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CHARACTERIZATION OF POSTHARVEST PHYSIOLOGY OF THERMISED DATES (*PHOENIX DACTYLIFERA* L.), PACKED UNDER A MODIFIED ATMOSPHERE (MAP).

MAROUF ARIBI Mohamed [1*] and KHALI Mustapha [3,2]

1.Department of Biotechnology, Laboratory of Biotechnology and Plant Productions, Faculty of Nature and Life Sciences, University of Blida 1, B.P 270 Road of Soumâa-Blida, Algeria.

2.Department of Biotechnology, Laboratory for the Protection and Valorisation of Agrobiological Resources, Faculty of Nature and Life Sciences, University of Blida 1, B.P 270 Road of Soumâa-Blida, Algeria

3. General Manager of the Technical Center for Agri-Food Industry (CTIAA), Ibn Khaldoun Street Boumerdès B.P 71A, Algeria.

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Abstract

Description of the subject*:* The quality of the fruit is largely determined by growing conditions, a link must be made between this initial quality, linked to the agronomic conditions, and the preservation of this quality, linked to the harvest and the techniques of conservation or maturation applied thereafter. This study therefore focuses on the physiological characterization of the date stored under MAP after harvest and in the course of conservation.

Objective: The effect of PET packaging on the postharvest physiology of Deglet-Nour Dates (*Phoenix dactylifera* L.) during storage was studied under different storage conditions (22°C ±1°C and 75-80% RH, 10°C ±2°C and 85-90% RH).

Methods: The experimental setup consists of a box with internal dimensions of 7.5×15.00×7.5 cm. It is made of PET film thickness 0.0025 mm. The modified atmosphere inside the box is generated by the exchange between the product and the outside through the film. The dates are packaged in batches of 350g ±5g. The date samples were divided into two groups of batches with six samples each, corresponding to the storage period (0, 1, 2, 3, 4 and 5 months) before to be tested for the first at room temperature (22°C ±1°C) with a relative humidity of 75% to 80% and the second at low temperature of 10°C ±2°C with a relative humidity of 85 % to 90%.

Results: We found that PET packaging to limit respiratory intensity during storage. The O_2 and CO_2 concentration of the samples stored under PET (at 22°C ±1°C) after harvesting at the Tamar stage experienced a sharp decrease in oxygen (from 20.25% to 12.86%). Likewise, the PET film packaging limited the degassed CO_2 concentration after seven hours of storage compared to the control sample. After harvest, dates showed a typical respiration of non-climacteric fruit (less than 5 mmoles O_2 $kg^{-1}.h^{-1}$) and low ethylene production thus with very low metabolic activities.

Conclusion: The combination of thermization-packaging and cold storage (10°C ±2°C) is a storage method that ensures an optimal physiological criterion for dates by limiting their respiratory activity. Deglet-Nour dates so packaged in PET packaging, pre feel excellent storage ability beyond the five months tested.

Keywords: Post-harvest, Cold storage, Respiratory activity, PET packaging, Thermization.

CARACTÉRISATION DE LA PHYSIOLOGIE POST-RÉCOLTE DES DATES THERMISÉES (*PHOENIX DACTYLIFERA* L.), EMBALLÉES SOUS UNE ATMOSPHÈRE MODIFIÉE (MAP)

Résumé

Description du sujet *:* La qualité du fruit est largement déterminée par les conditions de croissance, un lien doit être établi entre cette qualité initiale, liée aux conditions agronomiques, et la préservation de cette qualité. Cette étude se concentre donc sur la caractérisation physiologique de la datte stockée sous MAP après récolte et en cours de conservation.

Objectifs : L'effet des emballages en PET sur la physiologie post-récolte des dattes Deglet-Nour (*Phoenix dactylifera* L.) pendant le stockage a été étudié dans différentes conditions de stockage.

Méthodes : Le montage expérimental consiste à des boîtes fabriquées en PET. L'atmosphère modifiée à l'intérieur de la boîte est générée par l'échange entre le produit et l'extérieur à travers le film. Les dattes sont emballées par lots de 350 g ±5 g. Les échantillons de dattes ont été divisés en deux groupes de lots de six échantillons correspondant chacun à la période de stockage (0, 1, 2, 3, 4 et 5 mois) avant d'être testés en premier lieu à température ambiante (22°C ± 1°C) avec une humidité relative de 75% à 80% et la seconde à basse température de 10°C ± 2°C avec une humidité relative de 85% à 90%.

Résultats : Les emballages en PET limitaient l'intensité respiratoire pendant le stockage. La concentration en oxygène et en CO_2 des échantillons stockés sous PET (à 22°C ±1°C) après la récolte au stade Tamar a connu une forte diminution de l'oxygène (de 20,25% à 12,86%). De même, les emballages en film PET ont limité la concentration en CO_2 dégazé après sept heures de stockage par rapport à l'échantillon témoin. Après la récolte, les dattes montraient une respiration typique des fruits non climatériques (moins de 5 mmol O_2 $kg^{-1}.h^{-1}$) et une faible production d'éthylène, donc avec une activité métabolique très faible.

Conclusion : La combinaison de la thermisation-conditionnement et de la conservation au froid (10°C ±2°C), est une méthode de conservation qui assure un critère physiologique optimal pour les dattes et offrent une excellente capacité de stockage au-delà des cinq mois testés.

Mots clés : Poste récolte, Conservation au froid, Activité respiratoire, Film PET, Thermisation.

* Auteur correspondant: MAROUF ARIBI Mohamed, E-mail: mar-bio-tp@live.fr

INTRODUCTION

Deglet-Nour is the commercial variety that occupies most of the international date trade [1, 2, 3, 4]. For Algeria, it represents 60% of the dates produced, that is to say 40% of the total revenue of agricultural exports [5]. The economic and commercial importance of this fruit is paramount. The knowledge of the physiology of the date is necessary to be able to better control the maturation, and thus to recommend the best conditions of storage.

