
Research Article

Development of physicochemical properties and color of *Arbutus unedo* L. fruit during osmotic process

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Abstract

Arbutus unedo L. fruit, rich in bioactive compounds with health benefits, experiences rapid softening and significant postharvest quality changes, affecting its consumer appeal and storage life. This study investigates the effect of osmotic dehydration (OD) on the physicochemical composition, water loss (WL), sugar gain (SG), weight reduction (WR) and color during drying. The fruit was subjected to OD using sucrose solutions of varying concentrations (30, 50, and 60 °Brix) and temperatures (30 and 40 °C). The fresh fruit exhibited a moisture content of 57 %, a pH of 4.37, and 16.90 % of total soluble solids (TSS). The total phenolic content of *arbutus* fruit was 15.62 ± 0.78 µg/mg extract and the total flavonoid content was 1.63 ± 0.06 µg/mg extract. Our findings revealed that OD at 30 °Brix enhanced the color and reduced the browning compared to untreated fruit ($p < 0.05$). OD using a 60 °Brix solution notably reduced the moisture content by approximately 13% while simultaneously lowering the pH and increasing the TSS significantly ($p < 0.05$). These changes strongly correlated with WL, SG and sucrose concentration ($R = 0.89, 0.79, \text{ and } 0.82$, respectively). OD prevented the color deterioration during drying with ΔE ranging between 6.43 ± 3.37 and 19.97 ± 3.52 . The study proposes that OD at 60 °Brix and 40 °C produces dried *arbutus unedo* fruit with reduced moisture content and minimized color deterioration after the application of convective drying, rendering it suitable for industrial applications as functional food and the production of value-added dried berries.

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1. Introduction

The strawberry tree, scientifically known as *Arbutus unedo* L., belongs to the Ericaceae family and is typically found in the Mediterranean region and North Africa (Albuquerque et al., 2017; Takwa et al., 2018; Morales, 2022). It appears as an evergreen tree and bears spherical berries that turn a dark red color when fully ripe during autumn and winter (Delgado-pelayo et al., 2016). Recognized for its health-promoting properties attributed to its bioactive compounds, *Arbutus unedo* L. is particularly prevalent in Algeria, where it has been utilized for its medicinal attributes (Guendouze-bouchefa et al., 2015; Salem et al., 2018). This resurgence of interest in the fruit-tree species underscores the need for diverse preservation methods, given its high moisture content and limited seasonal availability.

Among the various existing pre-treatment methods, osmotic dehydration (OD) entails partial moisture removal from cellular tissues by submerging the food in a hypertonic aqueous solution (Porciuncula et al., 2013). Numerous studies have investigated the impact of OD on water loss, solute gain, and the physicochemical properties of various fruits (Kaur & Sogi, 2017; Ghellam et al., 2021). Islam et al., (2019) reported that higher osmotic conditions retained maximum bioactive compounds in Papaya fruit and a better mass transfer. Nevertheless, Falade et al., (2007) reported that a third stream of nutrients and minerals may leach from watermelon cubes into the osmotic solution, this can significantly cause an imbalanced pH (Ahmed et al., 2016). Particularly when the fruits have a high moisture or sugar/salt content, this can pose challenges in predicting the chemical composition of the final product (Ghellam et al., 2021). In order to minimize this, many studies have explored the use of edible coatings prior to dehydration to limit excessive solute absorption (Jansrimanee & Lertworasirikul, 2020). Color degradation has been extensively studied in various products, with the a^* parameter being identified as the most sensitive parameter (Steet & Tong, 1996). During OD, color degradation due to extensive browning can be effectively minimized, which operates at low temperature and involves a high concentration of sugar that surrounds the product, thereby preventing any discoloration (Ahmed et al., 2016). In the case of strawberry tree fruit, which contains anthocyanins responsible for its red color (de Bruijn & Bórquez, 2014). An increased acidity may alter the balance of anthocyanin compounds, favoring the formation of flavylum cations. As a result, pH-related color changes, along with other enzymatic reactions, can be particularly noticeable (Zielinska & Markowski, 2017; Enaru et al., 2021). As the fruit undergoes osmotic dehydration, careful monitoring of pH could help preserve its attractive red color or guide it towards desired hues, enhancing the final product's visual appeal and quality.

Osmotic process can also result in a relatively low dehydration rate and might not achieve a sufficiently low moisture content to qualify as a shelf-stable product. Consequently, osmotically dehydrated food necessitates supplementary drying techniques like convective drying (Zielinska & Markowski, 2017). Many studies have been focusing on improving this technique due to its simplicity and economical attributes, by integrating other processes and pre-treatments (Onwude et al., 2016; Pashazadeh et al., 2024; Amami et al., 2017). Various methods were utilized to prolong the storage of *arbutus unedo* L. fruit (Orak et al., 2011; Orak et al., 2012; Özcan & Uslu, 2023; Bajoub et al., 2023). To the best of our knowledge, there hasn't been any research examining how *arbutus* berries behave during osmotic dehydration. Therefore, the primary aim of this study was to extend previous knowledge on osmotic dehydration by exploring its effect on physicochemical composition of *arbutus unedo* L. fruit including pH and total soluble solids, at varying temperatures and concentrations. The study started by characterizing fresh strawberry tree fruit, focusing on its bioactive composition. Changes in color parameters were then measured during OD and following convective drying. Additionally, the variations in moisture content and mass transfer throughout the process were examined. The findings of our study could lead to the development of novel, shelf-stable *Arbutus unedo* product by informing potential changes in visual appeal, flavor, and nutritional quality during processing. Optimized OD parameters could be integrated into

