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Original research

Effects of various osmotic concentrations, time, and temperature on button mushroom (*Agaricus bisporus*) during osmodehydrofreezing process

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ABSTRACT

The effect of osmotic dehydration pretreatment on the quality attributes (e.g., color, moisture content, water absorption, shrinkage, hardness, weight reduction, and biotin content) of button mushroom was investigated in different osmotic solution concentrations (5, 10, and 15%), temperature (30, and 50 °C), and time (60, 120, 180, 240 min) before and after final freezing. The results revealed that both solute concentration and temperature had significant effects on mushroom shrinkage. Furthermore, dehydrofrozen samples had higher quality in terms of biotin content (decreased by 32%), browning index (decreased by 94%), and weight loss (decreased by 8.89-31.69%) than those not pretreated in salt. The hardness of samples after salt treatment increased by 110.11%. Osmotic dehydration in 15% salt at 50C for 120 min was proposed as the most favorable pretreatment based on the highest water absorption (0.98) after freezing. These findings provide a practical basis for improving the quality of frozen mushrooms through osmotic dehydration, and may be applied to other moisture-sensitive produce. Future studies can further investigate scalability and nutritional retention across different osmotic agents.

Keywords: Freezing; Mushroom; Color; Osmotic dehydration; Quality attributes.

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1. Introduction

For many years, mushrooms have been a popular food choice in numerous countries around the world due to their distinctive delicate flavor and taste (ÇElen et al., 2010). They are also high in carbohydrates, proteins, fiber, vitamins, minerals, and unsaturated fatty acids. Mushrooms are known to be a rich Origin of bioactive substances. As a result, they have antibacterial, antifungal, antioxidant, antitumor, antiallergic, antiatherogenic, and anti-inflammatory properties (Shams et al., 2022). They are also a good Origin of bioactive substances like polyphenolics, which are free radical blockers (Yahia et al., 2017). Gallic acid, protocatechuic acid, pyrogallol, myricetin, and naringin are the main phenolics found in edible mushrooms such as *Agaricus bisporus*, *Flammulina velutipes*, *Pleurotus ostreatus*, and *Pleurotus eryngii* (Kim et al., 2008). There are more than 38,000 types of mushrooms found in nature, but only 22 of them are cultivated, including the white button mushroom (*Agaricus bisporus*), being one of the most popular. The button mushroom is one of the most widely grown and consumed mushrooms in the world, accounting for more than 40% of total global mushroom production (Shams et al., 2022). This cultivar has a low calorie count but is high in purine, carbohydrate, and sodium, as well as vitamins, phosphorus, potassium, and trace minerals (Yahia et al., 2017). The button mushroom is very easily spoiled, with a shelf life of only about 24 hours in ambient conditions. Therefore, it is recommended to consume or process mushrooms shortly after they are harvested. This is why mushrooms are mainly sold in dried or frozen form on the global market.

Due to the growing need for products that are available year-round, freezing is a widely utilized technique in the food industry to preserve food for extended periods. Frozen foods are considered the second most popular choice after fresh and refrigerated products, mainly due to consumer perception and the advantages of low temperature preservation, which helps protect them from thermal damage and allows for long-term storage at lower temperatures (Alabi et al., 2022). Freezing can affect the texture of food products

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negatively because of the formation and growth of ice crystals, which is influenced by factors such as freezing speed, storage duration, storage temperatures, and thawing techniques (Schudel et al., 2021).

When compared to conventional freezing, osmotic dehydration before freezing, also known as osmodehydrofreezing (ODF), offers numerous benefits such as enhancing texture qualities and minimizing browning, structural breakdown, and liquid loss in frozen fruits and vegetables (Schudel et al., 2021). Osmotic pretreatment is effective in decreasing both the volume of water required for freezing and mitigating any adverse impacts on the properties of food (Shinde and Ramaswamy, 2020). To the best of our knowledge, ODF has been used to preserve fruits such as strawberries, apples, and pineapples (Blanda et al., 2009, 2008; Dermesonlouoglou et al., 2007; Ramallo and Mascheroni, 2010a). In a study of Reyes-Alvares and Lanari (2023) involving arazá fruit, findings indicated that OD pretreatment before freezing increased the freezing rate by 58% and reduced drip loss by 40%, while also enhancing the bioaccessibility of total polyphenols by 22%. Sette et al. (2016) examined how dry and wet sucrose infusions affected the physical and mechanical properties of raspberries dried by air- or freeze-drying. Pretreated samples had lower glass transition temperatures, reduced firmness, and varied rehydration and hygroscopic behavior. Ben Haj Said et al. (2015) examined how varying water content levels (700%, 200%, 100%, and 30% dry basis) and practical freezing rates (high and low) affected freezing characteristics in apples. Results indicated that reducing water content prior to freezing significantly decreased freezing times and thaw exudate water, with minimal impact on firmness, suggesting improved structural integrity post-thaw. The findings supported dehydrofreezing as an effective method to enhance the quality of frozen apples by mitigating negative effects associated with conventional freezing processes. Li et al. (2023) compared immersion freezing (IF), ODF, and air freezing (AF) techniques. Among the ODF treatments, mangoes pretreated with a 50% glucose solution (G-50) exhibited the highest quality, indicating that the freezing rate has a more significant impact on quality than the difference between freezing temperature and the glass transition temperature. Immersion freezing maintained the best physicochemical quality and the highest total phenol content in frozen mangoes, followed by osmodehydrofreezing and air freezing.

