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Araştırma Makalesi (Research Article)

Effects of Freezing Rate on The Quality of Cherry Tomatoes**

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Quality,
Quick freezing,
Slow freezing.

Abstract: In this study, the effects of different freezing rates on some physical and chemical quality properties of cherry tomatoes were investigated. Cherry tomatoes were frozen slowly at -18°C at the freezer section of the home type refrigerator and quickly at -30°C in the modified freezer cabinet which is capable of blowing air at a speed of 1.2 m/s at -30°C , designed and produced by Bosch und Siemens Hausgerate GmbH (Çerkezköy, Turkey). The freezing rates were calculated on the bulk basis of the samples in the middle, bottom and top positions. The freezing rate in the middle for -30°C found as 1.55 ± 0.16 (cm/h) which was slow freezing and 0.11 ± 0.01 (cm/h) for -18°C between 4 and -15°C which was in the range of quick freezing. Drip loss, total dry matter content, total soluble solid content ($^{\circ}\text{Brix}$), color values, pH, ascorbic acid, total phenolic content, titration acidity and lycopene were investigated for cherry tomatoes frozen at different rates. Drip loss values were $11.01 \pm 0.21\%$ for quick frozen cherry tomato samples and $19.95 \pm 0.44\%$ for slow-frozen samples. The decrease in $^{\circ}\text{Brix}$ value of slow frozen sample was more than quick frozen samples. Brightness and a/b values of the quick frozen tomatoes were better compared to the slow frozen ones. Ascorbic, phenolic and lycopene contents were found higher in quick frozen sample.

Kiraz Domateslerin Kalitesine Donma Hızının Etkileri

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Anahtar kelimeler

Kiraz domates,
Modifiye dondurucu,
Kalite,
Hızlı dondurma,
Yavaş dondurma.

Öz: Bu çalışmada farklı hızlarda dondurulmuş kiraz domatesinde donma hızının bazı kalite özellikleri üzerine etkisi araştırılmıştır. Kiraz domatesler, ev tipi buzdolabının dondurucu bölümünde -18°C 'de ve 1.2 m/s hava hızına sahip Bosch ve Siemens (Hausgerate GmbH, Çerkezköy, Türkiye) tarafından üretilen modifiye dondurucu kabinde ise -30°C 'de dondurulmuştur. Donma hızları, farklı konumlardaki örnekler için ölçülmüştür. -30°C 'de orta nokta donma hızı 1.55 ± 0.16 (cm/saat) olarak hızlı donma sınıfında saptanmıştır. -18°C 'de ise orta nokta donma hızı 0.11 ± 0.01 (cm/h) bulunmuş ve yavaş donma olarak belirlenmiştir. Farklı hızlarda donmuş olan kiraz domateslerin damlama (sızıntı) kaybı, toplam kuru madde, suda çözünür kuru madde ($^{\circ}\text{Briks}$) miktarları, renk değerleri, pH, askorbik asit, toplam fenolik, titrasyon asitliği ve likopen miktarları incelenmiştir. Damlama kaybı değerleri hızlı dondurulmuş kiraz domates örnekler için 11.01 ± 0.21 , yavaş dondurulmuş örnekler için 19.95 ± 0.44 bulunmuştur. Yavaş hızda dondurulmuş örneklerde $^{\circ}\text{Briks}$ değerindeki azalma, hızlı dondurulmuş örneklere göre daha fazla olmuştur. Parlaklık ve a/b değerleri hızlı dondurulmuş domates örneğinde yavaş dondurulmuş örneklere kıyasla daha fazla saptanmıştır. Askorbik asit, fenolik ve likopen içeriği hızlı dondurulmuş örneklerde daha yüksek bulunmuştur.

**Çalışma "Farklı Hızlarda Dondurulmuş Kiraz Domateslerin Fiziksel Kalite Özelliklerinin Belirlenmesi" konulu Lisans Bitirme tezinden üretilmiştir.

1. Introduction

Fruits and vegetables contain approximately 95% of water. Because of the high level of water content, the rate of degradation reactions in fruits and vegetables is high. This situation increases the significance of preservation techniques (Demiray and Tülek, 2010). Freezing is one of the oldest and most common methods for long-term preservation of food samples especially for the fruits and vegetables. The freezing process is a combination of the beneficial effects of low temperatures at which microorganisms cannot grow, chemical reactions are reduced, and cellular metabolic reactions are delayed (Delgado and Sun, 2000). Nutrient losses can be kept to a minimum level as 1-3% by freeze storage technique and also they are converted into standard and easy to prepare products which can be consumed every season (Karabağlı and Alpkent, 1998; Anonymous, 2009).

