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**Research Paper / Araştırma Makalesi**

# Effect of Osmo- and Convective Dehydrofreezing on Energy Efficiency and Some Physicochemical Properties of Frozen Red Pepper

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## ABSTRACT

The effect of osmotic and convective drying treatments on main physicochemical properties of frozen sliced red peppers was investigated. Sliced red peppers were dried partially using either osmotic dehydration or convective hot air drying before freezing in an air blast freezer at constant air velocity (2 m/s) and temperature (-25°C). The center temperature of osmo- and convective dehydrofrozen peppers reached -25°C in about 105 min, while it took 270 min for control samples. Frozen samples were stored at -18±2°C for 60 days, and the color, texture, ascorbic acid, enzyme activities, antioxidant activity (DPPH and ORAC) and total carotenoid content of samples were monitored during storage. Results showed that skin puncture values of samples decreased by storage time. The ascorbic acid content of sliced red pepper decreased by both treatments and storage time. The antioxidant activity values of control samples were higher than those of convective dehydrofrozen and osmo-dehydrofrozen samples. Both partial drying treatments reduced carotenoid loss significantly. The losses in total carotenoid contents were 58.0, 47.5 and 46.9% at the end of the storage period in control, osmo-dehydrofrozen and convective dehydrofrozen peppers, respectively. Significantly lower energy was used in osmotic dehydration compared to convective drying since no heating required for osmotic dehydration. Moreover, pre-drying of sliced red pepper required one-third of lower energy for freezing compared to direct freezing. This study showed that osmo-dehydrofreezing can be an economical method for sliced red peppers production.

**Keywords**: *Capsicum annuum* L., Red pepper, Osmo-dehydrofreezing, Convective dehydrofreezing

## Osmotik ve Konvektif Kurutma Sonrası Dondurma İşleminin Enerji Verimliliğine ve Kırmızıbiberin Bazı Fizikokimyasal Özellikleri Üzerine Etkisi

## ÖZ

Ozmotik ve konvektif kurutma işlemlerinin kısmen kurutularak dondurulmuş kırmızıbiber dilimlerinin başlıca fizikokimyasal özelliklerine etkisi araştırılmıştır. Dilimlenmiş kırmızıbiberler, ozmotik dehidrasyon veya konvektif sıcak havayla kurutma sonrasında sabit hava hızında (2 m/s) ve sıcaklıkta (-25°C) bir dondurucuda dondurulmuştur. Dondurma işleminde kısmen kurutularak dondurulmuş biberlerin merkez sıcaklığı yaklaşık 105 dakikada -25°C'ye ulaşırken, kontrol örnekleri bu sıcaklığa 270 dakikada ulaşmıştır. Dondurulmuş örnekler 60 gün süreyle -18±2°C'de depolanmış olup, bu süreçte örneklerin renk, yapı, askorbik asit, enzim aktiviteleri, antioksidan aktivite (DPPH ve ORAC) ve toplam karotenoid içeriği takip edilmiştir. Yapı analiz sonuçları örneklerin kabuk delinme değerlerinin depolama süresi ile azaldığını göstermiştir. Dilimlenmiş kırmızıbiberin askorbik asit içeriği hem uygulamalar ile hem de depolama süresi ile azalmıştır. Kontrol örneklerinin antioksidan aktivite değerleri, osmo- ve konvektif kurutma ile kısmen kurutulduktan sonra dondurulmuş örneklerden daha yüksek bulunmuştur. Her iki kısmi kurutma işlemi de

karotenoid kaybını önemli ölçüde azaltmıştır. Kontrol örneği ile osmo- ve konvektif kurutma işlemleriyle kısmen kurutulduktan sonra dondurulmuş kırmızıbiberlerde depolama süresinin sonunda toplam karotenoid kayıpları sırasıyla %58.0, 47.5 ve 46.9 olarak tespit edilmiştir. Ozmotik dehidrasyon işleminde ısıtma gerekmediğinden, konvektif kurutmaya kıyasla daha düşük enerji girdisi hesaplanmıştır. Ayrıca dilimlenmiş kırmızıbiberin kısmi kurutma sonrası dondurma işleminde, doğrudan dondurmaya kıyasla üçte bir oranında daha düşük enerji kullanılmıştır. Bu çalışma, dilimlenmiş kırmızıbiber üretiminde ozmotik dehidrasyonla kısmi kurutma sonrası dondurma işleminin ekonomik bir yöntem olabileceğini göstermiştir.

**Anahtar Kelimeler:** Capsicum annuum L., Kırmızıbiber, Ozmotik kurutma, Konvektif kurutma

## INTRODUCTION

Pepper (*Capsicum annuum* L.) is in the family Solanaceae as potato, tomato, tobacco and petunia. The annual global production of pepper is about 30 million tons fresh fruits. Peppers are an excellent source of vitamin A, C and B. It also contains significant amount of magnesium, iron, thiamine, riboflavin and niacin [1]. It is widely used in production of paste, pickle, soups, ketchup, pizza, baby food, sausage, flavored cheese and stuffed olive etc.

