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Chilling and Freezing Storage for Keeping Overall Quality of *"Deglet Nour"* Dates

M. Jemni[1,2,*], J. G. Ramírez[3], M. Otón[4], F. Artés-Hernandez[3,4], K. Harbaoui[5], A. Namsi[1], A. Ferchichi[6], and F. Artés[3,4]

ABSTRACT

The effect of storage at 0 and 20°C for 30 days with and without a passive Modified Atmosphere Packaging (MAP) and the effect of a freezing storage at -20, -40 and -80°C for 10 months followed by 1 week at 5°C on overall quality of *Deglet Nour* dates were studied. After the storage time, the physicochemical properties and sensory quality, microbial development, and moth infestation (*Ectomyelois ceratoniae*) of dates were monitored. It was observed that the storage temperature greatly affected the overall quality of dates. The 0°C was recommended for a short-term storage of fresh dates of one month. The MAP technique (6 kPa O_2+12 kPa CO_2) showed a positive effect on keeping overall quality of dates at 20ºC. However, for a long-term storage (10 months in frozen conditions plus 1 week at 5ºC), all freezing temperatures assayed kept the overall quality of dates and no differences were observed among them. In order to minimize the global costs, -20°C was considered as the most adequate temperature for a long-term freezing storage period. In conclusion, these chilling and freezing techniques could be recommended for commercial use at industrial scale.

Keywords: Cold storage, Commercial life, Date palm, *Ectomyelois ceratoniae*, MAP technique.

INTRODUCTION

Date palm (*Phoenix dactylifera* L.) production is the principal activity and the source of life for people in south of Tunisia. The date fruits have an exceptional nutritional, biochemical, and physicochemical characteristics. Dates are an important part of diets of South of Tunisia and are consumed fresh or in various processed forms. The sensitivity of *Deglet Nour* dates to alteration poses serious problems for commercial shelf-life (Jemni *et al*., 2014a). For that reason, many studies have been conducted to define a satisfactory storage method.

Harvested fruits and vegetables progressively lose water, firmness, nutritive value, and sensory quality (visual appearance, texture, taste, and aroma), while safety risks are increased. The postharvest treatments basically determine their final overall quality and safety. Dates are commonly consumed raw and, although effective intervention strategies for keeping quality of plant foods have been developed, they cannot totally eliminate microbial safety hazards linked with uncooked produce consumption (Mohammadzai *et al*., 2010; Artés *et al*., 2013). Refrigeration is the most important factor for keeping quality and extending the shelf-life of harvested fruit and vegetables. It is the most universally applicable method for food quality

[1] Regional Research Center in Oasis Agriculture of Degache, Tunisia.
[2]Arid Lands and Oases Cropping Laboratory. Institute of the Arid Regions Medenine, Medenine, Tunisia.
[3]Postharvest and Refrigeration Group, Department of Food Engineering, Universidad Politécnica de Cartagena (UPCT), Paseo Alfonso XIII, Cartagena, Murcia, Spain.
[4]Institute of Plant Biotechnology, UPCT, Campus Muralla del Mar, Cartagena, Murcia, Spain.
[5]Regional Center for Research in Field Crops, Beja, Tunisia.
[6]National Agronomic Institute of Tunisia, Street Charles Nicolle, Tunis, Mahrajene, Tunisia.
*Corresponding author; e-mail: monia.jemni@iresa.agrinet.tn

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and safety preservation, which causes the least changes from the fresh state (Lorentzen, 1978). The main role of refrigeration is to preserve foodstuffs and to reduce losses during handling, processing, storage, transportation, distribution and retail sale. In addition, refrigeration is crucial to ensure food safety by reducing microbial growth, occurrence of foodborne diseases, and overall quality losses, while it increases the shelf-life of fresh fruit and vegetables (Artés, 2004; Coulomb, 2008; Mattos *et al*., 2013; Artés *et al*., 2013).

In fact, low temperature storage, when combined with the appropriate use of Modified Atmosphere Packaging (MAP) technique, is a cheap and very effective method in lowering metabolic processes of fresh fruit and vegetables (Artés *et al*., 2002; Rosset *et al*., 2002; Al Jasser, 2010; Mattos *et al*., 2013). Plant material under MAP consumes O_2 and releases CO_2 and H_2O until an equilibrium atmosphere with low O_2 and high CO_2 levels is reached. Under MAP, the Respiration Rate (RR) is depressed and, as a direct effect, the consumption of respiratory substrates such as organic acids and sugars is lowered. In addition, MAP reduces weight loss, delays ripening and softening, and could minimize the incidence of some physiological disorders, decay and pests, improving shelf-life (Artés and Martínez, 1996; Pesis *et al*., 2000; Artés *et al*., 2002; Mattos *et al*., 2013).

Very few and incomplete works are available on the *RR* and ethylene emission of dates. However, both are key factors in the design and operation of refrigerated storage facilities, since they affect chilling storage and transportation, air exchange and circulation needs, loading density, and handling, packaging, and stacking methods. Also, the *RR* values are needed for an optimum design of polymeric packages when MAP takes place (Artés *et al*., 2002).

There is renewed interest in using physical treatments as alternative to postharvest agrochemicals, to reduce quality losses, physiological disorders, diseases and insects in plant foods. This fact is because many of such chemicals may cause ecological problems or are potentially harmful to humans and may be withdrawn from use (Artés, 1995). This problem is highly important in date fruit since the decreasing use of postharvest pesticides due to their toxic effects necessitates researches on technically and economically feasible sustainable commercial alternatives for keeping their overall quality and safety. In particular, CH_3Br is the most widely used pesticide for controlling the moth of pyrale (*Ectomyelois ceratoniae* Zeller), the major insect pest of dates both in field and during storage. But, due to its acute toxicity to applicators and to the environment, its use will be forbidden for the current year, except for some critical uses (EPA, 2012; Jemni *et al*., 2014a, b).