During freezing of the food tissue, ice crystals are formed at extracellular and intracellular spaces. Crystallization continues particularly in extracellular spaces or it can proceed in intracellular spaces as well depending on the freezing rate. If the applied speed was high during freezing, small ice crystals are formed; in cases where the freezing rate was low, larger and fewer ice crystals were formed (Sun, 2015). For these reasons, slower freezing results in more damage to the cells (Erickson and Hung, 2012). In quick freezing process without destroying the cell membrane and without allowing cytoplasmic content to come out from the outside of the cell, whether vegetable or animal origin; cell membranes, cytoplasm and nuclei are preserved. Thus, vitamins, fats, carbohydrates, proteins, minerals and aromatic substances can be preserved without any loss (Çetin et al., 2003).

Foods according to freezing rates were collected in 4 main groups. In the first group, the freezing rate does not have any effect on the quality of the food. For example, peas harvested in the late maturity period with high dry matter content and greasy meat are included in this group. The freezing rate of these foods are not significantly effective on the quality. In the second group, the freezing rate should not fall below the minimum speed (0.2-1 cm/h). The higher freezing rate does not make the quality better. Examples for this group are fish, lean meat, starch and flour based meals. In the third group, the quality of the food is protected with increasing freezing rate. Fruits and vegetables such as strawberries, carrots, fresh beans which require a freezing rate of 1-5 cm/h or higher are included in this group. In the fourth group, there are the foods that have significant improvement in quality with increasing freezing rate. However, due to the formation of temperature tension in the food in this group, cell structures are damaged. Tomatoes and cucumbers are the vegetables that belong to this group. The rate of the freezing process directly affects the quality of the product, affecting the size and distribution of the ice crystals formed during the freezing process significantly (Leygonie et al., 2012). Turkey is among the tomato producing countries due to climatic conditions and production has a big role in the economy (Bayram and Gülser, 2018). Cherry tomatoes which are in the last group affected from the freezing rate mostly, have higher dry matter than tomato fruits and higher levels of soluble solids. Moreover, due to high sugar and organic acid content, cherry tomatoes have a more sweet and aromatic flavor (Raffo et al., 2002).

The purpose of this study was to determine some physical and chemical properties of cherry tomatoes frozen at different rates. In the study, cherry tomatoes were frozen at two different temperatures, at -18°C in home type and at -30°C in a modified freezer cabinet, and freezing rates were determined. Drip loss, pH, water soluble dry matter (Brix°), total dry matter, color values, ascorbic acid, total phenolic content, titration acidity and lycopene contents were compared for each group.

2. Materials and Methods

2.1. Material

Cherry tomatoes (*Solanum lycopersicum* L.) were supplied from a local market belongs to the same harvest of NEBBA (Agricultural products, distribution and Marketing, Serik Antalya, Turkey) at the last ripening stage with original red color and were stored at +4°C with 90% relative humidity in the Fruit and Vegetable Processing Pilot Plant, Department of Food Engineering, before the freezing process. The samples with a diameter of 3.5 cm were washed with +5°C mains water then dried with filter paper for removing the water from the surface prior to freezing.

2.2. Methods

2.2.1. Processing methods

Cherry tomatoes were washed, eliminated then cut into two pieces and separated into 3 groups: raw material group (control), quick frozen group at -30°C with air flow rate of 1.2 m/s and slow frozen group at -18°C without air blowing. The freezing process was performed in 2 replicates, and analyses were replicated at 3 times.

2.2.2. Freezing methods and determining freezing rates

Slow freezing was achieved in home type freezer at -18°C for 8.68 without blowing air to reach the center point of -15°C. Modified freezer cabinet which was designed and produced by Bosch und Siemens Hausgerate GmbH (Çerkezköy, Turkey) used for quick freezing. This unit situated in the freezer section of home type refrigerator has an air blowing speed of 1.2 m/s at -30°C for 1.5 h to reach the center point temperature of -15°C. The temperatures were set and measured with the pretreatments. The quick freezing part was cooled with blowing air at a temperature of -35°C with a rate of 1.2 m/s. When the cabin cooled temperature was constant and then the samples and thermocouples were placed and temperature data was recorded.

Cherry tomatoes were placed in a stainless steel perforated basket measuring 20 cm x 11 cm x 6 cm for freezing at -30°C; 17 cm x 12 cm x 11 cm for freezing at -18°C. In each freezing process, approximately 400 grams of tomatoes with a diameter of 3.5 cm were placed in the basket after halved. During the entire freezing process, temperature changes occurring in the products and in the freezing environment were monitored by T-type thermocouples which were fixed to the top, bottom and center points of the individual samples. The rates were calculated taking into account the measurements of the length-cut piece of a cherry tomato. The time required to decrease the temperature of the product from its initial value to a target value at its thermal center can be described as freezing time. The freezing rate was defined for the foods as the time to reach the temperature of -15°C from 0°C at the cold point. In this study also the freezing rate from +4°C to -15°C was calculated and compared. The freezing rate was calculated as the ratio of the distance of the center point in the frozen sample to the freezing time given in the Eq. 1 (Cemeroğlu, 2003). The distance was the radius matching the characteristic length. It was carried out according to the speed ranges in Table 1.

$$V=L/t \quad (\text{Eq.1})$$

V: freezing rate (cm/h)

L: the minimum distance from the thermal center to surface of the food (cm)

t :nominal freezing time (h)

2.3. Analysis methods

Raw materials as control, quick freezing (-30°C) samples and slow freezing (-18°C) samples were compared statistically for the physical (drip loss, pH, total soluble solid content, total dry matter and color) and chemical (ascorbic acid, total phenolic, titration acidity and lycopene content) quality properties. Samples were thawed at +4°C in refrigerator before the analyses. All experiments were performed in triplicate.

