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CHANGES OF NUTRITIONAL AND PHYSICAL QUALITY CHARACTERISTICS DURING STORAGE OF OSMOTIC PRETREATED APPLE BEFORE HOT AIR DRYING AND SENSORY EVALUATION

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ABSTRACT

The aim of this research was to increase the application of different osmotic dehydration solutions to decrease the drying time, and decrease the loss of quality after drying and during storage of apples. Sucrose and trehalose solutions with 20 and 50 Brix concentrations were applied. Drying experiments were performed at 50, 60 and 70C using a hot air dryer. Changes in color, water activity, vitamin C, dry matter, total phenol content and mechanical properties were determined with 3-month intervals. Trehalose pretreatments, especially with 50 Brix concentration, generally decreased the drying time. Trehalose pretreatment with 20 Brix had better effects on quality characteristics. Texture of the samples pretreated using 50 Brix sucrose and trehalose stayed more stable just after drying. Lowest change in puncture force was found in 50 Brix trehalose-treated samples even after 12 months. Samples pretreated using 20 Brix trehalose had the higher preference by the panelists.

PRACTICAL APPLICATIONS

Apple drying is rather important because of large production capacity in the world. For reducing quality losses and the cost, osmotic pretreatments and then using cabin or tunnel dryers, which are based on hot air circulating, have been widely used. Usually sucrose, dextrin, glucose have been used for osmotic dehydration implementations to fruits like apple, kiwi and mango, until now. Sucrose implementation is the most successful for fruits and therefore it has widest usage in fruit processing. But there are many disadvantages of using sucrose like caramelization and changes in flavor and viscosity. Our previous research showed that trehalose has rather good effects to improve the quality of dried vegetables such as carrot and potato. The results of this research can also serve as a valuable resource to further researches for utilization of alternative osmotic materials such as trehalose similar to our research to decrease negative effects of drying process.

INTRODUCTION

Drying of foods, including fruits and vegetables, has been widely used for removing and lowering water activity to reduce the risk of microbial development and to decrease enzymatic reactions and chemical degradations. The drying process allows flexibility in availability of these products regardless of season. Therefore today, the dehydrated food industry occupies an important place within general food industries throughout the world (Vega-Gálvez *et al.* 2012).

Consumption of dried apples has been increasing recently, and dried apples are part of numerous prepared foods including snack preparations, breakfast foods and others (Akpinar *et al.* 2003; Vega-Gálvez *et al.* 2012). Apples contain rather high amounts of polyphenols, and this is important because polyphenols have important contributions to the sensory quality of the fresh and processed products. The preference for apple and dried apple products is also due to the antioxidant activity of their polyphenols. During the drying of apples, degradation of phenolic compounds occurs rapidly, because of both enzymatic and thermal reactions that induce the browning phenomena.

The most important issue in the drying process of fruits is keeping their original characteristics as much as possible. One way of producing good quality dried fruits is to apply pretreatments, such as osmotic dehydration, which can reduce the energy requirement and minimize adverse effects of the drying process (Torreggiani 1993). The method of using salts, such as NaCl and KCl, as osmotic agents is very effective in reducing the water activity, especially for vegetable drying process. On the other hand, salt usage in foods is limited from 1 to 3% because of the food's suitability for consumption (Evranuz and Kilic 2005). In much research on fruit drying, osmotic dehydration was performed using sucrose or glucose. Minimizing the disadvantages of tectonic solutions usually has been done by changing osmotic dehydration methods (type of osmotic agent, solution concentration, temperature, solution/product rate, etc.).

Trehalose, a nonreducing disaccharide and a major reserve carbohydrate, has been generally accepted as a protection metabolite against various stresses, such as heat, dehydration, freezing and hyperosmotic stress (Aktas *et al.* 2004a, 2008; Li and Tian 2006). In this research, the effects of pretreatments performed using sucrose and trehalose solutions to accelerate the drying rate and to keep quality characteristics of dried apple slices such as contents of total phenols, vitamin C, color, water activity and some mechanical properties, etc., will be evaluated for three different drying temperatures and two different osmotic solution concentrations. Besides, effect of storage time on the changing of quality properties of dried samples will be determined during the 12-month storage. Sensorial analyses will be performed to compare samples that were treated with trehalose and sucrose solutions.

MATERIAL AND METHODS

Materials

Apples (var. *Granny Smith*) were purchased from a local market in the city of Tekirdag, Turkey. Degree of maturity, freshness, color, size and absence of any mechanical damage were used as the selection criteria. They were then stored at 4C until the moment of the drying experiments.

Sample Preparation and Pretreatments

For sample preparations, the apples were washed, peeled and the seeds were removed. Apples were sliced into 5-mm thickness slices.

Osmotic dehydration procedures were applied as 200 g fresh material/400 g osmotic solution. Sterilized distilled water was used to prepare all solutions to avoid contamination and other confounding factors. Osmotic solutions of 20 Brix sucrose, 50 Brix sucrose, 20 Brix trehalose and 50 Brix trehalose were used. Samples were immersed and stirred with 80 rpm using a shaker in the solutions for 30 min and drained (not rinsed; Aktas *et al.* 2008).

Drying Process

Pretreated apple slices were placed in a single layer on the tray of the hot air dryer. Samples were dried until their weight stayed stable at 50, 60 and 70C drying temperatures. Untreated samples were also dried to be used as control samples. Circulating air temperature within the dryer was controlled for assigned temperature. Air relative humidity in the constant-air dryer was tried to be constant at 12% during the experiments using a dessicant (silica gel; Aktas and Polat 2007). Decreases in sample weight were monitored and recorded over the drying period using WinCT Balance Software (A&D Company, Tokyo, Japan) that was used for transmitting the weighing data from balance (AND GF-600) to computer (Aktas *et al.* 2008). Drying tests were performed in triplicate, and mean weight values were calculated to obtain drying curves.

Storage

Dried samples were stored in sterile plastic bags during storage at room temperature (21 ± 1C; Brennand and Hendricks 1995). Changing of color properties, water activity, dry matter amount, vitamin C and amount of total phenols were determined every 3 months to determine the effect of storage time on the quality of the dried apple samples.

Color Analysis

Color measurements of osmo-air-dried apple slices were determined using Hunter-Lab tristimulus colorimeter (D25LT, Hunter Associates Laboratory, Reston, VA). CIE $L^*a^*b^*$ color parameters of samples were measured from 10 points of every sample just after drying processes. CIE L^*, a^* and b^* tristimulus values were also measured during the 12 months storage period in every 3 months. In this system, L^* value represented the lightness of color (0 = black, 100 = white), a^* represented the red color and b^* represented the yellow color. Total color difference (ΔE^*), lightness difference (ΔL^*), color chroma (C^*), color chroma difference (ΔC^*), metric hue value (α^*), The magnitude of change in hue ($\Delta\alpha^*$) were calculated according to the Eqs. (1)–(6) (Anon 2006; Aktas *et al.* 2008). No color standard could be found for dry apples; therefore, color properties of fresh apples were accepted as reference values.

$$\Delta E^* = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \tag{1}$$

$$\Delta L^* = L^*_{\text{sample}} - L^*_{\text{standart}} \tag{2}$$

$$C^* = \sqrt{\Delta a^{*2} + \Delta b^{*2}} \tag{3}$$

$$\Delta C^* = C^*_{\text{sample}} - C^*_{\text{standart}} \tag{4}$$

$$\alpha^* = \arctan\frac{b^*}{a^*} \tag{5}$$

$$\Delta\alpha^* = \sqrt{\Delta E^{*2} - \Delta L^{*2} - \Delta C^{*2}} \tag{6}$$

Water Activity Measurements

Water activity values of dried apple slices were measured in triplicate using a water activity measurement device by combining Testo 650 data logger. During the measurements, the sample was placed in a small chamber and the water in the air is measured after it equilibrates with the sample. The basics of this method for water activity determination is detailed in the Official Methods of Analysis of AOAC International (1995; Aktas and Polat 2007; Aktas *et al.* 2008).

