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Determination of the effects of different pretreatments and modified atmosphere packaging on the storage of dried persimmon

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ABSTRACT

This study was conducted to determine the effects of different pretreatment and modified atmosphere packaging applications on the quality of dried persimmons during storage. Peeled 'Hachiya' variety persimmon fruits; 1) Control (without pretreatment), 2) Hot water (HW) (10 sec immersion in 80°C water), 3) Ascorbic acid (AA) (10 sec immersion in 3% ascorbic acid), 4) Sodium metabisulfite (Following pretreatment with sodium metabisulfite (SMBS) (immersion in 3% $Na_2S_2O_5$ for 1 min), the fruits were hung to dry. After the sun drying process is completed; Persimmon fruits; packaged as three different gas compositions: air, 70% N_2 + 30% CO_2 and 100% N_2. Dried persimmon fruits were stored at 4±1°C and 55-65% relative humidity for 9 months, with measurements and analyzes performed on samples taken at the beginning of storage and at 3-month intervals during storage. It was determined that persimmon fruits dried by applying SMBS pretreatment had more limited color changes and browning during storage, sugaring was not observed, and retained higher levels of vitamin C, total phenol amount and antioxidant activity. The amount of sulfur dioxide in these products varied between 45.23 and 74.24 $mgkg^{-1}$ during storage. No mold growth was observed in products packaged with N_2 and N_2+CO_2 gas compositions during the storage period, they retained their color and had a higher total phenol content. The study results showed that packaging persimmon fruits dried with SMBS pretreatment with N_2 and N_2+CO_2 gas compositions was the most successful treatment during 9 months of storage.

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1. Introduction

Persimmon (*Diospyros kaki*) is a fruit species cultivated mostly in subtropical climatic zones such as the Mediterranean region (Anonymous, 2021). Persimmon fruit contains high levels of fiber, magnesium, phosphorus, calcium, fat, potassium (Matheus et al., 2020; Tardugno et al., 2021), as well as vitamins A, C, and B, carbohydrates, and pectin (Rashwan et al., 2017). It contains carotenoids, anthocyanin and total phenolic pigments, which are extremely important, as can be seen from the special orange color of the fruit (Ferrara, 2021).

In Türkiye, in addition to the fresh consumption of persimmons, the practice of drying these persimmon fruits and making them available for consumption has become increasingly widespread. Drying, which enables year-round consumption of persimmon fruits, is the oldest preservation method applied to extend the shelf life of foods (Çelen, 2019). Applying some physical and/or chemical pretreatments to some fruits and vegetables before drying has many positive contributions such as limiting color changes in dried products, slowing down nutrient loss, and accelerating the drying process. For this purpose, sulphur dioxide fumigation, salt, different solutions (sodium metabisulphite, citric acid, ascorbic acid, etc.) and hot water are widely applied as pretreatment before drying (Şen, 2013).

Hot water application is one of the pretreatments commonly used in fruits and vegetables and cleans the product, removes sticky substances and prevents enzymatic browning during drying (Özdemir et al., 2009). Studies have shown that applying hot water as a pretreatment in machine drying of persimmon fruits accelerates drying (Tülek and Demiray, 2014). Similarly, it was reported that apple (Soydan, 2019), eggplant (Doymaz and Aktaş, 2018), melon and watermelon (Tepe, 2023) dried faster in hot air dryers. It was reported that apple, melon and watermelon dried by hot water application gave more positive results in terms of color, total phenolic matter content and flavonoid content (Soydan, 2019; Tepe, 2023).

Sodium metabisulphite ($Na_2S_2O_5$) is a widely used pretreatment in the drying of fruits and vegetables, as it effectively preserve color by controlling enzymatic and non-enzymatic browning during the drying process (Kayran, 2019), prevents mould and yeast growth (Jay et al., 2008), and insect infestation (Şen, 2013). It was determined that the total phenolic content of sliced persimmon fruits dried by applying sodium metabisulphite solution was higher (Akyıldız et al., 2004). It has been reported that sodium metabisulphite application as a pretreatment limits the color changes in apricot (Kayran and Doymaz, 2021), tomato (Şahin et al., 2012; Duri, 2021), red hot pepper (Phomkong et al., 2010) and banana (Demirel and Turhan, 2003) fruits during drying.

Ascorbic acid contributes to the prevention of discoloration and enrichment of fruits and vegetables in terms of vitamin C during drying. Thus, it helps to prevent the darkening of the salvaged products and to preserve their natural color (Cemeroğlu, 2009; Şen, 2013; Nadian et al., 2016). It was found that 3% ascorbic acid application of persimmon fruits improved the appearance and ascorbic acid content of the dried product (Bölek, 2013). Ascorbic acid application before drying was reported to limit color changes in peach (Cemeroğlu, 2009) and apple (Nadian et al., 2016) fruits.

In the packaging of dried fruits, carbon dioxide, nitrogen and their combinations are mostly used as protective gases to eliminate the negative effects of oxygen. In this way, storage and shelf life can be extended by differentiating/changing the gas composition in the package (Fişekci, 2013). This is because oxygen in the environment induces reactions, such as many enzymatic reactions and pigment oxidation, which accelerate the deterioration of dried products. In addition, in order to prevent the development of many fungi and bacteria and to limit the activities of microorganisms, the oxygen in the packaging should be absent or very low (Sandhya, 2010; Çelikkol, 2011).