2.3.1. Physical analysis

2.3.1.1. Drip Loss

One cherry tomato sample (10.89±1.00) was thawed at +4°C for 12 hours. The amount of liquid removed from the sample after thawing was calculated as percentage (Moraga, 2006).

2.3.1.2. pH assay

The pH values of the cherry tomato samples (20°C) were measured using a pH meter (Inolab WTW) (Anonymous, 1995).

2.3.1.3. Determination of total soluble solid content

Total soluble solid (TSS) contents of samples were determined using a refractometer (Kruss, Germany) at 20 °C (Anonymous, 1995).

2.3.1.4. Determination of total dry matter

Total dry matter (TDM) values were determined using an infrared moisture equipment (MOC63u, Shimadzu Inc. Japan).

2.3.1.5. Color estimation

In the Hunter colorimeter, the L*(lightness), a* (redness and greenness) and b* (blueness-yellowness) values after calibration of white standard (Y=93.9, x= 0.313, y=0.321) were determined. The total color difference (ΔE), chromatic difference (ΔC) and Hue angle values were calculated according to the following equations given below. In the calculations, the color values of the raw material (control) for the related sample were taken as reference values.

$$\Delta E = \sqrt{[(L^* - L^*_{ref})^2 + (a^* - a^*_{ref})^2 + (b^* - b^*_{ref})^2]} \quad (1)$$

$$\Delta C = \sqrt{[(a^* - a^*_{ref})^2 + (b^* - b^*_{ref})^2]} \quad (2)$$

$$\text{Hue angle} = \tan^{-1}(b^*/a^*) \quad (3)$$

2.3.2. Chemical analysis

2.3.2.1. Ascorbic acid analysis

Analyses were made by the spectrophotometric method of Hışıl (2004). Standard curve and sample was prepared. A series of standard solutions were prepared at different concentrations by using the stabilizer solution (4% oxalic acid, Merck, Germany), the dye solution (2,6-dichloroindophenol, Na salt) and the ascorbic acid solution. The standard curve showing the concentration of vitamin C against absorbance at a wavelength of 518 nm has been obtained. Then 10 ml of sample and 90 ml of stabilizer solution were mixed with stirring. In 2 separate test tubes, 1 ml of sample was mixed with 9 ml of purified water and 9 ml of dye solution. The amount of ascorbic acid in 100 ml was calculated by the concentration determined from the standard curve which is against the absorbance value of the sample.

2.3.2.2. Total phenolic content

The samples were crushed with a blender (Arzum Ar 1092 Chopper, Turkey). 2 g of blended sample was treated with 20 mL of (50:50 v/v) ethanol:water mixture (Merck, Germany) for total phenolic content extraction procedure. Then, samples were homogenized for 1 min using homogenizer (IKA T-18 Ultra-Turrax Homogenizer, Germany) at 14000/min for 1 minute. Following the extraction, samples were centrifuged at 15000 rpm and 4°C (Sigma 1-16 K, Germany) for 10 min to remove the solid fraction (Bulut, 2015). The filtered extract was used for the analysis. 5 ml of Folin-Ciocalteu (10%, v/v, Merck, Germany) and 15 ml of NaHCO₃ (20% w/v, Merck, Germany) are added to 1 ml of extract. After completing to 100 ml, the mixture was filtered and stored 2 hours in the dark. Absorbance values were recorded at 760 nm and calculated by taking the concentration corresponding

to the absorbance from the standard plot which was prepared by the addition of folin solution and NaHCO_3 to different concentrations of the stock gallic acid solution (Franke et al., 2004).