Chemical Analysis

The Folin–Ciocalteu method was used to obtain total phenols content. Two hundred forty microliters of 50% methanol–water solution was added to 20 mg apple sample, and the solution was centrifuged at 16,400 rpm for 10 min at 4C using a refrigerated centrifuge. The upper aqueous phase was transferred to another tube and 240 μL of 100 % methanol was added to the remaining sample. The same centrifugation procedure was repeated and the upper aqueous phase was again transferred to other tube. To the tube containing 300 μL of the sample solution, 1.5 mL Folin–Ciocalteu reagent and 1.2 mL Na_2CO_3 solution (7.5%, w/v) were added. The same procedure was applied for the gallic acid standard solutions. After the samples were incubated for 1.5 h at room temperature, absorbance values were measured at 765 nm in a ultraviolet (UV)-visible spectrophotometer. Total phenols were expressed as mg gallic acid equivalents (GAE) per 1 g extract (Cheung *et al.* 2002; Aktas *et al.* 2008).

Vitamin C (ascorbic acid) values were determined from the changing of colors of 2,6 dichloroindophenol dye (Cemeroglu 2007; Aktas *et al.* 2008).

Oven drying method was used to determine dry matter amounts at 105C (Cemeroglu 2007; Aktas *et al.* 2008).

All chemical analyses were conducted in triplicate.

Measurements of Mechanical Properties

The most important changes in agricultural products after the drying and during the storage processes are changes in mechanical properties such as puncture and fracture forces that can be indicators of texture of samples. An experimental setup had been established for determination of these forces. A dynamometer (Shimpo FGN-5B model; Nidec-Shimpo Corporation, Kyoto, Japan) was fixed on the setup to apply force to sample with a constant speed. The dynamometer was applied to the product with the speed of 30 mm/min. Different probes were used depending on the measured properties namely fracturing and puncturing forces. Maximum force occurred during the measurements was read from dynamometer directly and accepted as a force that was required for fracturing or puncturing of sample. Measurements of mechanical properties were repeated 10 times.

Sensory Analysis

Sensory evaluation of apple samples after the drying process performed at 60C drying temperature was performed by a selected group of 20 semi-trained panelists that are graduate students and staff (made up of 10 women and 10 men, aged between 23 and 50 years old) that were previously involved as members of the sensorial analysis panels. The quality attributes tested were appearance (color, browning and shrinkage), taste (flavor, sourness, aroma and foreign flavor), texture (hardness and chewing, etc.) and overall quality features considering minimum specifications for dry fruits that were defined in TS 541 (Anon 1989), TS 3411 (Anon 1983) and TS 3688 (Anon 2002). Samples were evaluated using a hedonic scale from 9 to 1 (9 = like extremely, 8 = like very much, 7 = like moderately, 6 = like slightly, 5 = neither like nor dislike, 4 = dislike slightly, 3 = dislike moderately, 2 = dislike very much, 1 = dislike extremely; Renna *et al.* 2013). All samples were presented to the panelists at room temperature under normal lighting conditions in glass containers randomly coded with three-digit numbers and presented to each panelist at the same time. Each panelist evaluated five samples (untreated, sucrose-treated samples using 20 and 50 Brix concentrations, and trehalose-treated samples using 20 and 50 Brix concentrations) in triplicate. Namely every panelist evaluated 15 samples. The sensory analysis was divided into sessions, in which the panelists evaluated three samples at a time, working in individual booths and drinking water for oral rinsing. The average value of scores of all sensory evaluations was used in the analysis. Scores of at least five were considered acceptable (Zou *et al.* 2013).

Data Analysis

Three individual experimental trials were carried to evaluate the influence of osmotic treatment variables (two types osmotic agent: sucrose and trehalose; two osmotic solution concentration: 20–50 Brix), drying temperatures (50, 60 and 70C) and storage periods (just after drying, third, sixth, ninth and 12th month) on color properties (measured properties: L^*, a^*, b^*; calculated properties: ΔE^*, ΔL^*, C^*, ΔC^*, α^*, $\Delta\alpha^*$), water activity, vitamin C, dry matter, total phenol content and mechanical properties (fracture and puncture forces) of dried apples. While color and mechanical properties measurements were repeated 10 times, water activity measurements and chemical analyses were performed in triplicate.

Two-way analysis of variance (ANOVA) was conducted to investigate the effect of osmotic treatment variables, drying temperature, storage time and their interactions on quality characteristics of dried apple samples such as color, water activity, vitamin C, dry matter, total phenol content and mechanical properties (fracture and puncture forces). Tukey's test was used for multiple comparisons between means. The analysis was carried out using the Statistical Package for the Social Sciences (SPSS) 18.0 for Windows (SPSS Inc., Chicago, IL) software package.

Data analysis of sensory evaluation was performed using SPSS 18.0 for Windows using one-way ANOVA and Tukey's multiple-range tests. Significant differences were defined at $P < 0.05$.

RESULTS AND DISCUSSIONS

Drying Kinetics

As seen in Fig. 1, either sucrose treatment or trehalose pretreatments decreased the initial moisture content and drying time of apple samples. Increasing the solution concentration decreased the drying time.

Changes in the moisture content of untreated sample started to be very low after 8 h, and it was determined as 19.53% after 10 h. Moisture content of samples that were pretreated by 20 Brix sucrose solution was found as 17.55% after 10 h, while both 20 and 50 Brix trehalose treatments decreased the moisture content of samples 17.92 and 15.5% after 10 h drying, respectively. Increasing the drying temperature from 50 to 70C highly decreased the drying time. Many research studies support that increasing the osmotic solution concentration and drying temperature reduce the drying time (Mastrantonia *et al.* 2006; Khoyi and Hesari 2007).