Studies on pretreatments in the drying of persimmon fruits have been focused on machine drying of sliced fruits. Research investigating the effect of pretreatments on sun drying as a whole is very limited. In this study, it was aimed to determine the effect of different pretreatments and modified atmosphere packaging on the quality changes of dried 'Hachiya' variety persimmon during storage.

2. Material and methods

2.1. Plant materials

This study was conducted using fruits harvested from a commercial persimmon orchard established with the 'Hachiya' variety in Sarayköy district of Denizli province. The fruits were harvested at the commercial maturity stage when the skin colour was green-orange. Harvested persimmon fruits were stored in plastic crates in Ülkü Meyvecilik San. Tic. A.Ş. company's drying area in Tavas district of Denizli province.

2.2. Pretreatment applications and drying

Homogenous and intact persimmon fruits were selected and peeled manually with a knife. These peeled fruits were tied to a rope with 10 of them at equal intervals from the stems. As a pretreatment of persimmon fruits; a) Control; drying without pretreatment, b) Sodium metabisulphite (SMBS); drying after immersion in 3% $Na_2S_2O_5$ for 1 min. c) Ascorbic acid (AA); drying after immersion in 3% ascorbic acid for 10 sec. d) Hot water (HW); drying after immersion in 75±5 °C water for 10 sec.

These pretreated persimmon fruits were hung on ropes and left to dry under normal sunlight conditions. Drying was completed after 42 days under these conditions. were collected and transported to Ege University, Faculty of Agriculture, Department of Horticulture.

2.3. Packaging of dried persimmon fruits

Dried persimmon fruits were placed in gas-tight vacuum packages (polyethylene-polyamide-polyethylene) at Pamukkale University, Faculty of Engineering, Department of Food Engineering. The storage conditions included: 1) Air (control; 78% N_2 and 21% O_2, 0.03% CO_2), 2) N_2 + CO_2 application (given 70% N_2 and 30% CO_2) and 3) N_2 treatment (100% N_2 treatment). The study was established according to the random plots experimental design with 4 replicates, and each package containing 3 dried persimmon was considered as one replicate.

2.4. Storage

Packaged dried persimmon fruits were brought to Ege University, Faculty of Agriculture, Department of Horticulture and stored under 4±1°C, 55-65% relative humidity conditions for 9 months. Some measurements and analyses were performed on the samples taken at the beginning of storage and at 3 month intervals during storage.

2.5. Physical analyses

Surface color; the color of dried persimmon fruits was measured in terms of CIE L* a* b* with a Minolta colorimeter (CR-400, Minolta Co., Tokyo, Japan) from 3 different parts of the equatorial region, and the chroma (C*) value was calculated from the a* and b* values using the formula $C^*= (a^{*2}+b^{*2})^{1/2}$ (McGuire, 1992).

2.6. Chemical analyses

Total soluble solids (TSS) content; samples of dried persimmon fruits passed through a meat grinder were kept in pure water for a certain period of time and then homogenized by crushing with a hand blender and filtered through coarse filter paper. The amount of TSS was determined by digital refractometer (PR-1, Atago, Japan) and the results were presented as % dry matter (DM) (Karaçalı, 2016). Titratable acid (TA) content was determined by titration by adding 0.1 N NaOH until the pH value of the obtained filtrate was 8.1. The amount of TA was calculated as g malic acid 100 g^{-1} DM from the amount of NaOH consumed during titration (Karaçalı, 2016).

Vitamin C content was determined by adding 30 ml oxalic acid (0.4%) to 3 g of dried persimmon fruits and filtered through filter paper. The samples taken from this filtrate were measured with 2,6-dichloroindophenol in a spectrophotometer (Varian Bio 100, Australia) at a wavelength of 518 nm using the titrimetric method AOAC (1995) and the results were given as mg vitamin C 100 g^{-1} DM.

Total phenol content was determined by extraction of 3 g of dried persimmon fruits with 25 ml methanol according to Thaiponga et al. (2006). Total phenol content was measured by a spectrophotometer (Varian Bio

100, Australia) with a modified Folin-Ciocaltaeu colorimetric method (Zheng and Wang, 2001). In this method, gallic acid was used as standard and total phenolic content was given as mg gallic acid equivalent (GAE) 100 g^{-1} DM.

Antioxidant activity; Ferric Reducing Antioxidant Power (FRAP) method was used to determine the antioxidant activity in dried persimmon fruits. The absorbances of the solutions were determined in a spectrophotometer at 593 nm wavelength and the determined antioxidant activity was presented as μmol trolox equivalent (TE) g^{-1} DM (Benzie and Strain, 1996).

