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Effect of Different Sugars on Mass Transfer and Cell Integrity of Osmo-Dehydrofrozen Garden Egg

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ABSTRACT

Fast freezing methods like osmotic dehydrofreezing (ODF) have gained tremendous research interest worldwide. Meanwhile, plant cell structures are often altered when exposed to hypertonic sugar solutions during the ODF process. This study investigated the effect of different sugars on mass transfer, and cell integrity of garden eggs that were frozen using ODF. Garden egg slices, with dimensions of 1 × 1 × 1 cm, were pretreated with sucrose and glucose solutions in a water bath at osmotic solution concentrationsand temperatures of 55 and 65°Brixand 30 and 35°C, respectivelyfor 10 minutes. The treated and untreated (control) samples were frozen at -12 °C. The effects of the pretreatment on mass transfer indices, including water loss, solid gain, and drip loss, were observed using standard methods. A scanning electron microscope (SEM) was employed to study the effect of sugar-induced ice crystal imprintson the microstructure of optimized osmo-dehydrated frozen samples. The results showed that sucrose solution at 65 °Brix and solution temperature of 35°C significantly ($P \leq 0.05$) decreases drip loss by 91%, whereas glucose solution at the same premixes decreases drip loss by 28% when compared with the untreated samples. In addition, samples treated with sucrose solution showed lower water loss and higher solid gain and exhibited stable cells when compared with the samples treated with glucose solution and untreated ones. In conclusion, sucrose solution is the most suitable for the osmodehydrofreezing of garden egg for the food industry.

Keywords: Freezing, Fast Garden Eggs, Sugar Solutions, Mass Transfer, Food Industry

1. INTRODUCTION

Postharvest techniques, including drying(Alabi et al., 2016), cooling(McDonald and Sun, 2000), and freezing(Alabi et al., 2020) are commonly used in the preservation of fresh fruits and vegetables. Fruits and vegetables posses delicate cells which are prone to damage during uncontrolled freezing.Freezing damage leads to significant losses in minerals, sensory attributes, and nutritional quality (Chassagne-Berces et al., 2009; Li et al., 2018; Dalvi-Isfahan et al., 2019).To overcome this menace, the utilisation of osmotic dehydrofreezing (ODF),a combination of osmotic dehydration (OD) and freezing,a process that enhances freezing and preserves food quality. OD before freezing accelerates the freezing rate and protects cellular structures by integrating osmotic solutes into plant tissues, a phenomenon that strengthenspectin substances (Monnerat et al., 2010; Ando et al., 2012; Zhao et al., 2014; Alabi et al., 2022). In addition, OD reduces refrigeration load and lowers packaging, distribution, and storage costs (Li and Sun, 2002). ODF has been successfully applied to mango (Zhao et al., 2017), tomato (Chottanom and Srisa-Ard, 2011), grape (Cao et al., 2018), pineapple (Ramallo and Mascheroni, 2010), and apple (Bunger et al., 2004; Ben et al., 2016). Sugars (e.g., sucrose, trehalose, or glucose)

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are the commonagents in OD as cryoprotectants that induce mass transfer processes: (i) water loss from the sample to the osmotic solution and (ii) solute infusion into the sample. While OD improves freezing tolerance (Velickova et al., 2013)and texture in thawed tissues (Ando et al., 2012), slight degradation of microstructure causes some leaching of minerals,which affectsthe final product's organoleptic and nutritional properties (Talens et al., 2003). Some studieshavehighlighted sugar's role in reducing electrolyte permeability and drip loss while enhancing texture and volatile compounds in treated fruits (Talens et al., 2003; Lowithum and Charoenrein, 2009).

Due to their hydrophilic nature, sugars stabilize cell structures differently, either via hydrogen bonding ordering or electron spinning of ionic molecules, and thus produce different effects during the crystallization process(Talens et al., 2003; Lowithum and Charoenrei, 2009; Alabi et al., 2022). This study focuses on the effect of different sugars (sucrose and glucose) solutions on the mass transfer and microstructure of garden egg that was frozen using ODF, providing a suitable technique for high-performance freezing of garden egg tissue.

2. MATERIALS AND METHODS

2.1 Experimental design

The experiment followed a randomized complete block design (RCBD) with two main variables: (1) osmotic concentration, and (2) osmotic solution temperature. The study involved two control samples: (1) fresh samples and (2) fresh samples frozen without osmotic dehydration. Garden egg slices were randomly assigned to treatment groups (osmotic dehydration 1-2) as illustrated in Table 1:

Table 1: Agents, factors and their levels.

Agent	Factors	Levels	
Sucrose	Osmotic Concentration (°Brix)	A1 = 55	A2 = 65
	Osmotic solution temperature (°C)	B1 = 30	B2 = 35
Glucose	Osmotic Concentration (°Brix)	A1 = 55	A2 = 65
	Osmotic solution temperature (°C)	B1 = 30	B2 = 35

Osmotic dehydration 1: Garden egg slices were dehydrated using and 55 °Brix, 65 °Brix and 30 °C (Assigned as: A1B1; A2B1)

Osmotic dehydration 2: Garden egg slices were dehydrated using and 55 °Brix, 65 °Brix and 35 °C (Assigned as: A1B2; A2B2)

Control group 1: Fresh samples

Control group 1: Garden egg slices frozen without osmotic dehydration

All tests were carried out in triplicates making a total of 12 experimental runs that were individually tested and measured for each sugar.