Water Activity

Water activity values of all samples were found to be lower than 0.62, which is a critical value for storage (Anon 1998). Water activity values increased during storage for all samples (see Fig. 2). The water activity of untreated sample that had the lowest activity just after the drying process performed at 50, 60 and 70C, increased more than those other samples after 6-month storage (see Fig. 2). Trehalose treatment decreased the increasing of water activity value. Especially 20 Brix trehalose treatment, which was found to be more effective in preventing the increase of water activity. This is a very important advantage of the trehalose treatment because reducing the water activity of samples also decreases the nonenzymatic browning reaction (Krokida *et al.* 2000). Increasing the drying temperature from 50 to 70C generally decreased the increase of water activity values of samples during storage. After a 12-month storage period, the water activity of all samples increased, and the highest water activity value was determined for the untreated sample dried at 60C to be 0.61, which is very close to the critical limit of 0.62. Therefore, it is clear that osmophilic yeasts that are efficient at 0.60–0.65 water activity values can cause the spoilage of untreated samples after this stage (Troller and Christian 1978). According to results of statistical analyses, effects of pretreatment, storage time and their interaction on the changing water activity values were found significant ($P < 0.05$). Means for groups in homogeneous subsets showed that the difference between the water activity values that were treated using 20 and 50 Brix trehalose were not significant ($P > 0.05$). Also, differences between the water activity values for 20 and 50 Brix trehalose-treated samples that were measured after 9 and 12 months were found insignificant ($P > 0.05$). The effect of drying temperature on water activity value changes during storage, and the interaction between the storage period and the drying temperature of samples were found significant ($P < 0.05$).

Vitamin C

As seen in Fig. 3, the amount of vitamin C decreased in all samples during storage. Villota and Hawkes (1992) have also presented some kinetics of vitamin C destruction in several agricultural products during thermal processing and storage. Maximum vitamin C amount determined just after drying was found in the samples treated by 50 Brix trehalose solution. Generally, vitamin C loss was found more in samples treated with both 20 and 50 Brix trehalose solutions compared with untreated and sucrose-treated samples. Vitamin C loss was found to be rather high especially in the first 6 months of storage for all samples dried at different drying temperatures, as seen in Fig. 3. After 12

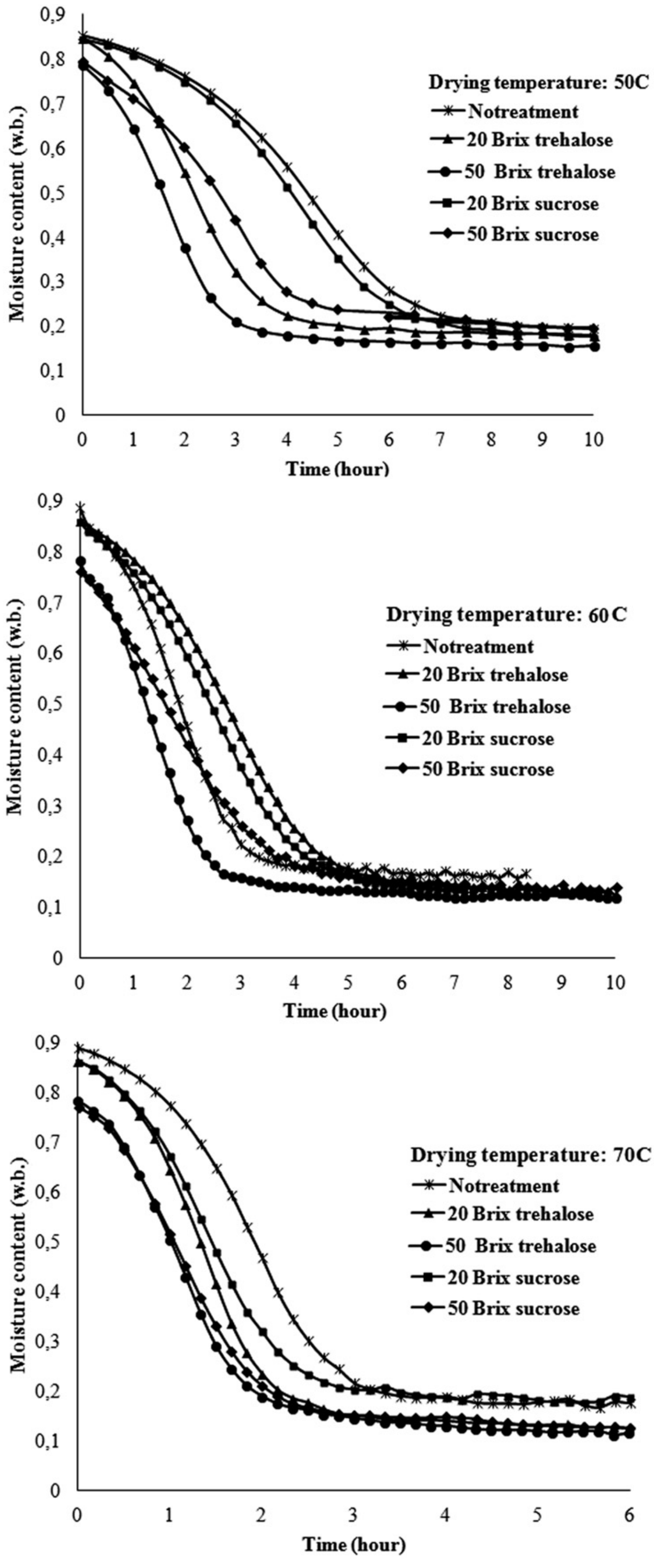

FIG. 1. THE EFFECTS OF PRETREATMENTS ON THE ISOTHERMAL DRYING CURVES OF APPLES FOR DIFFERENT DRYING TEMPERATURES

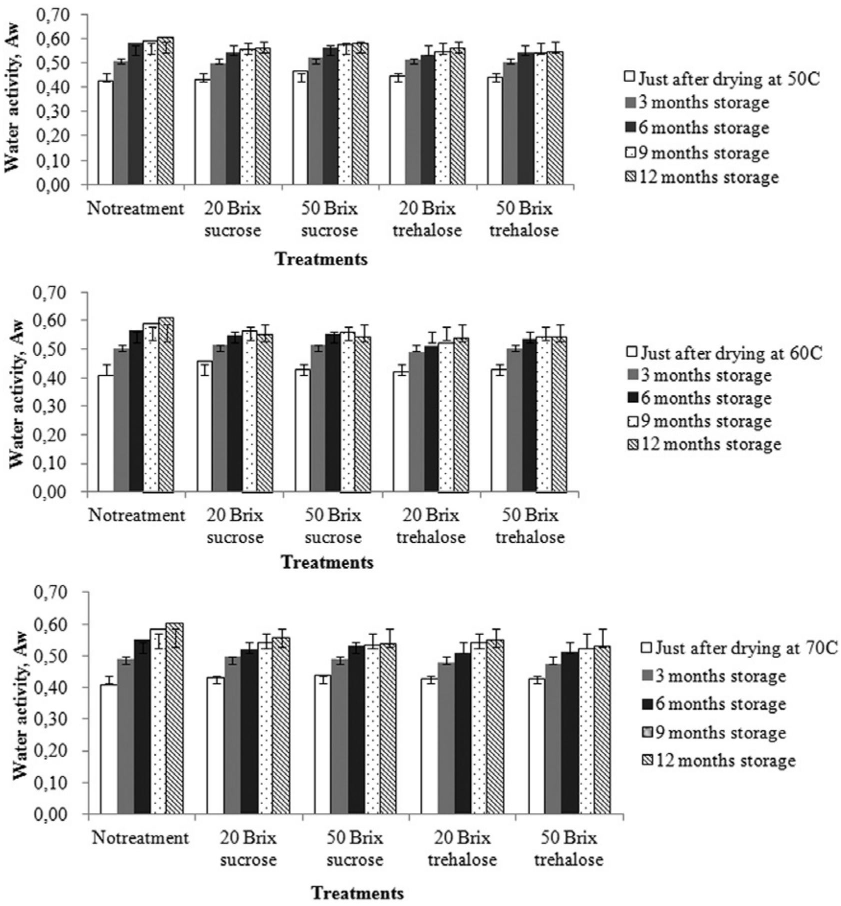

FIG. 2. CHANGES IN WATER ACTIVITY DURING STORAGE
Water activity of fresh apple is 0.89