2.7. Sensory evaluation

The state of sugaring and browning in dried persimmon fruits was determined by four trained panelists using a 1-5 scale (1: none, 2: little, 3: moderate, 4: intense, 5: very intense). The sugaring and browning index was found by summing the product of the sugaring and browning rate and the degree of sugaring and browning in each class (Karaçalı and Şen, 2018). Sugaring/browning index= (%None*1+%Mild*2+%Moderate*3+%Severe*4+%Very severe*5)/Number of fruits

2.8. Sulphur dioxide (SO_2) content

Determination of sulphur dioxide content in persimmon fruits dried with sodium metabisulphite was carried out by using distillation 52 apparatus (K-355, Büchi, Switzerland) by modifying the Monier-Williams method (Reith and Williams, 1958) and the results were given as mg kg^{-1}.

2.9. Statistical analysis

The data obtained from the experiment were subjected to analysis of variance using JMP (8.0) statistical package programme. The data were analyzed within each storage period and the differences between the averages were determined separately by Tukey test ($P<0.05$).

3. Results

3.1. Surface color

The changes of a* value of dried persimmon fruits according to pretreatment and gas compositions during storage period are given in Table 1. The effect of pretreatment*gas composition interaction on a* value of dried persimmon fruits was found to be significant in all storage periods, and it was found to be higher in SMBS + N_2 in the 3rd month, SBMS + N_2 + CO_2 in the 6th and 9th months compared to other treatments. The effect of different pretreatments on the a* value of dried persimmon exhibited significant ($P\leq0.01$) differences across storage periods. Notably, the a* value of dried persimmon fruits subjected to SMBS pretreatment was significantly higher. The effect of different gas compositions on the a* value of dried persimmon fruits was statistically significant ($P\leq0.01$) after 3 months of storage, with treatments involving N_2 and N_2+CO_2 gas compositions demonstrated significantly higher a* values than those stored in the air treatments.

The changes of b* value, which indicates (+) yellow and (-) blue on the vertical axis, of dried persimmon fruits according to the treatments during storage period are presented in Table 2. The interaction effect of pretreatment and gas composition on the b* value of dried persimmon fruits was found to be significant in all storage periods. This effect persisted in the third month of storage with the SMBS + N_2 treatment and in the 6th and 9th months with the N_2 + CO_2 gas combination. The effect of different pretreatments on the b* value of dried persimmon fruit during the storage period showed significant differences ($P\leq0.01$), and the b* value (35.89) was significantly higher in those treated with SMBS at the beginning of storage compared to those treated with other pretreatments (12.01-16.18). This effect of SMBS pretreatment on the b* value persisted throughout the subsequent storage periods, with the b* value being 177% higher than that of the other treatments. The influence of different gas compositions on the b* value of dried persimmon fruits was significant ($P\leq0.01$) only after 3 months of storage, and it was found that the b* value was higher in those packed with N_2 and N_2+CO_2 (13.80-14.95) compared to those packed with air (8.46).

The changes of C* value, which expresses the brightness and dullness of the color of dried persimmon fruits, according to the treatments during storage period are given in Table 3.

Table 1. Effects of pretreatments and modified atmosphere packaging on a* value of dried persimmon fruits during storage

Pretreatment	Gas composition	0. month	3. month	6. month	9. month
Control	Air		4.54 ef^{z**}		
	N_2+CO_2		6.37 c-f	11.49 ab*	6.42 cd*
	N_2		5.15 def	10.93 ab	6.44 cd
Average		*9.94 BC***	*5.35 C***	*11.21 B***	*6.43 BC***
HW	Air		6.40 c-f		
	N_2+CO_2		10.20 abc	5.17 c	3.05 d
	N_2		6.65 cde	10.05 b	6.85 cd
Average		*11.06 B*	*7.75 B*	*7.61 C*	*4.95 C*
AA	Air		3.47 ef		
	N_2+CO_2		2.39 f	11.69 ab	7.59 c
	N_2		5.42 def	12.43 ab	8.00 bc
Average		*6.72 C*	*3.76 C*	*12.06 AB*	*7.80 B*
SMBS	Air		8.93 bcd		
	N_2+CO_2		12.50 ab	14.97 a	12.95 a
	N_2		13.83 a	13.94 ab	12.30 ab
Average		*16.04 A*	*11.75 A*	*14.45 A*	*12.63 A*
Average gas composition	Air		*5.83 B***		
	N_2+CO_2		*7.87 A*	*10.83*^{ns}	*7.50*^{ns}
	N_2		*7.76 A*	*11.84*	*8.40*

^{Z} Differences between the means of pretreatment. * gas composition interaction were determined for each gas composition separately by HSD test according to P≤0.05. ns: not significant: significant according to * P≤ 0.05 or significant according to ** P≤ 0.01. HW: Hot water. AA: Ascorbic acid. SMBS: Sodium metabisulfite.