The shelf life of fruits and vegetables can be extended by modifying the surrounding atmosphere of these products in the packaging (Modified Atmosphere Packaging, MAP) or in controlled atmosphere storage chambers (Controlled Atmosphere Storage, CAS). Fresh produce is only found under MAP because the composition of the MAP atmosphere tends to be longer to change with the respiratory activity and microbiological activity of the fruit [6, 7, 8]. In addition, the permeability of the gas packaging film also modifies the composition [9].

The three main gases used are CO_2, N_2 and O_2, alone or in combination [10]. Other gases have been successful such as CO, SO_2, NO, He, H_2, Ar, etc. For these gases their applications have been very limited due to regulations (health hazards) and organoleptic and technical problems associated with them [11]. N2 is a gas with no antimicrobial activity but its main role is to substitute for O_2 in MAP [12]. In the absence of O_2, only strict or facultative anaerobic microorganisms can develop [12]. In addition, it is responsible for several alteration reactions such as oxidation, acceleration of ripening of fruits and vegetables [8]. The principle of modified atmospheres is based on the use of a specific gas mixture with determined concentrations of CO_2, O_2, and N_2, which play a definite role in the physiology of living products, which are plants and also in fungal attacks. Varoquaux and Nguyen-The [13], give a very simple definition: a modified atmosphere is simply a conservation atmosphere whose composition is different from that of air and can result for living tissues from a balance between respiratory exchanges of plant product and gaseous diffusion through a semipermeable membrane.

Some fresh vegetable products and especially products of 4th and 5th ranges have been the subject of many works for their conservation in so-called "modified" atmospheres (also called MAP=Modified Atmosphere Packaging) or "controlled" atmospheres (also called CAP=controlled atmosphere packaging [14, 15, 13].

This work has led to tremendous progress in the development of biodegradable and edible packaging [16, 17, 18, 19], and many theoretical models to predict respiration rates of fresh products as a function of CO_2 and O_2 concentration have been proposed [20, 21, 22, 23].

This bibliographic prolixity contrasts with the virtual absence of work on the application of MAPs or CAPs to dates, which do not seem to have yet - at this stage-attracted this interest. The rare studies on packaging and dates. Glasner et *al*. and Awad [24, 25], have focused on increasing maturation of dates in diets and not as post-harvest conservation atmospheres.

In the literature, the use of modified or controlled atmospheres for plant products is often associated with low temperature storage. All of these studies, although combining various percentages of CO_2 and O_2, provided by different modified atmospheres, have for the most part shown positive effects [26, 27, 28, 29, 30, 31, 32, 33].

The use of innovative packaging technologies (modified atmosphere packaging, active and intelligent packaging) for dates is on a relatively limited basis as compared to some other fruits [34]. However, potential exists to expand these technologies to dates and date products to further improve their shelf life and nutritional quality [34].The effects of MAP in maintaining quality and extending shelf life of fresh and dried dates as well as some date products have been reported in the literature [34]. Packaging protects dates from physical damage, moisture absorption or loss and insect reinfestation during subsequent storage and handling steps [34].

Losses during harvesting and postharvest handling and marketing are high in most producing countries due to incidence of physical, physiological, and pathological disorders and to insect infestation [36]. Many different types of polymer films are available for use in MAP with a wide range of CO_2 and O_2 permeabilities [37]. In addition, many models have been developed to predict equilibrium package atmospheres for passive MAP [22, 38]. However, none of these models can fully account for the variability in product respiration rates that may occur due to variation in holding temperature,product age, interactions with atmosphere composition, product biology, and effects of handling [22]. Plastics with high barrier to oxygen are polyethylene terephthalate (PET), Nylon 6 (0% RH), Nylon MXD6, ethylene vinyl alcohol (EVOH), polyvinyl alcohol (PVOH), etc. [39]. The response of different fruits and vegetables to atmosphere modification varies considerably and therefore the response of each commodity must be determined [40].

The proposed alternative is a physical treatment - dry cure - at 55°C for 20 min as a disinsectisation treatment, associated with a modified PET atmosphere packaging and to follow their simple or combined actions on the respiration of the date (*Phoenix dactylifera* L.) over a period of five months of cold storage (10°C) and at room temperature (22°C). The combination of heat loss is reported [23, 41].

According to Khali [41], on different thermal scales tested, the thermization at 55°C/20 min, showed a significant reduction in the infestation of dates (destruction of eggs and larvae of *Ectomyelois ceratoniae* Zellers), in more of a more positive influence on the main quality criteria of the date and a better preservation of organoleptic and sensory characteristics.

MATERIALS AND METHODS

1. Plant material

The Deglet Nour variety dates, coming from the Tolga palm grove (Wilaya of Biskra-Algeria), were harvested on different regimes at the end of October (at Tamar stage), then transported and kept in cold rooms at 4°C. The dates are sorted and separated from their branches and the infested or crushed dates are eliminated.

2. Thermization

The thermization is carried out for 20 minutes in a ventilated oven set at 55°C (±1°C). A not-thermised control batch is constituted. Dates (Thermised or Not) are divided into homogeneous batches in plastic trays.

3. AM creation methods

The Modified Atmosphere within the plastic packages can be created actively or passively or by a combination of both. In our case of the passive method, the modified atmosphere is created by a dynamic in which product respiration and gas exchange occur through the packaging. In a closed package containing dates, the atmosphere is naturally modified as a result of oxygen consumption and carbon dioxide production. Optionally, a stationary concentration deemed optimal can be established in the case where the flow of gas through the package compensates exactly the breathing of the product.

4. The properties of the film packaging for modified atmosphere

Modified Atmospheres or MAPs are ensured by the use of Polyethylene Terephthalate Polyester (PET). Control lots are packaged in a macroperforated non-sealed film and are considered unpackaged (Table 1).

Table 1: Physical characteristics of the films used. Source: © Goodfellow (2008 – 2019) [90].