months storage, 50 Brix trehalose treatment could keep vitamin C amount in the samples. Statistical analysis results showed that effects of pretreatment, storage time and their interaction on the changing water activity values were found significant ($P < 0.05$). Means for groups in homogeneous subsets for pretreatments showed that differences among the vitamin C values in the samples that were treated using 50 Brix sucrose and both 20 and 50 Brix trehalose were not significant ($P > 0.05$). Also differences between the vitamin C contents for 20 and 50 Brix trehalose-treated samples that were measured after 9 and 12 months were found insignificant ($P > 0.05$). Interaction of storage period and drying temperature of samples was also found significant ($P < 0.05$).

Dry Matter

As seen in Fig. 4, dry matter amount decreased slightly in the first 6 months, then increased at the ninth month. These changes occurred slightly differently in the all samples with storage time dependent on the drying temperature and pretreatments. Samples that were treated osmotically had higher dry matter compared with untreated sample. After a 6-month storage period, dry matter content of untreated sample and 20 Brix sucrose-treated samples were found to be lower than those of other samples. Dry matter content of samples treated with higher sucrose concentration (50 Brix) and trehalose (20 and 50 Brix) were found generally higher than those of untreated sample and 20 Brix sucrose-treated sample. Dry matter content determined at the ninth and 12th months showed that these values highly increased at the end of storage. The lowest dry matter content that was determined just after drying was found as 72.3% in the samples untreated and dried at 50C. Dry matter amounts in the sucrose-treated samples were found lower than those of trehalose-treated samples. While effects of pretreatment and storage time on the changing water activity values were found significant ($P < 0.05$), their interaction was found insignificant ($P > 0.05$). Difference between the dry matter contents determined just after drying, third and sixth month, were found insignificant ($P > 0.05$) as can be clearly seen in Fig. 4. Means for groups in homogeneous subsets for pretreatments showed that differences among the dry matter content in the samples that were treated using 50 Brix sucrose and both 20 and 50 Brix trehalose were not significant ($P > 0.05$). Interactions of storage period and

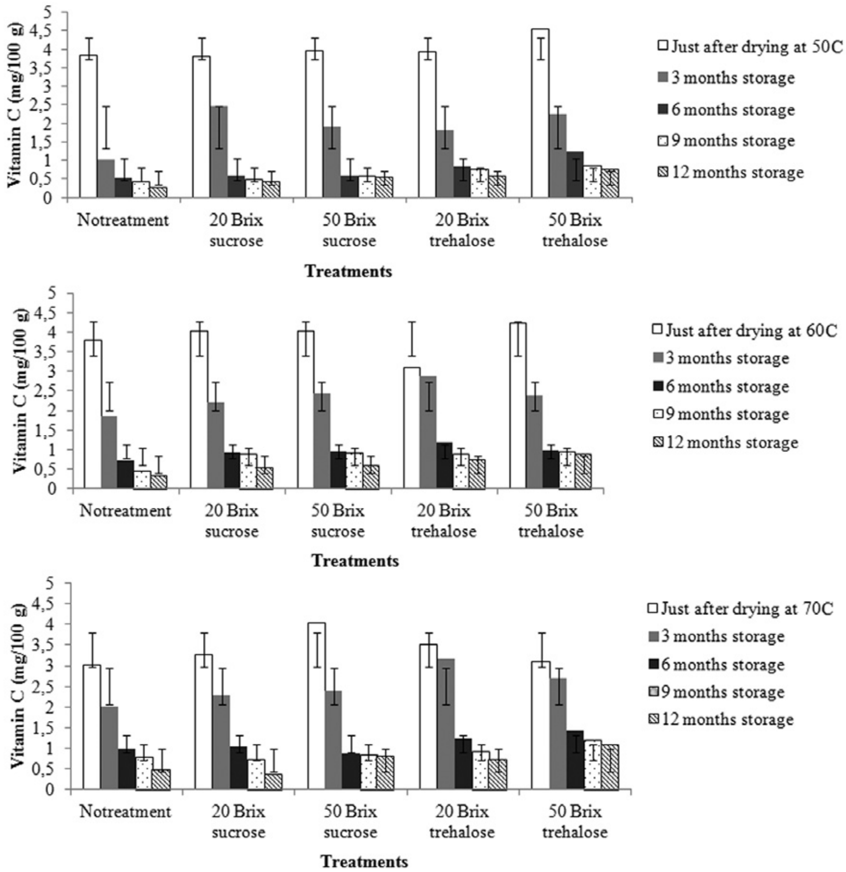

FIG. 3. CHANGES IN VITAMIN C OF APPLE SAMPLES DURING STORAGE

drying temperature of samples was also found insignificant ($P > 0.05$).

Total Phenols Content

As seen in Fig. 5, total phenols content of samples after drying increased compared with total phenols content of fresh samples that was determined as 137.1 mg/100 g dry matter. Cemeroglu (2004) stated that browning happens in products of fruits and vegetables by reactions that are catalyzed by polyphenoloxidase enzymes of phenols. Research on the drying of apple pomace and peels showed that the drying process increases the total phenols amount in the final product (Wolfe and Rui 2003). Schieber *et al.* (2003) dried and then extracted the apple pomace to recover the phenolic matter. They determined that total phenols content of fresh apple pomace was lower than total phenols content of dried apple pomace. Hagen *et al.* (2007) determined that postharvest irradiation UV-B caused increasing of the total phenols content in the apple.

Irregular changes of total phenol content were seen throughout the storage period. Total phenol contents of untreated samples were found to be higher than those of treated samples after 12 months storage. Also, maximum browning occurred in the untreated samples at the end of storage period. It can be concluded that more reactions that are catalyzed by polyphenoloxidase happened in the untreated samples and this contributed to browning (Cemeroglu 2004).

Statistical analysis results showed that effects of storage time on the changing total phenols contents was found significant ($P < 0.05$) while pretreatments, and interaction of pretreatment and storage period were found insignificant ($P > 0.05$). This proved that all sucrose and trehalose treatments to apple samples could decrease the phenols amount that stayed in the samples and caused to enzymatic browning reactions. Effect of drying temperature, storage period and their interaction on the changing total phenols contents were found significant ($P < 0.05$).

