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FULL LENGTH ARTICLE

Cryogenic freezing of fresh date fruits for quality preservation during frozen storage

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Abstract Fresh date fruits, especially *Barhi* cultivar, are favored and widely consumed at the Khalal maturity stage (first color edible stage). These fruits are seasonal and perishable and there is a need for extending their shelf life. This study evaluates two different freezing methods, namely cryogenic freezing using liquid nitrogen and conventional deep freezing on preserving the quality and stability of date fruits (cv. *Barhi*) at Khalal maturity stage. Fresh date fruits (cv. *Barhi*) at Khalal stage were frozen utilizing the two methods. The produced frozen dates were stored under frozen storage conditions for nine months (at −20 °C and −40 °C for the conventional and cryogenic freezing, respectively). Color values, textural properties (hardness, elasticity, chewiness and resilience), and nutrition attributes (enzymes and sugars) for fresh dates before freezing and for the frozen dates were measured every three months during the frozen storage. Color values of the frozen dates were affected by the freezing method and the frozen storage period. There are substantial differences in the quality of the frozen fruits in favor of cryogenic freezing compared to the conventional slow freezing. The results revealed a large disparity between the times of freezing of the two methods. The freezing time accounted to 10 min in the cryogenic freezing method, whereas it was 1800 min for the conventional slow freezing system.
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1. Introduction

The date palm (*Phoenix dactylifera* L.) is a dominant tree in South West Asia and North Africa. Presently global production, consumption and industrial development of dates are constantly growing as date fruits are important source of energy and essential nutrients and possess some medicinal benefits (Al Farsi and Lee, 2008; Al-Abdoulhadi et al., 2011; Chandrasekaran and Bahkali, 2013). There is a necessity to

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utilize freezing and frozen storage for prolonging the shelf life of fresh date fruits, especially *Barhi* cultivar, which is favored and widely consumed at Khalal maturity stage (the first edible where the fruit is sweet, crispy and yellow in color).

Freezing and frozen storage can be utilized for the long-term preservation of some fruits and vegetables. Freezing decreases the water activity, inhibits microorganism growth and reduces enzymatic activity resulting in extending the shelf life of the product (Fellows, 2000; Heldman, 1992). Many published research works have confirmed the close relationship between quick freezing and high quality frozen products and the resulting increase shelf life with maximum preservation of initial quality (Sanz et al., 1999; Sun and Li, 2003; Zhang et al., 2004).

Color plays a fundamental part in the consumers' evaluation of the food quality. Color changes are considered as the major quality attribute that affects consumers' selection (Zhang et al., 2004). Enzymatic oxidation of phenolic substances is the main reason that induces color changing (browning). Ice crystals formed during freezing will enhance enzymatic oxidation due to the destruction of the cells and tissues of the product and therefore increased contact between phenolics, oxygen and enzymes (Ruenroengklin et al., 2008).

Textural parameters of frozen foods play an essential part in determining the acceptability of these products by consumers. Higher values of hardness, chewiness and resilience of the pulp indicate better quality products (Zhang et al., 2007; Krause et al., 2008; Kaushik et al., 2014). Several researchers have studied the effects of freezing on textural quality of fruits (Delgado and Rubiolo, 2005; Van Buggenhout et al., 2006; Sousa et al., 2007).

Enzymatic activity is responsible for the quality deterioration in most of the frozen fruits. The enzyme activity decreases as the temperature decrease; however as a result of freezing, the chemical reactions catalyzed by the enzymes occur due to the increase in concentration of salts (Maier et al., 1964; Whitaker, 1972; Marin and Cano, 1992).

Fruit sugars have a significant part in preserving fruit quality and determining its nutritional status (Akhatou and Angeles, 2013). Dates, irrespective of the cultivars, contain more than 75% sugars on a dry-weight basis (Kanner et al., 1978). Al-Mashhadi et al. (1993) found that the reducing sugars (fructose and glucose) in date fruits increased while the sucrose sugar decreased at the end of twelve months of frozen storage. In another study a decrease in the reducing sugars of date fruits was reported at the end of six months of frozen storage (Mikki and Al-Taisan, 1993).

This research work deals with the study of the utilization and comparison of three freezing methods *viz*., cryogenic freezing using liquid nitrogen, individual quick freezing and conventional deep freezing on the quality and stability of date fruits (*Barhi* cultivar) at Khalal stage by evaluating color attributes, textural parameters, sugar contents, enzymatic activity and freezing rates during nine months of frozen storage.

2. Materials and methods

2.1. Fresh dates

Fresh yellow dates (cv. *Barhi*) at Khalal stage of maturity were obtained from a commercial farm in Qassim, Saudi Arabia. Dates were sorted to discard the damaged fruits and immediately kept for less than 6 h in a cold store at 5 °C. Physical properties of the fresh date fruits (length and diameter, surface area, volume, mass, density), moisture content and water activity were measured. The color values, textural properties (hardness, elasticity, chewiness and resilience), and nutrition (enzymes, sugars) properties of the date fruits were evaluated for the fresh date fruits before freezing and for the frozen ones after thawing every three months during a period of nine months of frozen storage.

2.2. Moisture content and water activity determination

Moisture content was determined for the flesh of dates using Association of Official Analytical Chemists (AOAC) standard procedure (AOAC, 2005), where the samples were dried at 70 °C for 48 h under a vacuum of 200 mm of mercury (Vacutherm model VT 6025, Heraeus Instrument, D-63450. Hanauer, Germany). Water activity of the dates flesh was measured at room temperature using Aqua-lab (Model CX-2T, readability 1 mg, Decagon Devices Inc., Washington).

2.3. Color examination

The fruits' color values were expressed by the parameters (L^*, a^*, b^*) measured by a spectrophotometer device (Color Flex, Model No. 45/0, Hunter Associates Laboratory. Inc., VA, USA).

Here L^* indicates (whiteness or brightness/darkness), a^* (redness/greenness) and b^* (yellowness/blueness). In addition the color was expressed by the total color difference (ΔE), Chroma, hue angle and browning index (BI) as defined by the following equations (Maskan, 2001):

$$\Delta E = \sqrt{\left(L_0^* - L^*\right)^2 + \left(a_0^* - a^*\right)^2 + \left(b_0^* - b^*\right)^2} \quad (1)$$

where L_0^*, a_0^* and b_0^* are the color parameters of fresh fruits (before freezing).

$$\text{Chroma} = \left(a^{*2} + b^{*2}\right)^{0.5} \quad (2)$$

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

$$\text{BI} = \frac{[100(x - 0.31)]}{0.17} \quad (4)$$

where

$$x = \frac{(a^* + 1.75L^*)}{(5.645L^* + a^* - 3.012b^*)} \quad (5)$$

2.4. Texture profile analysis (TPA)

The texture profile analysis parameters were measured using a texture analyzer (TA-HDi, Model HD3128, Stable Micro Systems, Surrey, England). Fruit samples were compressed with a rod velocity of 1.5 mm/s to a depth of 5 mm. The compression was done twice to give two complete texture profile curves. The force–time deformation curves were obtained in which the following parameters were obtained: Hardness (the maximum force required to compress the sample), Resilience (the ability

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