large-scale fruit preservation operations, potentially reducing energy costs and processing time. Moreover, this technique could interest the confectionery, snack food, and nutraceutical industries, opening new avenues for utilizing *Arbutus unedo* in various food products while contributing to sustainable food production practices.

2. Materials and methods

2.1 Product

Fresh *arbutus unedo* L. berries were harvested from Ouled Hbaba forest (36° 30' 13" N, 6° 57' 27" E, 736 m) marked by its Mediterranean climate in Skikda, Algeria. The berries were visually selected based on their identical degree of ripeness, visible fruit quality, rigidity, and geometric dimensions using a digital caliper with 0.05 mm precision (radius $\approx 9.44 \pm 0.27$ mm). After the initial visual selection, a representative sample of the berries underwent comprehensive characterization to assess their biochemical composition. This analysis included determination of total soluble solids (TSS), pH, titratable acidity, Ash content, bulk density, color properties, and bioactive composition including total phenolic and flavonoid content. The berries were then stored in a ventilated room at 4 ± 2 °C. The initial moisture content of the strawberry tree berries was determined to be $59 \% \pm 0.04$ (wet basis).

2.2 Processing method

Sucrose solutions with concentrations of 30, 50, and 60 °Brix were prepared from commercial sucrose. Whole strawberry tree fruits were subjected to osmotic dehydration (OD) in the sucrose solution, with the process conducted at 30 and 40 °C. The ratio of fruit to solution was maintained constant at 1:4 (w = w). Moisture and sugar content were analyzed at 30 minutes' intervals for four hours of osmotic process under constant conditions, with the operation performed in triplicate. Based on this data, we quantified the mass transfer during the treatment by computing water loss (WL), Weight Reduction (WR), and solids gain (SG) using the following equations (Silva et al, 2012):

$$\text{Water Loss (WL)} = \frac{mw_0 - mw}{m_0} \quad (1)$$

$$\text{Solid Gain (SG)} = \frac{(ms - ms_0)}{m_0} \quad (2)$$

$$\text{Weight Reduction (WR)} = \frac{m_0 - m}{m_0} \quad (3)$$

Here, mw_0 and mw represent the initial and final water content of the sample, respectively. ms_0 denotes the initial soluble solids content, and ms is the soluble solids content at the end of the process. m_0 stands for the initial mass of the sample, and m represents the sample mass after the treatment.

The hot air drying process was conducted in a forced convection laboratory oven (Memmert Model UFE 600, GmbH + Co. KG, Germany, 230 V (± 10 %), 50/60 Hz, 2400 W) at 40 °C and an average air velocity of 2.0 ± 0.1 m/s until achieving a constant weight of samples.

2.3 Color assessment and browning index (BI)

The color change of strawberry tree berries was evaluated by measuring L^* (lightness), a^* (redness), b^* (yellowness), Chroma (C), and hue angle (H) for fresh, osmo-dehydrated, and hot air-dried samples utilizing a Konica Minolta (CR 10, Japan) colorimeter. The total color change (ΔE) was computed as follows:

$$\Delta E = \sqrt{(L^0 - L^*)^2 + (a^0 - a^*)^2 + (b^0 - b^*)^2} \quad (4)$$

The browning Index (BI) was calculated using [Dziki et al. \(2018\)](#) equation:

$$BI = 100 \cdot \left(\frac{X - 0.31}{0.17} \right) \quad (5)$$

Where,

$$X = \frac{a^* + 1.75L^*}{5.645L^* + a^* - 3.012b^*} \quad (10)$$

2.4 pH and total soluble solid content (TSS)

A twenty-gram (20 g) strawberry tree fruit sample was ground using a grinder, and the extracted juice was used for pH measurement with a pH meter. To assess the total soluble solids of both fresh and dehydrated strawberry tree fruit samples, a portable refractometer was utilized. A small amount of juice extracted from one gram of fresh and dehydrated samples was placed onto the refractometer's surface, and the values were expressed as degrees Brix (°Brix).

2.5 Statistical analysis

To assess the significance of pre-treatment temperature and concentration on mass transfer kinetics and quality parameters, we conducted statistical analyses using SPSS software. The experiments were independently performed three times, and the results are presented as mean $\pm$ standard error (SEM). Mean values were compared using one-way analysis of variance (ANOVA) followed by Duncan's multiple range test to determine significance at a level of $p < 0.05$. Additionally, a correlation analysis was conducted to explore the relationship among the physicochemical components of the strawberry tree samples and process variables. Subsequently, principal component analysis (PCA) was carried out to illustrate the associations among the quality attributes of the osmo-dehydrated product and the effect of different processing conditions, thereby informing practical decisions in optimizing *arbutus* fruit dehydration protocols for industrial applications.