Color Characteristics

Changing of lightness difference (ΔL^*) and the magnitude of change in hue ($\Delta\alpha^*$) that were calculated from the average values of three chromatic scales (L^*, a^*, b^*) measured for apple samples were given in Figs. 6 and 7. As seen

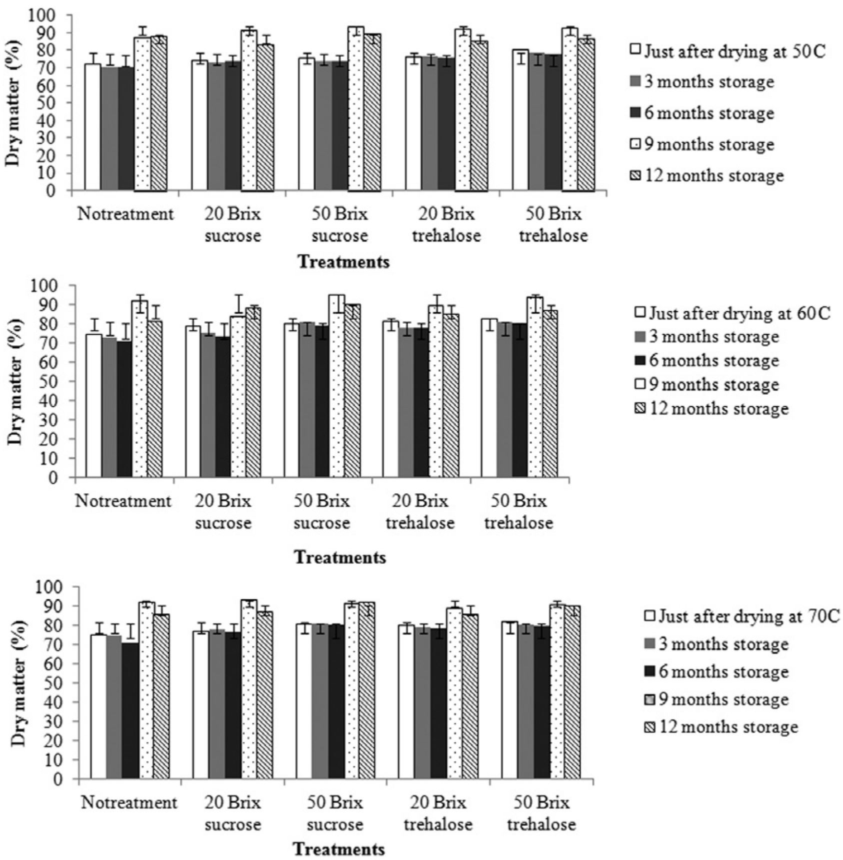

FIG. 4. CHANGES IN DRY MATTER DURING STORAGE
Value for fresh apple: 19.44%

in these figures, rather high deviations in the color parameters occurred just after drying and especially after 9 months storage period. These changes were determined to be rather higher in the untreated samples compared with others. For example, total color changes (ΔE^*) in the untreated sample dried at 60C was calculated as 24.03, lower changes for osmotic treated samples were found (14.24–17.14). After 12 months storage, browning were seen in all samples and some part of untreated samples were getting to be spoiled; 50 Brix sucrose treatment could keep the sample color more than 20 Brix sucrose treatment while both 20 and 50 Brix treahalose treatment could keep the sample color more stable. As seen in Figs. 6 and 7; maximum brightness changes and changes in hue were found in untreated samples and 20 sucrose-treated sample followed this. Figures 6 and 7 showed that changes in the lightness and hue increased especially the last 6 months storage period with the increase of the water activity values. Trehalose applications, especially 20 Brix trehalose treatment, decreased these deviations in the first 6 months of the storage period even for the samples dried at 70C. Color parameter measurements on the ninth and 12th months showed that the effects of osmotic treatments were rather close to each others at the last 6 months storage.

Although there are not many research conducted on osmotic treatment using trehalose and its effect on the color parameters of fruits, there have been several research on the evaluation of color change during osmotic dehydration using different osmotic agents such as sucrose, maltodextrin, fructose, glucose, sorbitol, etc. Chauhan *et al.* (2011) reported that different osmotic solutions have different effect of on color changes. L^* value after sucrose application was found higher than applications of fructose, sorbitol, glucose and honey. According to our findings in this research, osmotic treatments using osmotic solutions with higher concentration sucrose (50 Brix) and both lower (20 Brix) and higher (50 Brix) concentration trehalose reduce the discoloration of apple slices by enzymatic browning by limiting exposure of fruits to oxygen, and the sugar uptake increases the stability of pigments during further drying and subsequent storage period as mentioned by Azarpazhooh and Ramaswamy (2010).

Variance analyses showed that effects of storage period and pretreatments on almost all color parameters including L^*, a^*, b, ΔL^*, Δa^*, Δb^*, ΔE^*, $\Delta\alpha^*$ were found significant ($P < 0.05$) while interaction of storage period and pretreatments were found insignificant ($P > 0.05$). It was

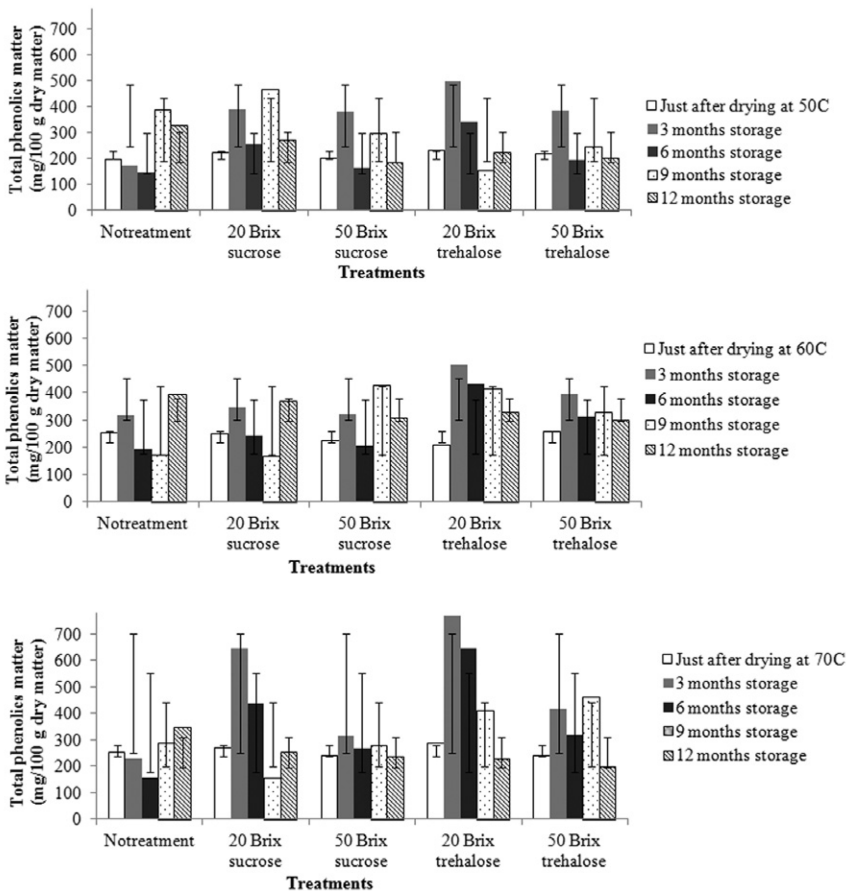

FIG. 5. CHANGES IN TOTAL PHENOLS DURING STORAGE
Value for fresh apple sample: 137.1 mg/100 g dry matter

determined that all pretreatments had good effect on these parameters. Differences between those parameters of untreated sample and samples pretreated using sucrose and treahalose were found significant ($P < 0.05$). Effect of pretreatments on α^* and effect of storage period on ΔC^* and their interaction on both α^* and ΔC^* were found insignificant ($P > 0.05$).