2.2 Sample preparation

Fresh garden eggs (Solanum aesthiopicum) of good quality were obtained from Malete market and were used as a model tissue. To prepare samples for osmotic pretreatment, large-sized garden egg (weight 180 ± 1g, diameter 6 ± 0.5 cm), with distinct white colour, suitable degree of maturity, and lack of any apparent damage, were selected, and rinsed. The garden eggs were stored in a refrigerator at 8°C before use, becauserefrigeration helpsslow down microbial growth and enzymatic activity, thereby maintaining their freshness and quality prior to use.

2.3 Osmotic dehydration treatment

The osmotic dehydration treatment of garden egg was conducted using an aqueous solution of sugars (sucrose: 55 °Brixand 65 °Brix, glucose: 55 and 65 °Brix). The samples were cut into 1 x 1 x 1cm cubesand placed into a 2 L beaker, and the ratio of 1:4 (w/w) between the samples and the osmotic solution was maintained to avoid changes in the solution concentration during the treatment. The temperature of 30 and 35 °C and the process time of 10 min were used. After the OD treatment, the dehydrated samples were blotted with tissue paper to eliminate the remainingsyrup and weighed using a weighing balance (0 – 500g; sensitivity: ±0.01 g); afterwards, the dehydrated samples were packed in a low-density polyethylene bags before freezing.

2.4 Freezing and thawing

The freezing process of garden egg was done using an ultra-low temperature freezer (model NX-150W/ NX-160W/NX-265W; Temperature range of -1 °C to -20 °C; sensitivity: ± 1 °C at target temperature -12°C (to achieve quick freezing) after OD treatment according to Ando et al. (2012). Freezer temperature was monitored throughout the experiment using a DZBW Beckman Coulter digital thermometer model 135 with ± 0.01 °C precision, 0.5 mm in diameter (Exhibition Electrical and Mechanical Technology Research Institute, Nanjing, China). The storage temperature was maintained at -12 ±1 °C for 21 days. After the 21 days of storage, thawing experiments were conductedby placing the sample into the BCD-206 ZMZB (Mei Ling Co., Ltd., Hefei, China) refrigerator maintained at 8°C with ± 0.01 °C precision for 6 hours and the cell integrity was assessed using SEM. Figure 1 shows the experimental procedure of the effect of different sugar on mass transfer and cell integrity of osmo-dehydrofrozen garden egg.

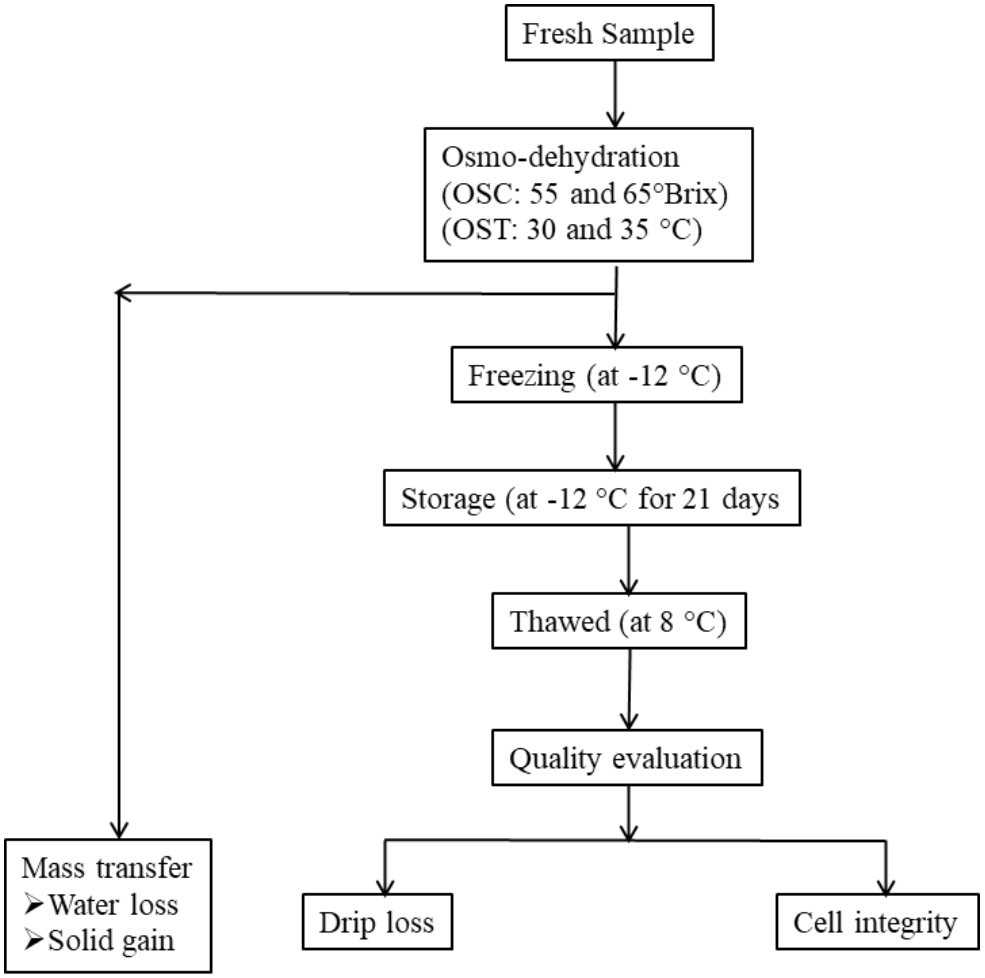

Figure 1: Experimental procedure of the effect of different sugar on mass transfer and cell integrity of osmo-dehydrofrozen garden egg.