Freezing is one of the most efficient methods to preserve food products in better qualities such as color, flavor, and nutritional value. On the other hand, it causes some losses especially in textural properties of the fruits and vegetables due to the formation of ice crystals. As a consequence of freezing the cellular membranes lose their semi-permeability and turgor [2]. Additionally, some biochemical deterioration reactions could occur especially during slow freezing [3]. Thus, prevention of textural losses and biochemical reactions is important. Therefore, dehydration pre-treatment have been applied before freezing to reduce the water content and limit ice crystal damage in foods [4]. Different drying techniques can be used as a pre-treatment. One of these techniques is osmotic dehydration that can be applied prior to freezing which is named as osmo-dehydrofreezing [5].

Osmotic dehydration is the phenomenon of partial removal of water from cellular materials by diffusion in a hypertonic solution [6, 7]. The mass transfer rate and efficiency of the osmotic process are dependent on various factors such as type and concentration of osmotic solution, solution temperature, ratio of the solution to food, pre-treatments, stirring and raw material properties [8-11]. As a result of osmotic dehydration prior to freezing, destruction of the integrity of cellular membrane is minimized and food quality is better preserved [12]. Moreover, osmotic pretreatment improves the texture characteristics [13, 14], reduces enzymatic browning [15], structural collapse and drip loss during thawing [16], energy demands for water freezing, costs of packaging, distribution and storage [17, 18].

There are many studies on the physicochemical quality of osmo-dehydrofrozen fruits and vegetables such as kiwi, pineapple, broccoli, rambutan, cucumber, apple, strawberry, potato, green pea, tomato, carrot, and apricot [19-21]. To the best of our knowledge, there is no study on osmo-dehydrofreezing of pepper. Therefore, in the current study, the effectiveness of osmo-dehydrofreezing on some quality characteristics and energy efficiency of red pepper (*Capsicum annuum* L.) for frozen sliced red pepper production were comparatively investigated to convective dehydrofreezing. Additionally, frozen peppers without any pretreatment, osmo-dehydrofrozen and convective dehydrofrozen peppers were stored at -18±2°C for 60 days, and some physical (water activity, color, texture) and chemical (moisture, ascorbic acid, antioxidant activity, carotenoid, peroxidase, and lipoxygenase enzyme activity) properties of pepper samples were determined during storage. Energy consumption during each of the treatments was also calculated.

## MATERIALS and METHODS

### Materials

Fresh red peppers (*Capsicum annuum* L.) without any physical damage were purchased from a local market. Undamaged peppers were stored at +4°C in the refrigerator until the treatments. For sample preparation, red peppers were cut into discs of 6.0±0.1 mm in thickness using laser slicing knife after removal of their stems and seeds. Then, samples were blanched in water vapor under atmospheric pressure for 5 min to inhibit enzymatic activity prior to treatments (osmo-dehydrofreezing, convective dehydrofreezing and direct freezing).

Methanol (%99.8), metaphosphoric acid, fluorescein sodium salt, 2,2-diphenyl-1- picrylhydrazyl (DPPH), Trolox®, 2,2'-azobis (2-amidinopropane) dihydrochloride (AAPH), acetone (99.5%), sodium phosphate monobasic monohydrate, sodium phosphate dibasic heptahydrate, guaiacol (99%), hydrogen peroxide (50%), linoleic acid (99%) and Tween 20 were obtained from Sigma-Aldrich (Germany).

### Osmotic Dehydration

Osmotic dehydration was performed in 660 mL jars. Sorbitol and NaCl mixture (2.41:1) were used as osmotic agents at a total concentration of 27g/100mL. Approximately 30 g of sample were immersed into 450 mL osmotic solution. Dehydration was carried out in a thermostatic water bath maintained at 25ºC under 140 rpm agitation for 90 min. At the end the osmotic drying treatment, samples were removed from the solution by draining, rinsed with distilled water, removed surface water with an absorbent paper. Then, the moisture content of osmotically dried red peppers was

determined. The conditions of osmotic dehydration were determined by preliminary studies to achieve 70.0% wet basis (w.b.) moisture content in the final product which was critical moisture content.

### Hot-Air Drying

Hot-air drying pretreatment of the sliced red pepper was performed in a tray dryer maintained at 60°C air temperature and 2 m/s air velocity. The samples were dried until 70.0% (w.b.) final moisture content.

### Freezing and Thawing

Freezing was performed in an air blast freezer (Ugur Ucf 10 Sf, İstanbul, Turkey) equipped with a fluidized bed air blower and three stage trays located on the blower. Freezing was achieved under constant air velocity (2 m/s) and temperature (-25˚C). The fresh sliced red peppers (as control) were also frozen under same condition. During the freezing, air and sample temperatures were periodically recorded using type K thermocouple (Extech SDL 200, USA) at 5-s intervals. Three of the temperature probes were placed in the center of sliced red pepper on each tray and the other probe was located inside the freezer to measure ambient temperature. After freezing, samples were stored at -25ºC for 2 months and physicochemical properties of the peppers were determined after frozen red pepper samples were thawed in a refrigerator at constant temperature (+4±1°C) overnight.