3. Results and discussion

3.1 Physicochemical and Bioactive Properties of *Arbutus unedo* L. Fruit

Fresh strawberry tree characteristics were assessed in terms of physicochemical and antioxidant properties ([Table 1](#)). The characteristics and phytochemical elements of newly harvested fruits are subject to influence by various factors, including fruit geographic origin and environmental conditions ([Ruiz-Rodríguez et al., 2011](#), [Maieves et al, 2015](#)). Our findings were consistent with previous characterization studies of fresh strawberry tree fruits reported by [Alarcão-E-Silva et al. \(2001\)](#), [Orak et al. \(2012\)](#) and [Boussalah et al. \(2018\)](#).

Table 1. Physicochemical properties of fresh strawberry tree fruit (*Arbutus unedo* L.)

Physicochemical properties	Mean $\pm$ SEM
Total phenolic content (mg GAE/g extract)	15.62 $\pm$ 0.78 ^c
Flavonoids (μ g QE/mg extract)	1.63 $\pm$ 0.06 ^c
Ash (%)	1.12 $\pm$ 0.33 ^c
Titration acidity (% Malic acid)	1.55 $\pm$ 0.03 ^d
Total soluble solids TSS (°Brix)	16.26 $\pm$ 1.46 ^d
Moisture content (% w.b)	59 $\pm$ 0.04 ^c
pH	4.17 $\pm$ 0.03 ^d

Continued Table 1

Physicochemical properties	Mean $\pm$ SEM
Color parameters	
L*	31.19 $\pm$ 3.23 ^b
a*	21.48 $\pm$ 4.52 ^b
b*	21.22 $\pm$ 2.28 ^b
Average radius (mm)	9.44 $\pm$ 0.27 ^a
Length (mm)	19.69 $\pm$ 0.82 ^a
Width (mm)	20.12 $\pm$ 0.79 ^a
Density ($\times 10^3$ Kg/m ³)	1.16 $\pm$ 0.02 ^d

Superscripts, a, b, c and d represent the means ($\pm$ SEM) of 17, 9, 6 and 3 measurements, respectively.

3.2 Development of physicochemical composition during osmotic process

The impact of composition and temperature of osmotic dehydration on selected properties of this fruit is illustrated in Table 2. Osmotic dehydration aims to enhance sugar uptake while removing water from food products, thereby improving their storage stability. The fruit's moisture content decreased by approximately 13 % during the process. This minimal decrease suggests the potential benefit of complementing the pre-treatment with additional drying techniques such as convective drying (Calín-Sánchez et al., 2020). The OD process did not significantly increase the total soluble solids (TSS) content of arbutus fruit, as shown in Table 2. A marginal increase of about 2 °Brix was observed, with more noticeable effects in samples pre-treated in a 60 °Brix solution at 40 °C ($p < 0.05$), likely due to the formation of a superficial solute layer from sucrose concentration (Mari et al., 2024). Although higher sugar uptake can indicate improved dehydration efficiency, the minimal change in TSS, even under more intense conditions, suggests that the process primarily removed water without substantial solute gain ($p > 0.05$). This outcome is favorable from a health perspective, as it indicates that the fruit's sugar content remained largely unchanged, preserving much of its nutritional value. The limited sugar gain also mitigates concerns about osmotic dehydration increasing sugar content or causing nutrient loss (Ahmed et al., 2016). However, while TSS provides insight into sugar content, a more comprehensive nutritional analysis would be needed to fully evaluate the retention of vitamins, minerals, and bioactive compounds. The effect of process conditions on pH variations is depicted in Figure 1. The pH level decreased to approximately 3.54, with significant reductions observed in samples treated at higher sucrose concentrations compared to raw fruit ($p < 0.05$). During osmotic dehydration, the pH of a fruit can change due to several mechanisms, water removal and solute transfer into the fruit can be associated with an exchange of acids and other compounds due to cellular disruption caused by osmotic pressure (Ahmed et al., 2016). This change can also happen due to concentration effect of the remaining acids as moisture decreases inside the fruit (Ghellam et al., 2021).