Freeze-dried pretreated raspberries showed better texture and are suitable for use in snacks or cereal mixes. However, few studies on ODF mushrooms have been conducted (Bashir et al., 2020). Furthermore, there is a lack of scholarly investigation regarding the impact of osmotic dehydration on the freezing parameters of button mushroom.

As a result, the current study sought to utilize osmotic dehydration as a pretreatment method for mushroom freezing. The effect of different osmotic solute concentrations (5, 10, and 15%), temperature (30 and 50 ℃), and time (60, 120, 180, and 240 min) on the physicochemical properties of frozen button mushroom was studied. This study is based on the hypothesis that osmotic pretreatment using salt solutions of varying concentration, temperature, and duration can significantly enhance the quality of frozen mushrooms by reducing moisture content, and improving textural integrity. While osmotic dehydration has been widely studied in fruits such as apples, pineapples, and strawberries, its application to mushrooms—especially button mushrooms—remains limited. This study addresses this gap by evaluating not only textural and structural changes but also micronutrient retention (biotin) post-freezing, offering novel insights into the pretreatment's efficacy.

2. Material and Methods

2.1. Materials

The button mushroom was sourced from a nearby food supplier in Shahrekord, Iran, and stored at a temperature of 2 ºC prior to processing. Commercial sodium chloride (IANSA S.A., Chile) was used to prepare the osmotic solution.

2.2. Processing

2.2.1. Pre-treatment

Trials were performed on button mushrooms of the same batch. Mushrooms were hand- and cut into uniform dimensions (1×3×4).

2.2.2. Osmotic Dehydration

Mushroom slices were submerged in the osmotic solution (5, 10, and 15 %) within a water bath under precise temperature control. To avoid enzymatic browning, sodium chloride solutions were prepared with tap water and containing 1% ascorbic acid and 0.2% citric acid. The osmotic solution's dehydration temperature and time were 30 and 50 ℃ for 60, 120, 180, and 240 min, respectively. Finally, the osmo-dehydrated mushrooms were stored at 2 ºC for 24 h before freezing to homogenize the internal moisture and salt concentration.

2.2.3. Freezing

The samples were placed on a chest freezer (S500, Ardo, UK) set to -20 ℃. Prior to the analyses, frozen mushroom slices were thawed at refrigerator temperature (1 ℃) until equilibrating temperature. Osmodehydrofreezing experiments were according to Table 1.

2.3. Quality analysis

2.3.1. Water rehydration

The rehydration properties were investigated by immersing the mushroom slices in 50 ℃ water for 30 min as equation follows (Eq. (1)):

$$R\ (\%) = \frac{W_r}{W_d} \times 100 \quad (1)$$

where W_r, and W_d was the weight of the dehydrated, and dry sample (Kg), respectively (Ramallo and Mascheroni, 2010b).

2.3.2. Weight reduction

After thawing, mushroom slices were placed on a strainer for 15 min to remove excess water, and the amount of dripping water was calculated based on the difference in weight before (M_0), and after (M_t) thawing (Wray and Ramaswamy, 2015) as follows (Eq. (2)):

$$WR\ (\%) = \frac{M_0 - M_t}{M_0} \times 100 \quad (2)$$

2.3.3. Shrinkage ratio

A volumetric movement technique was used to calculate the mushroom shrinkage ratio (S) by Eq. (3):

$$S = (1 - \frac{V_t}{V_0}) \times 100 \quad (3)$$

where V_t and V_0 represents the apparent volume of the dehydrated sample after t, and the raw sample (m^3) (Maftoonazad and Ramaswamy, 2008).

2.3.4. Color

The tristimulus Minolta Chroma Meter (Minolta Corp, Ramsey, NJ, USA) was used to determine the L* (lightness), a* (green-redness) and b* (yellow-blueness) value. Total color difference (ΔE) and Browning index (BI) were then calculated using Eq. (4) and Eq. (5), respectively. The color parameters of mushroom were measured before and after treatments (Soleimanifard et al., 2024).

$$\Delta E = \sqrt{(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2} \quad (4)$$

$$BI = (1 - \frac{(100 \times (x - 0.31)}{0.17}) \quad (5)$$

2.3.5. Texture

A puncture test was performed using a TA 41 plus Texture Analyzer (Texture Technologies Corporation, Hamilton, MA, USA/ Stable Micro Systems, Godalming, Surrey, UK) equipped with a 2 mm diameter round tipped puncture probe with a speed of 2 mm/s. The force-deformation curve was used to determine the hardness of the fruit samples (Maftoonazad and Ramaswamy, 2008).

