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Prediction of shelf-life and changes in the quality characteristics of semidried persimmons stored at different temperatures

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Abstract This study was performed to investigate changes in the quality characteristics and shelf-life of semidried persimmons stored at different temperatures using acceleration experiments. In order to estimate quality changes in the samples, we evaluated the physicochemical properties, microbiological changes, and sensory features of the samples periodically after storage at −20, −10, 0, and 10 °C. At all storage temperatures, CIE $L^*a^*b^*$ values decreased significantly. Based on the results of this study, regression equations are set up. L^* had the highest correlation and were therefore used to determine quality factor. The activation energy, which was calculated using the Arrhenius equation, was found to be 12.98 kcal/mol, and the Q10-values were 3.81, 2.07, and 2.06 at −20 to −10 °C, −10 to 0 °C, and 0 to 10 °C, respectively. Therefore, the expected expiration dates of the semidried persimmons were estimated to be 203.83, 53.46, 22.00, and 8.71 days at −20, −10, 0, and 10 °C.

Keywords Semidried persimmons · Quality factor · Q10-value · Shelf-life · Arrhenius equation

Introduction

The persimmon (*Diospyros kaki*) is an edible fruit native to East Asia, primarily China, and is also plated in Italy, Spain, the United States of America, Brazil, Israel, Australia, and New Zealand. There are over 400 species of persimmons, which vary widely in shape and colour [1]. Persimmons are abundant in some nutrients, such as vitamin C (70 mg/100 g pulp), vitamin A (65 mg/100 g pulp), calcium (9 mg/100 g pulp), and iron (0.2 mg/100 g pulp) [2]. Persimmons are broadly classified into two major groups: non astringent and astringent persimmons. The fruit is mainly eaten fresh, but can also be dried, frozen, or canned [1]. Astringent persimmons are hard to eat without any processing; therefore, they are typically, consumed after drying. However, the drying process affects product quality, including density, sorption properties, texture, porosity, and colour [3]. Because the appearance of the fruit is subjected to a rigid quality control process, a significant proportion of persimmons have no commercial value as a fresh product [4].

Dried persimmon products distributed in Korea are classified as dried or semidried persimmons depending on the moisture content [5]. In the case of semidried persimmons, it is in the form with texture between Hongshi and dried persimmon. Because of its rich sweetness and unique physical properties, it has a moist texture and is highly preferred. Therefore, it is a high value-added product expected to increase in the future [6]. It is difficult to store semidried persimmons for prolong times at room temperature, because of the occurrence of hygiene problems, such as fungal contamination. Most dried persimmons are produced using sun drying; thus, there are major concerns regarding, potential mixing of foreign substances, colour changes, mould growth, and other damage during drying. After drying, the quality of semidried persimmons is rapidly reduced, with tissue hardening and the formation of white powder during storage and distribution [7]. Nowadays, consumers demand high quality products with acceptable appearance, flavour, taste, and texture, as well as good nutritional value after processing.

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Therefore, determining the properties of food products during their shelf life is critical for research and development centres in the food industry.

Shelf-life experiments can take a long time. Accelerated shelf-life tests (ASLTs) are often used to overcome this problem [8]. The basic process involves the following steps: (1) selection of the kinetically active elements, (2) performing the kinetic study such that the rate of deterioration is sufficient, (3) extrapolation of the kinetic parameters to normal storage conditions, and (4) use of the extrapolated kinetic data to calculate the shelf-life under real storage conditions [8]. The length of the shelf-life can be determined from sensory data using several graphical techniques [9]. Determination of the shelf-life by hazard analysis has generally been used in the mechanical and electrical industries [10]. The Arrhenius equation is the most common model for these purposes since it creates a specific relationship between the temperature and reaction rate constant [11]. This approach has been adapted and developed for determination of the shelf-life of foods. When the semidried persimmons are stored in under freezing conditions, they may expire within 6 months if packaged in normal paper box packaging. In contrast, the expiration date is typically 1 year for products stored in modified atmosphere packaging. The objectives of the present study were to monitor the quality characteristics of semidried persimmons stored at different temperature; (i) to analyse the association between quality parameters and sensory characteristics; (ii) to calculate the Q_{10}-values, activation energy (Ea), and shelf-life of semidried persimmons using Arrhenius equation.