2.3.2.3. Titration acidity

Acid contents of samples were determined by colorimetric titration method. 10 g of the samples were taken and completed to 100 ml. After filtration, 10 ml of the filtrate was titrated with 0.1 N NaOH solution (Merck, Germany) up to the color changing point of phenolphthalein indicator. Acidity values were calculated from the spent NaOH (Anonymous, 1995).

$$\text{Acidity (\%)} = ((V \times F \times E) / m) \times 100 \quad (4)$$

V: volume of the 0.1 N NaOH solution spent in the titration (ml)

N: normality

E: equivalent acid

m: sample weight (g)

2.3.2.4. Lycopene content

Lycopene content was found according to the method Davis et al. (2003). 0.3 g sample, 0.3 g starch and 20 ml acetone homogenized for 40 sec. with the homogenizer (Ultra-Turrax, Ika-Werke, Germany), then centrifuged at 3000 rpm for 3 minutes (CFC free Universal Hettich Zentrifugen, Germany), the absorbance of liquid phase was determined by spectrophotometer at 503 nm (Varian Cary 50 Scan, Australia). Lycopene amount was calculated with Equation 5.

$$\text{Lycopene content (\mu g/g)} = (A_{503} \times 62.43) / \text{sample amount (g)} \quad (5)$$

2.3.3. Statistical analyses

Results of analyses were statistically analyzed by ANOVA using the software SPSS 18 (SPSS Inc., Chicago, IL, U.S.A.) with the Duncan test to evaluate differences between treatments at a level of significance $P < 0.05$. Each experiment was repeated 3 times.

3. Results

3.1. Changes in Freezing Rates of Tomato Samples

The freezing process at modified cabinet was completed in a much shorter time than domestic refrigerator, as expected. The freezing process was finished when each of the thermometers in the sample reached -15°C . The graphs of temperature changes with the aid of thermometers during freezing were as given in Figure 1 and Figure 2.

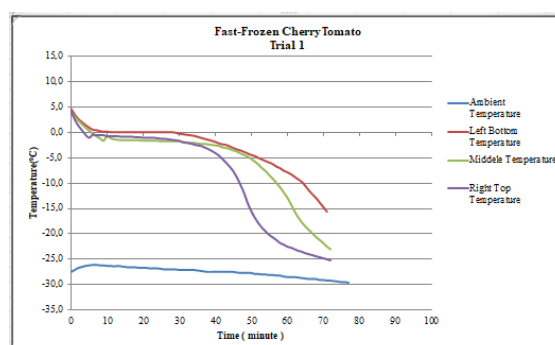


Figure 1. Graphs showing the temperature changes during the freezing of quick-frozen cherry tomatoes.

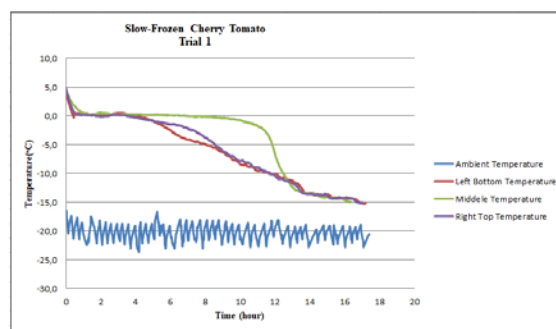


Figure 2. Graphs showing the temperature changes during the freezing of slow-frozen cherry tomatoes.

The rates were calculated taking into account the measurements of the length-cut piece of a cherry tomato. The evaluation of the freezing rate results was carried out according to the rate ranges in the Table 1.

The average rate of freezing for the cherry tomato samples were given in Table 2 and Table 3.

Table 1. Ranges used in rate evaluation

Freezing Type	Freezing Rate (cm/h)
Very slow	<0.2
Slow	0.2-1
Quick	1-5
Very quick	>5

Table 2. Freezing Rates of Cherry Tomatoes (-30°C)

Samples	Top		Middle		Bottom	
	0-(-15)°C	4-(-15) °C	0-(-15) °C	4-(-15) °C	0-(-15) °C	4-(-15) °C
Freezing rate (cm/h)	2.21±0.03	1.68±0.43	2.00±0.26	1.55±0.16	2.19±0.35	1.30±0.25

Table 3. Freezing Rates of Cherry Tomatoes (-18°C)

Sample	Top		Middle		Bottom	
	0-(-15) °C	4-(-15) °C	0-(-15) °C	4-(-15) °C	0-(-15) °C	4-(-15) °C
Freezing rate (cm/h)	0.12±0.04	0.10±0.02	0.18±0.05	0.11±0.01	0.13±0.01	0.10±0.01

The calculated values were compared with the speed ranges in Table 1. Freezing in the cabinet (-30°C) was classified as quick freezing. The rate in the top samples was more than others due to the fact that the bottom surface of the basket is in contact with the surface of the refrigerator and therefore the heat transfer mechanism is effective. In home type freezer (-18°C), freezing is classified as slow freezing. The freezing operation at -18°C is freezing at very slow speed according to freezing types in Table 1. Physical and chemical analyses for the slow and quick frozen samples were shown in the Table 4.

Table 4. Results of physical and chemical analysis (% or mg/kg dry basis (DB)).

