*., 2010; Mothibe *et al*., 2011). Photomicrographs by Garcia-Noguera *et al*. (2010) suggest that the formation of these microscopic channels during UAOD can occur via two mechanisms: the elongation and separation of cells due to cavitation or the disruption of cells through the combined effects of cavitation and osmotic pressure.

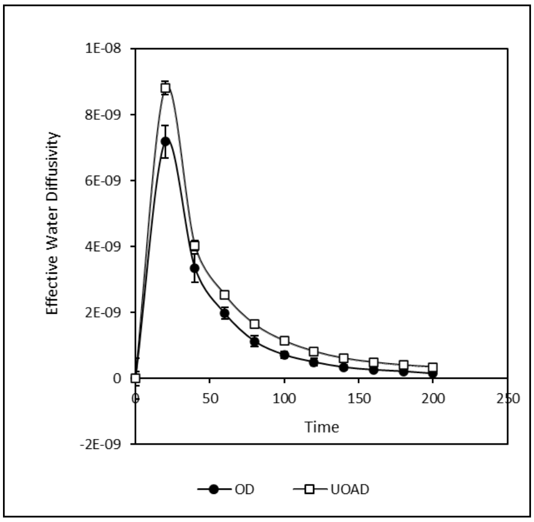

Figure 6. Effective water diffusivity over time of optimised pineapple core samples.

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The higher effective water diffusivity observed during the drying process is a clear indicator of the advantages of UAOD pretreatment. This technique not only facilitates microchannel formation but also enhances energy efficiency, as evidenced by the fact that UOAD samples reached equilibrium moisture content in 200 mins, while OD samples required 260 mins (Kek *et al.*, 2013).

4. Conclusion

There is a significant correlation between immersion time and sucrose solution volume, with optimal conditions identified as 37.76 mins of immersion time and 50 mL of sucrose solution for UAOD of pineapple core. The experimental values at optimal conditions for water loss, solid gain, Δhardness and Δstickiness were 106.888%, 105.385%, -56.5674 g, and -17.4127 g, respectively. The application of ultrasonic treatment significantly outperformed conventional osmotic dehydration by facilitating enhanced water removal from the pineapple core and improving the textural quality of the final dehydrated product. This work not only increases understanding of UAOD, but it also provides useful information for optimizing fruit dehydration processes in the food industry.

Conflict of interest

The authors declare no conflict of interest.

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