Materials and methods

Sample preparation and storage conditions

Semidried persimmons (*Diospyros kaki* Thumb.) were obtained from Sangju (Kyungpook, South Korea). The selected fruits were of uniform external colour, similar in firmness, and packed in nylon film (20 × 30 cm). The fruits were incubated at 20, −10, 0, and 10 °C. Analysis were conducted over 80 days of incubation.

Changes in quality characteristics

Physicochemical analysis

Soluble tannin (ST) contents were measured using the Folin–Denis method [12], with slight modifications. The absorbance was read at 760 nm using a spectrophotometer, and the results were expressed as mg tannic acid equivalents per 100 g fresh weight. The total soluble solids (TSS) of the juice sample were measured by using a digital refractometer (Master-α; Atago, Tokyo, Japan). TSS values were expressed as °Brix. Free sugar composition was determined by high-performance liquid chromatography (Shimadzu Co. Model Prominence, Kyoto, Japan) in semidried persimmons. The 5 g of the semidried persimmons mixed with 45 mL of distilled water and extracted by ultrasonic generator (40 kHz, Daihan Scientific Co. Ltd, Seoul, Korea) for 3 h at 50 °C. After extracting, followed by filtration through Whatman No.4 and the extracts were passed to a 0.45 µm syringe filter. The separation of free sugar composition was carried out by Sugar-Pak I column (6.5 × 300 mm, Waters Co.) at 90 °C. The mobile phase consisted of 0.01 mol/L Ca-EDTA buffer and the flow rate was kept constantly at 0.5 mL/min. The chromatographic peak coinciding with each sugar was identified by comparing the retention time with that of each standard. Three fruits were randomly selected for the color measurement. Colour values of the surfaces of semidried persimmons were measured using a colourimeter (CR-400; Minolta Co., Osaka, Japan) calibrated using a standard white plate ($L^* = 97.79$, $a^* = -0.38$, $b^* = 2.05$). Each sample was measured 30 times. The CIE L^*, a^*, b^* value represented lightness, redness, and yellowness, respectively.

Microbiological analysis

Semidried persimmons were analysed for microbiological counts according to the APHA standard method [13]. Seventy grams of sample was homogenised in 280 mL of 0.1% peptone using a stomacher (WS-400; Shanghai Zhisun Equipment Co, Ltd, China) and diluted 10-fold. Next, 1 mL of sample was transferred to a Petri dish in duplicate. Total aerobic bacteria were determined using Plate Count Agar (Difco Lab., Franklin Lakes, NJ, USA) after incubation at 35 ± 1 °C for 48 h. Yeasts and moulds were enumerated on Potato Dextrose Agar (Difco Lab.) after incubation at 25 ± 1 °C for 5 days. After culturing, white colonies were counted and expressed as logCFU/g.

Sensory evaluation

Sensory evaluation of the quality of semidried persimmons was conducted by 15 panellists who studied Food Science and Technology at Kyungpook National University. The attributes selected overall preference on a 7-point scale (from 1 = extremely dislike or low to 7 = extremely like or high) considering their surface brightness, surface smoothness, flavour, mould occurrence.

ASLT procedure and kinetics calculations

Alternative accelerated ageing methods under extreme conditions [14] have been used to measure quality attributes [15]. The most common model used for this purpose is the Arrhenius equation because, it relates temperature to reaction velocity (k) [16]. To determine the reaction order, we performed statistical analysis. For example, colour values followed zero-order kinetics better. Therefore, according to the values of k, the linear regression was carried out for colour [Eq. (1)]:

$$C = C_0 + kt \quad (1)$$

The temperature dependence of colour reactions was simulated by the Arrhenius equation [Eq. (2)):

$$K = Ae^{-\frac{Ea}{RT}} \quad (2)$$

When we converted the natural logarithm of the above equation, the following equation was obtained [Eq. (3)]:

$$LnK = -\left(\frac{Ea}{R}\right) \times \left(\frac{1}{T}\right) + LnA \quad (3)$$

where A is the Arrhenius constant, Ea is the activation energy (kcal/mol), R is the gas constant (1.986 cal/mol), T is the absolute reaction temperature (°K), and K is the reaction rate constant.