2.3.6. Assessment of biotin (Vitamin B7)

50 mL of phosphate buffer, 5 g of mushroom, 4 g of pancreatin, and 6 mL of 10% sodium ascorbate were mixed and heated to 37 ℃ for 2 hours, then heated to 100 ℃ for 30 min. Then the mixture was centrifuged before at 3500 rpm for 15 min. Finally, supernatant was injected into a 12-cm-long column of high-performance thin layer chromatography from the Biopharma Company to measure biotin using the biotin measurement method.

2.4. Statistical Analysis

The experimental design was a factorial experiment arranged in a completely randomized block design with three replications. The data was subjected to analysis of variance (ANOVA) using the SAS software version 9.4. Means of treatment were separated using Duncan's new multiple range test ($p < 0.05$).

3. Results and Discussion

3.1. Moisture content

Table 1 indicates the effect of various treatments on the moisture content of mushrooms immersed in a salt-based solution during osmotic dehydration. When compared to untreated mushroom samples, those subjected to osmopre-treatment had a significantly lower moisture content (90.13%). The sample with the lowest moisture content was treated with a 15% salt solution at 50 ℃ for 180 min (72.71%).

An increase in the temperature of the process speeds up the evaporation of water, with a little effect on solid uptake (Shinde and Ramaswamy, 2020; Wray and Ramaswamy, 2015). The increased and rapid loss of water with increasing solution temperature may be ascribed to the plasticizing impact of cellular membranes, along with the reduced viscosity of the osmotic solution. The kinetics of mass transfer during osmotic dehydration are also affected by osmotic agent concentration (Kailaje et al., 2025). According to Asghari et al., (2024), Elevating the concentration of an osmotic solution leads to an accelerated water loss rate until a state of equilibrium is attained. The variance in osmotic potential between the solution and the fruit sample led to a faster solute and water diffusion rate.

Extended immersion duration leads to higher levels of moisture loss in the process of osmotic dehydration (Mari et al., 2024). In general, the higher the osmotic solution concentration, the lower the final moisture content and the greater the removal of water from the tissue. Furthermore, osmotic pretreatment, which increased the temperature and concentration of the osmotic solution, accelerated moisture transfer and dissolved substances. Similarly, Blasi et al., (2023) discovered that at a concentration of 45 to 60% and a temperature range of 20 to 50 ℃, pineapple slices lost about 25% of their water within the first hour and 40% after the third hour of osmotic treatment. The initial period of time, however, is critical, the swift occurrence of mass transfer plays a crucial role in influencing the subsequent advancement of the osmotic process.

3.2. Water absorption

Water absorption can be used to assess food quality. During freezing, irreversible changes such as texture changes, migration of soluble substances, and losses of volatile substances occur on the imported product; refrigeration reduces the elasticity of cell wall, reducing the product's water holding capacity. The water absorption index is affected by structural changes in plant tissues and food cells that occur during freezing, causing them to shrivel and collapse (Alabi et al., 2022).

Table 1 shows the water absorption of osmotic-dehydrated mushrooms and a control sample. The samples with the highest and lowest water absorption are related to osmotic treatment at 50 ℃, concentration 15%, and time 120 min (98%) and osmotic treatment at 30 ℃, concentration 10%, and time 60 min (67%).

Water absorption increased as salt concentration increased. In general, removing water from high moisture materials causes intercellular space blockage. As a result, they only absorb a small amount of water when rehydrated. However, as the moisture in the mushroom decreases during the osmosis process, some solid materials from the osmotic solution penetrate into the mushroom. As a result, the tissue is less damaged, and rehydration increases, because foods that are frozen under optimal conditions are less damaged and have a higher rehydration rate (Qiu et al., 2022; Silva Vidal et al., 2025). The ability of products to absorb water has significantly increased through the use of the osmosis process during freezing; as a result, the products sustain less damage and absorb water more quickly (Alabi et al., 2022). Osae et al., (2024) also demonstrated that the osmotic pretreatment has a detrimental impact on rehydration which are contradictory with this results. The cause of this is the rapid saturation of the lower layer of the food material's surface with sugar and the sugar layer's reduced ability to absorb water compared to the food's natural texture. The difference in the

Table 1. The moisture content (MC), water absorption (WA), and water reduction (WR) of button mushrooms after thawing at different osmotic conditions.