2.4 Mass transfer

2.4.1 Water loss

Water loss (WL),which is the percentage of weight loss after OD treatment when compared with the original sample weight, was calculated according to Alabi et al. (2025) inEquation (1)

$$WL = \frac{(M_o - m_o) - (M - m)}{m_o} \quad (1)$$

2.4.2 Solid gain

Solid gain (SG) was calculated according to Alabi et al. (2025) inEquation (2)

$$SG = \frac{m - m_o}{m_o} \quad (2)$$

2.4.3 Drip loss

Drip loss (DL) was calculated according to Alabi et al. (2025) inEquation (3)

$$DL, \% = \frac{W_o - w}{W_o} \times 100 \quad (3)$$

Where:

M_o= Initial mass before osmotic treatment, (g)

M = Mass after time t of osmotic treatment, (g)

m_o= Dry mass of samples before osmotic treatment, (g)

m= Dry mass of samples after time t of osmotic treatment, (g)

W_o= Weight of sample after freezing, (g)

w= Weight of sample after thawing, (g)

2.5 Microstructure

The microstructures of both untreated and treated frozen garden egg samples were analyzed using a scanning electron microscope (SEM), following the procedure outlined by Kockro et al. (2000). The primary objective was to evaluate whether osmotic dehydration followed by freezing (ODF) effectively preserved the cellular structure of the garden egg. Small specimens, approximately 2 mm² in size, were carefully excised from the samples for analysis. These were initially fixed in a 2.5% glutaraldehyde solution prepared in 0.1 M sodium phosphate buffer (pH 7.2) and kept at 4°C for 24 hours to stabilize the cellular components. Following fixation, the samples were dehydrated through a graded ethanol series, beginning at 30% and increasing incrementally to 100%, with each step lasting 10 minutes.

After dehydration, the samples were briefly rinsed with distilled water to eliminate potential artifacts. They were then subjected to critical point drying using CO_2 to avoid collapse of cellular structures. Once dried, the specimens were mounted onto aluminum stubs using conductive adhesive. To enhance conductivity and improve image quality under SEM, the samples were sputter-coated with a thin layer of gold for 2 minutes using an ion sputter coater. Finally, the prepared specimens were observed and imaged using a Philips PSEM 500 scanning electron microscope.

2.6 Statistical analysis

All experimental data were analyzed to assess the effects of osmotic dehydration on both mass transfer characteristics and cellular integrity of frozen garden egg samples. In the analysis, osmotic solution concentration and osmotic solution temperature were treated as fixed input variables (independent variables). The measured outcomes,specifically mass transfer parameters (such as water loss, solid gain, and drip loss) and microstructural integrity,were considered as response variables.A two-way analysis of variance (ANOVA) was conducted in SPSS (version 21, IBM Corp.) to determine the individual and interactive effects of the input variables on the response variables. To further identify significant differences among treatment means, Duncan's Multiple Range Test (DMRT) was applied at a 5% significance level ($P \leq 0.05$). This statistical toolenabled the identification of statistically significant variations in mass transfer and microstructural changes resulting from differences in osmotic treatment conditions.

3. RESULTS AND DISCUSSION

3.1Mass transfer

3.1.1Water loss

Water loss is a critical parameter in the processing of plant-based foods, as it directly influences the concentration of solutes in the final product. As presented in Figure 2, a linear relationship was observed between water loss and the treatment temperature across the sample. The lowest water loss (0.08 g/g) was recorded at 65 °Brix and 30 °C, whereas the highest (0.23 g/g) was observed at 65 °Brix and 35 °C when the sample was treated with sucrose solution. Moreover, the lowest water loss (0.17 g/g) was recorded at 55 °Brix and 30 °C, whereas the highest value (0.31 g/g) was observed at 65 °Brix and 35 °C, when the sample was treated with glucose solution. These results demonstrate that increasing the temperature of the osmotic solution enhances water loss. Furthermore, the use of osmotic agents wasfound to significantly affect moisture diffusion during osmotic dehydration, with water loss rates increasing proportionally at 30°Cwith concentration up to 65 °Brix in sucrose solution. It also increased slightly at both 30 °C and 35 oC with concentration up to 65 oBrix in glucose solution. This finding aligns with Moyanoet al. (2002), who also observed that higher osmotic solution concentration significantly influenceswater losspapaya. Figures 2 (a) and (b) show the effect of osmotic solution

temperature on water loss of garden eggat 55 °Brix and 65 °Brix, respectively.