Ea signifies the minimum energy necessary to trigger the reaction. The Q_{10}-value, which is also related to the reaction rate according to temperature and is defined as the relationship of the reaction rates at (T + 10) and T, was defined as described by Labuza [16] [Eqs. (4, 5)]:

$$lnQ_{10} = \frac{10Ea}{RT(T+10)} \quad (4)$$

$$Q_{10} = \frac{K_{T+10}}{K_T} \quad (5)$$

where Q_{10} is the Q_{10}-value, Ea is the activation energy (kcal/mol), R is the gas constant (1.986 cal/mol), k is the rate constant, and T is the absolute reaction temperature (°K).

Statistical analysis

Determinations were carried out in triplicate, and data were subjected to analysis of variance (ANOVA). Significant differences between means were determined by Duncan's multiple range tests. Differences with p values of less than 0.05 were considered statistically significant. Experimental results are presented as means ± standard deviations (SDs).

Results and discussion

Changes in quality characteristics

Physicochemical analysis

The change processes of semidried persimmons are shown in Fig. 1. Surface of semidried persimmons at 10 °C appeared white moulds and discolouration after just 10 days of storage. This indicated that group in the higher temperature conditions develops discolouration and browning earlier. Also, moisture in the persimmons came out the surface and the texture became softer. At −20 °C, deterioration wasn't shown until 80 days of storage. Unlike the other groups, white powder was formed on the surface at −20 °C. This white powder means that sugar components are released outside of persimmons and they become white sugar crystal. The major component of white powder developed on the surface of dried persimmons was almost glucose [17].

ST contents and TSSs of semidried persimmons during storage are shown in Table 1. ST is a type of polyphenolic compound related to, astringency during the production and processing of products [18]. At all storage temperatures, the ST contents reached maximum values after storage for 10 days, and values then decreased significantly. In previous studies, the ST contents decreased with the progress of drying [17]. This means that the water content and tannin content are proportional. Park et al. [21] reported that the moisture content of dried persimmons increased by 5% and the ST increased in the nylon laminates. However, as the microorganisms proliferate using the increased moisture, the water content decrease again, so the ST contents decreased. The TSSs of the juice samples were measured. The TSS value of samples stored at 10 °C decreased from 5.20°Brix to 3.75°Brix. The free sugar composition can significantly affect sweetness, which is an important aspect of the sensory quality of fruits. Glucose and fructose were identified as the most predominant sugars in semidried persimmons (Table 1). Similar results have been reported by Im and Lee [19] and Moon et al. [20]. Study of Moon and Sohn [17] showed that the content of sucrose was rapidly decreased in early stage of drying, while glucose and fructose were rapidly increased. In all samples, glucose and fructose decreased and then increased during storage. Interestingly, lower storage temperatures were associated with slower free sugar content reduction rates. As mentioned above, the moisture content is increased by packaging but the moisture content is reduced due to microbial growth. The results are expressed in mg/ml, so the free sugar content per volume of the sample varies with the water content. The palatability of fruits can be decreased by changes in the colour of the fruit surface due to contact with oxygen, evaporation of water, and growth of fungi [22]. Changes in the CIE $L^*a^*b^*$ values were estimated using a colourimeter are shown in Fig. 2. Notably, L^* values decreased significantly during storage for all samples. The value was reduced to less than 30 after storage for 20, 25, and 80 days at 10, 0, and −10 °C, respectively. The CIE a^* and b^* values also decreased significantly.