The purpose of this study was to investigate the effect of chilling, combined or not with passive MAP, and freezing storage, on the survival of the moth of pyrale, on natural microflora growth and on several quality attributes of *Deglet Nour* dates throughout shelf-life. As far as we know, this study has not been previously reported.

MATERIALS AND METHODS

Plant Material

Deglet Nour dates (*Phoenix dactylifera* L.), the most produced date palm cv. in Tunisia, were harvested at the end of October at fully mature stage (‘Tamar’ stage) from a farm located in an Oasis of the Governorate of Kebili (South of Tunisia). Professional pickers detached the bunches of dates from the tree palm and placed them on the ground to avoid crushing and the abscission of dates. The bunch was then cut into spikelets and about 50 kg were placed in polystyrene boxes. Immediately, fruits were transported by car at ambient temperature about 500 km to Tunis, then by plane to Madrid (Spain), and finally by car about 450 km to the Pilot Plant of the Technical University of Cartagena. Total transportation duration was about 7 days. After arrival to the Pilot Plant, dates were manually detached from spikelet and inspected. Damaged dates were discarded and sound fruit were sorted to achieve uniformity in the whole lot.

Treatments

The dates were handled and processed in a disinfected area at room temperature (about 20

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ºC). Then, the following treatments were applied: (1) About 200 g of dates were placed in 750 mL PolyPropylene (PP) baskets that were thermally sealed at the top with a 30 µm thickness bioriented PP film (Plásticos del Segura S.L., Murcia, Spain). Sealed baskets were then randomly divided into 2 lots with 3 replicates per treatment: one lot was stored with and without passive modified atmosphere at 0°C and 75% RH and the other lot at 20°C. Both treatments were stored up to 1 month. (2) About 200 g of dates were placed in open PP bags and stored at 0, -20, -40 and -80°C during 10 months followed by 1 week at 5°C. Three replicates per treatment were prepared.

Respiration Rate and Ethylene Emission

Samples of about 200 g of dates, previously washed with tap water and rinsed, were placed into 1 L glass jars and placed at 0 and 20°C. For each temperature, three jars were connected to a gas flow panel with an air flow of 0.1 to 0.2 L h^{-1}, humidified to 95% RH in order to avoid CO_2 accumulation higher than 0.3 kPa. On each sampling time, the jars were closed for 2 hours and then the increase in CO_2 was measured by taking a 1 mL gas sample from the headspace through a silicone septum using a plastic syringe. This sample was injected into a gas chromatograph (Thermo Finningan Trace, Thermo-Quest, Milan, Italy) equipped with a thermal conductivity detector (150°C), oven (from 40 to 90°C), injector (150°C) and with a Porapack-N 80/100 column and a molecular sieve 5A 45/60 (Barcelona, Spain) columns for CO_2 and O_2, respectively. Helium was used as a carrier gas (20 mL min^{-1}). The measurements were done every 2 days during 30 days. Calibration of CO_2 and O_2 was done with known standards from gas cylinders (Air Liquid SA, Murcia, Spain).

The C_2H_4 emission (within glass jars closed for 4h) was measured with a GC (Agilent Technologies 7890 A GC system, California, USA) equipped with an Agilent micro-electron capture detector. Between measurements, the jars were continuously flushed with humidified air.

Passive Modified Atmosphere

The O_2 and CO_2 partial pressures within the MAP baskets were analyzed every two days by removing 1 mL gas samples taken through a silicone septum with a plastic syringe from the headspace. The O_2 and CO_2 levels within sealed baskets were measured by injecting gas samples into a Perkin Elmer Clarus 500 gas chromatograph (USA).

Microbial Analyses

To determine natural microflora growth on the epidermis of dates, three randomized samples from each treatment were taken on the processing day and after each storage period. Ten grams of dates were blended (NFV 08-010, 1996) with 90 mL of sterile tryptone phosphate water (pH 7.0) (Scharlau Chemie SA Barcelona, Spain) for 1 min in a sterile stomacher bag (BA6/4/cpg, London, UK) by using a masticator (Seward Medical, London, UK). Serial dilutions were prepared in 9 mL tryptone phosphate water (NFV 08-010, 1996). By using saboraud oxytetracycline agar base (Scharlau Chemie SA Barcelona, Spain), mold and yeast colonies were counted three days after incubation at 25°C (NF V 08-059, 1995) and total mesophilic were counted on plate count agar after 48 hours of incubation at 30°C (NF V 08-05, 1996). Coliforms bacteria were counted on violet red bile dextrose agar (VRBD, pH 7.2) (Scharlau Chemie SA Barcelona, Spain) after 24 hours at 37°C (NF V 08-015, 1991). All microbial counts were reported as $\log_{10}$ colony forming units per g of sample (log cfu g^{-1}).

Evaluation of Physical and Chemical Properties

The effect of the above described treatments on date quality was evaluated by monitoring some key parameters: pH, Titratable Acidity (TA), firmness, moisture content, sugars content, color, total phenolic concentration, total antioxidant activity and sensory evaluation. The methods of determination of all these parameters were recently described in Jemni *et al.* (2014a).