	Permeability to Oxygen at 25°C $\times 10^{-13}$ cm^3. Cm cm^{-2} s^{-1} Pa^{-1}	Permeability to Carbon Dioxide at 25°C $\times 10^{-13}$ cm^3. cm cm^{-2} s^{-1} Pa^{-1}	Permeability to Water at 25°C $\times 10^{-13}$ cm^3. Cm cm^{-2} s^{-1} Pa^{-1}	Permeability to Nitrogen at 25°C $\times 10^{-13}$ cm^3. cm cm^{-2} s^{-1} Pa^{-1}	Thickness µm
Polyethylene terephthalate Polyester film	0.03	0.2	100	0.004	2.5
Macro-perforated film	Control	Air	>100	Air	-

Polymeric compounds are the main materials for flexible package structures used for MAP but they can also be applied to a rigid or semi-rigid packaging solution such as a lidding on a tray [42]. Low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE), high-density polyethylene (HDPE), polypropylene (PP), polyvinyl chloride (PVC), polyester, i.e. polyethylene terephthalate (PET), polyvinylidene chloride (PVDC), polyamide (Nylon) are some of the plastic films used in MAP [43]. Characteristics of the fi lm that can affect atmosphere modification and must be carefully selected are film permeability to O_2, CO_2 and water vapor, fi lm thickness, package surface area and free volume inside the package [44]. Polyesters are formed by a condensation reaction that is very similar to the reaction used to make polyamide or nylons [45]. PET polyester is the most common thermoplastic polyester and is often called just "polyester" [45]. PET exists both as an amorphous (transparent) and as a semicrystalline (opaque and white) thermoplastic material [45]. The semicrystalline PET has good strength, ductility, stiffness and hardness [45].

5. Mounting experimental boxes

The control batches are packaged in experimental boxes made of polyethylene terephthalate polyester film (PET). The experimental setup consists of a box with internal dimensions of 7.5×15.00 × 7.5 cm. It is made of PET film thickness 0.0025 mm. The modified atmosphere inside the box is generated by the exchange between the product and the outside through the film.

The manufacture of the experimental boxes had to ensure their tightness. The lid placed and fixed on the box is provided with a foam rubber. The tightness of the boxes was verified by measuring the concentration of air inside the box after 5 and 24 hours. The boxes were considered watertight knowing that the variation in indoor air concentrations was less than 0.5%.

6. Achieving homogeneous batches

Before proceeding to the distribution of samples in homogeneous batches, dates go through a period of "thermal equilibrium rest" [46]. The dates are mixed manually carefully and carefully, several times in order to obtain homogeneous batches from an appearance point of view (color, caliber), then arranged in a uniform layer of small thickness.

The dates freed from impurities and dust, were placed in clean trays at a rate of 350g ±5 g each and kept in a freezing chamber (-18°C) in order to block the ripening process.

7. Constitution of experimental batches and storage

The dates are packaged in batches of 350g ±5g. The date samples were divided into two groups of batches with six samples each, corresponding to the storage period (0, 1, 2, 3, 4 and 5 months) before to be tested for the first at room temperature (22°C ±1°C) with a relative humidity of 75% to 80% and the second at low temperature of 10°C ±2°C with a relative humidity of 85 % to 90%. The experimental batches are thus constituted (Fig. 1.).