### Color Analysis

The color of sliced red pepper samples was measured using a colorimeter (UltraScan VIS HunterLab, USA) throughout the storage and expressed in *L* (darkness/whiteness), *a* (greenness/redness) and *b* (blueness/yellowness) [22]. It was carried out in three different parts of sliced red peppers and each value was reported as the mean of three replicates.

### Texture Analysis

Skin puncture force of the samples was conducted using a Texture Analyzer (TAXT plus Stable Microsystems, Godalming, Surrey, UK) using the method performed by [23] with slight modification. SMSP/5 probe was used in the analyses. For each treatment, skin puncture force was measured at three different samples on four different parts of each sample.

### Ascorbic Acid Content

Ascorbic acid content of the samples was determined by HPLC (Shimadzu, Tokyo, Japan) according to [24] with some modifications. For this purpose, approximately 2 g of sliced red peppers were homogenized in 8 mL metaphosphoric acid (6%) for a minute using a rotor stator homogenizer (IKA K18, Germany). Extracts were centrifuged (Sigma 3-18K, Germany) at 10000 rpm for 10 min at 4°C. The supernatant was filtered through a 0.45 µm filter and 20 µL of supernatant was injected into the HPLC system. Acidified MilliQ water (pH was adjusted to 2.2 with sulfuric acid) was used as mobile phase at 0.8 mL/min. Separation of the peaks was done in a Nucleosil 5-C18 column (Macherey Nagel, Germany). The detection and quantification of the ascorbic acid were performed at 245 nm using the external standard of L-ascorbic acid.

### Peroxidase Activity

Enzyme extract for the determination of peroxidase activity was prepared by homogenizing of 5 g of sliced pepper in 10 mL sodium phosphate buffer (67mM, pH 6). After centrifugation at 12000 g for 10 min, the supernatant was filtered using Whatman 1 filter paper and used as enzyme extract in peroxidase activity assay. The activity of peroxidase was determined according to the method of [25]. The reaction mixture was contained 450 µL sodium phosphate buffer (67mM, pH 6), 1.25 mL $H_2O_2$ (3 mM), 1.25 mL guaiacol (30 mM) and 50 µL enzyme extract. Changes in absorbance at 420 nm were measured at 30-s intervals, for 10 min using spectrophotometer (Shimadzu 160A, Japan). The slope of linear part in absorbance-time curve was used in the calculation of the peroxidase activity and it was expressed as the change in absorbance per minute in mL enzyme extract.

### Lipoxygenase Activity

Enzyme extract was prepared by homogenizing 5 g of sliced pepper sample in 15 mL sodium phosphate buffer (50mM, pH 7) and clarified by a similar procedure used in peroxidase enzyme extract. Lipoxygenase activity was determined using the spectrophotometric method performed by [26]. To prepare substrate solution, 0.5 g Tween 20 and 0.5 g linoleic acid (99%) were shaken in an ultrasonic bath until its color became white and transferred into a flask. 1 mL NaOH (2N) was added to the flask and completed to 25 mL with distilled water (degassed). After 25 µL enzyme extract, 25 µL substrate solution and 3 mL sodium phosphate buffer (200mM, pH 6.5) were mixed in a quartz cuvette, absorbance change was recorded at 234 nm, for 2 min at 6-s intervals. The slope of linear part in absorbance-time curve was used in the calculation of the lipoxygenase activity and it was expressed as the change in absorbance per minute in mL enzyme extract.

### Antioxidant Activity

#### Free Radical Scavenging Capacity (DPPH)

In order to prepare the extract used in antioxidant activity assays, 5 g sample was homogenized in 15 mL ethanol (80%) for a minute and extracted for 30 min at room temperature in an ultrasonic bath. Then, extracts were centrifuged at 7000 *g* for 10 min and the supernatant was transferred into a test tube. The residue was reextracted and centrifuged again at the same conditions and the supernatants were combined [27, 28].

Free radical scavenging activity of the extracts was determined using the DPPH method [29]. For this

purpose, 50 µL extract was added into 950 µL of DPPH (60 µM, dissolved in methanol) and incubated for 30 min at room temperature in a dark place. After incubation, absorbance was measured at 516 nm. The inhibition of DPPH by the extract was used in the calculation of free radical scavenging activity using the plot obtained from the standard solution of Trolox®. The free radical scavenging activity was expressed as g Trolox® equivalent/100 g dry matter.