Table 2. Effects of pretreatments and modified atmosphere packaging on the b* value of dried persimmon fruits during storage

Pretreatment	Gas composition	0. month	3. month	6. month	9. month
Control	Air		6.12 d^{z**}		
	N_2+CO_2		9.19 cd	16.41 b*	11.49 b*
	N_2		6.97 cd	16.38 b	11.88 b
Average		*15.34 B***	*7.43 C***	*16.39 BC***	*11.68 B***
HW	Air		8.68 cd		
	N_2+CO_2		13.67 c	9.16 b	7.77 b
	N_2		10.22 cd	13.92 b	10.64 b
Average		*16.18 B*	*10.86 B*	*11.54 C*	*9.21 B*
AA	Air		6.07 d		
	N_2+CO_2		4.29 d	18.05 b	9.87 b
	N_2		7.52 cd	20.74 b	13.06 b
Average		*12.01 B*	*5.96 C*	*19.40 B*	*11.47 B*
SMBS	Air		12.95 c		
	N_2+CO_2		28.07 b	40.98 a	33.60 a
	N_2		35.08 a	36.35 a	31.46 a
Average		*35.89 A*	*25.37 A*	*38.67 A*	*32.53 A*
Average gas composition	Air		*8.46 B***		
	N_2+CO_2		*13.80 A*	*21.15*^{ns}	*15.68*^{ns}
	N_2		*14.95 A*	*21.85*	*16.76*

^{Z} Differences between the means of pretreatment. * gas composition interaction were determined for each gas composition separately by HSD test according to P≤0.05. ns: not significant: significant according to * P≤ 0.05 or significant according to ** P≤ 0.01. HW: Hot water. AA: Ascorbic acid. SMBS: Sodium metabisulfite.

The interaction effect of pretreatment and gas composition on the C* value of dried persimmon fruits showed significant differences in all storage periods. The C* value of products subjected to SMBS pretreatment and packed with N_2 and N_2+CO_2 gas compositions (33.79-43.63) was significantly higher than that of other treatments (4.95-24.21).

The effect of different pretreatments on the C* value of dried persimmon fruits during storage was found to be statistically significant (P≤0.01), and the C* value of dried persimmon fruits dried by applying SMBS (28.07-41.29) was higher than the C* value of other treatments (7.07-22.06). The effect of different gas composition on the C* value of dried persimmon fruits was significant (P≤0.01) in the 3rd month of storage, and the C* value of those packed with N_2+CO_2 and N_2 was higher than those packed with air (10.29).

Table 3. Effects of pretreatments and modified atmosphere packaging on the C* value of dried persimmon fruits during storage

Pretreatment	Gas composition	0. month	3. month	6. month	9. month
Control	Air		7.62 d $^{z\,**}$		
	N_2+CO_2		11.18 bcd	20.03 bc *	13.17 b *
	N_2		8.68 cd	19.70 bc	13.55 b
Average		*18.28 B***	*9.16 C***	*19.87 BC***	*13.36 B***
HW	Air		10.78 bcd		
	N_2+CO_2		17.06 b	10.52 c	8.37 b
	N_2		12.19 bcd	17.17 bc	12.66 b
Average		*19.61 B*	*13.35 B*	*13.85 C*	*10.51 B*
AA	Air		7.00 d		
	N_2+CO_2		4.95 d	21.52 bc	12.46 b
	N_2		9.28 cd	24.21 b	15.33 b
Average		*13.77 B*	*7.07 C*	*22.86 B*	*13.89 B*
SMBS	Air		15.74 bc		
	N_2+CO_2		30.74 a	43.63 a	36.02 a
	N_2		37.73 a	38.96 a	33.79 a
Average		*39.33 A*	*28.07 A*	*41.29 A*	*34.91 A*
Average gas composition	Air		*10.29 B***		
	N_2+CO_2		*15.98 A*	*23.93^{ns}*	*17.50^{ns}*
	N_2		*16.97 A*	*25.01*	*18.83*

^{Z} Differences between the means of pretreatment. * gas composition interaction were determined for each gas composition separately by HSD test according to P≤0.05. ns: not significant: significant according to * P≤ 0.05 or significant according to ** P≤ 0.01. HW: Hot water. AA: Ascorbic acid. SMBS: Sodium metabisulfite.

3.2. Total soluble solids (TSS) content

The interaction effect of pretreatment and gas composition, as well as the individual effects of pretreatments and gas compositions on the TSS content of dried persimmon fruits, exhibited similar trends throughout the storage period, with values ranging between 77.57% and 85.45% (Table 4).

Table 4. The effects of pretreatments and modified atmosphere packaging on the amount of TSS (% DM) of dried persimmon fruits during storage

Pretreatment	Gas composition	0. month	3. month	6. month	9. month
Control	Air		85.45^{ns}		
	N_2+CO_2		84.08	80.31^{ns}	85.22^{ns}
	N_2		78.91	81.96	81.00
Average		*84.21^{ns}*	*82.82^{ns}*	*81.14^{ns}*	*83.11^{ns}*
HW	Air		82.36		
	N_2+CO_2		82.73	82.39	80.94
	N_2		83.88	82.98	81.78
Average		*83.31*	*82.99*	*82.68*	*81.37*
AA	Air		80.33	0.00	
	N_2+CO_2		82.99	81.52	84.88
	N_2		81.19	77.57	82.11
Average		*82.62*	*81.51*	*79.54*	*83.49*
SMBS	Air		83.66		
	N_2+CO_2		82.88	84.32	79.94
	N_2		79.45	83.04	81.76
Average		*83.37*	*82.00*	*83.68*	*80.86*
Average gas composition	Air		*82.95^{ns}*		
	N_2+CO_2		*83.17*	*82.13^{ns}*	*82.75^{ns}*
	N_2		*80.86*	*81.39*	*81.66*

ns: not significant. HW: Hot water. AA: Ascorbic acid. SMBS: Sodium metabisulfite