Table 2. Physicochemical properties and kinetics parameters of *arbutus unedo* fruit after osmotic pretreatment in different sucrose concentrations and temperature levels

Fruit properties	Untreated fruit	Osmotic dehydration conditions					
		30 °C, 30°Brix	30 °C, 50°Brix	30 °C, 60°Brix	40 °C, 30°Brix	40 °C, 50°Brix	40 °C, 60°Brix
Total soluble solids (°Brix)	16.26 ± 1.46 ^a	16.3 ± 0.26 ^{ab}	17.87 ± 0.06 ^{ab}	17.87 ± 0.07 ^{ab}	17.47 ± 0.56 ^{ab}	18.3 ± 0.26 ^{ab}	18.63 ± 0.02 ^b
pH	4.18 ± 0.03 ^b	3.86 ± 0.73 ^{ab}	3.79 ± 0.19 ^{ab}	3.95 ± 2.11 ^{ab}	3.66 ± 2.11 ^{ab}	3.62 ± 0.08 ^a	3.54 ± 0.1 ^a
Moisture content wb. (%)	59 ± 0.04 ^b	48 ± 0.01 ^a	46 ± 0.02 ^a	44 ± 0.06 ^a	49 ± 0.01 ^a	47 ± 0.02 ^a	42 ± 0.01 ^a
Dry matter (%)	41 ± 0.02 ^a	52 ± 0.01 ^b	54 ± 0.01 ^b	56 ± 0.09 ^b	51 ± 0.01 ^b	53 ± 0.01 ^b	58 ± 0.01 ^b
Weight reduction (%)	-	7 ± 0.00 ^a	6 ± 0.02 ^a	10 ± 0.00 ^a	11 ± 0.02 ^a	10 ± 0.04 ^a	31 ± 0.13 ^a
Water loss (%)	-	24 ± 0.00 ^a	31 ± 0.03 ^a	30 ± 0.10 ^{ab}	21 ± 0.05 ^{ab}	34 ± 0.08 ^{ab}	47 ± 0.07 ^b
Sugar gain (%)	-	7 ± 0.09 ^a	10 ± 0.15 ^a	17 ± 0.78 ^a	9 ± 0.04 ^a	16 ± 0.18 ^a	17 ± 0.12 ^a

Notes: Means in one row with different letters (a, b, c, d, e) are significantly different as shown by Duncan's test ($p < 0.05$). (-) indicates no value available or not applicable.

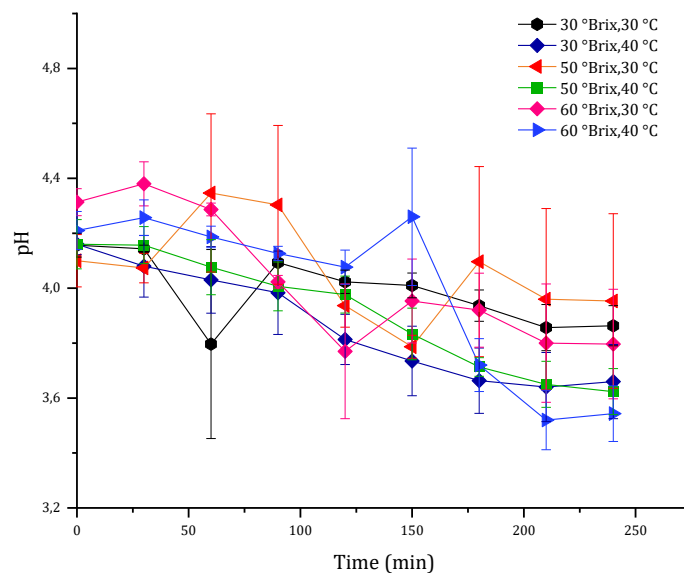


Figure 1. pH development during osmotic dehydration of *arbutus* berries in different concentrations and temperature levels

3.3 Effect of operating variables on mass transfer

Aside from the effects of product structure, contact surface, and the product-to-solution ratio, our study highlights the mass transfer dependency on operating conditions such as temperature, duration, and osmotic agent concentration, in terms of moisture evolution, water loss (WL), weight reduction (WR), and solid gain (SG) over time. As illustrated in Figure 2, an initial rapid water loss was detected at the beginning of the osmotic process, especially when temperature and solution concentration were elevated, driven by the existing gradient between the fruit and the hypertonic solution (Ramya & Jain, 2017; Asghari et al., 2024). Subsequently, the mass transfer rate gradually stabilized until the end of the osmotic process (Table 2). Solution concentration was the most significant factor affecting WL (Nowacka et al., 2019). However, sugar uptake values were less significant for all processing conditions compared to previous studies on osmotic dehydration of fruits (Islam et al., 2019). The high viscosity of the hypertonic solution could form a superficial solute layer that inhibits mass transfer from the solution to the fruit (Giraldo et al., 2003). Many authors have observed an increase in water loss rate without a corresponding change in solids gain when the temperature or concentration of the solution increases (Abrahão & Corrêa, 2021).