### Oxygen Radical Absorbance Capacity (ORAC)

The determination of ORAC was performed according to [30]. For this purpose, 37 µL of phosphate buffer (75 mM, pH 7.4), 75 µL of the extract and 2750 µL of fluorescein (0.6136 µM) were mixed and incubated for 30 min at 37°C. 75 µL of AAPH solution (0.32 µM prepared in phosphate buffer) was then added. The fluorescence intensity was measured using fluorescence spectrophotometer (Cary Eclipse, Agilent Technologies, CA, USA) at excitation and emission wavelengths of 490 and 512 nm, respectively. Fluorescence intensities of prepared solutions with phosphate buffer (blank) and Trolox® standard (100 µM) were also determined. The oxygen radical absorbance capacity was expressed as µM Trolox® equivalent/g dm using following equation (1):

$$\text{ORAC (µM TE)} = Df \times \frac{S_{sample} - S_{blank}}{S_{Trolox} - S_{blank}} \quad (1)$$

### Total Carotenoid Content

Total carotenoid content was determined using the spectrophotometric method reported by [31]. 0.5 g of the sample was extracted with 5 mL acetone-water (9:1, v/v) and then centrifuged at 3000 rpm for 10 min at 4°C. The same treatment was continued until extract was colorless and obtained extracts were combined and made up to 50 mL with acetone-water mixture. The absorbance of final solutions was measured by a spectrophotometer (Shimadzu UV1800, Tokyo, Japan) against acetone at 472 nm. Total carotenoid contents of samples were calculated according to the following equation (2):

$$\text{Total carotenoid content (mg/100g fresh pepper)} = \frac{Abs \times 50 \times 100}{\text{sample weight}} \quad (2)$$

### Energy Efficiency

The energy consumption during hot-air drying of sliced red peppers was calculated using equation (3) described by [32]

$$E = A \times \upsilon \times \rho \times c_p \times \Delta T \times t \quad (3)$$

The energy consumption during osmotic drying of sliced red peppers was calculated using below equations (4, 5, 6, 7, 8) according to [33];

$$Q = Q_{OD} + Q_i + E_p \quad (4)$$
$$Q_{OD} = m_{mo} \times cp_m \times (t_r - t_0) + m_v \times cp_v \times (t_r - t_0) \quad (5)$$
$$Qi = W \times r \quad (6)$$
$$W = m_{m(OD)} \times (1 - (g_{m(OD)} / g_{mk})) \quad (7)$$
$$m_{m(OD)} = m_{mo} + m_w - m_{sm} \text{ (kg)} \quad (8)$$

The energy consumption during freezing of sliced red peppers was calculated using below equations (9, 10, 11, 12, 13, 14) used by [34], [35];

$$Q_1 = m \times c_{p1} \times \Delta T_1 \quad (9)$$
$$Q_2 = m \times L_g \quad (10)$$
$$L_g = 334 \times w \quad (11)$$
$$Q_3 = m \times c_{p2} \times \Delta T_2 \quad (12)$$
$$c_{p1} = 3.35w + 0.84 \quad (13)$$
$$c_{p2} = 1.26w + 0.84 \quad (14)$$

### Statistical Analysis

Treatments were performed triplicate and analyses were performed duplicate or triplicate. Results were subjected to variance analysis and appropriate means separation was conducted using Duncan's Multiple Range Test in SAS 9.0 (SAS Institute Inc., Cary, NC, USA).

## RESULTS and DISCUSSION

### Color

The color *L* values of all sliced frozen red peppers were between 31.09 and 33.73 during storage (Figure 1). During storage *a* and *b* values of frozen red peppers were between 29.18 and 34.02, 15.58 and 19.31, respectively (Figure 1). *a* and *b* values of control and convective dehydrofrozen samples were determined significantly ($p<0,05$) higher compared to osmo-dehydrofrozen samples. Control and convective dehydrofrozen samples presented higher color stability during frozen storage.

### Texture

Results showed that skin puncture forces of the frozen red peppers changed between 10.10 - 17.83 N and these values decreased during storage (Figure 2). Skin puncture force of control and osmo-dehydrofrozen samples were found to be similar but higher than convective dehydrofrozen samples. In a similar study, it was determined that the skin puncture values of the samples frozen after osmotic drying were high [21]. The researchers explained these differences in skin puncture force can be related to the increasing turgor pressure in the cell. In another study, it was reported that since the water content before freezing in the dehydrofreezing process decreases, the texture of the product will be less damaged by the less amount and small size of ice crystals [36]. Additionally, during the storage, skin puncture values were significantly different ($p<0.05$) in the control and convective dehydrofrozen samples.