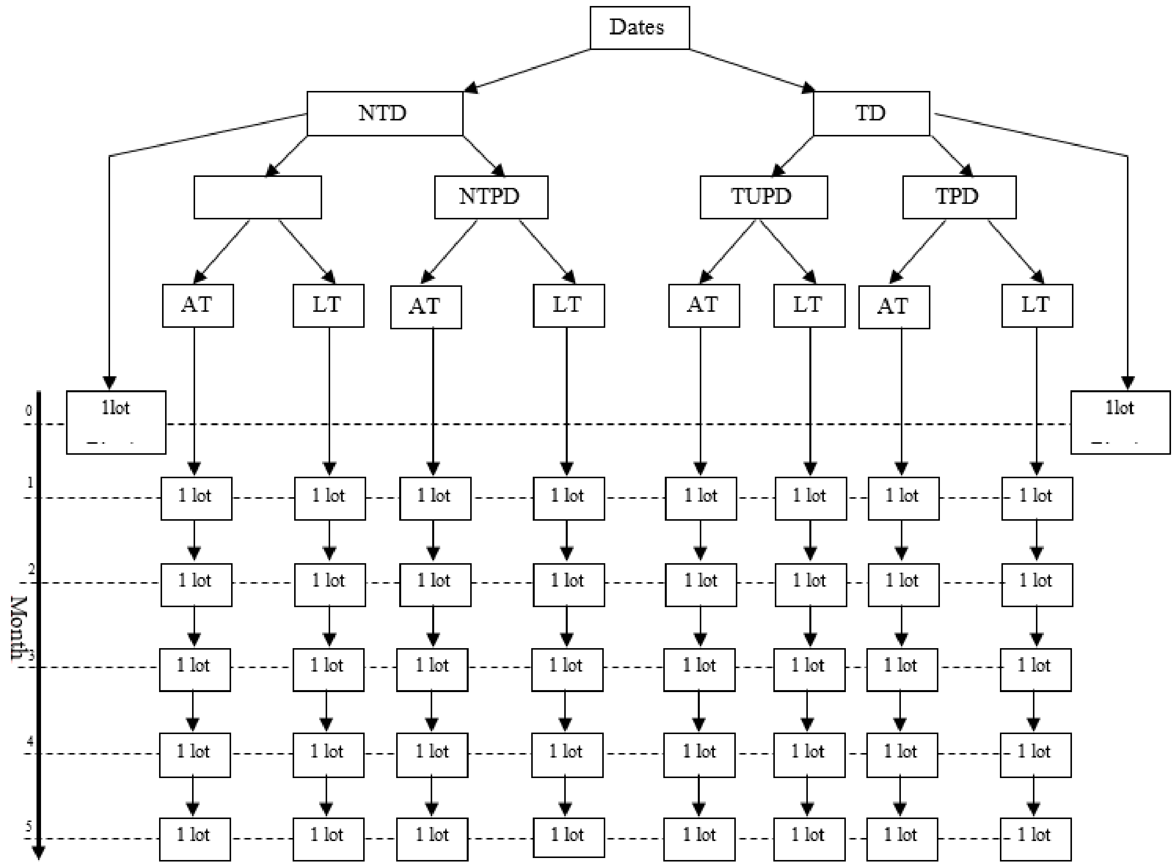

Figure 1: Diagram of constitution of the experimental batches. Reproduced with permission of Khali [41].
(NTD: Not Thermised Dates, TD: Thermised Dates, NTUPD: Not Thermised Unpacked Dates, NTPD: Non Thermised packed Dates, TUPD : ThermisedUnpacked Dates, TPD : Thermised packed Dates, AT: Ambient Temperature, LT: Low Temperature).

8. Respiratory intensity

The intensity of the dates is determined by placing the fruit in hermetically sealed jars. The evolution of O_2 and CO_2 concentrations is monitored after one hour of closure. For this, the volumes of gas are taken from the atmosphere of the jars through a septum and assayed by the gas analyzer.

The concentrations obtained (in O_2 or in CO_2) are expressed in ppm. The evolution of the concentration of the gas considered (O_2 or CO_2) in the packaging is followed in time.

The respiratory intensity, expressed as µg of gas per gram of fruit per hour (or in ml of gas per kg of fruit per hour), is evaluated using the following equations [47]:

$$\text{RI O2} = \frac{\text{Quantity consumed 02 (\%) x Volume of fruit (ml) x 273 x 1000}}{\text{Time (H) x [273 + measured temperature (°C)] x 22.4 x Weight x 100}}$$

RI O_2 is also expressed in mmol O_2 .kg^{-1}.h^{-1}.

$$\text{RI CO2} = \frac{\text{Quantity of degassed C02 (\%) x Volume of fruit (ml) x 273 x 1000}}{\text{Time (H) x [273 + measured temperature (°C)] x 22.4 x Weight x 100}}$$

As before, the RIco_2 is expressed in mmol CO_2 .kg^{-1}.h^{-1}

9. *Gas dosing instrument*

The control of the gas concentrations inside the experimental boxes was carried out using an OXYBABY® 6.0 gas analyzer from the German manufacturer WITTGAS.

OXYBABY® 6.0 is an alternative solution to fixed table analyzers for food packaging and welding. It provides all the benefits of the most modern technologies quickly and easily by option [89]. For example: bluetooth wireless communication and integrated barcode reader. The rapid control in all places makes it possible to guarantee a constant quality of your products (HACCP) for the benefit of your relations with your customers. Internal pressure information in the package via pressure indication.The dosage of ethylene emitted; 1 ml of air extracted from the hermetically sealed jars, where the dates to be studied were placed, was injected into a gas chromatograph (gas phase), equipped with suitable columns for the ethylene dosages. The temperature of the thermo conductivity detector was 150°C and that of the oven 35°C [48].

RESULTS AND DISCUSSION

1. *Change in O_2 and CO_2 concentration after harvest at Tamar stage*

For both samples studied during storage at room temperature (22°C ±1°C and 75-80% RH), we found a slight decrease (from 22.53% to 19.22%) in the mean concentration of oxygen from the dates fruit sample (fig 2.). In contrast to fruit samples of dates stored in packaging (PET film), there was a sharp decrease in the average oxygen concentration (from 20.25% to 12.86%) (Fig. 2.). In addition, a strong increase (from 0.75% to 10.54%) in the average CO_2 concentration of the date fruit sample, and a slight increase (from 0.23 to 6.45) in the Fruit sample of dates stored in packaging (PET film).

Indeed, as soon as the oxygen concentration was first measured after 45 minutes of storage under PET film, the packaging slightly limited the oxygen consumption of date fruits compared to the control sample (20.25% for date sample stored under PET film versus 22.53% for control sample). Date fruits from the control sample had the highest oxygen consumption (22.83%). Similarly, the PET film packaging limited the degassed CO_2 concentration after seven hours of storage compared to the control sample (0.55% for date sample stored under PET film versus 1.90% for control sample).The concentration of oxygen and CO_2 of date fruits stored under PET film was always lower than that of the control during storage.

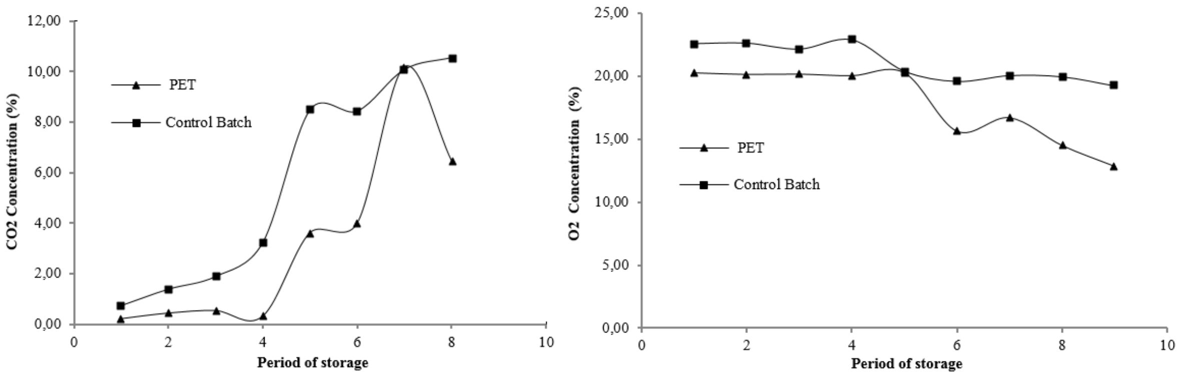

Figure 2: CO_2 and O_2 consumption of dates as a function of time at 22°C ±1°C and 75-80% RH.