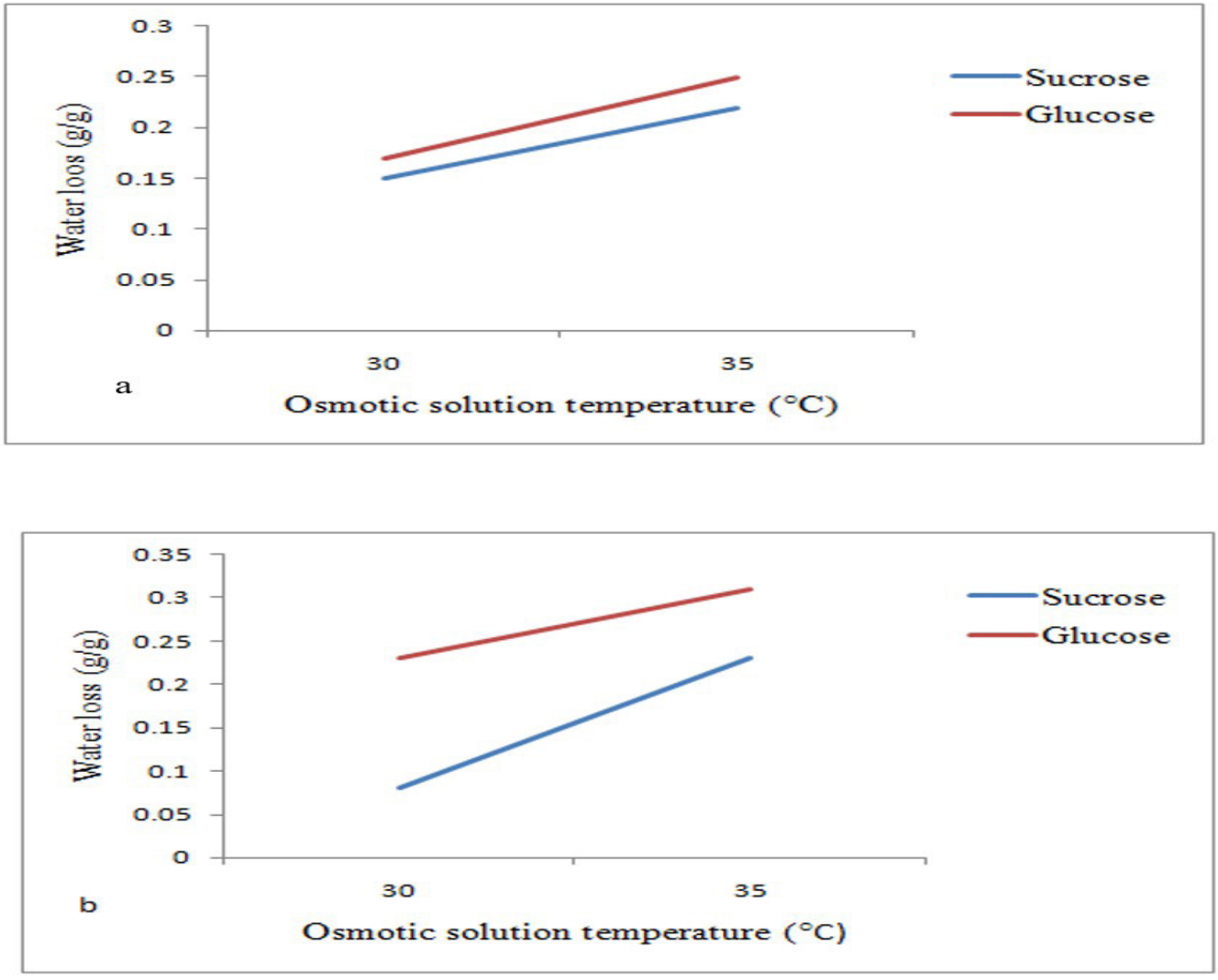

Figure 2: Effect of osmotic solution temperature on water loss of garden egg: (a) at 55 °Brix, (b) at 65 °Brix.

The observed increase in water loss with higher glucose concentrations and elevated solution temperatures is consistent with previous findings by Monnerat et al. (2010) and Lowithun and Charoenrein (2009) who reported thathigher solute concentrations generated a steeper osmotic pressure gradient, thereby enhanced the driving force for water migration from the intracellular to extracellular environment of apple and rambutan, respectively. Temperature also plays a pivotal role in this process. Elevated temperatures have been shown to increase the diffusion coefficient of water, thereby accelerating moisture transfer (Cao et al., 2018). This is attributed to enhanced molecular motion and increased membrane permeability at higher temperatures (Chattanom and Srisa-Ard, 2011). As temperature rises, water molecules exhibit greater mobility, which facilitates rapid water migration from the tissue matrix.

3.1.2 Solid gain

Significant differences in solid gain ($P \leq 0.05$) were observed across all treated samples, depending on the process agents applied. The lowest solid gain (0.07 g/g) was recorded at a sucrose concentration of 55 °Brix, and a temperature of 30 °C, whereas the highest solid gain (1.54 g/g) was achieved at a sucrose concentration of 65 °Brix, and a temperature of 35 °C. In the same vein, the lowest solid gain (0.036 g/g) was recorded at a glucose concentration of 55 °Brix, and a temperature of 30 °C, whereas, the highest solid gain (1.143 g/g) was achieved at a glucose concentration of 65 °Brix, and a temperature of 35 °C. These results suggest that high osmotic solution

concentration positively impacts solid gain, likely due to intracellular impregnation of solutes into the cells, thereby adding to the net accumulation of solids within the sample (Chottanom and Srisa-Ard, 2011). As the process advances, osmotic pressure drives water out of the tissue more effectively; however, the concomitant increase in solute uptake may outweigh solute efflux, ultimately increasing solid gain.Figures 3(a) and (b) present the effect of osmotic solution temperature on water loss of garden egg at 55 °Brix and 65 °Brix, respectively.