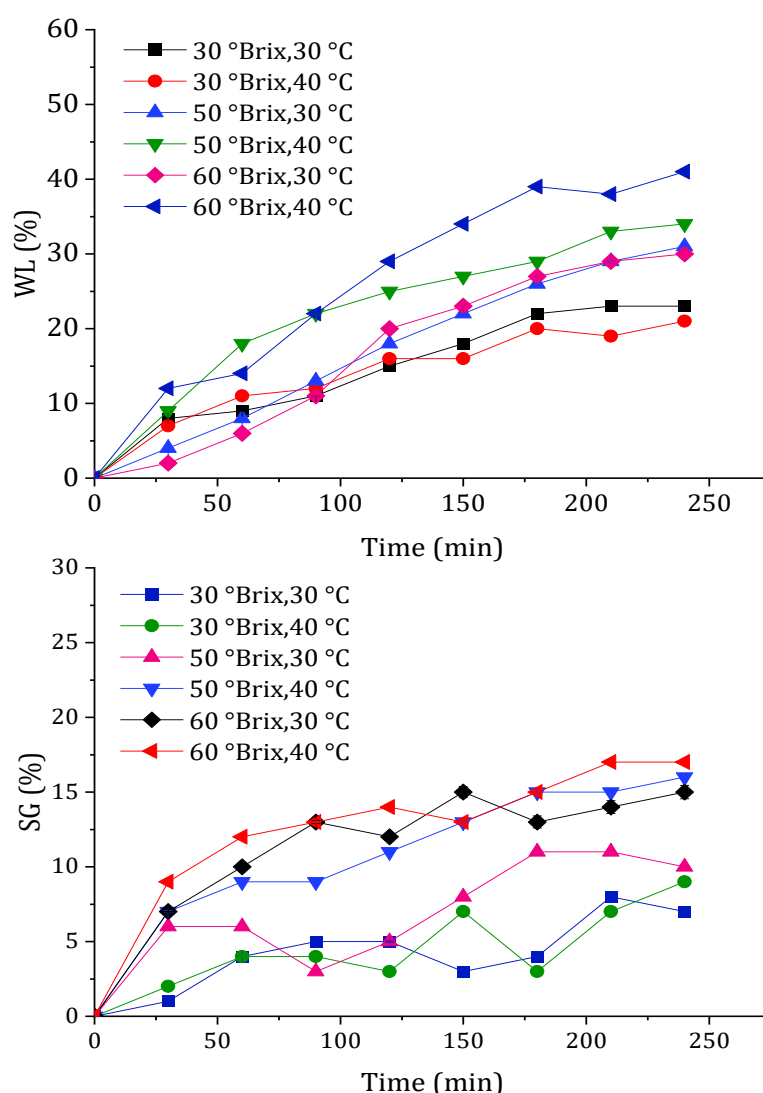


Figure 2. Weight loss and sugar gain kinetics of arbutus berries during osmotic dehydration at different temperatures and solution concentrations

3.4 Development of color during osmotic process

The variation in color parameters of samples pre-treated at varying temperatures and concentrations is presented in Table 3. Color parameters slightly increased when the treatment temperature was raised from 30 °C to 40 °C. It can be observed that the varying osmotic conditions did not significantly affect the color parameters compared to the fresh fruit (Dermesonlouoglou et al., 2018). Similar outcomes were reported by Leahu et al. (2020) during the osmotic dehydration of pear slices. The lowest values of lightness (L^*) were recorded for samples pre-treated in a 50 °Brix solution; this result correlates with redness (a^*) values, which increased under the same conditions, resulting in a darker fruit color. More stable a^* and b^* values were observed for samples pre-treated in 60 °Brix and 30 °Brix solutions. Total color difference (ΔE), which combines color parameters L^* , a^* , and b^* values, is used to assess the variation in color as a function of process conditions. It is also noticeable that treatments at high processing concentrations resulted in less color change ΔE . This may be due to the increased osmotic pressure on the surface of sample tissues, which can decrease the level of oxygen surrounding the berry and gradually reduce the enzymatic browning reaction (Özkan-Karabacak et al, 2022). Furthermore, the slight decrease in pH likely contributed to maintaining the red color of the fruit, as many pigments, including anthocyanins, are pH-sensitive. In acidic conditions, these pigments tend to produce brighter, more intense red hues, which may have helped preserve the *arbutus* fruit's color during processing (Zielinska & Markowski, 2017; Enaru et al., 2021). The color browning (BI) has slightly increased when solution concentration increased from 30 to 60 °Brix, while temperature variation had an insignificant effect ($p > 0.05$) (Hamdan et al, 2022). This may be due to the formation of brown pigments from the concentration of sugar at the surface of the sample under the effect of heat treatment (Lemus-Mondaca et al., 2009). Özkan-Karabacak et al., (2022) reported that the leaching of water-soluble pigments, such as anthocyanins, into the osmotic solution due to osmotic pressure, can also result in a loss of color intensity in the fruit.