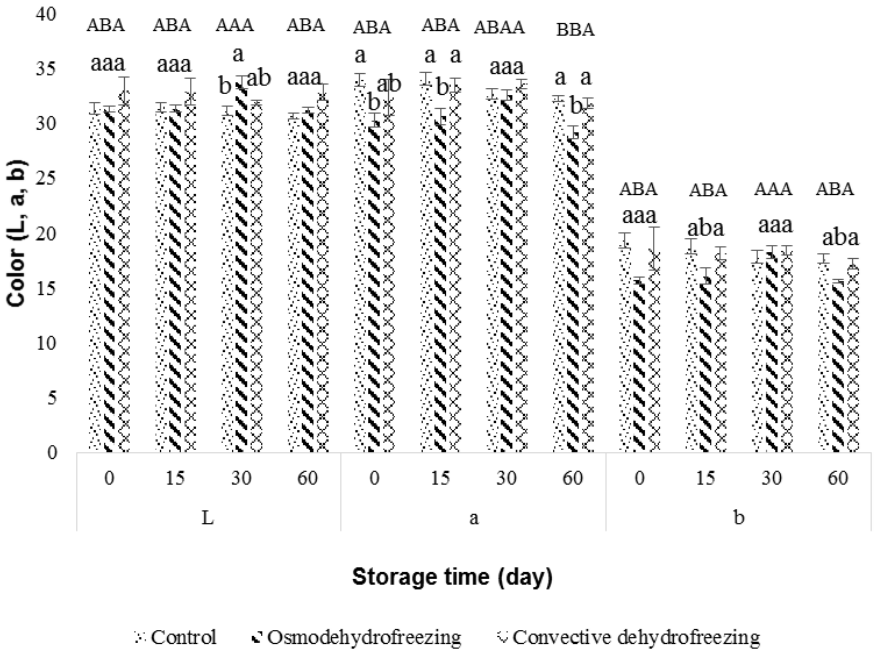


Figure 1. Changes in the color values of frozen red peppers during storage
The *different lowercase letters* (a–c) in the same storage time indicate significant differences within different treatments ($p<0.05$). The *different capital letters* (A–C) in the same treatment indicate significant differences within different storage times ($p<0.05$).

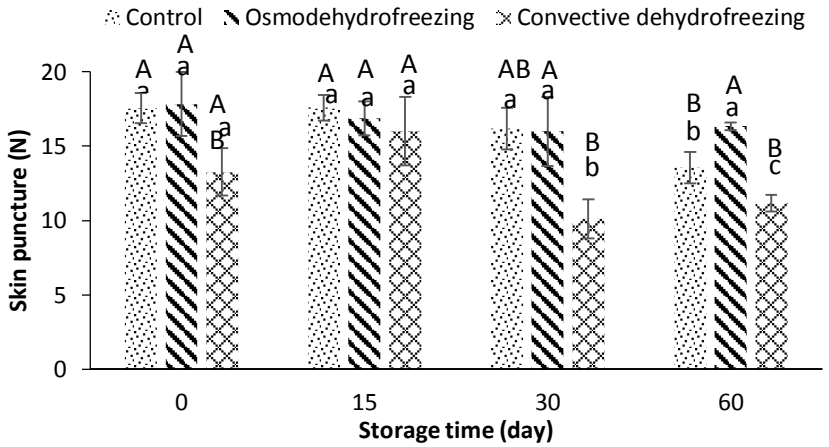


Figure 2. Changes in the skin puncture forces of frozen red peppers during storage
The *different lowercase letters* (a–c) in the same storage time indicate significant differences within different treatments ($p<0.05$). The *different capital letters* (A–C) in the same treatment indicate significant differences within different storage times ($p<0.05$).

## Ascorbic Acid Loss

The highest ascorbic acid loss was determined in osmo-dehydrofrozen red peppers. This could be related to the diffusion of ascorbic acid to the osmotic solution as well as chemical degradation during the osmotic dehydration process. Similar results were also reported by several researchers especially when applying high temperatures during dehydration [37-40]. Additionally, hot air-drying causing degradation of high amount of ascorbic due to oxidation reactions [41-44].

The ascorbic acid contents of frozen red peppers during storage were given in Figure 3. Storage test results revealed that, 78.16%, 84.32% and 97.53% of ascorbic acid was degraded at the end of 60 days of storage for the control, convective dehydrofrozen and osmo-dehydrofrozen samples, respectively. The ascorbic acid content of control and convective dehydrofrozen samples was similar to the initial content until the 15$^{th}$ day of the storage. However, a significant decrease in ascorbic acid content was determined at longer storage period. On the other hand, the amount of ascorbic acid in the osmo-dehydrofrozen samples steadily decreased from the beginning of the storage. At the end of the

storage, the highest amount of ascorbic acid was determined in control samples, while the osmo-dehydrofrozen peppers had the lowest ascorbic acid content.

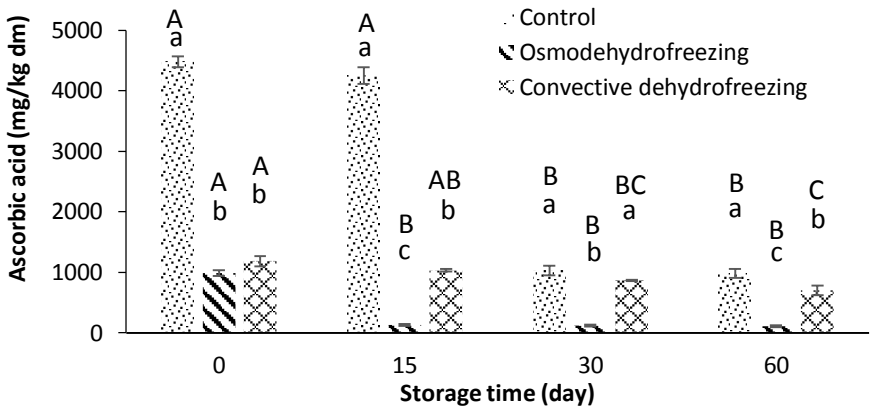


Figure 3. Changes in the ascorbic acid content of frozen red peppers during storage
The *different lowercase letters* (a–c) in the same storage time indicate significant differences within different treatments ($p<0.05$). The *different capital letters* (A–C) in the same treatment indicate significant differences within different storage times ($p<0.05$).