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Statistical Analysis

An ANOVA for each quality attribute was performed and values reported for treatment and storage period were compared to find significant differences. By the use of Info Stat (version 1), the least significant difference multiple range test at $P< 0.05$ was conducted.

RESULTS AND DISCUSSION

Respiration Rate and ethylene emission

Changes in *RR* and ethylene emission of dates throughout storage are shown in Figure 1. Taken into account that moisture content has a great influence on *RR* of dates (Rygg, 1975), it was determined before storage, reaching 20.13±1.35%.

At 0°C, the *RR* was 0.10±0.03 mL CO_2 kg^{-1} h^{-1}, with a maximum value of 0.83±0.02 mL CO_2 kg^{-1} h^{-1}. At 20°C, the *RR* increased with time, from 0.55±0.04 mL CO_2 kg^{-1} h^{-1} in the initial day, up to 8.1±0.58 mL CO_2 kg^{-1} h^{-1} in day 8. This increase was, very probably, due to fungal attacks which were firstly observed after 6 days of storage. Our result agreed with that of Kader and Hussein (2009) who reported for dates, at the same Tamar stage (without specifying cultivars or moisture), a *RR* at 20°C lower than 5 mL CO_2 kg^{-1} h^{-1}. No data of *RR* of dates at 0ºC have been published so far.

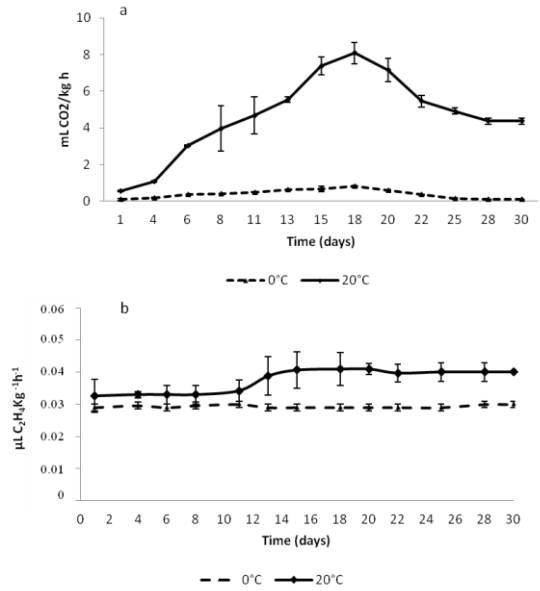

Figure 1. Changes in respiration rate (a) and ethylene emission (b) of dates with 20.13±1.35% moisture content at 0 and 20ºC.

According to Rygg (1975), cured *Deglet Nour* dates, with 20% to 22% moisture, like in our experiment, produce about 0.4 mg CO_2 kg^{-1} h^{-1} (0.22 mL CO_2 kg^{-1} h^{-1}), and about 2 mg CO_2 kg^{-1} h^{-1} (1.1 mL CO_2 kg^{-1} h^{-1}) in dates with 27% moisture at 24°C. In fact, the presence of growing mold, yeast, and bacteria on the dates increases the *RR* and the need for aeration during storage.

The C_2H_4 concentration within packages stored at 0°C was quite stable at 0.029±0.003 µL kg^{-1} h^{-1}. On the other hand, no relevant changes were found in the C_2H_4 levels within packages at 20°C whose values ranged between 0.033±0.005 and 0.041±0.006 µL kg^{-1} h^{-1}. The slight no significant rise in ethylene started at about the same time as that in CO_2 production and, consequently, it was very probably due to fungal development. According to Kader and Hussein (2009), the C_2H_4 production of date at Tamar stage was less than 0.1 µL kg^{-1} h^{-1} at 20°C. No data of C_2H_4 emission of dates at 0ºC have been previously reported.

The changes in *RR* and C_2H_4 emission were typical of a non-climacteric fruit. The reached *RR* levels might be considered as moderate according to Kader and Kasmire (1984).

Modified Atmosphere

Gas composition within packages strongly depends on *RR* of dates (Figure 2). As expected, the rate of modification of gas composition was greater at higher storage temperature, in agreement with early findings of Geeson *et al*. (1994) and Gil *et al*. (2002). After 13 days at 20ºC, partial pressures of O_2 (about 6 kPa) and CO_2 (about 12 kPa) became stable within packages. However, slight changes were found in O_2 and CO_2 partial pressures throughout the storage at 0ºC.

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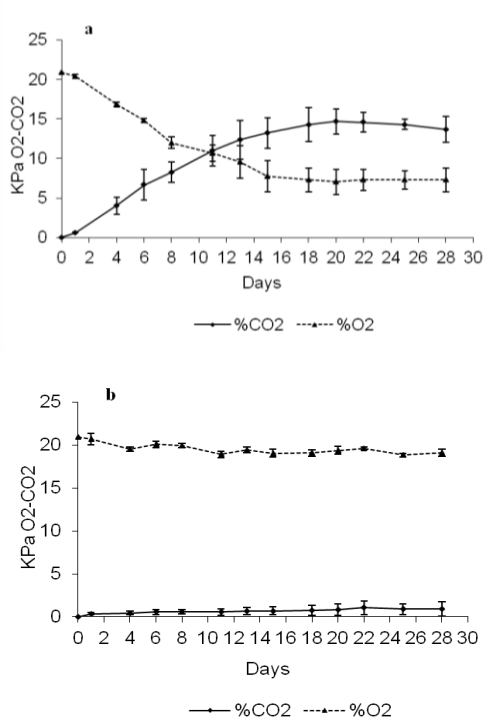

Figure 2. Changes of gas composition within packages at 20 (a) and 0°C.