Sample Groups	Drip Loss (%)	pH (20.1°C)	TSS (%;20.7°C)	TDM (%)	Titration Acidity (%)	Ascorbic Acid (mg/100g db)	Lycopene content (mg/kg db)	Total Phenolic Content (mg/kg db)
Raw Material	----	4.20 ^c ±0.01	3.75 ^a ±0.07	8.30 ^a ±0.21	4.19 ^a ±0.35	33.15 ^a ±0.36	67.21 ^a ±0.35	347.23 ^a ±0.70
Quick Frozen	11.01 ^b ±0.21	4.28 ^a ±0.01	3.58 ^b ±0.04	6.86 ^c ±0.10	4.00 ^b ±1.41	29.12 ^b ±2.25	61.24 ^b ±1.27	286.49 ^b ±1.00
Slow Frozen	19.95 ^a ±0.44	4.27 ^b ±0.02	3.42 ^c ±0.02	7.94 ^b ±0.11	4.15 ^b ±0.98	25.78 ^b ±3.17	59.67 ^c ±1.69	274.20 ^c ±3.43

a,b,c
 Different letters within columns are significantly different (P<0.05).

Drip loss values were $11.01 \pm 0.21\%$ for quick frozen cherry tomatoes and $19.95 \pm 0.44\%$ for slow frozen cherry tomato samples.

The pH values of the samples were found as 4.20 ± 0.01 for the raw material, 4.28 ± 0.01 for the quick frozen cherry tomato samples and 4.27 ± 0.02 for the slow frozen ones.

The difference between the samples for water soluble solid content values was statistically significant ($P \leq 0.05$).

Decreases were determined after freezing due to losses in ascorbic acid, but there was no significant difference between the titration acidities of control samples when applied different freezing rates and temperatures in freezing process ($P > 0.05$).

The ascorbic acid values of the cherry tomato samples were found as $33.15^a \pm 0.36$ mg/100 g for the raw material, $29.12^b \pm 2.25$ mg/100 g for quick frozen and $25.78^c \pm 3.17$ mg/100 g for slow frozen. The amounts of ascorbic acid in slow and quick frozen tomatoes had not been significantly changed compared to the raw material ($P > 0.05$).

In this study the total phenolic contents of the cherry tomato samples were found as $347.23^a \pm 0.70$ mg/kg for the raw material, $286.49^b \pm 1.00$ mg/kg for quick frozen and $274.20^c \pm 3.43$ mg/kg for slow frozen samples. Decreases were also observed in the amount of phenolics at two different temperatures during the freezing process.

Table 5. Color values of tomatoes.

	Raw Material (Control)	Quick-Frozen	Slow-Frozen
L*	$37.87^a \pm 0.04$	$36.14^b \pm 0.39$	$31.79^c \pm 0.23$
a*	$29.44^a \pm 0.15$	$28.07^b \pm 0.07$	$24.25^c \pm 0.39$
b*	$26.90^b \pm 0.54$	$27.93^c \pm 0.11$	$30.79^a \pm 0.49$
a*/b*	$1.09^a \pm 0.03$	$1.00^b \pm 0.01$	$0.79^c \pm 0.00$

a, b to c
 Different letters within lines are significantly different ($P < 0.05$)

The differences in L *, a * and b* values between frozen cherry tomatoes and control samples were statistically significant ($P \leq 0.05$). As a result of quick freezing, the brightness of samples was found to be higher than slow frozen samples. The b* value were lower in quick frozen products than that of slow frozen products.

4. Discussion and Conclusion

The difference between samples for drip loss was statistically significant ($P \leq 0.05$). As a result of quick freezing, the amount of water migrating from the frozen cell to the intercellular space was considerably less than the slow freezing. For this reason, quick freezing causes very little damage to the surface of the food by reducing drip losses (Erickson and Hung, 2012). Gonçalves et al. (2011) observed that frozen cells lost their water holding capacity over time as a result of being kept at -40°C , -20°C , -10°C and -5°C . In a study on frozen strawberries, it was also determined that loss of thawing was affected by freezing rate, cold storage time and storage temperature (Puksza and Palich, 2007).

Different freezing rates was not significantly effective on the pH values of the samples ($P > 0.05$), but the difference between the pH values was statistically significant ($P \leq 0.05$) when the control sample was compared with the frozen samples. The values in the study indicate that the cherry tomatoes undergoing freezing are suffering from acidity loss. In previous studies, it was reported that there was a decrease in acidity due to the loss of ascorbic acid during freezing and the pH value may increase due to the decrease in acidity (Sahari et al., 2004). However, it was observed that the freezing rate did not affect the pH values significantly ($P > 0.05$). Lisiewska and Kmiecik (2000), investigated the effect of freezing and storage periods on the chemical composition of cube-chopped tomatoes and found similar results to this study. The pH values of the samples stored at -40°C , -20°C and -30°C were found as 4.18, 4.26, 4.28 respectively. At another study, the pH values of tomatoes frozen at -33°C were determined as 4.27 (Uçurum, 2012).