Osmotic conditions			Physicochemical properties		
Concentration (%)	**Temperature (°C)**	**Time (min)**	**MC (g/g)**	**WA (%)**	**WR (%)**
Control	Control	Control	$91.45^{A} \pm 0.03$	$51.12^{Y} \pm 0.00$	$36.73^{A} \pm 0.00$
5	30	60	$83.27^{H} \pm 0.01$	$84.91^{Q} \pm 0.00$	$13.78^{N} \pm 0.01$
5	30	120	$85.29^{B} \pm 0.00$	$76.70^{V} \pm 0.00$	$13.70^{P} \pm 0.04$
5	30	180	$84.78^{F} \pm 0.00$	$75.56^{W} \pm 0.01$	$21.87^{E} \pm 0.02$
5	30	240	$85.82^{G} \pm 0.00$	$86.15^{N} \pm 0.00$	$12.74^{R} \pm 0.09$
10	30	60	$79.67^{Q} \pm 0.00$	$67.75^{X} \pm 0.02$	$18.26^{I} \pm 0.05$
10	30	120	$80.72^{N} \pm 0.00$	$85.26^{P} \pm 0.00$	$11.51^{V} \pm 0.07$
10	30	180	$80.04^{O} \pm 0.00$	$85.68^{O} \pm 0.00$	$9.00^{X} \pm 0.03$
10	30	240	$79.65^{P} \pm 0.00$	$88.70^{L} \pm 0.00$	$12.21^{T} \pm 0.00$
15	30	60	$76.89^{T} \pm 0.00$	$82.26^{U} \pm 0.00$	$18.34^{H} \pm 0.00$
15	30	120	$76.72^{U} \pm 0.00$	$82.58^{T} \pm 0.07$	$8.90^{Y} \pm 0.01$
15	30	180	$76.32^{V} \pm 0.00$	$86.76^{M} \pm 0.03$	$18.26^{J} \pm 0.06$
15	30	240	$73.56^{X} \pm 0.00$	$83.80^{S} \pm 0.06$	$17.36^{K} \pm 0.00$
5	50	60	$84.04^{K} \pm 0.00$	$92.92^{H} \pm 0.00$	$29.07^{C} \pm 0.02$
5	50	120	$84.87^{E} \pm 0.00$	$97.92^{B} \pm 0.00$	$31.61^{B} \pm 0.00$
5	50	180	$82.91^{C} \pm 0.00$	$90.02^{K} \pm 0.00$	$21.04^{F} \pm 0.02$
5	50	240	$84.59^{D} \pm 0.00$	$94.47^{F} \pm 0.01$	$25.88^{D} \pm 0.03$
10	50	60	$81.16^{I} \pm 0.00$	$94.49^{E} \pm 0.01$	$15.61^{M} \pm 0.00$
10	50	120	$80.63^{L} \pm 0.00$	$84.90^{R} \pm 0.00$	$12.39^{S} \pm 0.00$
10	50	180	$75.07^{M} \pm 0.00$	$96.07^{D} \pm 0.00$	$11.43^{W} \pm 0.03$
10	50	240	$81.89^{J} \pm 0.00$	$97.50^{C} \pm 0.02$	$16.57^{L} \pm 0.05$
15	50	60	$77.96^{R} \pm 0.00$	$93.32^{G} \pm 0.04$	$13.39^{Q} \pm 0.09$
15	50	120	$69.08^{Y} \pm 0.00$	$98.32^{A} \pm 0.00$	$12.04^{U} \pm 0.02$
15	50	180	$75.72^{W} \pm 0.00$	$91.87^{J} \pm 0.02$	$14.83^{N} \pm 0.00$
15	50	240	$76.57^{S} \pm 0.00$	$92.92^{I} \pm 0.00$	$19.69^{G} \pm 0.00$

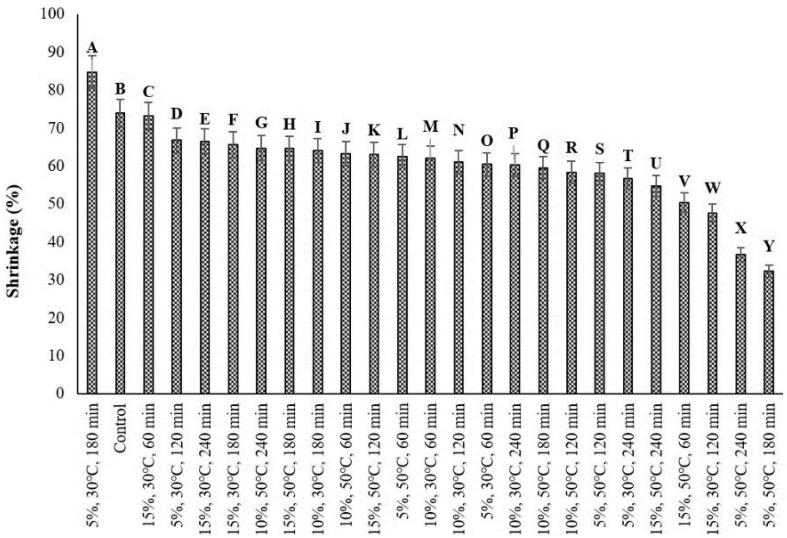


Fig 1. The shrinkage (%) of button mushroom after thawing.

osmotic solution's concentration may be the cause. Results on how the osmosis process affects rehydration capacity are inconclusive. The negative effect of osmosis on rehydration properties is due to the rapid saturation of the lower layer of the food material's surface with sugar or salt, as well as the lower water absorption of the sugar-salt layer compared to the natural texture of the food, as well as being affected by the permeability of the cell due to osmotic pressure. As a result, rehydrating these cells prevents them from absorbing as much water as the control sample. Because of structural changes caused by osmotic pretreatment, soluble nutrient loss in samples treated with osmotic solution increases during rehydration (Silva et al., 2014).