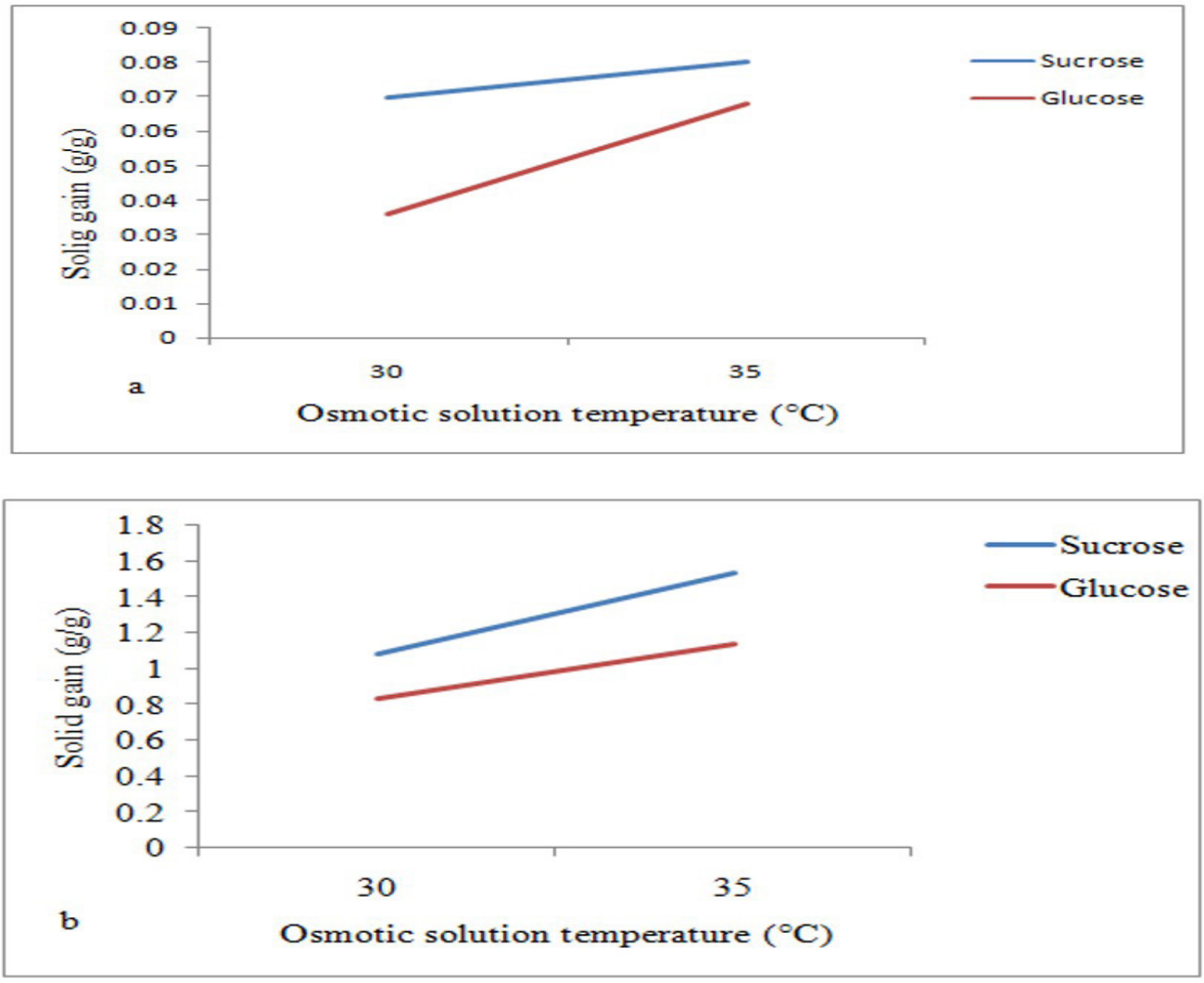

Figure 3: Effect of osmotic solution temperature on water loss of garden egg: (a) at 55 °Brix, (b) at 65 °Brix.

The linear relationship between processing temperature and solid gain observed in this study is consistent with findings reported in recent literature. Low process temperature has been shown to reduce solid gain by increasing the leaching of solutes from the food matrix into the surrounding solution. For instance, Ben et al. (2016) reported a significant decrease in solid gain in apple slices subjected to low osmotic temperature, attributing this to the sustained diffusion of sugars and organic acids into the osmotic solution. Similarly, Ramallo and Mascheroni (2010) observed reduced solid gain in pineapples at lower treatment temperatures, which they linked to higher losses of soluble solids. Zhao et al. (2014) further noted that lowered osmotic temperature leads to cellular shrinkage, primarily due to excessive efflux of intracellular solutes and water migration. Collectively, these studies highlight the critical role of processing temperature in determining the efficiency of osmotic dehydration. While the technique is effective for moisture removal, overly low treatment temperatures can compromise product quality by reducing solid retention and adversely affecting texture and structural integrity.

3.1.3 Drip loss

Drip loss refers to the liquid exudate released from frozen and subsequently thawed food products, primarily resulting from structural damage to cellular membranes due to ice crystal formation during freezing.

In the absence of protective measures, intracellular and extracellular water can form large ice crystals that rupture cell walls and membranes, leading to substantial fluid loss upon thawing (Alabi *et al*., 2020; Cao *et al*., 2018). The impact of osmotic dehydration pretreatment in different sugars on drip loss of frozen-thawed garden samples is presented in Figure 4. A marked reduction in drip loss was observed in sucrose (at 65 °Brix and 35°C) treated samples (0.38%) compared to glucose (at 65 °Brix and 35°C) treated samples (1.15%) and untreated frozen control ones (4.16%), representing a drip loss of 91% and 28% decrease in sucrose and glucose solution, respectively. This significant reduction highlights the effectiveness of the sucrose solution in enhancing tissue integrity during the freezing and thawing of garden egg.

The observed reduction in drip loss is attributed to the influence of osmotic solutes on freezing dynamics. Sucrose solution reduces the free water content in the tissue and promotes the formation of smaller, more uniformly distributed ice crystals during freezing, thereby minimizing mechanical damage to cellular structures. Previous studies by Chattanom and Srisa-Ard (2011) and Burger*et al*. (2004) support this mechanism, demonstrating that OD pretreatment contributes to improved preservation of cellular integrity, ultimately resulting in reduced drip loss upon thawing. Figure 4 presents the effect of osmotic concentration and osmotic solution temperature on drip loss of garden egg.