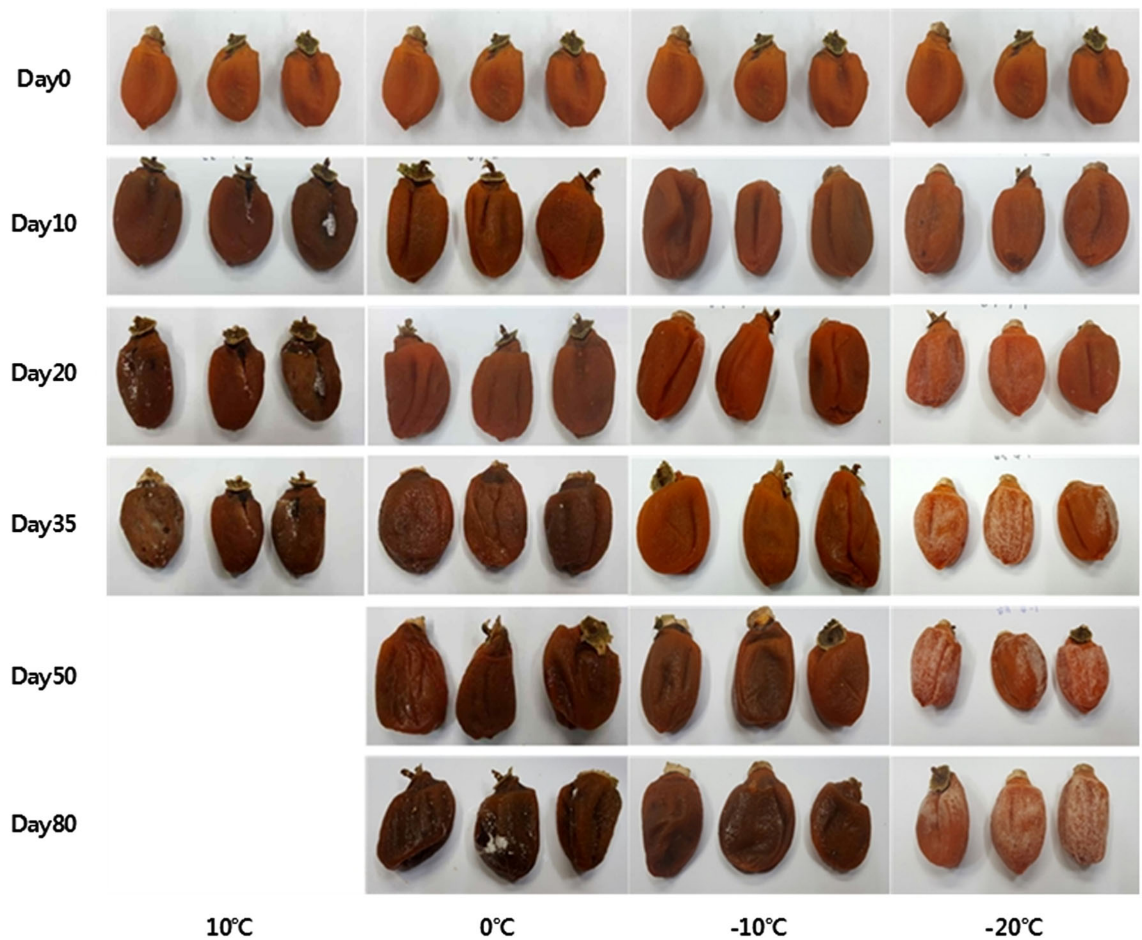

Fig. 1 Captured images of semidried persimmons at different temperature during storage

Microbiological analysis

The lag times and exponential growth rate constants of the total bacteria, yeasts, and moulds are presented in Fig. 3. During storage, the bacteria and moulds multiplied by using the sugars of the persimmon fruits. Because of this, dried persimmons lose commercial value [23]. At all temperatures, the initial number of bacteria was less than 2 logCFU/g. After 25 days of storage at 10 or 0 °C, total bacteria in semidried persimmons increased to more than 7 logCFU/g. The number of yeasts and moulds also increased to more than 7 logCFU/g. After 20 days of storage at −10 °C, there were no major changes in microbiological counts. According to a study by Kang et al. [24], the main contaminants were yeasts, including *Citeromyces matritensis* and *Metschnikowia* sp., and moulds, such as *Penicillium* sp. and *Aspergillus.* sp. [24]. The number of all microbes are pretty increased (7 logcfu/g) by about 20 days. Compared to samples at other high temperature, the moisture inside the semidried persimmons at −20 °C is less evaporated to the surface, and the amount of the sugar ingredient in the samples is also small. *Penicillium* sp. and *Aspergillus.* sp., which occurs using sugar and water, generated more inside than on the surface. Therefore, In Fig. 1, there is no growth of molds or yeast on the surface of the samples stored at −20 °C.