Microbial Analyses and Pyrale Growth

Storage period showed a significant effect on microbial growth. The yeasts and molds and total mesophilic counts decreased with storage time and with freezing temperature, with a reduction of 1 log cfug^{-1}, -80°C was the most effective temperature (Table 1). The freezing temperature showed a relative effect on the account of total coliforms with a maximum at 0°C and a minimum at -40°C. At 0°C, it was noted that there was no variation for yeasts and molds and there was a decrease in total mesophilic counts. In the same way, Dehghan-Shoar *et al*. (2010) found a lower infestation by yeasts and molds on Sayer date fruits stored for 150 days at -18°C. According to Archer (2004), yeast-leavened foods were reported to be tolerant to freezing, but the freezing rate and the storage temperature affect the susceptibility or the resistance of yeasts and molds to freezing.

The moth infestation reached 30±1.5% after 10 months at 0°C, while it was completely inhibited at all freezing temperatures assayed. Our results agree with those of Dehghan-Shoar *et al*. (2010), who found an absolute mortality of *Oryzaephilus surinemensis* adult insects of Sayer date fruit stored at -18°C for 150 days. In comparison with other treatments used for dates such as UV-C, O_3 and electrolyzed water, freezing is very effective against moth infestation (Jemni *et al.*, 2014a, b).

Both storage temperature and time commonly have a significant effect on yeasts, molds and total mesophilic growth. However, in the current experiment, the total coliforms were affected only by the storage time. At 20°C, the microbial counts increased with a rise of 2.29, 3.53, and 1.33 log cfu g^{-1} for yeasts and molds, total mesophilic, and total coliforms, respectively (Table 2). However, at 0°C the microbial load decreased with the time for yeasts, molds and total mesophiles with a reduction of 1.78 and 1.13 log cfu g^{-}1, respectively, and increased for total coliforms with a rise of 1.39 log cfu g^{-1}. In six dates *Cvs* (Khulas, Um-Ruhaim, Hilali, Shahal,

Table 1. Effect of storage conditions on moth infestation (%) and counts of molds, yeasts, total mesophilic and coliforms (log cfug^{-1}) of *Deglet Nour* date after 10 months at 0, -20, -40 and -80°C followed by 1 week at 5°C.[a]

	Before storage	After 10 months of storage+1 week at 5°C			
		0°C	-20°C	-40°C	-80°C
Moth infestation	1±0.10 b	30±1.5 a	0 b	0 b	0 b
Yeasts and Molds	3.75±0.05 a	3.79±0.03 a	2.84±0.05 b	2.6±0.2 c	2.3±0.19 d
Total mesophilic	3.9±0.03 a	2.48±0.08 b	2.37±0.08 bc	2.26±0.02 c	2.15±0.015 d
Total coliforms	3.2±0.08 c	4.6±0.35 a	4.20±0.04 b	3.9±0.05 bc	4.26±0.14 b

[a] Data are means (n= 3)±*SD*. Means with different letters in the same line are significantly different ($P \leq 0.05$) according to LSD test.

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Table 2. Changes in moth infestation (%) and counts of molds, yeasts, total mesophilic and coliforms (log cfu g^{-1}) of *Deglet Nour* date after 30 days at 0 and 20ºC in air and in passive MAP storage.[a]

	Before storage	After 30 days in air storage		After 30 days in passive MAP	
		20°C	0°C	20°C	0°C
Moth infestation	1±0.1 b	26.67±5.8 a	3.33±2.9 b	5±1 b	0 ± 0 b
Molds and yeasts	6.15±0.08 b	8.44±0.01 a	4.37±0.1 c	7.32±0.17 ab	4.55±0.48 c
Total mesophilic	5.16±0.16 b	8.69±0.03 a	4.08±0.09 c	7.57±0.04 ab	4.65±0.08 c
Total coliforms	3.88±0.1 b	5.43±0.02 a	5.27±0.12 a	5.54±0.03 ab	5.12±0.05 a

[a] Data are means (n = 3)±*SD*. Means with different letters in the same line are significantly different (P≤ 0.05) according to LSD test.

Tiar, and Megnaz) collected from the market, Hamad *et al*. (2012) found a contamination with aerobic mesophilic bacteria in the range of 10^2 to 10^5 cfu g^{-1}. Moreover, they found a contamination with mold and yeast at loads in the range of 10^2 to 10^3 cfu g^{-1}, while coliforms were detected at 10^2 cfu g^{-1} level. According to Umar *et al*. (2014), the bacteriological analysis of date fruit indicated high bacterial contamination. In agreement with the same authors, the temperature, O_2 and moisture content are the most important factors that influence the type of microbial growth and affect the shelf life of dates. Dehghan-Shoar *et al*. (2010) found that MAP (85% CO_2+3% O_2+12% N_2 and 75% CO_2+12% O_2+3% N_2) Sayer date at 4°C for 150 days decreased the mold and yeast counts compared to those stored at 30°C.

As expected, the moth infestation greatly increased during storage at 20°C, from 1.0±0.1% on the initial day to 26.67±5.8% after 30 days in air conditions. In contrast, the moth infestation increased slightly under air storage at 0°C and under passive MAP at both storage temperatures (0 and 20°C). Then, 0°C with or without passive MAP, seemed to be adequate for dates storage. This fact could be also due to increased RH within packages. Dehghan-Shoar *et al*. (2010) found that the effect of MAP (85% CO_2+3% O_2+12% N_2 and 75% CO_2+12% O_2+3% N_2) in Sayer dates stored at 4 and 30°C for 150 days was effective against *Oryzaephilus surinemensis* adult insects' survival, but the storage under air at 30 °C showed the highest number of live insects. Also, in agreement with these authors, the lower temperature showed less counts and a synergistic effect on mortality was found between CO_2 level and low temperature. In fact, these authors explained that the reduction of temperature increases the rates of CO_2 gas solubility, and thus slows down metabolic activities of insects.