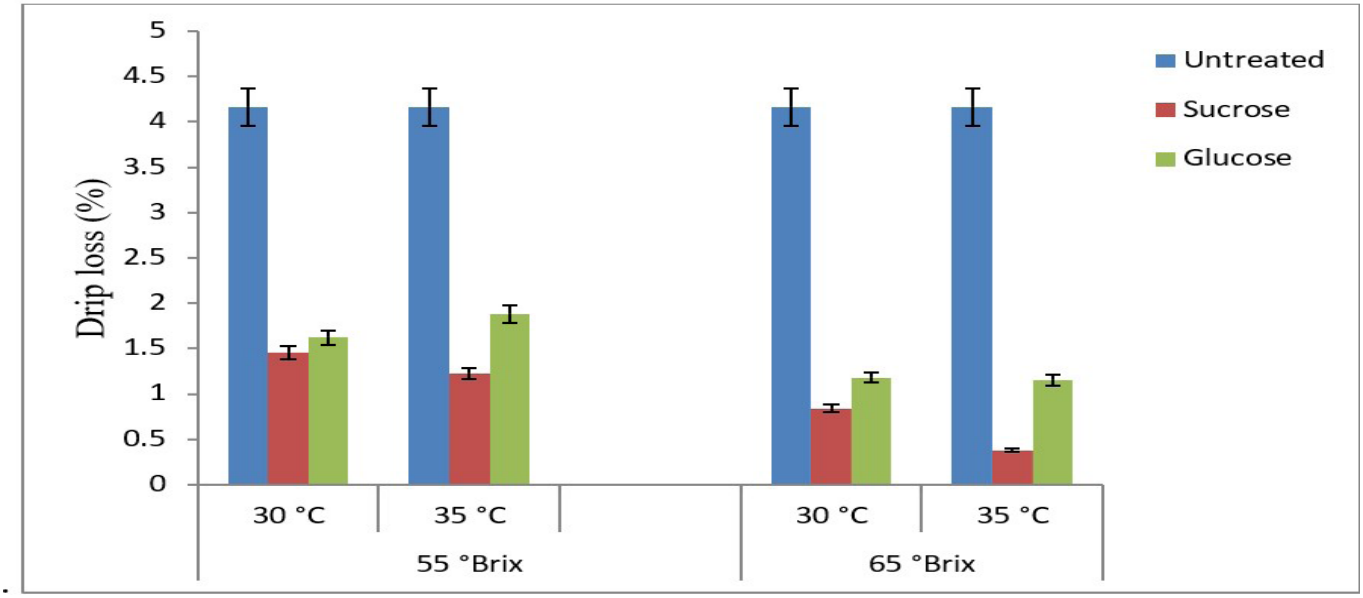

Figure 4: Effect of osmotic concentration and osmotic solution temperature on drip loss of garden egg.

In addition, Cao et al. (2018) observed that sucrose treatment enhances moisture retention in fruits during thawing, thereby reducing drip loss. This is consistent with the present findings, where a 91% decrease in drip loss was observed in sucrose-pretreated samples. The combination of osmotic dehydration (in different sugars) and freezing played a synergistic role in preserving water-binding components within the sample tissue, thereby minimizing moisture loss during freezing and thawing. The application of sucrose solution under optimized conditions of 65 °Brix osmotic solution concentration (OSC), and 35 °C osmotic solution temperature (OST), followed by freezing at -12 °C, effectively contributed to osmotic pressure equilibrium within the tissue. This equilibrium is critical for maintaining cellular microstructure, which in turn reduces structural degradation and drip loss during thawing.

3.2 Cell integrity

Cell stability associated with the optimized process conditions (at 65 °Brix and 35 °C) in sucrose and glucose solution when compared with fresh and untreated samples ispresented in Figure 5. Figures 5(a), (b), (c) and (d) illustratethe scanning electron micrographs of fresh, osmo-dehydrated in sucrose solution, osmo-dehydrated in glucose solution, and untreated frozen samples, respectively. The micrographs revealed significant structural differences among the samples. The fresh garden egg tissue (Figure 5a) exhibited an intact and detailed cellular architecture, indicating a stable cell. However, the osmo-dehydrated sample maintained a relatively preserved cellular network, suggesting the sugar treatment's effectiveness in mitigating severe cellular damage. Conversely, the untreated frozen

sample displayed pronounced cellular degradation, characterized by rupture and detachment of the outer cell walls, indicative of ice crystal-induced mechanical damage during freezing.