3.3. Weight reduction

Table 1 compares weight reductions in mushroom slides after osmotic dehydration at various concentrations, times, and temperatures. The lowest and the highest weight reductions were associated with samples treated with the 10% salt solution at 30 °C for 60 min (8.89%) and samples not treated (36.72%). As a result, osmotic dehydration was extremely effective in shortening the treatment time. Increasing osmotic concentrations caused water loss increment, which may be ascribed to the influence of increased osmotic pressure, which drives the process. It is noted that samples subjected to immersion in 15% osmotic solutions exhibited greater

weight reduction, suggesting caution against subsequent freezing to prevent tissue shrinkage. The reduction in size, attributed to significant water loss during osmotic dehydration, is considered the primary factor leading to cell shrinkage (Blasi et al., 2023). discovered similar results. The authors reported a significant reduction in the treatment time of pineapples with osmo-dehydration prior to freezing when compared to untreated samples.

3.4. Shrinkage

Shrinkage during freezing is an important factor in determining product quality. The mushroom tissue contains a large number of air bubbles in the intercellular spaces; the greater the intensity with which the bubbles exit the tissue, the greater the shrinkage of the product (Blasi et al., 2023). The comparison of shrinkage changes for all treatments shown in Fig. 1 revealed that the samples pretreated with 5% salt solution at 50 ℃ for 180 min and 5% salt solution at 30 ℃ for 180 min had the lowest and the highest shrinkage, respectively. The shrinkage of frozen osmo pretreatment was significantly influenced by pretreatments prior to freezing ($p < 0.05$). Salt causes water to escape from the mushroom before freezing, which is directly related to shrinkage. Because of the higher moisture content of the samples, the rate of shrinkage was higher at the start of the process, and as humidity decreased, so did the rate of shrinkage.

3.5. Color

Color is an important factor that influences consumer acceptance of a product. In the case of frozen products, the freezing techniques employed had a notable influence on the color characteristics of the mushrooms, serving as a comparative measure of alteration. The reduction in brightness (L* value) or elevation in yellow hue (b* value) is considered a crucial factor in assessing color degradation in mushrooms, as it is associated with the sensitivity of mushrooms to temperature variations Schudel et al., (2021). Fig. 2(a) displays the L* values of samples to describe lightness in the color space (L* = 100 indicates white, L* = 0 indicates black). After freezing, L* of sample without treatment was the highest (72.87) among all conditions. However, L* of osmodehydrofrozen samples was lower than that of fresh mushrooms (88.47). The osmotic treatment resulted in a reduction in the lightness value of mushroom slides due to surface dullness or darkening, as depicted in Fig. 2(a). Subsequent storage time had a further impact on the lightness of the treated samples, leading to additional decreases in L* values following 120 and 180 min of storage. Notably, the L* value of samples treated with 15% salt at 50 ℃ for 180 min exhibited the lowest value compared to other samples, measuring at 23.31. Statistical analysis using ANOVA revealed a significant difference in the L* value between the untreated (control) samples and the osmodehydrofrozen samples after thawing post 180 min of storage, as illustrated in Fig. 2(a). In a study by (Silva et al., 2014), it was noted that osmotically pretreated frozen pineapple exhibited a decline in L* value post-thawing, with a decrease in luminosity also observed in osmotically dehydrated samples when compared to fresh samples.

The b* value, which is the green/yellow indicator, was measured in both control and treated samples (Fig. 2(c)). The b* parameter exhibited a decrease in all samples following the thawing process. However, the b* values in samples with 15% salt, at 50 ℃ for 180 min was the lowest. Moreover, the presence of salt effectively maintained the yellow color of the fruit samples during the freezing process. Research demonstrated that following the thawing of strawberry fruits that had undergone osmotic pretreatment and were stored at temperatures above -12 ℃ or very low freezing temperatures below -12 ℃, a preservation of color was evident in the osmotically dehydrated samples in comparison to the untreated samples before freezing (Efimia K. Dermesonlouoglou et al., 2016).

Following the thawing process, the a∗ value was assessed in both untreated control and treated samples (Fig. 2(b)). After thawing, the a^* value increased in treated samples. The a^* values were observed as 8.15, in samples with 10% salt, at 30 ℃ for 120 min which was higher than untreated sample having a^* values of 0.07.

Browning index and total color difference were calculated to better understand the effect of osmo-pretreatment on mushroom color. Fig. 3(a) shows the color changes (ΔE) in mushrooms after osmotic dehydration pretreatment and freezing. The greatest color changes occurred at 50 ℃, 15%, 180 min (64.66) as opposed to 30 ℃, 5%, 60 min (18.19). Increased levels of salt and higher temperatures led to higher ΔE values in defrosted mushrooms due to the increased penetration of salts into the cellular tissue driven by concentration differences (Schudel et al., 2021). Furthermore, an increase in salt concentration and time led to a notable decrease in the formation of brown products. Indeed, the minimum browning index was achieved at 50 ℃, 15%, 180 min (122.68) when compared to the control sample (2145.9) (Fig. 3(b)). Exposing fruit pieces to a concentrated solution of sugar or salt during osmotic treatment results in color stability increment. Salt reduced browning of mushrooms during drying by inhibiting the activity of the tyrosinase enzyme (Bashir et al., 2020). Because button mushrooms contain polyphenol oxidase compounds, enzymatic browning occurs more quickly, lowering the quality of foods produced with them. Furthermore, this enzyme may become active as a result of shocks caused by processes such as freezing and unfreezing or heat, which, if carried out correctly and appropriately, can result in the inactivation of this enzyme to some extent and its destructive effects on the product and prevent during shelf life.