Physical and Chemical Quality Parameters

The pH and TA did not change throughout freezing storage in any samples, whichever temperature was assayed (-20, -40 and -80°C), while after the storage at 0°C, the pH decreased from 5.73±0.13 to 5.27±0.09 and the TA increased from 0.18 g to 2.02 g citric acid 100 g^{-1} FW (Table 3). However, no differences in TA were found among samples after storage at -20, -40 and -80°C. These results agree with those reported by Aleid *et al*. (2014) who showed a decrease in pH and an increase of TA of Sukkary and Khalas dates stored for 12 months at -18°C. Similar results were earlier obtained by Dehghan-Shoar *et al*. (2010) on Sayer date stored for 150 days at -18°C. On the other hand, Al-Yahyai and Al-Kharusi (2012) reported that the freezing storage up to 6 months of dates at -18°C increased the TA and pH. According to Chassagne-Berces *et al*. (2010), after freezing at -20 and -80°C, the pH changes differed among the types of fruit.

After 10 months of storage at 0°C+1 week at 5°C, firmness decreased from 6±0.49 N to 2.71±0.62 N, while it was kept after freezing storage+1 week at 5°C (Table 3). Chassagne-Berces *et al*. (2009) reported that freezing kept apples firmness better than those of fresh apples, and freezing at -80°C provoked less

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Table 3. Changes in pH, titratable acidity (g citric acid 100 g^{-1} FW), firmness (N), moisture (%) and sugars content (g 100 g^{-1} FW) of *Deglet Nour* date after 10 months at 0, -20, -40 and -80°C followed by 1 week at 5°C.[a]

	Before storage	After 10 months of storage+1 week at 5°C			
		0 °C	-20 °C	-40 °C	-80 °C
pH	5.73±0.13 a	5.27±0.09 b	5.56±0.10 a	5.63±0.02 a	5.65±0.06 a
TA	0.18±0.03c	2.02±0.02a	1.78±0.06 b	1.77±0.05 b	1.78±0.05 b
Firmness	6±0.49a	2.71±0.62b	7.03±2.32 a	6.68±3.21 a	6.96±1.32 a
Moisture	28.07±0.63 a	15.11±0.43c	19.65±0.23 b	17.27±0.2c	20.24±0.18 b
Fructose	13.05±0.66 a	11.37±1.3 b	9.63±0.90c	11.64±0.85 b	11.09±1.45 b
Glucose	16.28±1.3 a	17.11±2.6 a	14.28±0.85 b	16.07±1.45ab	15.71±1.65ab
Sucrose	42.28±3.06ab	40.03±3.5bc	44.78±1.76a	36.97±2.55 c	35.77±2.69 c
Total sugars	71.61±4.22 a	68.52±3.45ab	68.69±4.30ab	64.69±4.35b	62.57±3.67b

[a] Data are means (n = 3)±*SD*. Means with different letters in the same line are significantly different (P≤ 0.05) according to LSD test.

firmness degradation than at -20°C. Aleid *et al*. (2014) showed an increase of firmness of Sukkary and Khalas dates stored for 12 months at -18°C. These authors attributed such increase to the water loss during the storage period, while Jemni *et al*., (2016b) observed a decrease of firmness of *Deglet Nour* treated by UV-C (6 Kj m^{-2}). This result confirmed the importance of freezing on maintaining of firmness.

Dates progressively dehydrated throughout the storage time, being more pronounced at 0°C than at -20, -40 and -80°C. The moisture content changed from 28.07±0.63 to 15.11±0.43% (Table 3). This result agrees with those reported by Ismail *et al*. (2008) on Khalas and Barhee dates stored 12 months at -3°C and by Aleid *et al*. (2014) on Sukkary and Khalas dates stored for 12 months at -18°C. Chassagne-Berces *et al*. (2010) found also a decrease in the moisture content of apples, and no changes for mangoes, after freezing/thawing. But, in contrast with Al-Yahyai and Al-Kharusi (2012), they reported that the freezing storage up to 6 months of date fruit at -18°C did not affect the moisture content among storage durations.

Freezing and storage time affected also the total sugars, fructose, glucose, and sucrose content. As a general trend, it was reduced with the time for the different freezing temperatures, while slight or no changes were found after storage at 0ºC (Table 3). In contrast, Bartolome *et al*. (1996) found an increase in sucrose, glucose and fructose of pineapple after one year of storage at -18°C. In addition, Ismail *et al*. (2008) showed an effect of temperature storage on changes in total reducing sugars, especially in glucose of Khalas and Barhee dates stored for one year at -3 °C.

The *Deglet Nour* dates stored for 30 days at 0°C (with and without passive MAP) showed a higher pH than those stored at 20°C (with and without passive MAP) without differences in the TA (Table 4). According to Dehghan-Shoar et al. (2010), MAP storage for 150 days of Sayer date at 4 and 30°C decreased the pH, being more pronounced at 30 °C. The authors explained such decrease by a higher metabolic activity of the microorganisms at high temperatures. In addition, Bal (2016) found that the packaging in MAP maintained the TA of Nectarine fruits stored at 0-1°C for 40 days.