Table 3. Color parameters of fresh and osmo dehydrated arbutus fruits in different concentrations and temperature levels

Color indices	Untreated fruit	Osmotic dehydration conditions					
		30 °C, 30°Brix	30 °C, 50°Brix	30 °C, 60°Brix	40 °C, 30°Brix	40 °C, 50°Brix	40 °C, 60°Brix
L^*	31.19 ± 3.23 ^c	29.27 ± 1.36 ^{bc}	26.73 ± 3.70 ^a	29.23 ± 2.25 ^{bc}	29.59 ± 0.78 ^{bc}	28.20 ± 2.39 ^{ab}	30.64 ± 1.03 ^c
a^*	21.48 ± 4.52 ^{ab}	19.76 ± 1.00 ^a	37.99 ± 4.22 ^c	17.86 ± 2.15 ^a	20.01 ± 3.88 ^{ab}	43.68 ± 5.45 ^d	30.64 ± 1.03 ^c
b^*	21.22 ± 2.28 ^a	17.63 ± 0.40 ^a	38.89 ± 10.11 ^b	18.12 ± 1.48 ^a	18.77 ± 1.72 ^a	41.50 ± 4.00 ^b	19.60 ± 1.63 ^a
C	30.30 ± 4.19 ^{ab}	26.49 ± 0.83 ^{ab}	54.71 ± 8.79 ^c	25.48 ± 2.12 ^a	27.54 ± 3.41 ^{ab}	60.27 ± 6.53 ^e	30.68 ± 2.64 ^b
H	45.07 ± 5.41 ^b	44.99 ± 1.48 ^b	41.76 ± 7.05 ^{ab}	45.52 ± 3.38 ^b	43.62 ± 5.27 ^{ab}	43.56 ± 1.69 ^{ab}	39.83 ± 2.67 ^a
ΔE	-	6.43 ± 3.37 ^a	25.60 ± 11.13 ^b	5.76 ± 2.80 ^a	5.92 ± 1.85 ^a	29.85 ± 8.10 ^b	5.64 ± 2.18 ^a
Browning index (BI)	-	125.52 ± 6.34 ^a	264.55 ± 5.72 ^b	139.65 ± 7.62 ^a	141.08 ± 5.34 ^a	249.26 ± 6.99 ^b	141.60 ± 2.86 ^a

3.5 Effect of hot air drying on color properties

The effect of hot air drying on fresh and pre-treated strawberry tree fruit is presented in Table 4. It can be observed that osmotic pre-treatment enhanced red color retention, while the untreated samples, as expected, showed a more yellowish and pale aspect after drying (Kaur & Sogi, 2017). Lemus-Mondaca et al. (2009) studied the effect of osmotic pre-treatment on hot air drying of Chilean papaya and affirmed that there is a significant difference between pre-treated and untreated samples. The yellowness (b^*) significantly decreased during convective drying for all arbutus samples, while untreated samples showed a more yellowish aspect and high Chroma results. Similarly, our results revealed low ΔE and Browning index (BI) values after convective drying compared to untreated dry fruits, confirming the beneficial effect of osmotic dehydration in preserving product color by avoiding the damage of heat-sensitive molecules such as anthocyanins, responsible for the red color of *arbutus* fruit (de Bruijn & Bórquez, 2014). These results are in agreement with the findings of Falade et al. (2007) and Masztalerz et al. (2021) on watermelon and chokeberry subjected to osmotic pre-treatment and hot air drying.

Table 4. Color parameters of dry strawberry tree fruit using osmotic dehydration at different conditions and hot air drying, compared to dry arbutus fruits with no prior OD

Color	Untreated dry fruit	Osmotic dehydration conditions					
		30 °C, 30°Brix	30 °C, 50°Brix	30 °C, 60°Brix	40 °C, 30°Brix	40 °C, 50°Brix	40 °C, 60°Brix
L*	27.91± 3.36 ^b	27.98± 1.42 ^b	18.61± 2.99 ^a	29.39± 1.33 ^{bc}	29.52± 3.10 ^{bc}	19.69± 1.75 ^a	30.44± 2.81 ^{bc}
a*	27.91± 3.36 ^b	10.02± 3.62 ^a	27.45± 3.68 ^{de}	12.69± 4.2 ^{ab}	15.42± 5.14 ^b	30.60± 1.83 ^e	13.34± 3.37 ^{ab}
b*	33.89± 1.48 ^c	17.80± 2.81 ^a	26.94± 7.08 ^b	19.19± 1.32 ^a	20.80± 3.43 ^a	25.29± 6.42 ^b	18.80± 2.58 ^a
C	42.16± 1.80 ^e	20.56± 3.87 ^a	26.94± 7.08 ^b	20.80± 3.43 ^a	25.97± 5.81 ^b	39.97± 4.56 ^e	23.22± 3.04 ^{ab}
H	53.51± 1.00 ^b	61.43± 7.24 ^c	43.92± 7.93 ^a	57.38± 6.65 ^{bc}	54.33± 4.67 ^b	38.95± 7.24 ^a	54.89± 7.51 ^b
ΔE	14.85± 0.67 ^{cd}	6.43± 3.37 ^a	19.97± 3.52 ^e	9.61± 2.60 ^{ab}	7.69± 3.47 ^a	17.82± 4.26 ^{de}	10.36± 4.19 ^{ab}
(BI)	330.87± 44.7 ^b	118.16 ± 12.6 ^a	513.26± 78.89 ^c	133.36± 11.51 ^a	140.8± 11.69 ^a	411.1± 51.42 ^{bc}	123.7± 11.56 ^a

Means in one row with different letters (a, b, c, d, e) are significantly different as shown by Duncan's test ($p < 0.05$).