2. *Physiological evolution of the date (Phoenix dactylifera L.) in conservation according to its post-harvest stage*

The previous results allow characterizing the initial quality of the fruits according to their stage of harvest. It is now a question of following the evolution of these different batches of dates in order to appreciate their ability to ripen and their conservation potential in non-binding conditions (storage at 22°C ±1 °C and at 75-80% RH) and to be able to characterize the final quality of ripe fruits.

3. *Speed of evolution of dates (Phoenix dactylifera L.) in post-harvest*

Dates show typical non-climacteric fruit respiration after harvest (Fig. 3).

They do not evolve at the same rate according to the preservation time, the more the conservation is late, the more the respiratory peak is diminished. Thus, the respiratory activity of the date samples studied takes place during the first two days after harvest for the fruits harvested at the "Tamar" stage.

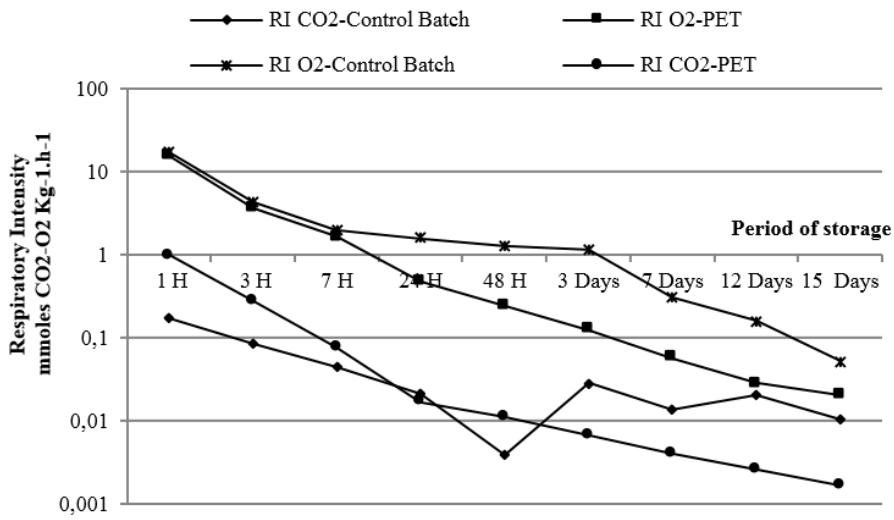

Figure 3: Respiratory intensity from dates observed in post-harvest

For the nine samples studied, we observed a decrease in the respiratory intensity of the fruits during storage at room temperature (22°C ±1 °C and 75-80% RH) for both batches of dates (control and stored under PET film). Indeed, from the first day of storage, with the control test, the oxygen consumption of the dates fruits is slightly higher compared to the batch stored under PET, (after 3 hours of storage 4.34 mmoles $O_2.Kg^{-1}$ for the control group against 3.62 mmoles $O_2.Kg^{-1}.h^{-1}$), (after 7 hours of storage 2.01 mmoles $O_2.Kg^{-1}.h^{-1}$ for the control group against 1, 66 mmoles $O_2.Kg^{-1}.h^{-1}$), (after 24H storage 1.58 mmoles $O_2.Kg^{-1}.h^{-1}$ for the control group against 0.48 mmoles $O_2.Kg^{-1}.h^{-1}$) The fruits of the control had the highest consumption (4.34 mmoles $O_2.Kg^{-1}.h^{-1}$) during this period of conservation.

The climacteric character or not of the date is not decided in the literature. Indeed, some authors [49, 50, 51] confirmed that the date is a climacteric fruit by the observation of an ethylene production.

In contrast to other authors consider that the date is non-climacteric [3].

Nevertheless, the date has a weak respiration which decreases with the decrease of its water content during the maturation. For dates stored at 20°C, CO_2 production is less than 25 $ml.kg^{-1}.h^{-1}$ at the Khalal stage, and less than 5 $ml.kg^{-1}.h^{-1}$ at the Routab and Tamar stages [52]. The same authors found under the same storage conditions ethylene production values of less than 0.5 $\mu l.kg^{-1}.h^{-1}$ at the Khalal stage, and less than 0.1 $\mu l.kg^{-1}.h^{-1}$ at the Routab and Tamar stages.

According to the tropical and subtropical fruit classification reported by Paull & Duarte and Gross et *al.* [53, 54], dates are non-climacteric fruits, with a very low respiration rate and low ethylene production, and therefore with very low metabolic activity. The respiratory intensity of date fruits stored under PET film was always lower than that of the control during storage, and decreased significantly during the last storage periods (after 7 days storage 0.057 mmole $O_2.Kg^{-1}$ h^{-1}, and 0.02 mmole O_2 $.Kg^{-1}.h^{-1}$ after 15 days of storage). The PET film has greatly limited fruit oxygen consumption of dates (*Phoenix dactylifera* L.), which helps extend the shelf life of fruits after harvest.

The characteristics of films that constitute a barrier to gases are of great importance. Indeed, by forming a thin film layer surrounding the fruit, the coatings modify the inner atmosphere by reducing the gas permeability of the skin of the fruit [55, 56]. This results in an increase in the carbon dioxide content and a decrease in the oxygen content within the fruit [57, 58].

Nevertheless, when the internal CO_2 content of the fruit is high, a fermentation may occur which risks giving the fruit a poor organoleptic quality, detrimental to the commercial level [59, 58, 91].

Decreasing the respiration of fruit allows to extend their storage period post-harvest. This is often achieved by combining a decrease in temperature with an increase in relative humidity [60].

It has been recommended for storing fresh fruit, a temperature of 15°C, a relative humidity of 80-90% to ensure a good sensory state for about three weeks [61]. The low temperatures showed their effectiveness in preserving the quality of the dates (reduction of the loss of color, flavor, texture...), as well as the alteration by the fungal microflora and the infestations by the insects [3].