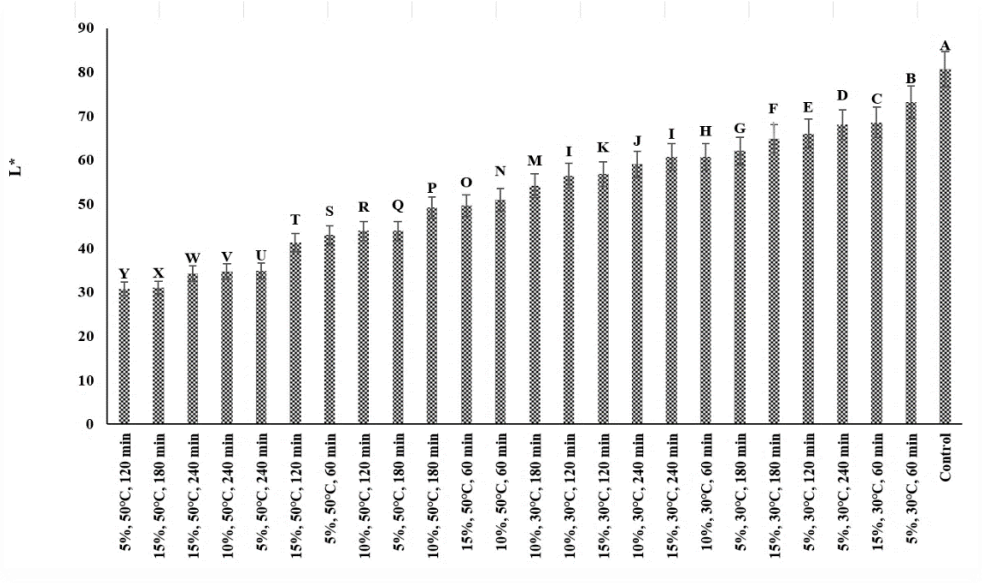
Osae et al., (2024) studied on the effect of osmotic dehydration on hot-air-dried apples was demonstrated that performing osmotic dehydration before hot air drying improved the transparency of the samples.

Finally, the ΔE and L* of osmodehydrofrozen maltose (30 and 45%) samples were higher than those of other samples. These findings showed that maltose had better protection against frozen mushroom color.

3.6. Hardness

The hardness of the sample was measured, and the results are shown in Fig. 4. The hardness of the sample was decreased to various levels after freezing. Fresh samples had a hardness of 202.58 N (Fig. 4), which was due in part to ice crystal formation during freezing. Nonetheless, irrespective of the specific freezing technique employed., osmodehydrofrozen samples had significantly higher hardness than control samples ($P < 0.05$). The highest and the lowest hardness values were determined by osmotic treatment at 30 ℃ for 120 min at a concentration of 15% (340.91 mm/s) and 50 ℃ for 120 min at a concentration of 10% (126.41 mm/s), respectively. This result could be attributed to salt consumption, which increased sample hardness. In general, salts can improve the structural integrity of fruits (Ataollahi Eshkour et al., 2023). Fig. 4 shows that the hardness value of osmodehydrofrozen samples increased by increasing salt concentrations (5 to 15%). Furthermore, the samples subjected to salt treatment exhibited lower water content, leading to an accelerated freezing rate. This phenomenon may mitigate cell

(a)



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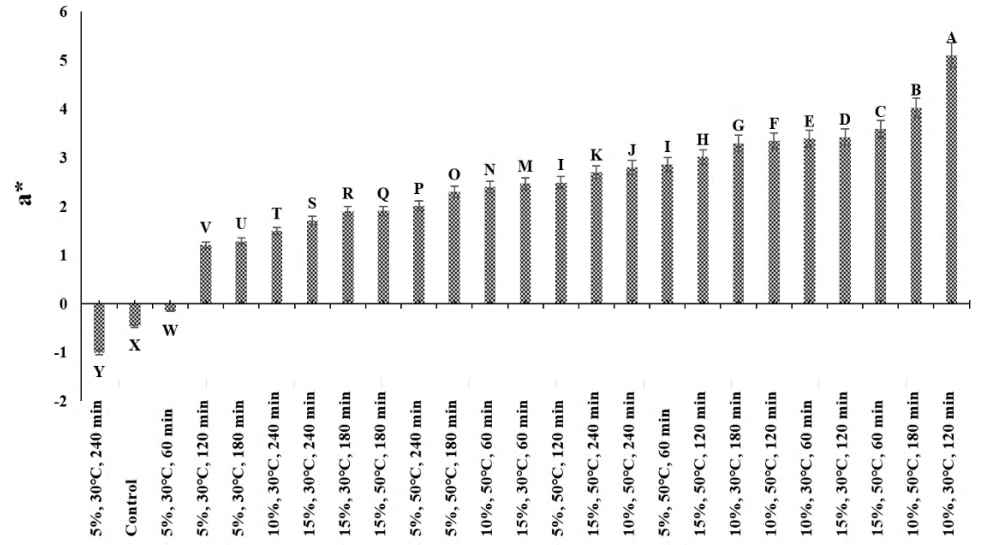