The chilling storage temperature, the passive MAP, and the storage time did not affect the moisture content and the firmness of dates (Table 4). In the same way, Ismail *et al*. (2008) found no effects of the storage temperature on moisture of Khalas and Barhee dates stored for 2 months at 25 and -3°C, but there was an increase in firmness in Barhee dates after 2 months of storage at 25°C. Also, they explained the insignificant decrease of moisture by the initially low moisture level and the high sugar content in the Tamar samples what would bound water living very little if any free water to be lost. More recently, Also, Hazbavi *et al*. (2015) reported no significant changes in moisture content of

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Table 4. Changes in pH, titratable acidity (g citric acid 100 g^{-1} FW), firmness (N), moisture (%) and sugars content (g 100 g^{-1} FW) of *Deglet Nour* date after 30 days at 0 and 20°C in air and in passive MAP storage.[a]

	Before storage	After 30 days at air storage		After 30 days at passive MAP	
		20°C	0°C	20°C	0°C
pH	5.64±0.03 a	5.11±0.04 b	5.48±0.02 a	5.13±0.06 b	5.29±0.025 ab
TA	0.11±0.01 b	0.15±0.02 a	0.12±0.02 ab	0.14±0.02 a	0.13±0.03 ab
Firmness	5.40±0.39 a	5.08±0.49 a	3.37±0.23 a	5.18±0.50 a	4.50±0.30 a
Moisture	20.29±0.01 a	20.16±1.29 a	19.08±2.32 a	19.43±0.80 a	19.82±0.25 a
Fructose	14.93±0.65 a	10.29±0.61 b	8.32±1.03 c	12.90±0.80 ab	10.80±0.40 b
Glucose	23.58±0.95 a	15.61±1.12 b	12.96±1.29 c	16.48±1.01 b	15.18±0.50 b
Sucrose	41.07±0.35 a	32.60±1.12 b	24.84±3.44 c	37.08±0.27 ab	36.44±0.71 ab
Total sugars	79.58±0.09 a	58.50±0.83 b	46.12±1.82 c	66.46±0.50 ab	62.42±0.57 ab

[a] Data are means (n= 3)±*SD*. Means followed by different letters in the same line are significantly different ($P \leq 0.05$) according to LSD test.

Iranian Stamaran date throughout 6 months storage at 25°C. Moreover, Bal (2016) observed that MAP retained the firmness of Nectarine fruits stored at 0-1°C for 40 days. On the hand, comparing the effect of cold storage with hot water treatment on *Deglet Nour*, the former treatment decreased the firmness of dates during the storage as it was remarked by Ben-Amor *et al.* (2016a). They explained that the high water temperature could cause disturbances in cell structure, which causes membrane damage in fruit samples, decreasing fruit firmness.

The total sugars content of *Deglet Nour* stored for 1 month at 0 and 20°C ranged between 46.12±1.82 and 79.58±0.09 g 100 g^{-1} FW. According to Chandrasekaran and Bahkali (2013), the total sugar concentration of dates varied between 44 and 88%. As expected, the sugar concentration of dates decreased with the storage time for the two temperatures assayed (Table 4). The decrease was more pronounced at 0°C, which may be explained by the higher dehydration of dates at 20°C, which maintained the sugars concentration. Similar results have been reported by Ismail *et al.* (2008) who showed the effect of storage temperature on sugar content of Khalas and Barhee dates after 2 months at 25 and -3°C. According to the later authors, changes in glucose and fructose content could be attributed to hydrolysis of sucrose and/or respiratory activity, or to the combination of both effects. Moradi *et al.* (2017) confirmed the effect of cold storage on total carbohydrate content of Iranian quince fruit stored for 120 days at 2°C and 80-90% RH. In fact, they found that the cold storage decreased the total carbohydrate. But, Ben-Amor *et al.* (2016b) found that the sucrose of *Deglet Nour* treated with hot air (55°C, 30 minutes) increased during storage at 2°C for 45 days.

Total Phenolics Content and Antioxidant Activity

After 10 months at 0°C followed by 1week at 5°C, total phenolics content slightly decreased from 0.052±0.001 to 0.045±0.002 g GAE 100 g^{-1} FW. In contrast, it increased under all freezing temperatures to about 0.075±0.003 g GAE 100 g^{-1} FW (Table 5). However, the antioxidant activity was quite stable in all freezing samples with a slight decrease reported in samples stored at 0°C (Table 5). A positive correlation between total phenolics content and antioxidant activity (R^2= 0.846) was observed. Our results agree with those of Reque *et al.* (2014) on blueberries stored 6 months at -18ºC. However, Allaith *et al.* (2012) found an increase in the total phenolic compounds content in Khalas and Khunaizi dates after 1 month at -20°C. According to the same authors, the capacity to quench DPPH radicals depends on date cultivar. In fact, the frozen Khalas date (1 month at -20°C) kept an antioxidant capacity similar to those of the fresh date. But, in frozen Khunaizi date, a

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Table 5. Effect of freezing on total polyphenols (g GAE 100 g^{-1} FW) and antioxidant activity (g ascorbic acid equivalent 100 g^{-1} FW) of *Deglet Nour* date after 10 months at 0, -20, -40, and -80°C followed by 1 week at 5°C.[a]

	Before storage	After 10 months of storage+1 week at 5°C			
		0°C	-20°C	-40°C	-80°C
Total polyphenols	0.052±0.001ab	0.045±0.002b	0.077±0.006 a	0.076±0.003 a	0.073±0.003 a
Antioxidant activity	0.024±0.003 a	0.020±0.004 b	0.025±0.001 a	0.024±0.002 a	0.026±0.005 a

[a] Data are means (n = 3) ± SD. Means with different letters in the same line are significantly different (P≤ 0.05) according to LSD test.

reduction of the total antioxidant capacity was found.