4. Evolution of the O_2 and CO_2 concentration (Phoenix dactylifera L.) packed under MAP (by passive channel) during conservation

4.1. Variation in O_2 and CO_2 concentration during storage

For the three lots studied in Test I, we found a decrease in the oxygen concentration of the inner atmosphere of the PET packaging of the not thermised - packed: NTP and Thermised - packed: TP batches during storage. at room temperature (22°C ±1°C and 75-80% RH) (Fig. 4).

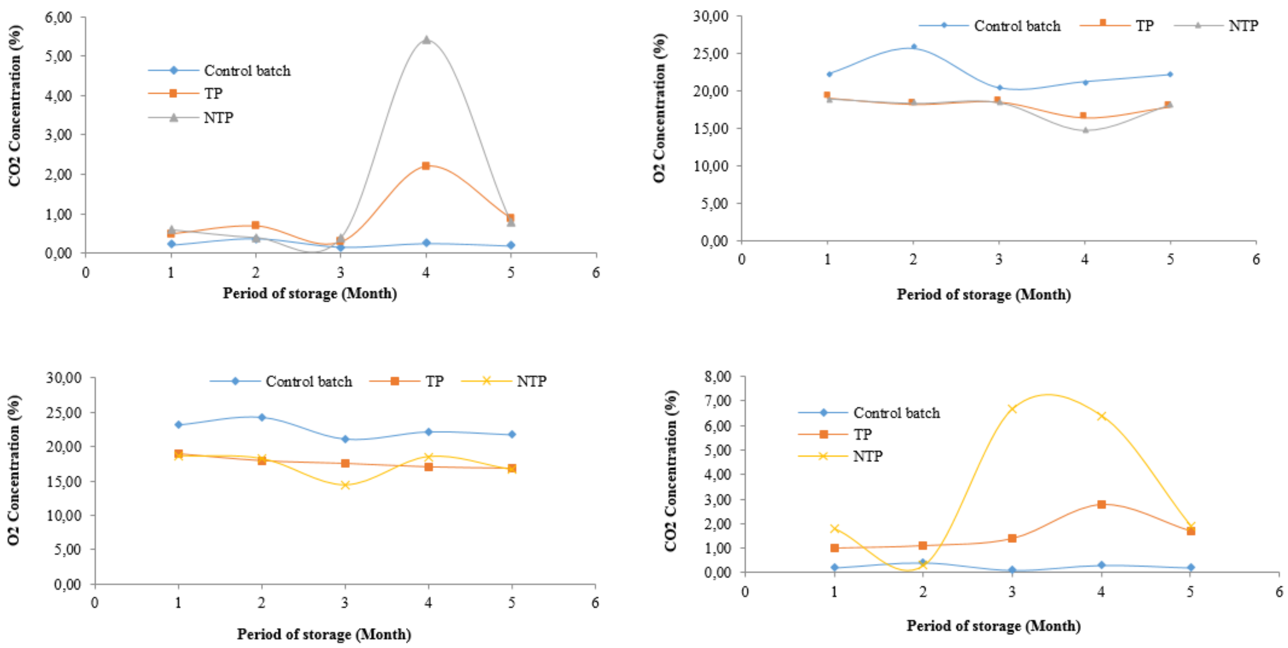

Figure 4: Evolution of the O_2, CO_2 concentration of dates stored at room temperature 22°C ±1°C / 75-80% RH (Test I-at the bottom of the image) and at low temperature 10°C ±2 °C / 85-90% RH (Test II-at the top of the image) as a function of time.

Indeed, from the first month of treatment, with the test I at room temperature 22°C ±1°C and at 75-80% RH, the packaging has strongly limited the oxygen concentration of the date fruits compared to the batch control (23.20% for the control group versus 19% for the TP lot and 18.60% for the NTP lot), ie a decrease rate of 22.38% for the TP lot and 22.40% for the NTP lot. The third month of storage of the NTP batch shows the lowest oxygen concentration estimated at 20.47% (14.40% against 21.15% for the control batch). And it is also the fifth month of storage of the lot TP with a decrease of 21% (16,90% against 21,78% for the control batch). At two months of storage, date fruits in the control group had the highest concentration of oxygen (24.30%). In contrast to the control group, the oxygen concentration of MAP packed fruit dates in the batch lots Not thermised - packed: NTP and Thermised - packed: TP was always lower than that of the control batch during storage.

During retention of dates fruit stored at room temperature at 22°C ±1°C and 75-80% RH, we found that the CO_2 concentration is greatly increased compared to the control group from the third month lots Not thermised - packed NTP and Thermised - packed: TP (respectively 6.4% and 1.4% against 0.10% for the control group) with a rate of increase of 40% Thermised - packed: TP and 570% for the batch batch Not thermised - packed: NTP. These packages have increased the CO_2 concentration of the indoor atmosphere of the PET packaging of date fruits compared to the control batch from the first month of storage (Fig. 4). During the conservation period, we found a stable CO_2 concentration between the first month and the third month. In the fifth month of storage, fruit of lots of dates Not thermised - packed: NTP Thermised - packed: TP had a decrease of CO_2 concentration 6.4% respectively 1.9% and 2.8% at 1.7%.

In addition, the CO_2 concentration of the date fruits in the control group increased slightly in the second and fourth months of the storage period (0.40% and 0.30%, respectively), while the date fruits of the batches thermised - packed: NTP and Thermised - packed: TP strongly increase their concentration over time.

In test II at low temperature at 10°C ±2°C and 85-90% RH, the PET packaging applied to date fruits also showed stable CO_2 concentration during the first three months of storage indoor atmosphere for all samples. In fact, after four months of storage, the CO_2 concentration of the indoor atmosphere of the PET packaging of date fruits is increased by 120% (TP) compared to the control batch (Fig. 4).