3.6 Correlation and principal component analysis (PCA)

Pearson's correlation was employed to assess the interrelationships among the 14 variables studied in osmo-dehydrated strawberry tree fruit (Figure 3). This analysis encompassed processing conditions such as temperature and the concentration of the osmotic solution. The correlation analysis indicated a strong negative correlation between moisture content (H %) and kinetics parameters, suggesting that the reduction in water content during the osmotic process depends on the rate of mass transfer (Nowacka et al., 2019). A significant positive correlation was observed between the color parameters and the browning index ($R = 0.96, 0.99, 0.97$), emphasizing the relationship between these variables, while it revealed a moderate correlation with processing conditions. Additionally, a strong correlation was found between temperature, osmotic concentration, mass transfer variables, and total soluble content. This indicates that higher initial

pre-treatment conditions lead to increased water and solute transfer, resulting in weight reduction. The PCA biplot illustrates the relationships between various parameters in the osmotic dehydration process and the quality characteristics of *Arbutus unedo* L. (Figure 4). The first two principal components captured a large portion of the data's variability, with PC1 and PC2 explaining 42.69 % and 40.49% of the variance, respectively. Proximity between vectors indicates correlation, while their length shows their contribution to the principal components. Color attributes (a^* , b^* , BI and ΔE) were grouped in the upper right quadrant, suggesting greater color degradation in fruits treated with 50 °Brix solutions. In contrast, treatments with 60 °Brix, found in the upper left quadrant and strongly correlate with lightness, water loss, sugar uptake, and weight reduction. The analysis indicates that higher concentration treatments (60 °Brix) at elevated temperatures (40 °C) may provide an optimal balance between dehydration efficiency and quality retention. These conditions seem to maximize moisture reduction and soluble solid content while minimizing unwanted color changes.

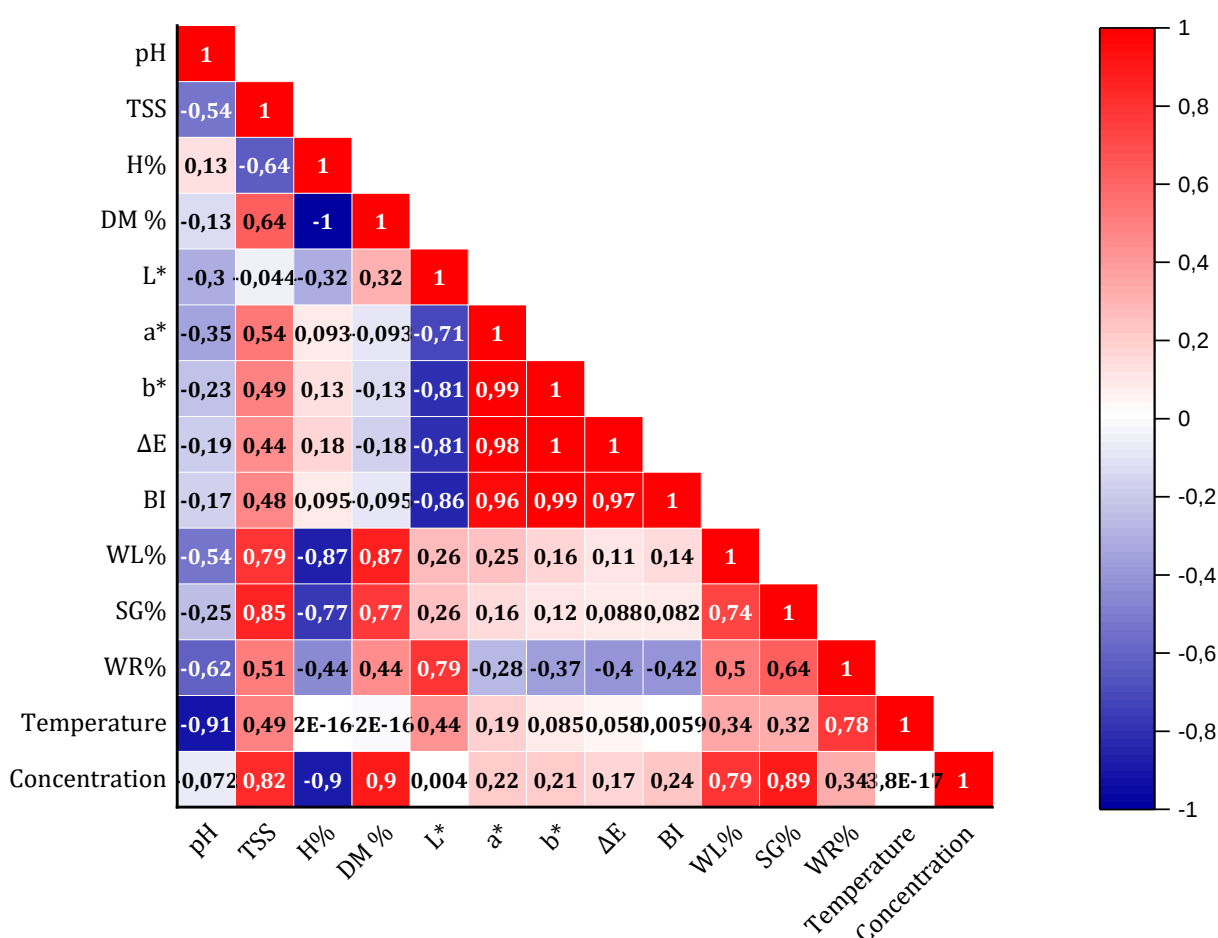


Figure 3. Correlation coefficient of osmotic dehydration variables of arbutus unedo fruit