There are several studies on the loss of ascorbic content of frozen red pepper during storage. In a study, it determined that the ascorbic acid loss was 40% at the end of 30 days stored at -18°C [45]. However, in another study, higher ascorbic acid loss (97%) was reported at -22°C stored frozen peppers for 30 days [46]. The variations in the studies could be related to the variety of pepper, pretreatments, and chemical composition of the samples.

## Peroxidase Activity

Results indicate that peroxidase enzyme was inactivated with the blanching of the samples. Additionally, no peroxidase enzyme activity was determined in the samples during storage period which indicates regeneration of peroxidase did not occur during storage.

## Lipoxygenase Activity

The highest lipoxygenase activity [22.59 ΔAbs/(min.mL)] was determined in osmo-dehydrofrozen peppers which were followed by control and convective dehydrofrozen samples, respectively. The lowest lipoxygenase activity [15.35 ΔAbs/(min.mL)] of the convective dehydrofrozen samples can be related to the partial inactivation of enzymes due to applied heat during hot air drying.

The lipoxygenase activity in all frozen sliced red peppers decreased by the storage (Figure 4). Similarly, [47] showed that lipoxygenase activity of blanched green bean samples decreased during storage at -18°C. Additionally, this decreasing trend was signified in pre-dried samples. Therefore, it was interpreted that partial drying treatments reduced the loss of carotenoids catalyzed by lipoxygenase enzyme. At the end of the storage, pretreated samples had lower lipoxygenase activity compared to the control sample.

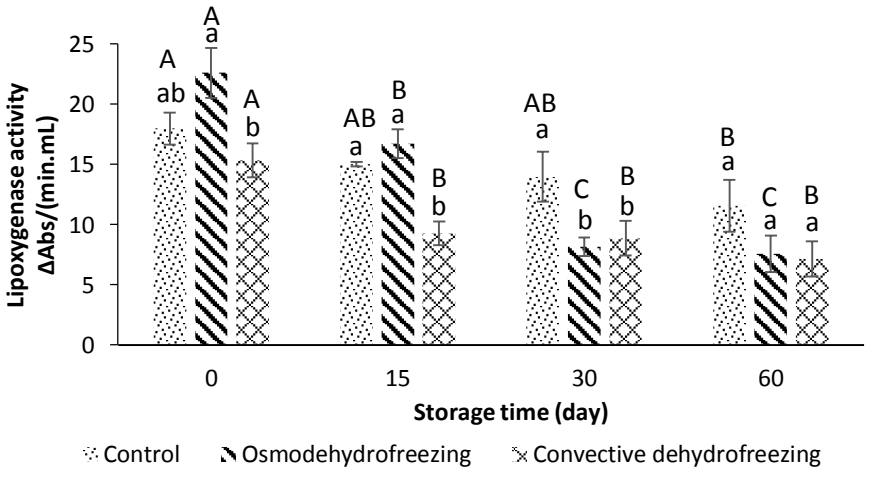


Figure 4. Changes in the lipoxygenase activity of frozen red peppers during storage
The *different lowercase letters* (a–c) in the same storage time indicate significant differences within different treatments ($p<0.05$). The *different capital letters* (A–C) in the same treatment indicate significant differences within different storage times ($p<0.05$).

## Antioxidant Activity

The antioxidant activity of samples was determined by DPPH radical scavenging activity and ORAC methods. According to DPPH and ORAC method, the antioxidant activity of the frozen red peppers was determined between 2.33-11.94 g Trolox® equivalent/100g dm and 64.49-197.50 µM Trolox® equivalent/g dm, respectively. For both methods, the highest antioxidant activity was determined in control peppers and followed by convective dehydrofrozen and osmo-dehydrofrozen samples, respectively (Figure 5-6). The lowest antioxidant activity of the osmo-dehydrofrozen peppers could be related to the diffusion of phenolic compounds with antioxidant activity in red peppers into the osmotic solution. Additionally, these compounds may undergo structural changes due to oxidation especially during hot air drying. It was observed that the antioxidant activities of the samples changed significantly ($p$<0.05) depending on the treatment and storage time.