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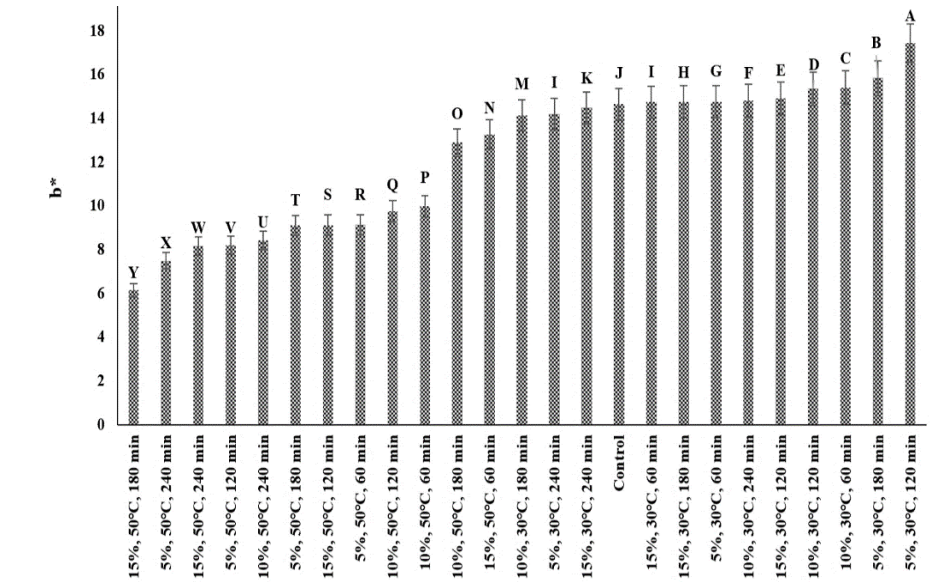
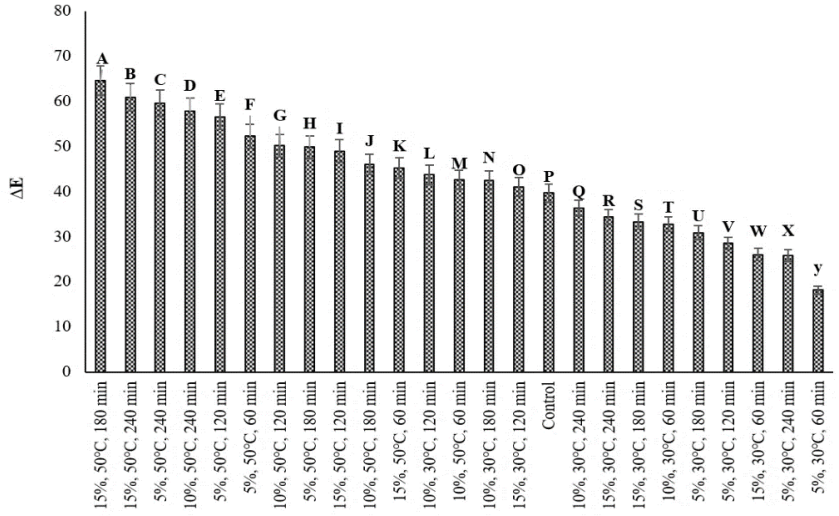


Fig 2. L*(a), a*(b), and b*(c) values of button mushroom after thawing.

(a)



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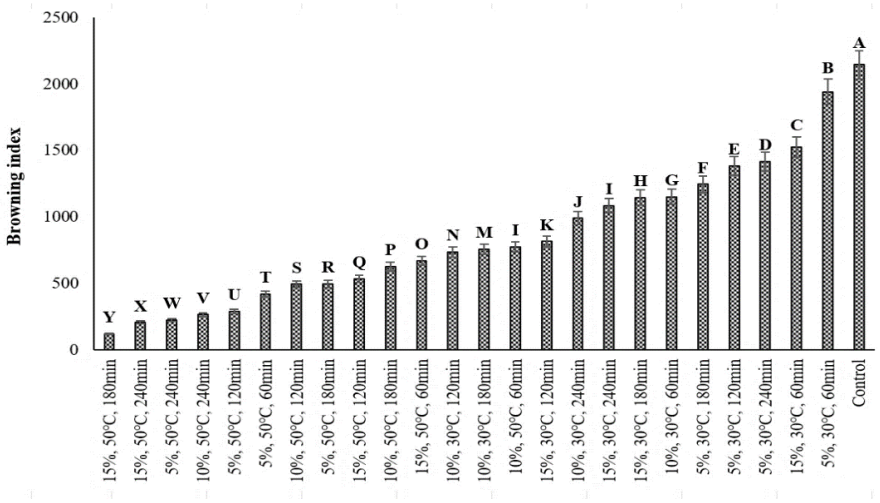

Fig 3. Total color change (a), Browning index (b) of button mushroom after thawing.