Effect of drying temperature on all color parameters were found significant ($P < 0.05$), except b^*, Δb^*, ΔC^*, while interactions of pretreatments and drying temperatures were found insignificant ($P > 0.05$). Difference between color parameters determined for samples dried at lower drying temperature namely 50C and for samples dried at relatively higher drying temperature namely 60 and 70C was found significant ($P < 0.05$).

Mechanical Properties

Changes in fracture force values of apple samples that were dried at 50, 60 and 70C and pretreated using sucrose and trehalose solutions were given in Fig. 8. In this figure, it can be seen that fracture force increased in all samples that were osmotically pretreated. This can be explained with decreasing of hardness and increasing of elasticity in texture after osmotic pretreatment. Lewicki and Lukaszuk (2000) prepared cubic apple samples (10 mm) and applied sucrose solution (61.5%) at 30C for 3 h. Then they dried the samples using air convection drying method at 70C drying temperature and 1.5 m/s air velocity. They indicated that sucrose applications lead to significant changes in apple tissue, increased its visco-elastic property and decreased shrinkage and hardness.

It was determined that fracture force value of untreated control samples was found approximately half of those values of sucrose-treated samples. Namely control samples are more fragile and harder. Lewicki and Lukaszuk (2000) also determined similar results. Results of this research showed that osmotic pretreatments with 50 Brix sucrose and 20 and 50 Brix trehalose have potential to improve the final product quality. Because one of the optimization criteria of drying process for air-dried apples was notified as obtaining product with minimum hardness (Azarpazhooh and Ramaswamy 2011).

Increasing drying temperature to 70C decreased fracture force. Higher increasing in fracture force was found for untreated samples compared with osmotic treated samples.

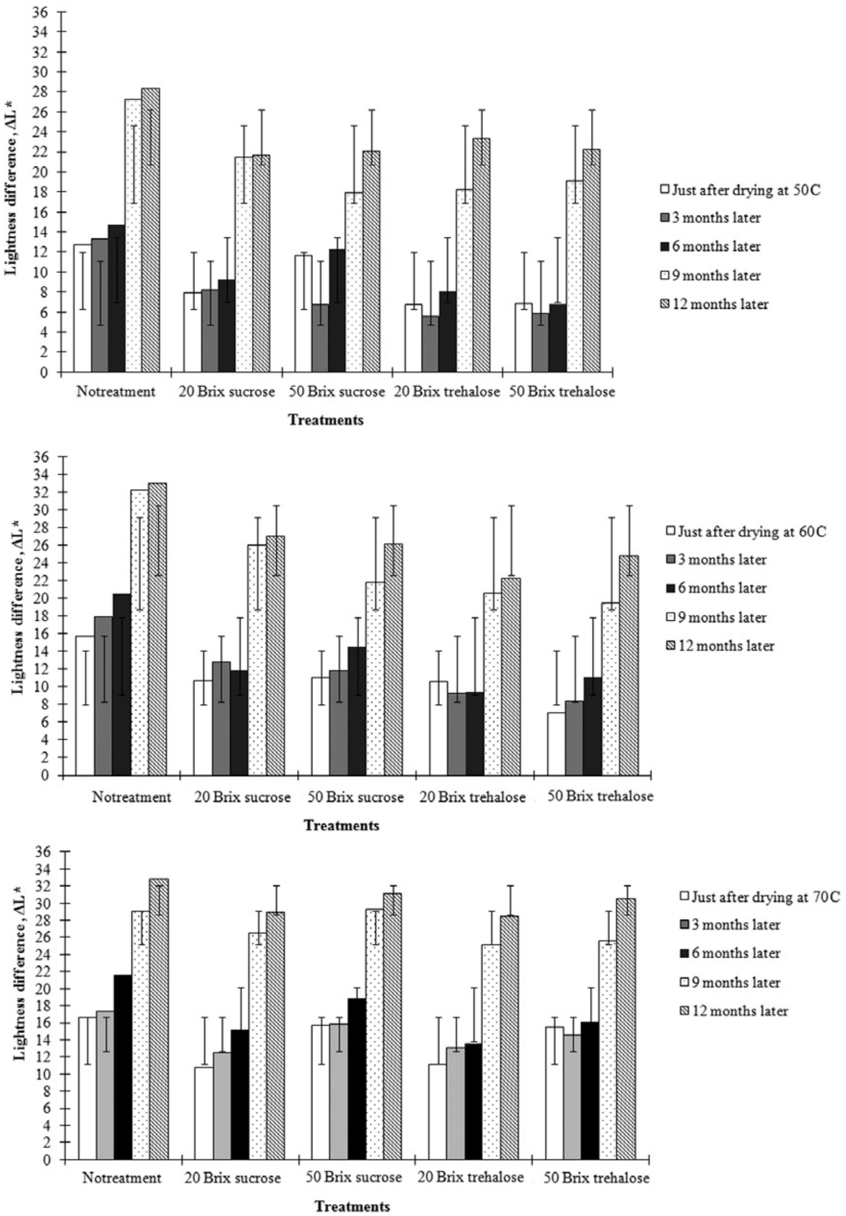

FIG. 6. CHANGES IN LIGHTNESS DIFFERENCE DURING STORAGE
*L**, *a** and *b** values for fresh apple were found as 86.73, –6.88 and 27.84, respectively

While harder texture was occurred in untreated and directly dried samples, softer and chewy texture was occurred in osmotic pretreated samples.

It was observed that samples were getting to be softer and had more plastic structure that can be explained with increasing of their moisture content during storage. Higher plasticity in untreated samples compared with osmotic-pretreated samples was seen at all drying temperatures as seen in Fig. 8. Untreated samples absorbed moisture and their fragile structure due to drying process had become plasticity structure rapidly. However, structures of samples that were pretreated using 50 Brix sucrose and 20 and 50 Brix trehalose stayed more stable just after drying (Fig. 8).

It was determined that effects of pretreatment and storage time on the fracture force values were found significant ($P < 0.05$), while their interaction was found insignificant ($P > 0.05$). Although fracture resistance increased for all samples throughout 12 months storage, differences among increases in fracture force determined after 3, 6, 9 and 12 months storage were found insignificant ($P > 0.05$). It was seen that pretreatments of 50 Brix sucrose, 20 and 50 Brix trehalose have better effect to decrease the negative effects on the sample tissue that were hot air dried compared with untreated and 20 Brix sucrose treated samples. Means for groups in homogeneous subsets for pretreatments showed that differences among the fracture forces