Loss of total soluble solids in the samples of quickly frozen was less than the loss in the slowly frozen samples. Significant loss of water-soluble matter occurs in frozen vegetables as they lose water (Gonçalves et al., 2011). During slow freezing, ice crystals formed in many tissues outside

the cell, with fewer crystals and larger size. Even though ice crystals occurred between the cells in quick freezing, while ice crystals were occurring inside the cell, the water was bound to the place, and the cell was not broken down. In this way, the soluble dry matter content was better preserved by quick freezing.

The dry matter contents of quickly frozen samples were similar to the values of raw material. The reason for this condition was quick frozen samples have lower dry matter values than slow frozen samples because slow frozen samples during thawing losses more water so increase the dry matter/total weight ratio. When the freezing rate increased, smaller ice crystals were formed so that tissue damage was less and loss after thawing was less (Chassagne-Bercesté et al., 2009).

In a study, the effects of the physico-chemical properties of the potato mash were investigated. It was determined that the total dry matter (TDM) content of the frozen puree of -80°C was higher than the TDM of frozen puree at -24°C . Slow-frozen vegetables have more water loss as their cells are more damaged. With increasing water loss during thawing, the dry matter/total weight ratio also increases. Accordingly, the total dry matter content of potato mash was also increased proportionally (Alvarez et al., 2005).

Lisiewska and Kmiecik (2000), investigated the changes in chemical composition of tomatoes frozen at different temperatures during the freezing period. The amount of vitamin C was determined as 23.6 mg/100 g for the raw material, 22.9 and 22.7 mg/100 g for -20 and -30°C respectively. Ascorbic acid is easily affected by many external factors such as temperature, humidity, light, etc. Two criteria could be the reason of differences in the contents of ascorbic acids in samples; difference in freezing temperatures and different tensile forces on cherry tomato cells at different freezing rates. Besides, the level of ascorbic acid was significantly reduced during thawing period because it is a water-soluble vitamin. Ascorbic acid is oxidized in 3 different ways at freezing temperatures. These are; mild oxidation and aerobic pathways catalyzed by copper and iron. This vitamin can be oxidized with enzyme in fruit and vegetables (Jaffe et al, 1984; Bradbury and Singh 1986). Therefore, loss of ascorbic acid content can be occurred after freezing. Quick freezing better preserves ascorbic acid levels than slow freezing.

Lycopene belongs to the carotenoid family and have an importance role in human health so the preservation of this compound is necessary to inhibit loss of color and offflavor (Xianquan et al., 2005). In a study by Garciaa and Barrett (2005), the lycopene contents of tomatoes were varied between 55 mg/kg and 181 mg/kg for 9 different regions of California. In another study with 40 tomato varieties, it was found that the content of lycopene varied according to the tomato varieties and cherry tomatoes have the highest content of lycopene among the others (Kuti and Konuru, 2005). Lycopene content was decreased approximately by 11% in slow freezing and 8% in quick method compared to raw material. Similar to our results, Lisiewska and Kmiecik (2000) found the lycopene contents of tomatoes which were frozen at two different temperatures (-20 and -30°C) as 2.99 and 3.28 mg/100g, respectively. Additionally, Shi & Le Maguer stated the the importance of lycopene and explain the lycopene degradation during processing by isomerization and oxidation. They informed that thermal processing (bleaching, retorting, and freezing processes) generally cause some loss of lycopene in tomato-based foods.

Phenolic contents were significantly decreased after freezing as expected but this decrease was less in the quick freezing than slow freezing ($P \leq 0.05$). Phenolic compounds are also water-soluble, rendering them susceptible to leaching (Rickman et al., 2007). Phenolic substances such as pelargonidin, quercetin, elagic acid, and p-coumaric acid are known to be the compounds that decrease especially by freezing (Oszmianski et al., 2009). They also found that 4.5–33.6% of polyphenols were lost after freezing. Similarly, a decrease was found in phenolic compounds after freezing of raspberry and blackberry (Türkben et al., 2009). Puupponen-Pimia et al. (2003) reported that freezing on phenolic compounds of peas, cauliflower and potatoes caused an average loss of 20–30% dry weight. De Ancos et al. (2000), found that freezing process slightly affected total phenolic content in raspberry fruit. Losses in total ellagic acid content which ranged between 14 and 21% were attributed to the enzyme polyphenol oxidase released from the cell wall of the fruit during storage.

As a result of the slow freezing, the yellowness value was increased. The redness of quick frozen products was protected better than slow frozen products. These differences in L^* , a^* and b^* indicate that quick freezing preserves quality better than slow freezing. In a study where tomato and tomato products were used as a material, it was stated that there was a linear relationship between

lycopene quantities and a/b values (Davis et al., 2003). In this study, this ratio which is important for tomato products was determined higher in quick frozen samples. The difference between a/b values of the control samples and the frozen cherry tomatoes were statistically significant ($P \leq 0.05$). a/b value of frozen tomato samples decreased parallel to the loss of lycopene (Baysal et al., 2006). It has been also reported that color properties can change due to color loss via pigment displacement during quick freezing (Urbany and Horty, 1992).