Quality factor and measurement of activation energy

The shelf-life of foods was evaluated based on sensory failure. On the 7-point scale used to measure overall preference, a cut-off score of 4 was used as a marker for product failure. In the present work, a cut-off score of 4, i.e., mild to moderate differences from the control, was used to mark the end of shelf-life because the sensory properties of the product started to change at this point. Correlation coefficients between sensory evaluation and quality factors of semidried persimmons are presented in Table 2. The L^* value was highly correlated at all temperatures, indicating that the CIE L^* value was a potential marker for ASLTs.

Table 2 shows the regression equations and correlation coefficients among sensory evaluation, storage period, and

Table 1 Changes in contents of soluble tannin, total soluble solids value and free sugar contents of semidried persimmon during storage

	Temp.(°C)	Storage periods (day)								
		0	5	10	15	20	25	35	50	80
Soluble tannin (mg %)	10	$198.59 \pm 1.27^{aD1)}$	231.10 ± 1.33^{aB}	242.11 ± 6.90^{cA}	213.86 ± 4.43^{cC}	212.69 ± 0.15^{dC}	218.02 ± 9.62^{bcC}	–	–	–
	0	198.59 ± 1.27^{aD}	197.32 ± 0.81^{cD}	261.84 ± 1.83^{bA}	234.25 ± 1.5^{bB}	231.71 ± 1.69^{cB}	211.22 ± 2.53^{cC}	213.76 ± 3.96^{bC}	235.36 ± 1.52^{aB}	–
	−10	198.59 ± 1.27^{aD}	199.86 ± 1.83^{cD}	259.30 ± 1.23^{bA}	246.11 ± 1.83^{aB}	241.14 ± 0.61^{bB}	235.46 ± 17.65^{abB}	203.51 ± 0.35^{cCD}	212.69 ± 2.89^{bC}	205.08 ± 1.98^{aCD}
	−20	198.59 ± 1.27^{aF}	206.86 ± 5.66^{bE}	273.05 ± 1.16^{aA}	245.25 ± 4.72^{aC}	262.14 ± 0.53^{aB}	240.69 ± 0.76^{aC}	240.84 ± 0.30^{aC}	231.86 ± 0.46^{aD}	187.74 ± 0.46^{bG}
Total soluble solids (°Brix)	10	5.20 ± 0.00^{aA}	5.00 ± 0.00^{bAB}	4.90 ± 0.05^{bBC}	4.65 ± 0.25^{aC}	4.65 ± 0.10^{bD}	3.75 ± 0.05^{cE}	–	–	–
	0	5.20 ± 0.00^{aA}	4.70 ± 0.00^{dB}	4.70 ± 0.00^{cB}	4.30 ± 0.05^{aC}	4.30 ± 0.05^{cD}	4.05 ± 0.05^{bF}	4.15 ± 0.05^{bE}	4.00 ± 0.10^{aF}	–
	−10	5.20 ± 0.00^{aA}	5.10 ± 0.00^{aB}	4.90 ± 0.00^{aC}	4.30 ± 0.05^{aDE}	4.30 ± 0.00^{bD}	4.40 ± 0.10^{aD}	4.30 ± 0.00^{aE}	4.00 ± 0.00^{aF}	4.30 ± 0.10^{aE}
	−20	5.20 ± 0.00^{aA}	4.80 ± 0.00^{cBC}	4.90 ± 0.00^{aB}	4.60 ± 0.20^{aC}	5.00 ± 0.00^{aAB}	4.30 ± 0.20^{aD}	4.35 ± 0.05^{aD}	4.20 ± 0.20^{aD}	4.95 ± 0.05^{bB}
Glucose (mg/mL)	10	20.50 ± 0.00^{aA}	–	16.95 ± 0.89^{cB}	–	19.71 ± 0.49^{abA}	–	–	–	
	0	20.50 ± 0.00^{aAB}	–	21.91 ± 0.36^{aA}	–	20.35 ± 0.40^{aAB}	–	15.65 ± 1.89^{aC}	18.85 ± 0.11^{aB}	–
	−10	20.50 ± 0.00^{aA}	–	20.24 ± 1.07^{abAB}	–	19.94 ± 0.05^{aAB}	–	17.47 ± 0.27^{aC}	17.10 ± 1.08^{bC}	19.22 ± 0.31^{B}
	−20	20.51 ± 0.00^{aB}	–	18.85 ± 1.09^{bB}	–	19.05 ± 0.55^{bB}	–	13.11 ± 0.69^{bC}	19.70 ± 0.51^{aB}	22.57 ± 1.62^{A}
Fructose (mg/mL)	10	19.50 ± 0.00^{aA}	–	15.81 ± 0.93^{cC}	–	18.05 ± 0.56^{aB}	–	–	–	–
	0	19.50 ± 0.00^{aA}	–	19.67 ± 0.26^{aA}	–	18.44 ± 0.47^{aAB}	–	14.41 ± 2.18^{bC}	17.00 ± 0.09^{aB}	–
	−10	19.50 ± 0.00^{aA}	–	18.40 ± 1.20^{abAB}	–	17.82 ± 0.13^{aBC}	–	15.94 ± 0.34^{abDE}	15.66 ± 1.06^{bE}	17.13 ± 0.21^{CD}
	−20	19.49 ± 0.00^{aA}	–	17.02 ± 0.94^{bcB}	–	15.28 ± 0.55^{bC}	–	17.56 ± 0.94^{aB}	17.97 ± 0.38^{bB}	20.09 ± 1.01^{A}