3.3. Titratable acid (TA) content

The interaction effect of pretreatment and gas composition, as well as the effect of different gas compositions on the TA content of dried persimmon fruits, was found to be insignificant in all storage periods and ranged between 0.50 and 0.71%. The effect of different pretreatments on the TA content of dried persimmon fruits was found to be significant (P≤0.05) only at the end of the storage period, and the TA content of the fruits dried with AA pretreatment was the highest with 0.68% and the lowest with 0.54% (Table 5).

Table 5. Effects of pretreatments and modified atmosphere packaging on the TA content (% DM) of dried persimmon fruits during storage

Pretreatment	Gas composition	0. month	3. month	6. month	9. month
	Air		0.59 ns		
Control	N_2+CO_2		0.61	0.63 ns	0.63 ns
	N_2		0.61	0.67	0.63
Average		*0.66*ns	*0.50* ns	*0.65* ns	*0.63 AB* *
	Air		0.59		
HW	N_2+CO_2		0.61	0.71	0.61
	N_2		0.61	0.55	0.50
Average		*0.65*	*0.55*	*0.63*	*0.55 AB*
	Air		0.61		
AA	N_2+CO_2		0.59	0.67	0.68
	N_2		0.61	0.71	0.68
Average		*0.68*	*0.54*	*0.69*	*0.68 A*
	Air		0.59		
SMBS	N_2+CO_2		0.59	0.60	0.56
	N_2		0.59	0.65	0.51
Average		*0.68*	*0.57*	*0.63*	*0.54 B*
	Air		*0.54*ns		
Average gas composition	N_2+CO_2		*0.51*	*0.65* ns	*0.62* ns
	N_2		*0.57*	*0.64*	*0.58*

Z Differences between the means of pretreatment. * gas composition interaction were determined for each gas composition separately by HSD test according to P≤0.05. ns: not significant: significant according to * P≤ 0.05 or significant according to ** P≤ 0.01. HW: Hot water. AA: Ascorbic acid. SMBS: Sodium metabisulfite.

3.4. Vitamin C content

The changes in vitamin C content of dried persimmon fruits based on pretreatment and gas composition during storage period are presented in Table 6. The effect of pretreatment*gas composition interaction on vitamin C content of dried persimmon fruits was significant (P≤0.05) in the 3rd month of storage, and vitamin C content was higher in SMBS + Air and SMBS + N_2 treatments (136.93-143.12 mg 100 g^{-1} DM) compared to control and SS pretreatment and air packed (89.63-91.94 mg 100 g^{-1} DM). The effect of different pretreatments on the vitamin C content of dried persimmon fruits showed significant (P≤0.01) differences in the 3rd and 6th month of storage, and the vitamin C content of those dried by applying SMBS pretreatment was the highest (136.25 and 140.18 mg 100 g^{-1} DM) and the lowest in the control (105.41 and 104.81 mg 100 g^{-1} DM). The effect of gas compositions on vitamin C content of dried persimmon fruits was similar during all storage periods.

3.5. Total phenol (TP) content

Total phenol (TP) content of dried persimmon fruits according to pretreatment and gas composition during storage period is given in Table 7. The effect of pretreatment*gas composition interaction on TP content of dried persimmon fruits was found to be statistically significant (P≤0.05) in all storage periods, and it was determined that SMBS pretreatments were higher (>153.54 mg GEA 100 g^{-1} DM) than other treatments regardless of gas composition in the 3rd month. This effect increased and continued in the 6th and 9th months of storage in SMBS + N_2 treatments (170.27 and 177.02 mg GEA 100 g^{-1} DM, respectively). The effect of pretreatments on the TP content of dried persimmon was significant (P≤0.01) during the storage period and the TP content of SMBS pretreated dried persimmon fruits (>162.72 mg GEA 100 g^{-1} DM) was found to be higher than other pretreatments in all storage periods. The effect of different gas compositions on the TP content of dried persimmon fruits was found to be significant (P≤0.05) in the 3rd month of storage, and the TP content of products with N2 + CO_2 gas composition was found to be higher than those with air.

Table 6 Effects of pretreatments and modified atmosphere packaging on vitamin C content (mg 100 g^{-1} DM) of dried persimmon fruits during storage