In the fifth month of storage, the concentration of CO_2 in the inner atmosphere of the PET packaging of the batch (TP) and (NTP) decreases sharply (is respectively 0.9% and 0.8% against 0.19% for the sample batch). As for the internal atmosphere of the lot (NTP), the figure shows that their CO2 concentration is faster than the batch of the fourth month of conservation (respectively 2.2% and 5.4%). Then the CO_2 concentration of the indoor atmosphere of the batch (TP) and (NTP) decreases (0.9% and 0.8% respectively in the fifth month of storage).

During storage of dates fruit stored at low temperature at 10 ±2 °C and 85-90% RH, we found that the oxygen concentration of the indoor atmosphere is greatly reduced throughout the storage period compared to the control batch, and after the first month in lots (NTP) and (TP) (respectively 18.8% and 18.9% against 22.16% for the control group) with a decrease rate of 14.71% Thermised - packed: TP and 15.16% for batch batch Not thermised - packed: NTP. These packages reduced the concentration of CO_2 in the inner atmosphere of the PET packaging compared to the control batch from the first month of storage (Fig. 4.).

During the storage period, we found a stability of the CO_2 concentration of the indoor atmosphere of the PET package of the lot (NTP) and (TP) between the first month and the third month. In the fourth month of conservation, batches of date fruitsNot thermised - packed: NTP and Thermised - packed: TP showed a decrease in the CO_2 concentration of the indoor atmosphere of PET packaging (respectively from 18.4% to 16.4%, and 18.3% to 14.6%). In addition, the CO_2 concentration of the indoor atmosphere of the PET packaging of the control batch increased slightly in the second month of the storage period (a rate of increase 15.75%).

4.2. Respiratory intensity

The measurement of the respiratory intensity makes it possible to show in many fruits a significant increase of the respiration at the beginning of the maturation. This sudden rise has been called a climacteric crisis. After this phenomenon, the ripening of the fruit is followed by senescence. According to our results of the two tests I and II, the application of the PET packaging inhibits the appearance of this crisis in our storage conditions (at low temperature 10°C ±2°C and at 85-90% RH and at temperature ambient 22°C ±1°C and 75-80% RH). This will extend the shelf life of date fruits by a few months longer than untreated fruit.

We found that all tested packages (TP) and (NTP) at room and low temperature limited the oxygen consumption of date fruits (Fig 5.).

Packaged date fruits did not show a respiratory peak, which is not the case for control batches of both trials. Indeed, for the control batches of tests I and II, the dates suffered this crisis in the first month of storage (respectively $7.81E^{-03}$ mmoles O_2 $Kg^{-1}.h^{-1}$ and $7.46E^{-03}$ mmoles O_2 $Kg^{-1}.h^{-1}$).

From tests I and II, the oxygen consumption of all the date fruits (NT) and (NTP) of test I decreased rapidly after the first month of storage $6,40E^{-03}$mmoles O_2 $Kg^{-1}.h^{-1}$ (NT), $6.26E^{-03}$ mmoles O_2 $Kg^{-1}.h^{-1}$ (NTP), against $7.81E^{-03}$mmoles O_2 $Kg^{-1}.h^{-1}$ for control group. Similarly, the oxygen consumption of all dates (NT) and (NTP) fruits of test II decreased rapidly after the first month of storage $6.36E^{-03}$ mmoles O_2 $Kg^{-1}.h^{-1}$ (NT), $6.33E^{-03}$ mmoles O_2 $Kg^{-1}.h^{-1}$ (NTP), against $7.46E^{-03}$ mmoles O_2 $Kg^{-1}.h^{-1}$ for control group. Then, a strong decrease was observed until the third month of storage for date fruits (NTP) of the test I $9,70E^{-04}$mmoles O_2 $Kg^{-1}.h^{-1}$ against $2,37E^{-03}$mmoles O_2 $Kg^{-1}.h^{-1}$ (a decrease rate of 59.07%). In addition, we notice a stabilization of the respiratory intensity during the last two months of storage for date fruits (NT) and (NTP) (Fig 5.). As for the control date fruits of tests I and II, we found that their respiratory intensity was higher compared to the other batches treated during the five months of storage. Subsequently, until the end of the experiment, this growth experienced a stability of the respiratory intensity. In addition, we note a higher oxygen consumption for the batch of control date fruits than for the other experimental batches (NT) and (NTP), in all batches during storage.

We conclude that PET packaging can limit the oxygen consumption of date fruits under different conditions (at low temperature at 10°C ±2°C and at 85-90% RH and at room temperature at 22°C ±1°C and 75-80% RH), as well as different storage periods of the date fruit.

The packages have limited the respiratory intensity of date fruits, which extends the shelf life of post-harvest date fruits. These PET packages are of great interest for long-distance transport, especially if they are used in combination with other techniques, such as refrigeration (storage at low temperature 10°C ±2°C and at 85°C). 90% RH) .We found from tests I and II that the release of CO_2 from the date fruits (NT) and (NTP) of test I increased after the first month of storage 3.37^{E-04}mmoles O_2 $Kg^{-1}.h^{-1}$ (NT), 6.06^{E-04}mmoles O_2 $Kg^{-1}.h^{-1}$ (NTP), against 6.73^{E-05}mmoles O_2 $Kg^{-1}.h^{-1}$ for control batch. Similarly, the respiratory intensity of CO_2 released from all date (NT) and (NTP) fruits of Trial II was greater than that of the control group after the first month of storage 1.68^{E-04}mmoles O_2 $Kg^{-1}.h^{-1}$ (NT), 2.02^{E-04}mmoles O_2 $Kg^{-1}.h^{-1}$ (NTP), against 7.07^{E-05}mmoles O_2 $Kg^{-1}.h^{-1}$ for control group. Then, a strong decrease was observed until the fourth month of storage for dates fruits (NTP) of test I 5.39^{E-04}mmolesO2$Kg^{-1}.h^{-1}$ against 7.52^{E-04}mmoles O_2 $Kg^{-1}.h^{-1}$ to the third month (a decrease rate of 28%). In addition, we note a stabilization of the respiratory intensity of CO_2 during the last month of storage for date's fruits (NT) and (NTP) of tests I and II (Fig. 5.). Indeed, for the control batches of tests I and II, the dates experienced a stability of the respiratory intensity of the CO_2 throughout the period of conservation.