1) Values are Mean ± standard deviation

$^{a–c}$ means in a column preceded and $^{A–F}$ means in a row followed by different superscripts are significantly different ($p < 0.05$) by Duncan's multiple range test

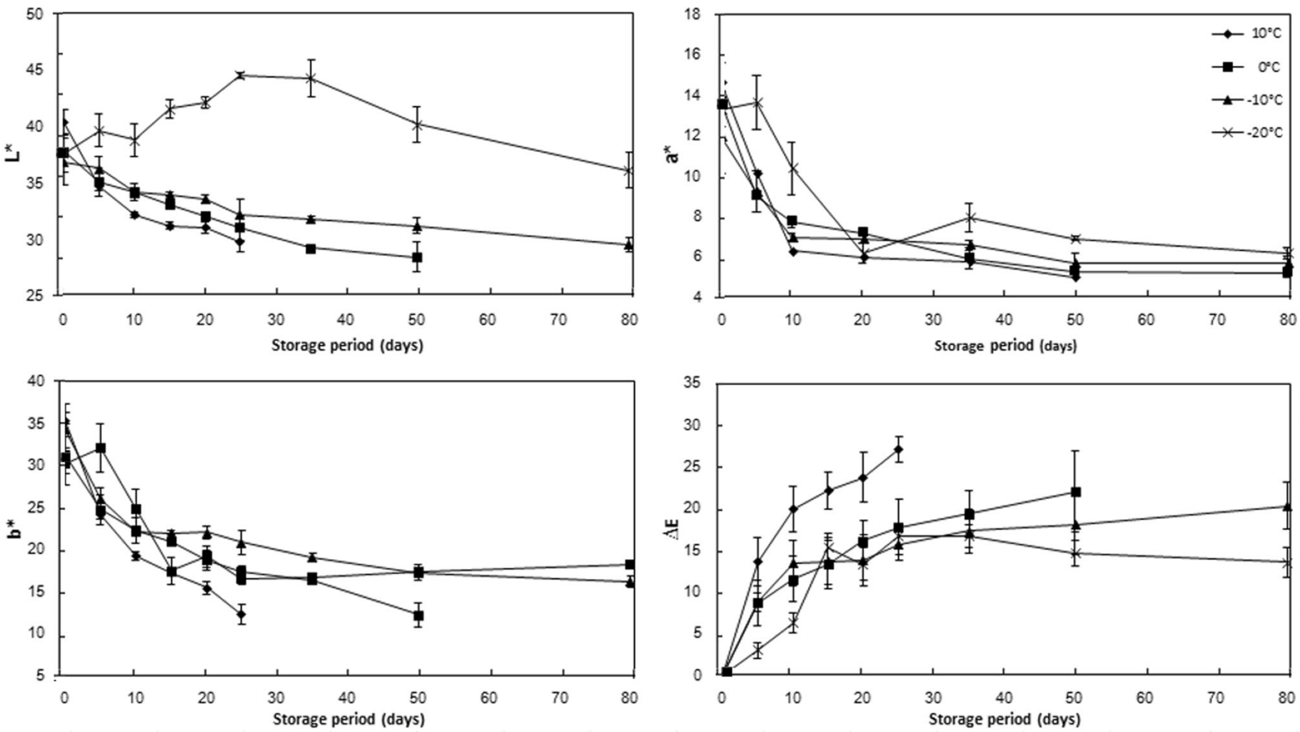

Fig. 2 Changes in CIE $L^*a^*b^*$, and ΔE values of semidried persimmon during storage. *Black diamond* group stored in the 10 °C, *black square* group stored in the 0 °C, *black