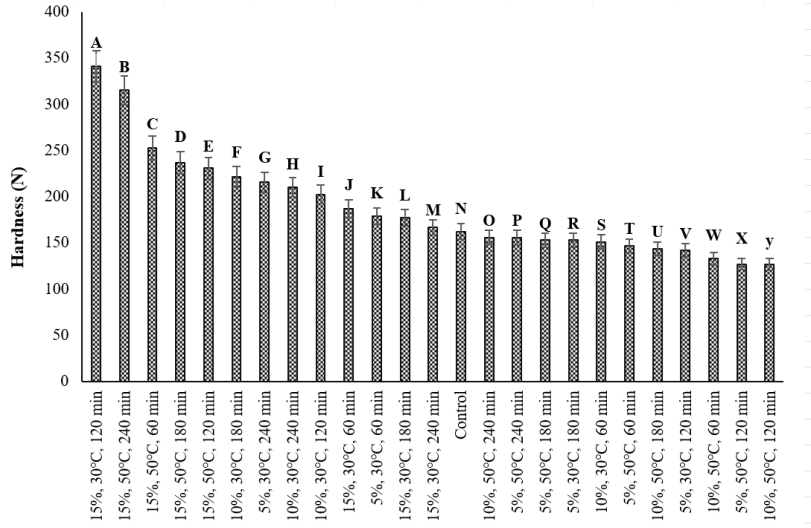

Fig 4. Hardness of button mushrooms after thawing.

structure deterioration and consequently yield firmer textures.

The slight increase in hardness observed after longer osmo-treatment times (120 min) is most likely due to Ca^{2+} penetration into mushroom tissue. Calcium ions have a significant impact on the structural integrity of the cell wall through their interaction with pectic acid polymers, leading to the formation of cross-bridges that enhance cell adhesion. This process ultimately reduces cell separation, a key factor contributing to the softening of plant tissues (Maftoonazad and Ramaswamy, 2008; Silva et al., 2014).

Similar results have been reported by Bashir et al., (2020) using the textural changes during the osmodehydrofrozen carrots and osmotic dehydration of pomegranate seeds, respectively.

3.7. Biotin content

Biotin is a vitamin B group that is found in trace amounts in all living cells and plays an important role in biochemical reactions. This vitamin is found in nature free or bound with protein or peptide, and it is one of the water-soluble vitamins. Mushrooms are high in vitamins B. The study investigated the impact of osmotic dehydration followed by freezing on the biotin content with the aim of maintaining the initial quality characteristics and nutritional value.

By applying osmotic dehydration, the amount of biotin in the treated samples was lower than in fresh button mushrooms (biotin content of fresh mashrooms was 98.4 ppb). Rincon and Kerr, (2010) noted that higher osmotic pressures could facilitate water removal from tissues, leading to a greater leaching of water-soluble vitamins with water during osmotic dehydration. Moreover, the results showed that the lowest biotin loss among the treated samples after freezing was at 15% salt at 30 ℃ for 120 min. Tian et al., (2016) emphasized the effect of the drying method and drying conditions of Shiitake mushroom on the amount of vitamin B_{12} remaining and concluded that the lower temperature and processing time, the greater the survival of vitamin B_{12}. Dibagar et al., (2022) also showed the lowest temperature and time were the best conditions for remaining vitamin B_3 for drying of rough rice. Hossain et al., (2021) reported the similar results for the effect of temperature on osmopretreatment taikor (*Garcinia pedunculata Roxb*.) slices on remaining of vitamin B_1, B_2, and B_3.

Comparison of frozen control and osmotic pretreated samples showed that the percentage of biotin reduction in pretreated samples was less than in frozen control samples. It was due to the reduction in moisture content of pretreated samples and the reduction in the percentage of water and biotin removal from the sample.

4. Conclusion

The research investigates the effect of different osmotic solute concentrations (5, 10, and 15%), temperature (30, and 50 ℃), and time (60, 120, 180, and 240 min) on the water absorption, weight reduction, shrinkage, hardness, color, and biotin content of frozen button mushroom. The findings indicated that both solute concentration and temperature exerted considerable influence on the shrinkage of mushrooms. The hardness of the samples subjected to salt treatment exhibited an increase of 110.11%. The research determined that osmotic dehydration in a 15% salt solution at a temperature of 50 ℃ for a duration of 120 min constituted the most effective pretreatment, as it yielded the highest water absorption rate (0.98) following the freezing process. Furthermore, samples that received dehydrofrozen treatment demonstrated enhanced quality with respect to biotin content, which experienced a reduction of 32%, browning index, which decreased by 94%, and weight loss, which ranged from 8.89% to 31.69%, in comparison to samples that did not undergo salt pretreatment. The present study highlights the substantial improvement in the quality of frozen mushrooms achieved via osmotic dehydration.

Conflict of interest

The authors declare that there is no conflict of interest.

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