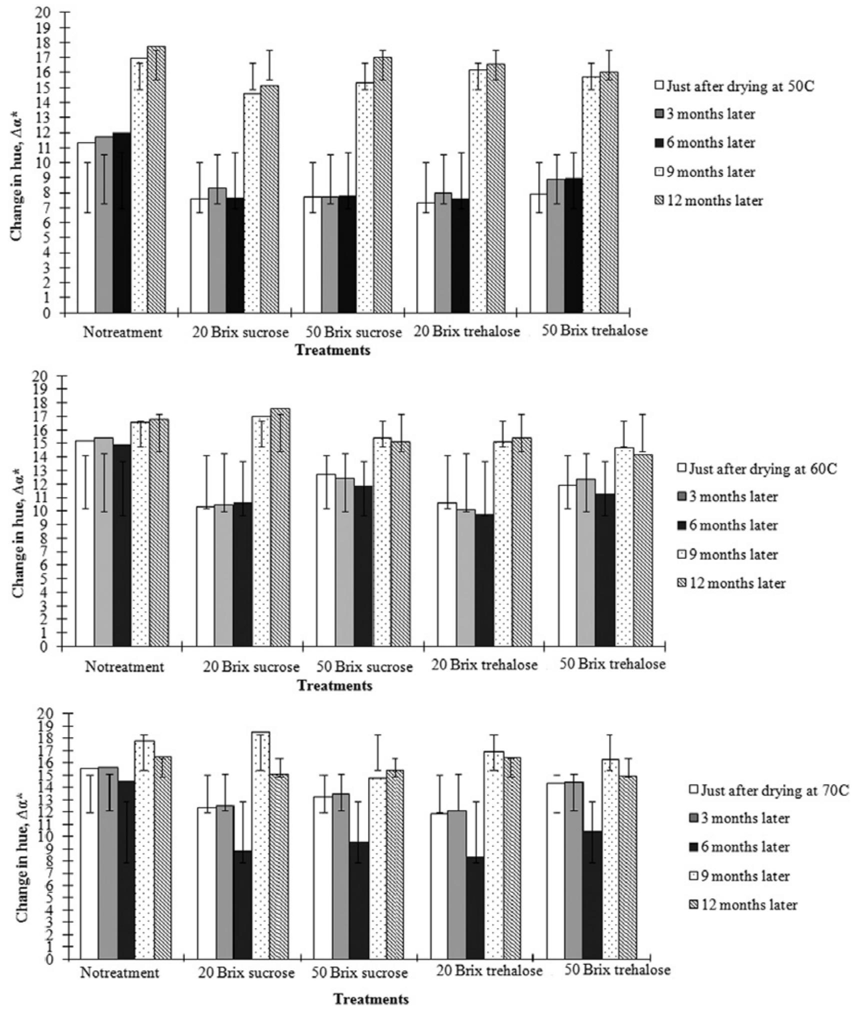

FIG. 7. THE MAGNITUDE CHANGE IN HUE (ΔA^*) DURING STORAGE

in the samples that were treated using 50 Brix sucrose and both 20 and 50 Brix trehalose were not significant ($P > 0.05$). Interaction of storage period and drying temperature of samples was found insignificant ($P > 0.05$) although effect of storage period and drying temperature on fracture forces changing was found significant ($P < 0.05$).

Figure 9 shows that puncture force values of untreated apple samples were found higher compared with those values of osmotic pretreated samples. Softer samples were obtained using osmotic pretreatments while rather hard untreated samples were obtained. This can be explained with sugar gaining and sugar diffusion intercellular spaces during osmotic treatments.

As seen in Fig. 9, increasing of drying temperature increased the puncture force. Puncture force of all samples decreased sharply even after 3 months storage. Bigger decrease in puncture force was found in especially untreated samples (Fig. 9). Changes in puncture force of trehalose treated samples were found lower compared with those values of the other samples. This change was found as minimum in 50 Brix trehalose treated samples even after 12 months storage period (Fig. 9). On the other hand effect of pretreatments on the changes in puncture force was found insignificant ($P > 0.05$) while storage period and interaction of pre-treatment and storage period found significant ($P < 0.05$). Interaction of storage period and drying temperature of samples was found insignificant ($P > 0.05$) although effect of storage period and drying temperature on puncture forces changing was found significant ($P < 0.05$).

Sensory Analysis

Difference between samples treated by 50 Brix sucrose and 50 Brix trehalose was found insignificant ($P > 0.05$) in almost all sensory attributes except texture (Table 1). In the evaluation method, scores of at least 5 were considered acceptable. Untreated sample stayed behind the pretreated

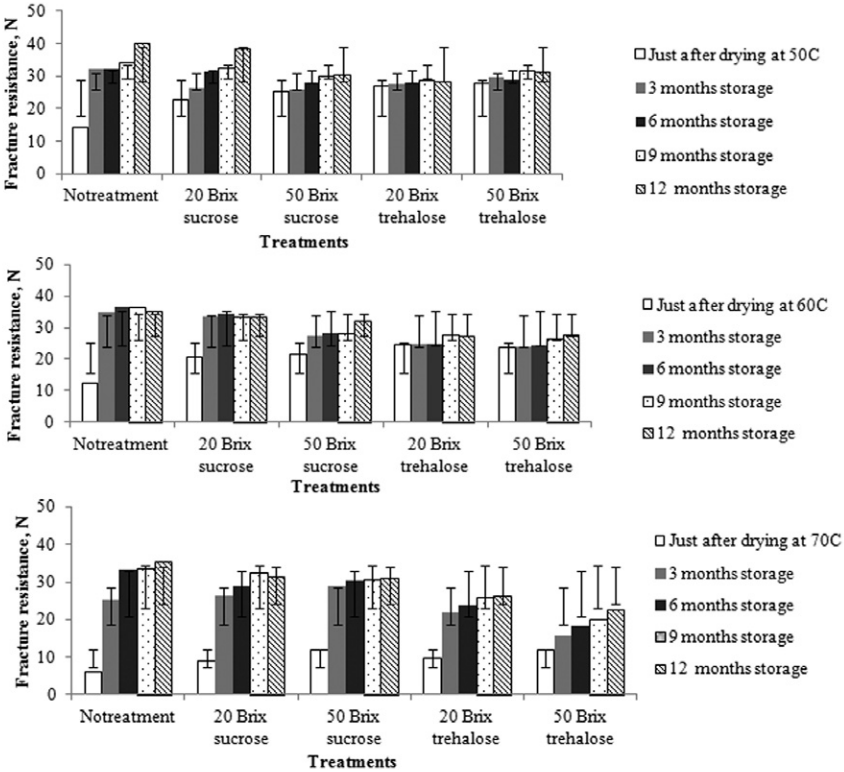

FIG. 8. CHANGES IN FRACTURE FORCE OF APPLE SAMPLES DURING STORAGE DEPENDENT ON DRYING TEMPERATURE

samples in terms of ranking of all the features and was found acceptable only in respect of taste attribute while all pretreated samples were found acceptable in respect of all attributes. The highest scores in terms of appearance, and taste were determined samples that were pretreated using 20 Brix trehalose solution (Table 1). Also overall acceptability scores showed that the highest preference was found for samples treated by 20 Brix trehalose. There was no significant difference between overall preference of 50 Brix sucrose and trehalose treated samples ($P < 0.05$). This can be explained that using of trehalose that has less sweetness degree compared with sucrose could keep the natural aroma and taste of the apple samples. Trehalose is 45% as sweet as sucrose when compared with a 10% sucrose solution (http://www.cargillfoods.com/na/en/products/sweeteners/index.jsp). It seems no research performed using trehalose about sensory analysis but Ochoa-Martinez *et al.* (2006) investigated the effect of convective-osmotic drying on texture and preference of apple. Similar to our results, their sensory evaluation showed that samples pretreated and dried using 50 Brix sucrose had the higher preference by the judges.