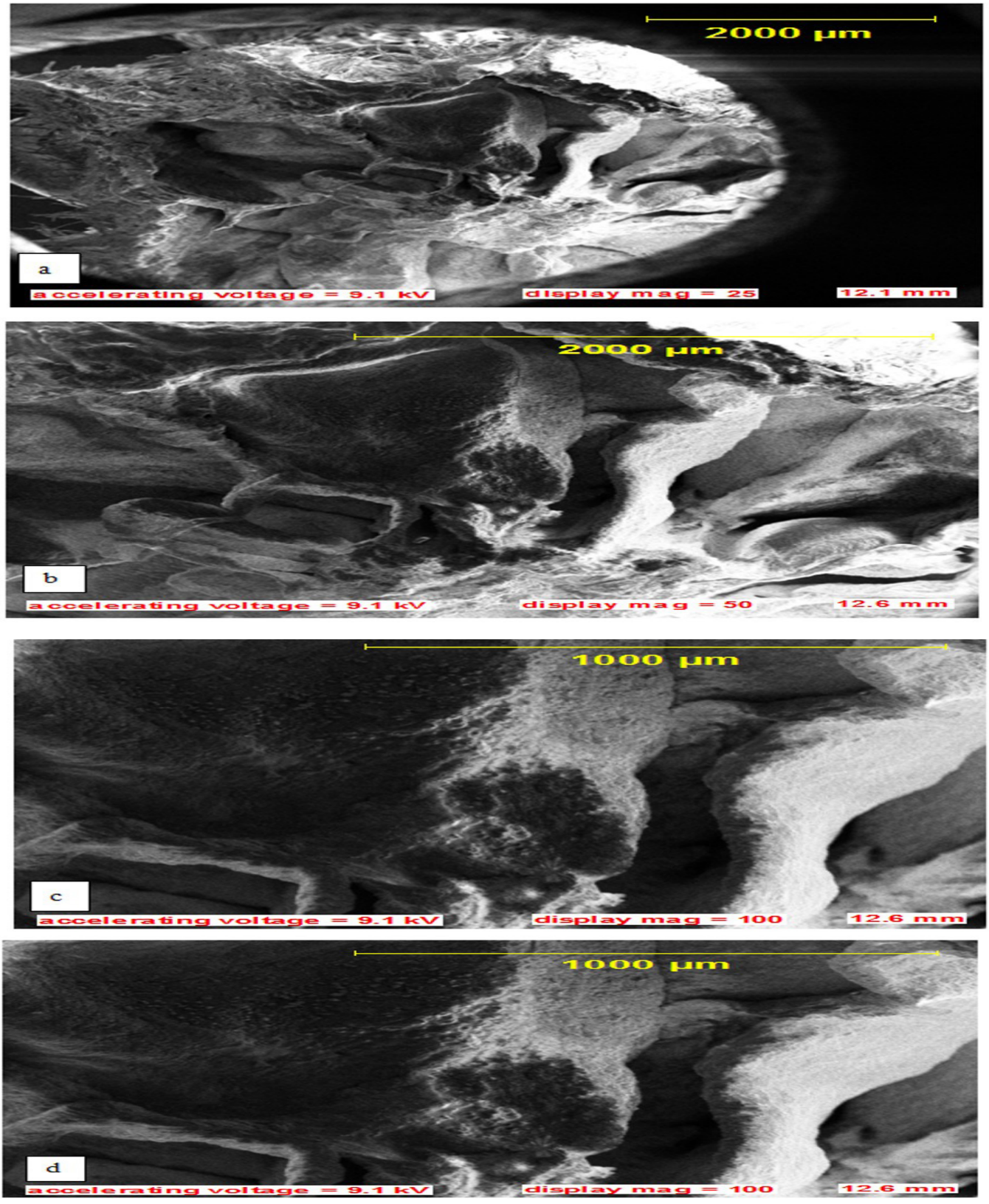

Figure 5: Effect of different sugars on cell integrity of osmo-dehydrofrozen garden egg (a) fresh sample; (b) maximally treated (in sucrose solution) frozen sample; (c) maximally treated (in glucose solution) frozen sample; (d) untreated frozen sample.

As shown in Figure 5d, the untreated frozen garden egg tissue exhibited pronounced cellular damage, primarily attributed to the formation of large ice crystals during the freezing process. In contrast, cell damage in the treated-frozen samples (Figure 5b and Figure 5c) wassignificantly minimized due to the application of a lower freezing load and the incorporation of cryoprotective solutes during the osmotic dehydration (OD) pre-treatments. These findings are consistent with observations by Alabi et al. (2025), who reported that osmotic solute uptake prior to freezing mitigated cellular degradation in apple tissues. Furthermore, application of sugars at 55 and 65 °Brix resulted in elevated freezing points, which facilitated more efficient heat and mass transfer while preserving cell integrity.

Quantitative texture analysis of microscopic images has been employed to assess the impact of freezing on cellular structure and ice crystal morphology in apple tissues (Chassagne-Bérces et al., 2009). Notably, freezing at −20 °C and subsequent immersion in liquid nitrogen led to significant cell membrane disruption, resulting in cell wall collapse and overall tissue disintegration. These structural changes have been directly linked to altered mechanical behavior, emphasising the importance of cell structure preservation in frozen products.

4. CONCLUSIONS

The effect of different sugars on mass transfer and cell integrity of frozen garden egg have evaluated and the results shown that the optimal treatment for improving mass transfer and preserving cell integrityinosmo-dehydrofrozen garden egg slices was achieved by pre-treating the samplesinsucrose solution at 65° Brix and 35°C. Under these conditions, the garden egg slices exhibited a 91% reduction in drip loss(DL) andlower water loss compared to samples pretreated with glucose and the untreated control. Solid gain analysis further confirmed the enhanced mass transfer in the sucrose treated samples, which showed significantly higher values than those that were frozen without osmo-dehydration. Microstructural observations also revealed that the cell integrity was best preserved in the optimally treated samples, in contrast to the structural degradation observed in untreated slices. These findings underscore the synergistic effect of osmo-dehydration and freezing in enhancing both the mass transfer and structural integrityof garden egg slices, providing valuable insights for improving the quality of frozen produce.

Author Contributions

Kehinde Peter Alabi conceived the idea, carried out the experiment and performed data analysis, wrote initial version, and Kazeem Koledoye Olatoye performed data analysis while Azeez Ayinla Adebayo conducted editing. Emmanuel Toyosi performed the experiment and Oyedele Timileyin Adeyinka assisted in experimentation and acquired experimental materials, journals, books, and conference proceedings.

Data Availability Statement:

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of Interest Disclosure:

The author declares that they have no conflict of interests, personal relationships, financial or otherwise that could have appeared to influence the work reported in this paper.

REFERENCES

Alabi, K.P., Fadeyibi, A., Adebayo, K. R., Gabriel, L. O. (2025) - Effects of osmotic dehydration-assisted freezing at different pressure rates on mass transfer and quality of fresh-cut apple, *Journal of food process engineering*, 48 (5), 1-11 Doi:**https://doi.org/10.1111/jfpe.70133**

Alabi, K. P., Olalusi, A. P., Olaniyan, A.M., Fadeyibi, A. and Gabriel, L. O. (2022) – Effects of osmotic dehydration pretreatment on freezing characteristics and quality of frozen fruits and vegetables. *Journal of Food Processing Engineering*, 45 (8), pg 1-12.