Pretreatment	Gas composition	0. month	3. month	6. month	9. month
Control	Air		89.63 b ^{z*}		
	N_2+CO_2		112.64 ab	103.77 ^{ns}	125.32 ^{ns}
	N_2		113.95 ab	105.86	119.42
Average		*105.0^{ns}*	*105.41 C***	*104.81 C***	*122.37^{ns}*
HW	Air		91.94 b		
	N_2+CO_2		123.60 ab	114.60	115.48
	N_2		119.16 ab	106.73	115.93
Average		*116.84*	*111.57 BC*	*110.67 BC*	*115.71*
AA	Air		123.09 ab		
	N_2+CO_2		129.95 ab	129.68	132.72
	N_2		123.43 ab	137.35	139.68
Average		*122.31*	*125.49 AB*	*133.51 AB*	*136.20*
SMBS	Air		136.93 a		
	N_2+CO_2		128.70 ab	148.37	144.10
	N_2		143.12 a	131.99	131.85
Average		*126.24*	*136.25 A*	*140.18 A*	*137.98*
Average gas composition	Air		*110.40^{ns}*		
	N_2+CO_2		*123.72*	*124.10^{ns}*	*129.41^{ns}*
	N_2		*124.92*	*120.48*	*126.72*

^{Z} Differences between the means of pretreatment. * gas composition interaction were determined for each gas composition separately by HSD test according to P≤0.05. ns: not significant: significant according to * P≤ 0.05 or significant according to ** P≤ 0.01. HW: Hot water. AA: Ascorbic acid. SMBS: Sodium metabisulfite.

Table 7. Effects of pretreatments and modified atmosphere packaging on the TP content (mg GEA 100 g^{-1} DM) of dried persimmon fruits during storage

Pretreatment	Gas composition	0. month	3. month	6. month	9. month
Control	Air		94.74 b ^{z*}		
	N_2+CO_2		104.94 b	122.42 bc *	113.38 c*
	N_2		105.98 b	129.17 abc	108.21 c
Average		*90.37 B***	*101.89 B***	*125.80 B***	*110.80 BC***
HW	Air		98.55 b		
	N_2+CO_2		112.48 b	120.08 bc	106.86 c
	N_2		102.13 b	115.96 c	110.24 c
Average		*109.10 B*	*104.39 B*	*118.02 B*	*108.55 C*
AA	Air		109.92 b		
	N_2+CO_2		117.13 b	112.10 c	132.12 bc
	N_2		106.82 b	112.76 c	125.97 c
Average		*103.49 B*	*111.29 B*	*112.43 B*	*129.04 B*
SMBS	Air		153.54 a		
	N_2+CO_2		163.65 a	161.28 ab	164.35 ab
	N_2		170.97 a	170.27 a	177.02 a
Average		*171.21 A*	*162.72 A*	*165.78 A*	*170.68 A*
Average gas composition	Air		*114.19 B**		
	N_2+CO_2		*124.55 A*	*128.97^{ns}*	*129.18^{ns}*
	N_2		*121.48 AB*	*132.04*	*130.36*

^{Z} Differences between the means of pretreatment. * gas composition interaction were determined for each gas composition separately by HSD test according to P≤0.05. ns: not significant: significant according to * P≤ 0.05 or significant according to ** P≤ 0.01. HW: Hot water. AA: Ascorbic acid. SMBS: Sodium metabisulfite.

3.6. Antioxidant activity

The changes of antioxidant activity of dried persimmon fruits according to pretreatment and gas composition during storage period are presented in Table 8. The interaction effect of pretreatment and gas composition on the antioxidant activity of dried persimmon fruits showed significant (P≤0.05) differences in all storage periods, and in general, the antioxidant activity of SMBS + N_2 and SMBS + N_2+CO_2 treated fruits (>18.90) was higher than the other pretreatments and gas compositions. The effect of different pretreatments on the antioxidant activity of dried persimmon fruits was significant (P≤0.01) during the storage period. The antioxidant activity of fruits treated with SMBS (18.51-22.25 μmol TE g^{-1} DM) was significantly higher than that of fruits subjected to other pretreatments (8.75-13.81 μmol TE g^{-1} DM). The effect of gas compositions on the antioxidant activity of dried persimmon fruits was similar during all storage periods.

Table 8. Effects of pretreatments and modified atmosphere packaging on the antioxidant activity (µmol TE g^{-1} DM) of dried persimmon fruits during storage.

Pretreatment	Gas composition	0. month	3. month	6. month	9. month
	Air		8.53 c [z] *		
Control	N_2+CO_2		9.30 c	12.63 b *	12.08 c *
	N_2		8.62 c	13.52 b	11.30 c
Average		*8.75 B* **	*8.82 B* **	*13.07 B* **	*11.69 B* **
	Air		9.41 c		
HW	N_2+CO_2		10.88 bc	12.94 b	11.95 c
	N_2		9.13 c	12.32 b	10.58 c
Average		*10.51 B*	*9.81 B*	*12.63 B*	*11.26 B*
	Air		8.77 c		
AA	N_2+CO_2		8.96 c	13.47 b	14.17 bc
	N_2		8.80 c	13.01 b	13.45 bc
Average		*11.08 B*	*8.85 B*	*13.24 B*	*13.81 B*
	Air		15.75 ab		
SMBS	N_2+CO_2		18.90 a	21.48 a	21.19 ab
	N_2		20.89 a	22.95 a	23.30 a
Average		*21.76 A*	*18.51 A*	*22.22 A*	*22.25 A*
	Air		*10.62* ns		
Average gas composition	N_2+CO_2		*12.01*	*15.13* ns	*14.85* ns
	N_2		*11.86*	*15.45*	*14.66*

[z] Differences between the means of pretreatment. * gas composition interaction were determined for each gas composition separately by HSD test according to P≤0.05. ns: not significant: significant according to * P≤ 0.05 or significant according to ** P≤ 0.01. HW: Hot water. AA: Ascorbic acid. SMBS: Sodium metabisülfite.