The total phenolics content and antioxidant activity of dates were kept stable after 30 days at 0°C (with and without passive MAP) but increased at 20°C (with and without passive MAP) (Table 6). This result was confirmed by Bal (2016) where the MAP maintained the antioxidant activity of Nectarine fruits stored at 0-1°C for 40 days.

However, Biglari *et al*. (2009) reported an increase in total phenolics of Bam and Kharak dates stored for 6 months at 4°C followed by one week at 18°C. These authors explained the increase by the ethylene action. In fact, this hormone stimulates the activity of phenylalanine ammonia lyase, a key enzyme in the biosynthesis of phenolic compounds. However, Arendse *et al*. (2014) found in pomegranate fruit that, after 2 months at 5, 7.5, 10 and 21°C, the total phenolics content increased while the antioxidant activity decreased. On the other hand, Ozturk *et al*. (2012) reported an increase in total phenolics content and antioxidant activity of plum fruit from harvest to the 21st day of storage at 0°C and a linear decrease at day 28. However, Ben-Amor *et al*. (2016b) reported a decrease in total phenolics content and antioxidant activity of *Deglet Nour* treated with hot air (55°C, 30 minutes) during storage at 2°C for 45 days.

Color Changes

The color of dates is an important quality parameter. The darkening of dates throughout storage is attributed to enzymatic browning reactions, being very noticeable after freezing and thawing as reported in apples by Chassagne-Berces *et al*. (2010). In the current experiments *L**, chroma, and Hue° of freezing dates increased with the storage time (Table 7). This increase was more pronounced on dates stored at -20, -40 and -80°C compared to those stored at 0°C where the color was stable. There was no difference in any color parameter among all frozen samples. Our result agrees with that from Aleid *et al*. (2014) on Sukkary and Khalas dates stored for 12 months at -18°C.

The storage of dates during 30 days at 0 and 20°C (with and without a passive MAP) kept the *L** value but decreased chroma and Hue° (Table 8). This decrease was more pronounced at 20°C regardless of the atmosphere within packages. According to Achour and Bagga (2005), the MAP and the storage temperature affected the

Table 6. Changes in polyphenols (g GAE 100 g^{-1} FW) and antioxidant activity (g ascorbic acid equivalent 100 g^{-1} FW) of *Deglet Nour* date after 30 days at 0 and 20°C in air and in passive MAP storage.[a]

	Before storage	After 30 days in air storage		After 30 days in passive MAP	
		20°C	0°C	20°C	0°C
Total polyphenols	0.105±0.01 b	0.141±0.012a	0.105±0.05 b	0.120±0.01 ab	0.106±0.04 b
Antioxidant activity	0.024±0.002b	0.031±0.001a	0.027±0.005ab	0.028±0.00ab	0.025±0.001b

[a] Data are means (n= 3)±*SD*. Means with different letters in the same line are significantly different (P≤ 0.05) according to LSD test.

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Table 7. Changes in skin color parameters of *Deglet Nour* dates after 10 months at 0, -20, -40, and -80°C followed by 1 week at 5°C.[a]

	Before storage	After 10 months of storage+1 week at 5°C			
		0°C	-20°C	-40°C	-80°C
L*	31.44±3.32 c	31.93±3 c	35.42±2.42ab	37.01±3.22a	34.02±2.73bc
Chroma	12.63±4.18d	17.59±3.45c	23.52±3.85ab	24.62±3.91a	21.10±2.89 b
Hue°	58.74±4.03b	60.38±6.4 b	66.18±6.76 a	66.38±1.90a	64.72±5.40 a
ΔE	0	4.98	11.59	13.22	8.85

[a] Data are means (n= 3)±*SD*. Means with different letters in the same line are significantly different (P≤ 0.05) according to LSD test.

Table 8. Changes in skin color parameters of *Deglet Nour* dates after 30 days at 0 and 20°C in air and in passive MAP storage.[a]

	Before storage	After 30 days in air storage		After 30 days in passive MAP	
		20°C	0°C	20°C	0°C
L*	32.07±2.40 a	32.78±2.92 a	33.60±1.65 a	32.59±3.01 a	32.90±2.25 a
Chroma	20.04±2.72 a	15.60±3.12 b	16.50±2.33 b	17.90±3.65 b	19.45±1.45 a
Hue°	62.29±4.80 a	55.30±4.45 b	61.45±3.98 a	57.45±2.50 b	62.05±1.30 a
ΔE	0	4.50	3.86	2.20	1.02

[a] Data are means (n= 3)±*SD*. Means with different letters in the same line are significantly different (P≤ 0.05) according to LSD test.

kinetic of color degradation of *Deglet Nour* date during storage at 10 and 25°C, mainly for *L** values. This result agrees with those obtained by Ozturk *et al*. (2012) on plum fruit stored for 4 weeks at 0°C, and also with those obtained by Fawole and Opara (2013) on pomegranate fruit stored for 4 weeks at 22°C and by Guo *et al*. (2008) on green beans stored for 6 days at 0 and 25°C.

Sensorial Analyses

Overall quality and texture of dates were well kept after storage at all freezing temperatures and the score of color increased after 10 months at freezing temperatures followed by 1 week at 5°C (Figure 3). According to Ismail *et al*. (2008), low temperature storage kept the sensory quality of Barhee dates up to 1 year at -3°C.