When the results of this study were taken into consideration, the freezing applied at low temperatures increases the freezing rate and consequently the freezing time is shortened. When higher freezing rates were applied, the rate of damage to the sample can also decrease. The quality characteristics of cherry tomatoes were better preserved by quick freezing than slow frozen samples. It was determined that quick frozen samples showed similarity to fresh samples in terms of quality characteristics analyzed after freezing. It has been determined that the quick frozen sample groups had minimum loss of total dry matter, phenolic, ascorbic acid and better color characteristics than slow frozen samples. It has been found that lower drip loss provides better preservation of fruit and vegetable samples. The maturity status and other quality characteristics of the frozen raw material, for any fruit or vegetable, should be taken into account for optimizing the freezing rate, the temperature and post-freezing conditions.

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References

- Alvarez, M.D., Fernandez, C., & Canet, W. (2005). Effect of freezing/thawing conditions and long-term frozen storage on the quality of mashed potatoes, 85(14), 2327-2340 s.
- Anonymous. (1995). *AOAC. Official Methods of Analysis of AOAC International* (16th Ed.).
- Anonymous. (2009). *Dondurulmuş Sebze ve Meyve Üretimi. Mesleki Eğitim ve Öğretim Sisteminin Güçlendirilmesi Projesi*, Gıda Teknolojisi, Ankara.
- Artes, F., Conesa, M.A., Hernandez, S., & Gil, M.I. (1999). Keeping quality of fresh-cut tomato, *Postharvest Biology and Technology*, 17,153-162 s.
- Bayram, S., Gülser, F. (2018). Van İlinde Domatesin Yaygın Olarak Yetiştirildiği Alanların Toprak Özellikleri ile Domates Bitkisinin Beslenme Durumunun Belirlenmesi *YYU J Agr Sci* 28(3): 358-367 s.
- Baysal, T., Demirdöven, A., & Ersus, S. (2006). *Dondurulmuş domateslerin depolanması sırasında oluşan renk kayıplarının belirlenmesi ve önleme yöntemleri*, Türkiye 9. Gıda Kongresi, 599-602 s.
- Bradbury, JH.,& Singh, U. (1986). Ascorbic acid and dehydroascorbic of tropical root crops from south pacific. *J Food Sci* 51(4), 975-8, 987.
- Bugianesi, R., Giuffrida, F., & Quaglia, G. (2002). Nutritional value of cherry tomatoes lycopersicon esculentum cv. naomi fl harvested different at different ripening stages, *J. Agric. Food Chemistry*, 50, 6550-6556 s.
- Bulut, M. (2015). *Effect of Different Freezing Rates on The Texture and Quality Parameters of Selected Fruit and Vegetable a Thesis Submitted to the Graduate School of Natural and Applied Sciences of Middle East Technical University* .109 p. METU, Ankara, Turkey.
- Chassagne-Berces, S., Poirier, C., Devaux, M. F., Fonseca, F., Lahaye, M., Pigorini, G., Girault, C., Marin, M. & Guillon, F. (2009). Changes in texture, cellular structure and cell wall composition in apple tissue as a result of freezing, *Food Research, International* 42(7), 788-797s.
- Çetin B., Tipi B., Turhan Ş. & Akbudak, N. (2003). *Türkiye’de Dondurulmuş Sebze ve Meyve Sanayinin Ekonomik Yapısı ve Pazarlama Sorunları*, 16-92 s.
- Davis, A.R., Fish, W.W. & Weazie, P.P. (2003). A quick spectrophotometric method for analyzing lycopene content in tomato and tomato products, *Postharvest Biology and Technology*, 28, 425-430 s.