3.7. Sensory evaluation

The saccharification index values determined in dried persimmon fruits according to pretreatment and gas composition during storage are given in Figure 1. The effect of pretreatment*gas composition interaction on the saccharification index of dried persimmon fruits was found to be significant (P≤0.05) in the 6th and 9th month of storage, and the HW + N_2+CO_2 treatment had higher sugar index (3.3 and 3.5) in the 6th month of storage, and Control + N_2+CO_2 and Control + N_2 treatments had higher sugar index (2.5-2.7) in the 9th month. It was determined that the fruits dried with SMBS pretreatment during the whole storage period did not show any saccharification in all gas compositions (1.0). The effect of different pretreatments on the saccharification index of dried persimmon fruits was significant (P≤0.05) in the 6th and 9th month of storage, and the saccharification index was higher in the fruits pretreated with HW in the 6th month, control and HW in the 9th month. The effect of different gas compositions on the saccharification index of dried persimmon fruits was similar during all storage periods.

The changes in browning index of dried persimmon fruits according to pretreatment and gas composition are presented in Figure 1. The effect of pretreatment*gas composition interaction on the browning index of dried persimmon fruits showed significant (P≤0.01) differences in all storage periods. Fruits treated with SMBS pretreatment and packed with N_2+CO_2 and N_2 exhibited lower browning indices (2.0–2.7) compared to other treatments (3.6-4.7). The effect of different pretreatments on the browning index of dried persimmon fruits was found to be significant (P≤0.05) during storage, the browning index of SMBS treated fruits was lower than the other treatments and the color change was very limited. The effect of different gas compositions on the browning index of dried persimmon fruits was insignificant in all storage periods.

3.8. Sulphur dioxide (SO_2) content

The amount of sulphur dioxide was found to be 74.24 mg kg^{-1} after drying (day 0) in persimmon fruits dried by applying SMBS pretreatment, while it was found to vary between 45.23-68.27 mg kg^{-1} based on the gas compositions in which it was packed during storage.

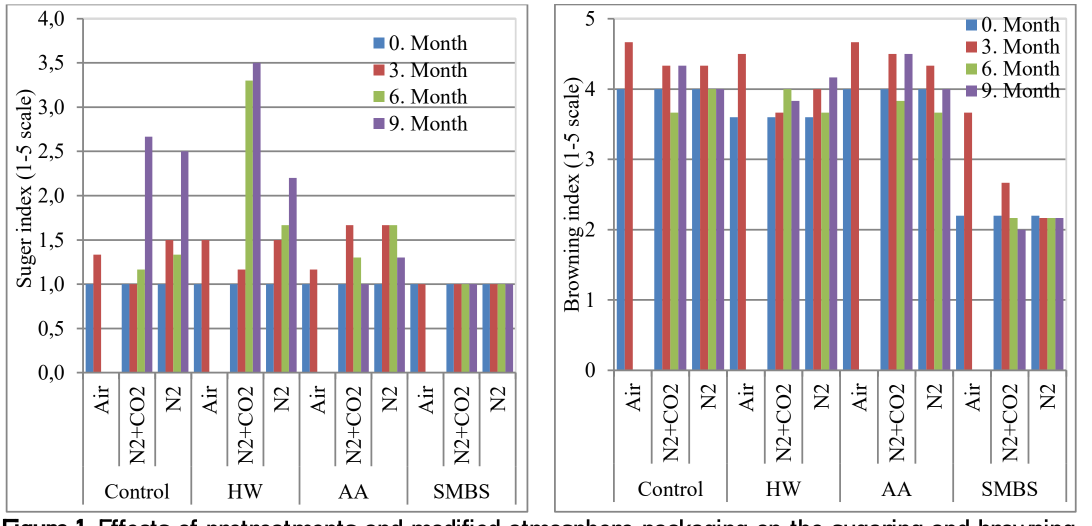

Figure 1. Effects of pretreatments and modified atmosphere packaging on the sugaring and browning index of dried persimmon fruits. HW: Hot water. AA: Ascorbic acid. SMBS: Sodium metabisulfite.

4. Discussion

The effect of different pretreatment applications and gas compounds on the color values (a*, b*, C*) of dried persimmon fruit during storage was found to be particularly influenced by the pretreatments. The positive impact of SMBS application on color retention until the end of storage is attributed to the inhibition of enzymatic and non-enzymatic browning reactions by sulphur dioxide released during sodium metabisulphite application (Şen, 2013). Similar results were reported in studies on dried persimmon (Akyıldız et al., 2004), dried tomato (Latapi and Barrett, 2006; Duri, 2021) and dried okra (Tanta, 2019). The fact that treatments containing N_2 and N_2+CO_2 gas compositions preserved the color parameters better than air treatment can be explained by the acceleration of color changes in dry products by oxygen. It is reported that oxygen in the environment where dry products are stored accelerates enzymatic reactions (Exama and Arul, 1993). In previous studies, it has been reported that gas compositions containing nitrogen and carbon dioxide positively affect the color parameters of the products as they allow the absence of oxygen in the environment (Çam, 2016).