When packages stored 1 month at 20°C were opened, just a slight off-odor was detected but quickly dissipated. However, non off-flavors were detected when dates were tasted. Meanwhile, those dates at 0°C did not show off-odors neither off-flavors at any time. Storage at 0 and 20°C for 30 days did not show any disorders on overall quality, color, texture, and flavor (Figure 4).

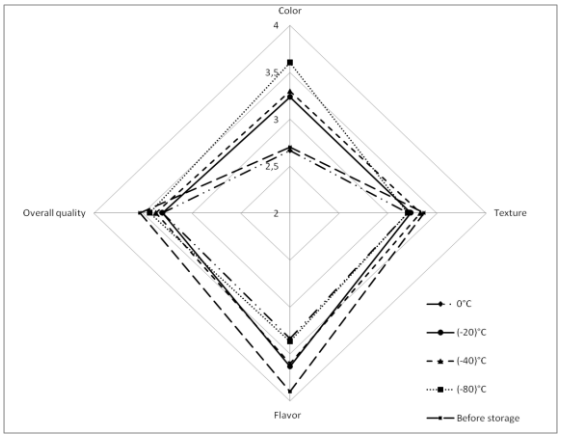

Figure 3. Changes in flavor, texture, color, and overall quality of *Deglet Nour* dates after 10 months at 0, -20, -40, and -80°C followed by 1 week at 5°C. Data are means (n= 3)± *SD*.

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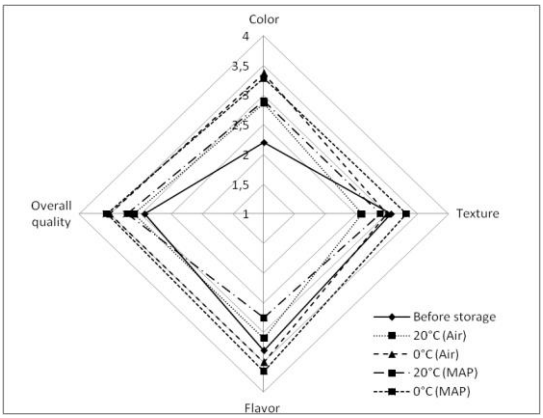

Figure 4. Changes in flavor, texture, color, and overall quality of *Deglet Nour* dates after 30 days at 0 and 20°C in air and in passive MAP storage. Data are means (n= 3)±*SD*.

CONCLUSIONS

The storage temperature greatly affects the commercial quality of dates. A passive MAP of 6 kPa O_2+12 kPa CO_2 (balanced with N_2) improves the quality of dates after storage at 20°C. There was no difference between dates stored with or without passive MAP at 0°C, due to slight gas composition changes. In fact, to preserve overall quality of dates for 1 month, 0°C was the most adequate temperature. However, for a storage period of 10 months, compared to samples stored at 0°C, freezing at -20, -40 and -80°C all kept the overall quality of dates better after a subsequent thawing period of 1 week at 5°C, without differences among them. Then, in order to prolong the shelf-life of dates for a long-term period and minimize global costs, -20°C must be considered as the optimal temperature. Both chilling and freezing could be recommended for commercial use on harvested dates because they can be easily implemented at industrial scale.

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انبارداری با سرما دهی و انجماد به منظور حفظ کیفیت کلی خرمای *"Deglet Nour"*

م. جمنی، ج. گ. رامیرز، م. اتون، ف. آرتز-هرناندز، ک. هربویی، ا. نامسی، ا. فرچیچی، و ف. آرتس

چکیده

در این پژوهش، کیفیت کلی خرمای *"Deglet Nour"* زیر تاثیر انبار داری در درجه صفر و ۲۰ درجه سانتی گراد به مدت ۳۰ روز با و بدون بسته بندی با هوای اصلاح شده (modified atmosphere packaging (MAP) و نیز تاثیر انبارداری با انجماد در ۲۰-، ۴۰-، و ۸۰- درجه سانتی گراد به مدت ۱۰ ماه وسپس نگهداری در ۵ درجه سانتی گراد به مدت یک هفته، بررسی شد. بعد از دوره انبارداری، ویژگی های فیزیکوشیمیایی و کیفیت حسی، رشد میکربی، و آلودگی به پروانه *Ectomyelois ceratoniae* در خرما پایش شد. چنین مشاهده شد که درجه حرارت انبارداری تاثیر زیادی روی کیفیت کلی خرما داشت. حرارت صفر درجه سانتی گراد برای انبارداری خرمای تازه به مدت کوتاه یک ماه توصیه شد. روش MAP ($6\ kPa\ O_2 + 12\ kPa\ CO_2$)تاثیر مثبتی روی حفظ کیفیت کلی خرما در ۲۰ درجه سانتی گراد داشت. با اینهمه، برای انبار داری به مدت طولانی (۱۰ ماه در شرایط انجماد و سپس یک هفته در ۵ درجه سانتی گراد) همه درجه حرارت های انجماد این آزمایش کیفیت کلی خرما را حفظ کرده و تفاوتی بین آن ها مشاهده نشد. از این قرار، به منظور کمینه کردن هزینه های کلی، درجه حرارت ۲۰- درجه سانتی گراد به عنوان مناسبترین درجه حرارت برای انبارداری انجمادی به مدت طولانی در نظر گرفته شد. نتیجه اینکه این روش های سرمادهی و انجماد را می توان برای مصارف تجاری در مقیاس صنعتی توصیه کرد.

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