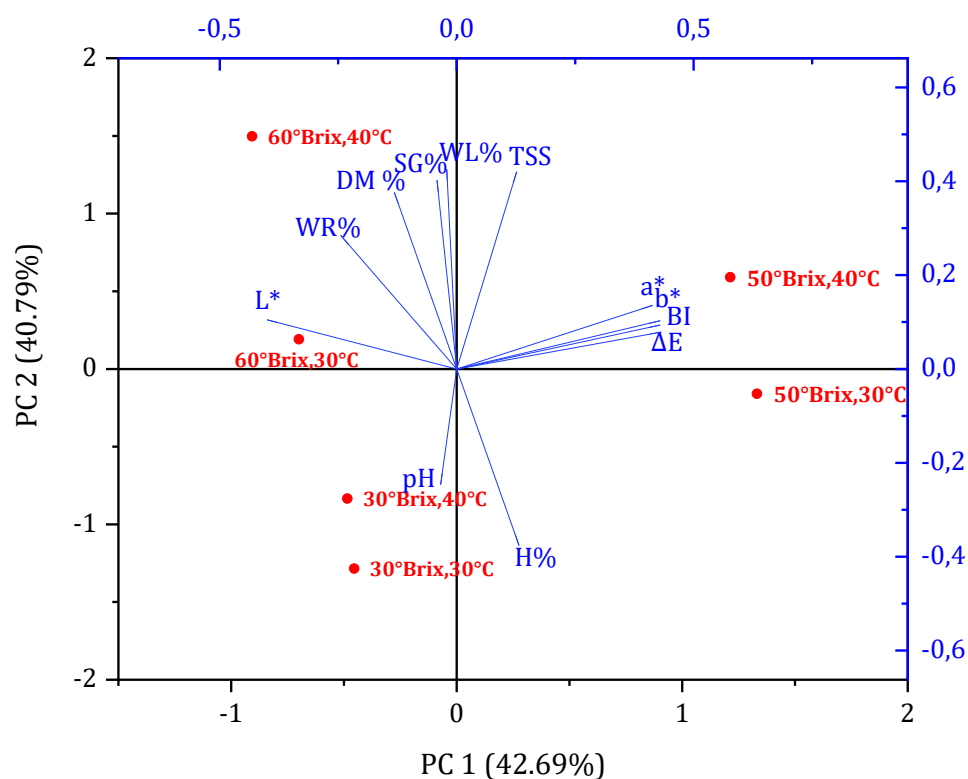


Figure 4. Principal component analysis (PCA) of quality attributes of osmo-dehydrated *Arbutus unedo* L. fruit

4. Conclusion

Our study investigated the mass transfer kinetics and quality changes during osmotic dehydration of *Arbutus unedo* L. fruits under varying sucrose concentrations and temperatures. The results revealed a moderate moisture reduction of approximately 13%, with minimal increase in total soluble solids, indicating limited sugar uptake even under intense treatment conditions. The process also led to a slight decrease in pH, likely due to the concentration of acids caused by osmotic pressure, which could potentially enhance the fruit's flavor. Color parameters were largely preserved during osmotic dehydration, with only slight changes observed. Higher processing concentrations resulted in less color change, possibly due to reduced enzymatic browning. Notably, osmotic pre-treatment enhanced red color retention during subsequent hot air drying compared to untreated samples. The combination of 60 °Brix solution at 40 °C appeared to yield the most favorable results, offering a balance between moisture removal and quality preservation. However, the moderate moisture reduction suggests that complementary drying techniques, may be necessary for optimal preservation and extended shelf life. These findings provide valuable insights into the osmotic dehydration of *Arbutus unedo* fruits for developing improved preservation methods. The minimal sugar uptake and enhanced color retention are particularly promising for maintaining the fruit's quality and nutritional value. Future research could focus on combining osmotic dehydration with other preservation techniques and investigating the retention of bioactive compounds to further optimize the overall quality and shelf-life of *arbutus unedo* L. fruits.

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Author's declaration

The authors confirm no conflict of interest. Refas I: Conducting laboratory experiments, data analysis and visualization, writing paper's first draft. Amiali M: Advisory and proofreading. Belkhir S: Assistance in lab experiments and data analysis. The authors confirm that they read and approved the submitted version of the manuscript.

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