It was observed that the TSS content in dried persimmon fruits varied between 80.31% and 85.45% on a dry matter basis and was unaffected by the treatments. The main factors determining the TSS content in dried products are the growing conditions, harvest time and the amount of water retained in the product after drying (Karaçalı, 2016). Since persimmon fruits were harvested from the same orchard and at the same time, it is assumed that ecological factors and harvest maturity were similar. Given that the TSS content was expressed as dry matter, the effect of water content in the product was deemed insignificant. Therefore, it is an expected that the TSS content, primarily composed of sugars, would be similar in the dried persimmon fruits. The TSS content of dried persimmon fruits was found to be comparable to the TSS content reported in some studies on this product (Akyıldız et al., 2004; Karakasova et al., 2013). Different pretreatments and gas compositions applied to dried persimmon had limited effect on the changes in the amount of TA between treatments. It is believed that the factors mentioned above regarding the TSS content also influence this outcome. The fact that there was no significant increase in the amount of TA during the later storage periods shows that no deterioration occurred in the products. This is because increases in TA level in dry products indicate the onset of fermentation (Unluturk and Turantas, 2002).

The higher vitamin C content in persimmon fruits dried by AA and SMBS pretreatment is attributed to the fact that these pretreatments help reduce vitamin C losses during and after the drying process. It has been reported that these treatments minimize vitamin C losses in preserved products (Saba and Sogvar, 2016). Similarly, Khademi et al. (2019) reported that these treatments reduce vitamin C losses in dried persimmon.

The TP content and antioxidant activity content of dried persimmon fruits were found to be significantly higher in SMBS pretreated fruits due to the limitation of the breakdown of compounds such as carotenoids, vitamins and phenols during the drying process by sulphur dioxide application (Karaçalı, 2002; Cemeroğlu and Özkan, 2009). The TP content and antioxidant activity values determined were similar to the findings of Kılıç et al. (2023). It is known that SMBS is widely used to utilize its antioxidant properties (Keleş, 1989). Akyıldız et al. (2004) reported that SMBS pretreatment was effective in the preservation of TP content and antioxidant activity. The positive effect of N_2+CO_2 gas composition on the TP content in the early stages of storage can be explained by the fact that N_2 gas prevents oxidation. As a matter of fact, it has been shown in studies that N_2 gas is important in limiting the change of many parameters that protect product quality (Ural and Pazır, 1984; Sanchez et al., 1999; Uzun et al., 2004).

In dried persimmon, the more intense candida formation in the later stages of storage in fruits subjected to control and HW pretreatments can be explained by the increased movement of water from the interior of the product to the peel. Sugaring is a physical process, and it is the movement of the sugars in the fruit towards the surface of the fruit with moisture in sugar-rich products such as dried persimmon, dried figs and raisins, where the water is removed and the sugars remain as crystals (Aksoy and Dokuzoğuz, 1984). A whitish appearance is formed on the surface of the products with saccharification. It is believed that the effect of these pretreatments on water movement plays a crucial role in the absence or very limited sugaring in persimmons dried by SMBS and AA pretreatments.

The lower browning observed in the products dried by applying SMBS pretreatment in all storage periods and packed with CO_2+N_2 and N_2 can be attributed to the inhibition of both enzymatic and non-enzymatic reactions, due to the absence of SO_2 and oxygen in the environment. This is because color browning in dried products, such as dried persimmons, apricots, tomatoes, is primarily caused by enzymatic or non-enzymatic reactions (Cemeroğlu and Özkan, 2009). It has been reported that reducing the oxygen content in the packaging of products slows down color changes (Exama and Arul, 1993). In similar studies, it has been observed that gas compositions containing nitrogen and carbon dioxide positively affect color parameters by preventing color browning (Sanchez et al., 1999; Uzun et al., 2004; Çam, 2016).

The MRL value of SO_2 in dried fruits for Türkiye and European Union countries is 2000 mg kg^{-1} (Asma et al., 2005; Aksoy et al., 2012). At the beginning of storage, the SO_2 content of dried persimmon fruits subjected to SMBS pretreatment was determined to be 74.24 mg kg^{-1}. By the end of storage, these values ranged between 45.23 and 68.27 mg kg^{-1}, depending on the gas compositions used for packaging. Factors such as the application method, dose, duration, drying time and fruit size of SMBS pretreatment likely contributed to these values being well below the permissible limit values.

As a result, persimmon fruits dried by applying SMBS pretreatment gave better results in N_2+CO_2 and N_2 gas compositions due to limitation of color change and browning during storage, high total phenol content and antioxidant activity, preservation of vitamin C content and absence of sugaring.

Compliance with Ethical Standards

Conflict of Interest

The authors declare that they have no conflict of interest.

Authors' Contributions

Enes YILMAZ: Investigation, Statistical analysis, Writing original draft, Formal analysis. **Fatih ŞEN**: Writing original draft, Review, Editing, Validation.

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