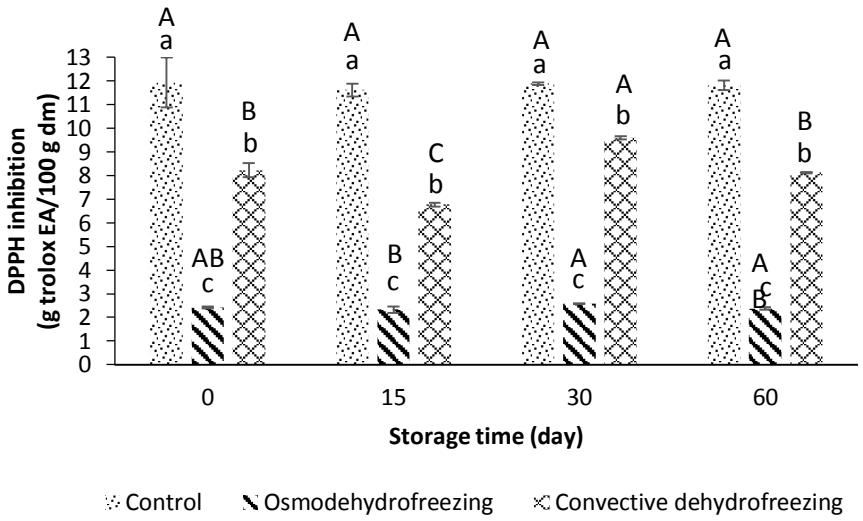


Figure 5. Changes in the antioxidant activity (DPPH radical scavenging activity) of frozen red peppers during storage
The *different lowercase letters* (a–c) in the same storage time indicate significant differences within different treatments (p<0.05). The *different capital letters* (A–C) in the same treatment indicate significant differences within different storage times (p<0.05).

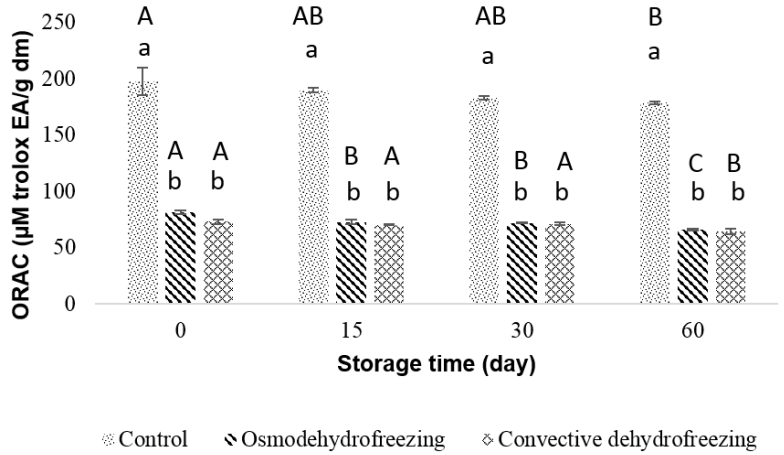


Figure 6. Changes in the antioxidant activity (ORAC) of frozen red peppers during storage
The *different lowercase letters* (a–c) in the same storage time indicate significant differences within different treatments (p<0.05). The *different capital letters* (A–C) in the same treatment indicate significant differences within different storage times (p<0.05).

## Total Carotenoid

Total carotenoid content (20.87 mg/100 g fw) of control samples was higher than the dehydrofrozen samples soon after processes (Figure 7). This can be explained by the degradation of carotenoids and pigment migration to solution during osmotic drying. Percent carotenoid loss was calculated as 57.97, 47.48, 46.93% control, osmo-dehydrofrozen and convective dehydrofrozen samples at the end of the storage period, respectively. This could be relate to the lipoxygenase activity of the samples since lipoxygenase enzyme is catalyzing the degradation reactions of carotenoids [48]. Hence, results showed that lipoxygenase activity of control samples was higher than other samples during storage.

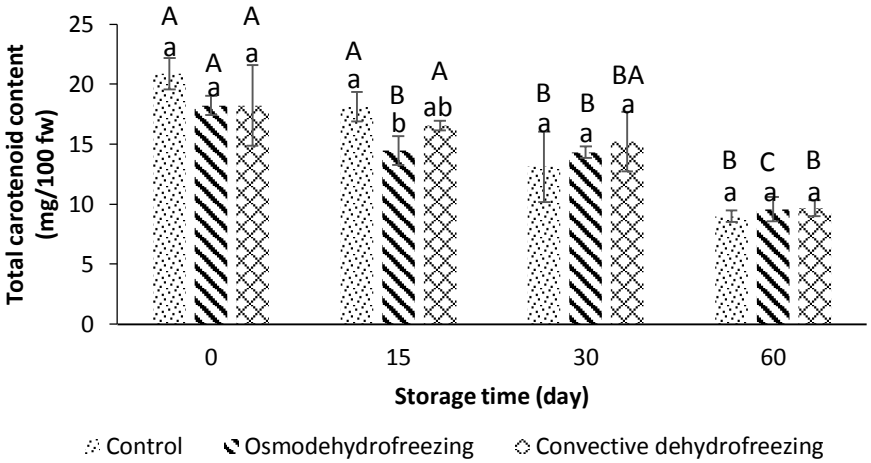


Figure 7. Changes in the total carotenoid content of frozen red peppers during storage
The *different lowercase letters* (a–c) in the same storage time indicate significant differences within different treatments ($p<0.05$). The *different capital letters* (A–C) in the same treatment indicate significant differences within different storage times ($p<0.05$).

## Energy Efficiency

Coefficients used to calculate energy consumption during osmotic dehydration and hot air drying of red peppers was given in Tables 1 and 2, respectively. QOD value was accepted zero since osmotic dehydration was done at room temperature.