triangle* group stored in the −10 °C, *X* group stored in the −20 °C. *Different letters* mean significant difference ($p < 0.05$)

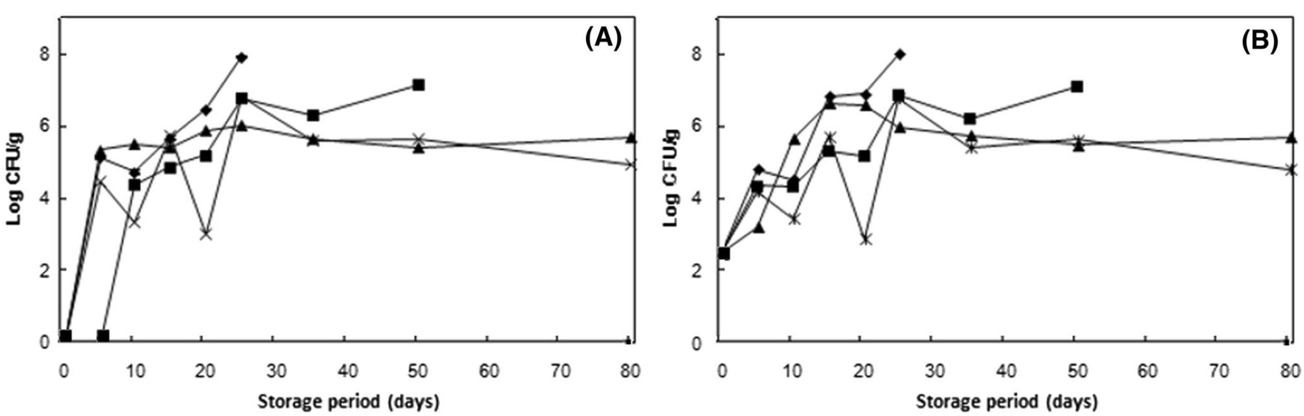

Fig. 3 The number of (**A**) total aerobic bacteria, (**B**) yeasts and moulds in semidried persimmon. *Black diamond* group stored in the 10 °C, *black square* group stored in the 0 °C, *black triangle* group stored in the −10 °C, *X* group stored in the −20 °C