DOI: 10.1111/jfpe.14037

Alabi, K. P., & Zhu, Zhiwei, & D.-W. S. (2020). Transport phenomena and their effect on microstructure of frozen fruits and vegetables. *Trends in Food Science & Technology*, *101*, 63–72.

Alabi, Kehinde Peter, Olaniyan, A. M. & Odewole, M. M. (2016). Characteristics of onion under different process pretreatments and different drying conditions. *Journal of Food Processing and Technology*, *7*(2), 1–8.

Ando, H., Kajiwara, K., Oshita, S., & Suzuki, T. (2012). The effect of osmotic dehydrofreezing on the role of the cell membrane in carrot texture softening after freeze-thawing. *Journal of Food Engineering*, *108*(3), 473–479.

Ben Haj Said, L., Bellagha, S., & Allaf, K. (2016). Dehydrofreezing of Apple Fruits: Freezing Profiles, Freezing Characteristics, and Texture Variation. *Food and Bioprocess Technology*, *9*(2), 252–261.

Bunger, A., Moyano, P. C., Vega, R. E., Guerrero, P., & Osorio, F. (2004). Osmotic dehydration and freezing as combined processes on apple preservation. *Food Science and Technology International*, *10*(3), 163–170. https://doi.org/10.1177/1082013204044828

Cao, X., Zhang, F., Zhu, D., Zhao, D., & Liu, L. (2018). Effect of different sugars on the freezing characteristics of Kyoho grape. *Journal of Texture Studies*, *49*(6), 604–611. https://doi.org/10.1111/jtxs.12366

Chassagne-Berces, S., Poirier, C., Devaux, M. F., Fonseca, F., Lahaye, M., Pigorini, G., Girault, C., Marin, M., & Guillon, F. (2009). Changes in texture, cellular structure and cell wall composition in apple tissue as a result of freezing. *Food Research International*, *42*(7), 788–797.

Chottanom, P., & Srisa-Ard, M. (2011). Osmotic dehydration as a factor in freezing of tomato. In *American Journal of Food Technology* (Vol. 6, Issue 6, pp. 483–491).

Dalvi-Isfahan, M., Jha, P. K., Tavakoli, J., Daraei-Garmakhany, A., Xanthakis, E., & Le-Bail, A. (2019). Review on identification, underlying mechanisms and evaluation of freezing damage. *Journal of Food Engineering*, *255*, 50–60.

Kockro, R. A., Hampl, J. A., Jansen, B., Peters, G., Scheihing, M., Giacomelli, R. & Aschoff, A. (2000). Use of scanning electron microscopy to investigate the prophylactic efficacy of rifampin-impregnated CSF shunt catheters. *Journal of Medical Microbiology, 49*(5), 441–450. https://doi.org/10.1099/0022-1317-49-5- 44

Li, B., & Sun, D. (2002). *Novel methods for rapid freezing and thawing of foods – a review*. *54*, 175–182.

Li, D., Zhu, Z., & Sun, D. (2018). Effects of freezing on cell structure of fresh cellular food materials: A review. *Trends in Food Science & Technology*, *75*, 46–55.

Lowithun, N., & Charoenrein, S. (2009). Influence of osmodehydrofreezing with different sugars on the quality of frozen rambutan. *International Journal of Food Science and Technology*, *44*(11), 2183–2188.

McDonald, K., & Sun, D. W. (2000). Vacuum cooling technology for the food processing industry: A review. *Journal of Food Engineering*, *45*(2), 55–65.

Monnerat, S. M., Pizzi, T. R. M., Mauro, M. A., & Menegalli, F. C. (2010). Osmotic dehydration of apples in sugar/salt solutions: Concentration profiles and effective diffusion coefficients. *Journal of Food Engineering*, *100*(4), 604–612. https://doi.org/10.1016/j.jfoodeng.2010.05.008

Moyano, P. C., Vega, R. E., Bunger, A., Garretón, J., & Osorio, F. A. (2002). Effect of combined processes of osmotic dehydration and freezing on papaya preservation. *Food Science and Technology International*, *8*(5), 295–301.

Ramallo, L. A., & Mascheroni, R. H. (2010). Dehydrofreezing of pineapple. *Journal of Food Engineering*, *99*(3), 269–275.

Talens, P., Escriche, I., Martínez-Navarrete, N., & Chiralt, A. (2003). Influence of osmotic dehydration and freezing on the volatile profile of kiwi fruit. *Food Research International*, *36*(6), 635–642.

Velickova, E., Tylewicz, U., Dalla Rosa, M., Winkelhausen, E., Kuzmanova, S., & Gómez Galindo, F. (2013). Effect of vacuum infused cryoprotectants on the freezing tolerance of strawberry tissues. *LWT - Food Science and Technology*, *52*(2), 146–150.

Zhao, J. H., Hu, R., Xiao, H. W., Yang, Y., Liu, F., Gan, Z. L., & Ni, Y. Y. (2014). Osmotic dehydration pretreatment for improving the quality attributes of frozen mango: Effects of different osmotic solutes and concentrations on the samples. *International Journal of Food Science and Technology*, *49*(4), 960–968.

Zhao, J. H., Xiao, H. W., Ding, Y., Nie, Y., Zhang, Y., Zhu, Z., & Tang, X. M. (2017). Effect of osmotic dehydration pretreatment and glassy state storage on the quality attributes of frozen mangoes under long-term storage. *Journal of Food Science and Technology*, *54*(6), 1527–1537.