Table 1. Coefficients used to calculate energy consumption during hot air drying

| Equation constant | Value |
|---|---|
| A | 1 ($m^2$) |
| υ | 2 (m/s) |
| ρ | 1.059 ($kg/m^3$) |
| $c_p$ | 1.007 (kJ/kg.°C) |
| ΔT | 15 (°C) |
| t | 3600 (s) |
| E | 23034.52 (kJ/kg) |

Table 2. Constants used to calculate energy consumption during osmotic drying

| Equation variables | Value (kg) |
|---|---|
| $m_{mo}$ | 0.45 |
| $m_w$ | 0.0108 |
| $m_{sm}$ | 0.0033 |
| $g_{m(OD)}$ | 0.12 |
| $g_{mk}$ | 0.27 |

Table 3. The amount of energy consumption during osmotic drying

| Stages | Energy (kJ/kg) |
|---|---|
| Qi | 587.2 |
| Ep | 360.0 |
| Q | 947.2 |

Table 4. The removal energy from red pepper slices during freezing processes (frozen directly, osmodehydrofreezing and convective dehydrofreezing)

| Treatments | Energy (kJ/kg) |
|---|---|
| Convective dehydrofreezing | 371.91 |
| Osmodehydrofreezing | 368.90 |
| Control | 1164.49 |

When comparing the amount of energy consumption during pre-drying processes, approximately 25-fold energy is required for convective drying (23034.5 kJ/kg) of red pepper slices in comparison to osmotic dehydration (947.2 kJ/kg). In addition, 3 times higher energy must be removed for freezing of control samples (1164.49 kJ/kg) than dried samples (368.90-371.91 kJ/kg) (Tables 3 and 4).

## CONCLUSIONS

Sliced frozen red pepper is used in preparing several meat and vegetable meals, sauces, pizzas, salads in restaurants, hotels, caterings, or houses. In this research, it was aimed to reduce energy consumption during freezing process of sliced frozen red peppers by applying convective pre-drying and osmotic dehydration. Additionally, some physicochemical properties were tested comparatively to directly frozen peppers. According to energy consumption calculations, osmotic dehydration was more advantageous than convective pre-drying. On the other hand, convective pre-drying was more successful in preserving physical and chemical quality characteristics of sliced red peppers. Moreover, pre-drying of sliced red pepper required one third of lower energy for freezing compared to direct freezing. Results indicated that osmotic dehydration is an economical alternative processing step for sliced

frozen red pepper. Nowadays, it is thought that osmotic dehydration can be an alternative to convective drying in the production of dehydrofrozen products. In addition, it will be possible to increase production by consuming less energy by semi-drying before freezing in frozen pepper production. For this reason, it is thought that osmotic drying is a preferable method in terms of energy efficiency and product quality for dehydrofrozen products. However, further studies are needed to prevent the diffusion of bioactive compounds to the osmotic solutions.

## NOMENCLATURE

| | |
|---|---|
| A | cross-sectional area of drying chamber ($m^2$) |
| $c_p$ | specific heat of the air (kJ/kg×°C) |
| $cp_m$ | specific heat of osmotic solution (kJ/kg×K) |
| $cp_v$ | specific heat of pepper (kJ/kg×K) |
| $c_{p1}$ | the specific heat in the temperature above the freezing point of the pepper (kJ/kg×K) |
| $c_{p2}$ | specific heat in the temperature below the freezing point of the pepper (kJ/kg×K) |
| Df | dilution factor, |
| E | total energy (kJ/kg) |
| $E_p$ | the mechanical energy required for the pump (kJ) |
| $g_{m(OD)}$ | experimentally measured total solids in the solution after osmotic drying |
| $L_g$ | freezing latent heat of pepper (kJ/kg) |
| m | amount of frozen pepper (kg) |
| $m_{mo}$ | amount of osmotic solution (kg) |
| $m_{m(OD)}$ | the amount of the solution after osmotic drying (kg) |
| $m_{sm}$ | the amount of dry matter of the solution (SG) (kg) |
| $m_v$ | amount of the red pepper (kg) |
| mw | the amount of moisture removed from fruits (WL) (kg) |
| Q | total energy consumption during osmotic drying (kj) |
| $Q_i$ | energy consumption for evaporation of osmotic solution (kJ) |
| $Q_{OD}$ | energy consumption for heating during osmotic drying (kJ) |
| $Q_1$ | the energy required for the temperature of pepper to decrease to the freezing point (kJ/kg) |
| $Q_2$ | the energy at the freezing point (kJ/kg) |
| ρ | air density ($kg/m^3$) |
| R | water-vapor change heat (kJ/kg) |
| $S_{sample}$ | fluorescence intensity of sample |
| $S_{blank}$ | blank |
| $S_{Trolox}$ | Trolox |
| t | drying time (s) |
| $t_r$ | temperature of osmotic solution (°C) |
| $t_0$ | ambient temperature (°C) |
| υ | air velocity (m/s) |
| W | the amount of water that is removed from the osmotic solution by evaporation (kg) |
| w | the water content of pepper (g/100g). |
| ΔT | temperature difference (°C) |
| $\Delta T_1$ | difference in temperature between initial temperature and freezing temperature of pepper (°C) |
| $\Delta T_2$ | difference between the freezing point and the final temperature (-25°C) of the pepper |

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