L^* values. The estimated shelf-life values of semidried persimmons are also shown. The temperature dependence of *ΔE* values of semidried persimmons can be expressed in terms of the Q_{10}-value, which is the ratio of the shelf-life at two temperatures (10 °C apart) on shelf-life plots [25]. The Arrhenius equation was used to express the temperature dependence of the reaction rate constant [26]. For this purpose, we used the "k" values in Table 2. Plotting of ln1/absolute temperature versus 1/absolute temperature produced a straight line with a coefficient of determination (r^2) of 0.9734, according to shelf-life plots of foods (Fig. 4) [27]. The temperature dependence of deterioration of foods is often indicated in terms of Q_{10}-value, which are calculated as the ratio of shelf-life to temperature (10 °C apart) on shelf-life plots [25]. Q_{10}-value, indicating deterioration of samples, were 2.06 and 2.07 for temperatures of 0–10 °C and −10–0 °C, respectively. The Q_{10}-value at temperature T (K) is related to the Ea as indicated in Eq. (4), with R being the universal gas constant [28]. Substituting the determined Q_{10}-value yielded an Ea of 12.98 kcal/mol. For almost all food products, Q_{10}-values are approximately 3 [29]. The reason why there is no data

Table 2 Regression equation and correlation coefficient between sensory evaluation, storage period and L-values, predicted shelf-life of semidried persimmons

Quality factor	Temp. (°C)	Regression equation	Correlation coefficient	Regression equation (zero order)	k	Q10 value	Shelf life (days)
L^*	10	Y = 0.4970X − 13.2256[1)]	0.9396	y = −0.37063x + 37.8895[1)]	−0.37063	2.06	8.71
	0	Y = 0.4353X − 10.0452	0.9070	y = −0.17984x + 36.2268	−0.17984	2.07	22.00
	−10	Y = 0.4433X − 9.7310	0.8950	y = −0.08693x + 35.6170	−0.08693		53.46

[1)] Y = AX + B, y = kx + B; Y, score of overall preference; X, value of quality factor; x, storage period (days); y, L^* value; k, reaction rate constant

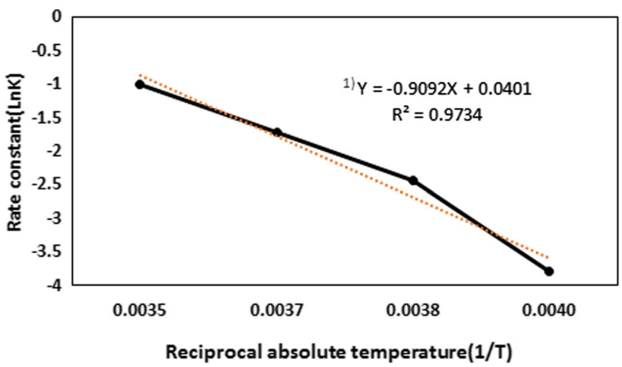

Fig. 4 Arrhenius plot of rate constant for Lightness in semi-dried persimmons versus reciprocal absolute temperature. 1) Y = AX + B. Y; LnK, X; 1/T, A; −Ea/R, R; gas constant (1.986 cal/mol), LnK; K = A e −Ea/RT (converted the natural logarithm of this equation) → LnK = −(Ea/R)(1/T) + LnA

at 20 °C is that temperature is so low, so there is little consistent quality change during short experiment period and correlation between quality index and storage period is low. Therefore, the accuracy of the derived equation was low, and the expiration date could not be set. For this reason, we use the above Eqs. (4) and (5) to estimate the distribution period at −20° C.

Determination of shelf-life

The results of the present study indicated that the shelf-life of semidried persimmons can be determined by monitoring of changes at different temperature. Based on the results of this study, regression equations were established using the correlation coefficients between sensory evaluation and quality characteristics. The L^* values, as a physicochemical quality factor, has been shown to be highly correlated with the sensory quality factor. Marginal L^* values were 30.97, 32.97, and 34.27, and 34.66 at −10, 0 and 10 °C, respectively. The Ea value for the L^* value based on the Arrhenius equation was found to be 12.89 kcal/mol, and the Q_{10}-values were 2.04 and 2.51 at −10–0 °C and 0–10 °C, respectively. Therefore, the expected expiration dates of semidried persimmons were 53.11, 22.00, and 8.71 days when stored at −10, 0 and 10 °C, respectively. From the Q_{10}-value of 3.81 for the temperature range of −20 to −10 °C, we concluded that the shelf-life of semidried persimmons was approximately 203.83 days when products were stored at −20 °C (the common temperature at which semidried persimmons are stored).

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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