CONCLUSIONS

The effects of various osmotic pretreatment combinations on the drying characteristics and some quality parameters of *Granny Smith* var. apple at 50, 60 and 70C drying air temperatures were investigated in this research. Sucrose and trehalose solutions with 20 and 50 Brix concentrations were used as pretreatments. The experimental results show that the use of trehalose solutions, especially with 50 Brix concentration, generally decreased the drying time compared with other applications.

Harder texture occurred in untreated dry samples while softer and chewier texture was seen in osmotic pretreated samples. During storage, puncture force decreased sharply, especially in untreated samples.

As it is known nonenzymatic browning occurs during conventional hot air drying and is major cause of color degradation in apple fruit. SO_2 is usually employed to prevent these browning reactions (Azarpazhooh and Ramaswamy 2011). Our findings showed that osmotic pretreatments even with lower concentration solutions using trehalose as osmotic agent have the potential to eliminate this step for apple drying and storage of dry product. Also decreasing of drying time using trehalose solutions as osmotic agents before hot air drying can be more effective to prevent poor quality product that is seen, especially after sucrose treatments using solutions with high concentration, due to caramelization, Maillard reactions, and ascorbic acid oxidation.

Chauhan *et al.* (2011) stated that osmotic pretreatments at high sugar concentrations resulted in products with

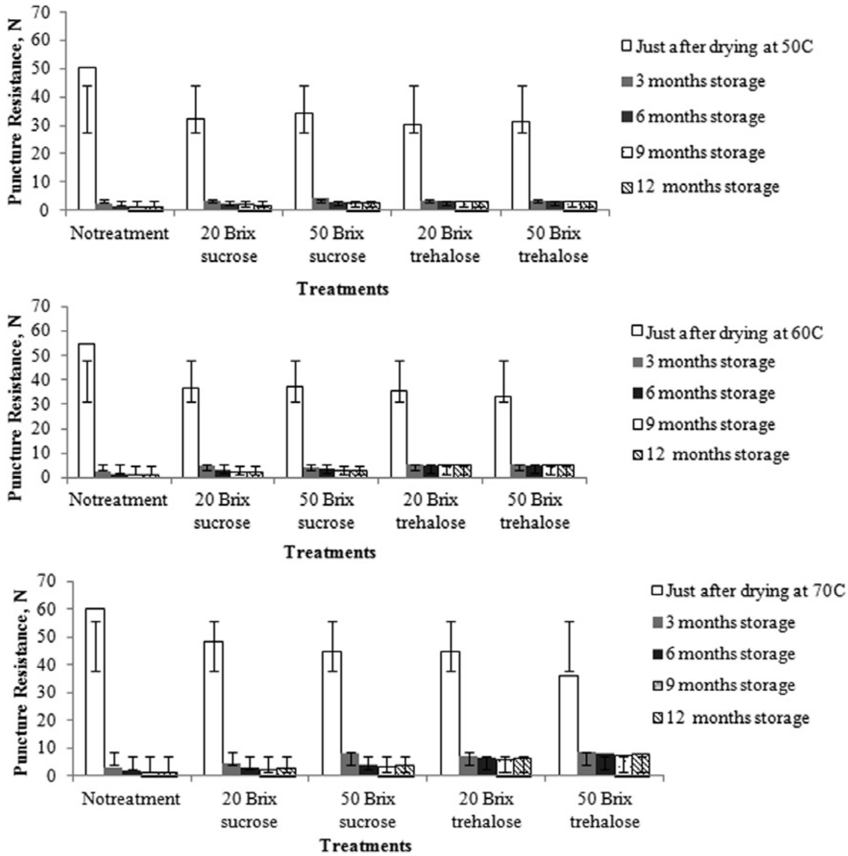

FIG. 9. CHANGES IN PUNCTURE FORCE OF APPLE SAMPLES DURING STORAGE DEPEND ON DRYING TEMPERATURE

better physical properties than those treated at lower concentrations. Our findings showed that even low concentration trehalose pretreatment resulted in products that have better quality properties after drying and also during storage. Several researchers have shown that pretreatment with different osmotic solutions had different effects on the quality properties of the apple slices including texture and structural changes due to the differences in solute uptake which resulted in lower transfer of O_2 to the surface, formation of sugar coating on the surface of the slices, degree of plasmolysis in the cells resulting in deformation, contraction and collapse (Gekas *et al.* 1998; Chauhan *et al.* 2011). Chauhan *et al.* (2011) reported that sucrose solution treated samples showed better color values; texture in terms of hardness, adhesiveness, springiness, cohesiveness and chewiness; structure in terms of cellular structure and cell wall integrity; and sensory attributes in terms of color, appearance, aroma, taste, texture, and overall acceptability as compared with the samples osmosed in honey, glucose, sorbitol, fructose or maltose. Its reason was explained with the occurrence of lower solid gain during osmotic treatment using sucrose that has higher molecular weight, which is desirable in osmo-dried fruits. Despite equal molecular weights of trehalose and sucrose (342.3 g/mol), solid uptake of potato samples treated using sucrose solution was found higher than those samples treated using trehalose (Aktas *et al.* 2004b). Chauhan *et al.* (2011) investigated the effect of different osmotic agents on the cell structure of apple samples and their results showed that cellular structure retained in sucrose dipped samples while more damage was observed in the other samples dipped into different osmotic agents. This was accepted as one of the reasons to obtain better quality final products. According to Anon (2013), trehalose can prevent the disruption of internal cell organelles, by effectively splinting them in position. Rehydration then

TABLE 1. RESULTS OF SENSORY ANALYSES ON DRIED APPLE SAMPLES

Pretreatments	Mean values for appearance	Mean values for texture	Mean values for taste	Overall acceptability
Untreated	3.0a	3.8a	5.4a	4.1a
20 Brix Sucrose	6.1b	6.7b	7.0b	6.6b
50 Brix Sucrose	7.9c	7.2c	7.3c	7.4c
20 Brix Trehalose	8.1d	7.1c	8.4d	7.9d
50 Brix Trehalose	7.9c	7.4d	7.4c	7.5c

Means sharing the same letter in rows are not significantly different from each other (Tukey's significant difference test, $P < 0.05$).

allows normal cellular activity to be resumed without the major, lethal damage that would normally follow a dehydration/rehydration cycle. Aktas *et al.* 2004a investigated the cell structure changes with sucrose and trehalose pretreatments and cell reconstruction after rehydration. They found that pretreatment with trehalose solution improved the reconstitutional properties of dried sliced carrot and potato samples compared with the dried products after pretreatment with sucrose solution. In this respect, the use of trehalose as an osmotic agent has good potential before drying of fruits and vegetables.

In conclusion, measured values related with quality and shelf life of samples showed that the use of trehalose solution with 20 Brix can highly keep the quality properties of the dry apple slices. 50 Brix trehalose pretreatment in respect to decreases in drying time and 20 Brix trehalose pretreatment in respect to keeping the quality properties, including sensory properties, can be recommended according to the results of this research.

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