- De Ancos, B., Gonz'alez, E.M., & Cano, M.P. (2000). Ellagic acid, vitamin C and total phenolic contents and radical scavenging capacity affected by freezing and frozen storage in raspberry fruit. *Journal of Agricultural Food and Chemistry* 48, 4565– 4570.
- Demiray, E. & Tülek, Y. (2010). Donmuş muhafaza sırasında meyve ve sebzelerde oluşan kalite değişimleri, *Akademik Gıda*, 8 (2), 36-44 s.
- Delgado, A.E. & Sun, D.W. (2000). Heat and mass transfer for predicting freezing processes, a review. *Journal of Food Engineering*. 47, pp. 157-174.
- Erickson, M. & Hung, Y. C. (2012). *Quality in Frozen Food*, Freeze-Cracking, Chapman&Hall, New York, 92-100 s.
- Franke, S. I. R., Ckless, K., Silveira, J. D., Rubensam, G., Brendel, M., Erdtmann, B., & Henriques, J. A. P. (2004). Study of antioxidant and mutagenic activity of different orange juices. *Food chemistry*, 88(1), 45-55.
- Garcia, E., & Barrett, Feb. D. M. (2006). assessing lycopene content in california processing tomatoes. *Journal of Food Processing and Preservation* 30(1), 56-70.
- Gonçalves, E.M., Abreu, M., Brandão, T.R.S., & Silva, C.L.M. (2011). Degradation kinetics of colour, vitamin c and drip loss in frozen broccoli (*Brassica Oleracea* l. ssp. *Italica*) during storage at isothermal and non-isothermal conditions, *International Journal of Refrigeration*, 34(8), 2136-2144 s.
- Hışıl, Y. (2004). *Enstrümental Gıda Analizleri Laboratuar Deneyleleri*, Ege Üni. Müh. Fak. Ders Kitapları Yayın No: 45, İzmir. 205-235.
- Jaffe, A., Armstrong, E. G., Robbins, A.C., & From, J. (1984). A comprehensive clerkship in family medicine, Volume18, Issue3, 159-163 s.
- Karabağlı, A., & Alpkent, N. (1998). *Türkiye ve AB'de Dondurulmuş Gıda Sanayinin Durumu ve Dış Ticaretinde Gelişmeler*, Ankara, Milli Prodüktivite Merkezi Yayınları, 628 s.
- Leygonie, C., Britz, T. J., & Hoffman, L. C. (2012). Impact of freezing and thawing on the quality of meat. *Meat science*, 91(2), 93-98.
- Lagerstedt, Å., Enfält, L., Johansson, L., Lisiewska, Z. & Kmiecik, W. (2000). Effect of storage period and temperature on the chemical composition and organoleptic quality of frozen tomato cubes, *Food Chemistry* 70, 167-173 s.
- Lundström, K., (2008) Effect of freezing on sensory quality, shear force and water loss in beef m. longissimus dorsi. *Meat Science*, 80(2), 457–461.
- Moraga, G., Martinez-Navarrate, N., & Chiralt, A. (2006). Compositional changes of strawberry due to dehydration, cold storage and freezing thawing processes, *J. Food Process, Preserv.* 30, 458-474 s.
- Oszmiański, J., & Wojdyło, A. (2009). Comparative study of phenolic content and antioxidant activity of strawberry puree, clear, and cloudy juices. *European Food Research and Technology*, 228, 4, pp 623–631.
- Puupponen-Pimiä, R., Häkkinen, S. T., Aarni, M., Suortti, T., Lampi, A. M., Eurola, M., & Oksman-Caldentey, K. M. (2003). Blanching and long-term freezing affect various bioactive compounds of vegetables in different ways. *Journal of the Science of Food and Agriculture*, 83(14), 1389-1402.
- Pukszta, T., & Palich, P. (2007). The effect of freezing conditions of strawberry storage on the level of thawing drip loss. *Acta Agrophysica*, 203-208 s.
- Raffo A., Leonardi, C., Fogliano, V., Ambrosino, P., Sallucci, M., Gennaro, L., Sahari, M. A. Boostani, M. & Hamidi, Z. (2004). Effect of low temperature on the ascorbic acid content and quality characteristics of frozen strawberry, *Food Chemistry* 86, 357-363 s.
- Rickman, J. C. Barrett, D. M., & Bruhn, C. M. (2007). Nutritional comparison of fresh, frozen and canned fruits and vegetables. Part 1. Vitamins C and B and phenolic compounds. *Journal of the Science of Food and Agriculture J Sci Food Agric* 87, 930–944.
- Shi, J., & Le Maguer, M. (2010). Lycopene in tomatoes: chemical and physical properties affected by food processing. *Critical Reviews in Food Science and Nutrition*. 40, 1-42.
- Türkben, C., Sarıburun, E., Demir, C., & Uylaşer, V. (2010). Effect of freezing and frozen storage on phenolic compounds of raspberry and blackberry cultivars. *Food Analytical Methods*, 3(3), 144-153.

- Xin, Y., Zhang, M., Xu, B., Adhikari, B., & Sun, J. (2015). Research trends in selected blanching pretreatments and quick freezing technologies as applied in fruits and vegetables: a review. *International Journal of Refrigeration*, 57, 11-25.
- Xianquan,, S., Shi,J., Kakuda, Y., & Yueming, J. (2005), Stability of lycopene during food processing and storage. *Journal of Medicinal Food*. 8, 4.
- Uçurum, H.Ö. (2012). *Organik ve konvansiyonel yöntemlerle yetiştirilmiş taze ve dondurulmuş domateslerde kalıntı miktarları ve kalite özelliklerinin belirlenmesi*, Namık Kemal Üniversitesi, Tekirdağ, 74-125 s.
- Urbany, G.,Y., & Horty, K. (1992). Changes of surface colorof the fruit and the anthocyanin content of sour cherriesduring frozen storage. *Acta Alimentaria*, 21, 3-4