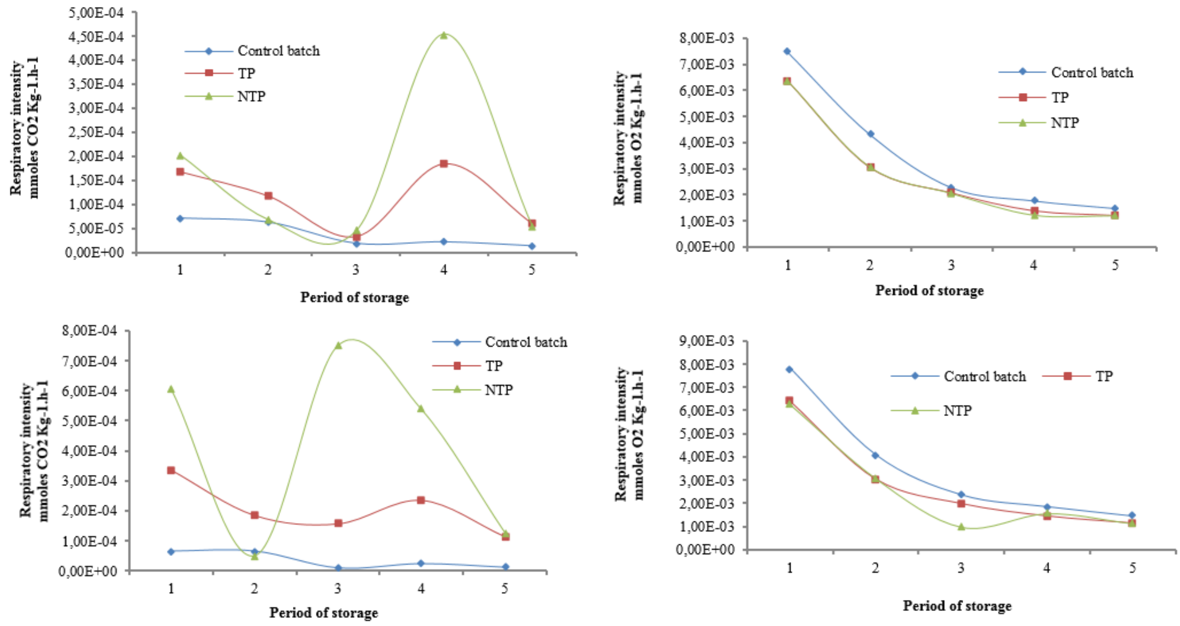

Figure 5: O_2, CO_2 consumption rate (Respiratory intensity) of date fruits as a function of time at room temperature 22°C ±1°C and 75-80% RH (Test I- at the bottom of the image) and at low temperature 10°C ±2°C and 85-90% RH (Test II-at the top of the image).

The use of MAP can result in reduction of respiratory activity, retardation of softening and ripening and restraint of pathogens and reduced incidence of various physiological disorders [92].

Temperature is an extremely important factor during packaging design due to its effect on the physiology of the product [42]. One of the main responses to stress is protein dysfunction, disrupting cellular homeostasis, known as heat shock proteins [42]. The production of these proteins is triggered by conditions like oxidative stress, low temperatures and fruit ripening [42]. Exposure of sensitive products to low storage temperatures may have beneficial effect on shelf life and preserve quality but there are some limitations [42]. If these limits are exceeded may lead to chilling injury [62].

Respiration rates of fruits and vegetables are affected by many environmental factors [63]. In cases where this leads to negative effects on plant tissue it is defined as stress [63]. During the storage of fruits and vegetables effects of low temperatures, reduction in oxygen (O_2) concentration and increase in carbon dioxide (CO_2) concentration in the storage atmosphere are utilized to extend the storage life of produce [63]. However, maintaining an adequate energy status is required to prevent browning or senescence of harvested fruits and vegetables [64, 95, 65, 66, 67]. It is well established that lowering of O_2 concentrations during controlled atmosphere storage reduces respiration rates and energy supply and that severe limitations of O_2 induce fermentative (anaerobic) respiration and metabolism in stored produce [63].

The net yield of ATP during anaerobic respiration is only 2 moles of ATP of hexose sugar compared with 36 moles of ATP per mole of hexose in aerobic respiration. Hence, energy status may be insufficient and provoke storage disorders [67].

Rygg [68], Suggested inert gas or vacuum packing for storage of high-moisture dates. Mohsen et *al.* [69], Noted that vacuum packaging is a useful technique for reducing darkening of the date for long-term storage [70]. Mutlak and Mann [71], reported that browning can be inhibited at low oxygen potentials. CA (5, 10, or 20 kPa CO_2) at 8 °C extended storage period and maintained quality of fully mature 'Bahri' date fruit [72]. The quality of fruit stored under 20 kPa CO_2 was maintained for up to 26 weeks compared to 17 weeks for fruit held under 5 and 10 kPa CO_2 and only 7 weeks for fruit kept in normal air [70].

A 20 kPa CO_2 maintained acceptable levels of fruit soluble solids, total sugar, total tannins, and caffeoylshikimic acid [70].

Dehghan-Shoar et *al.* [73], Compared the effects of MAP under high CO_2 on the quality of Sayer dates fruits with low temperature storage and freezing. The results showed that MAP with 85% CO_2 + 3% O_2 and 75% CO_2 + 12% O_2 maintained the best quality of dates with no physiological disorder, and off-odor and off-flavor throughout the 150-day storage. Dates were shown to be resistant to high CO_2 as well as low CO_2, which is probably due to the low respiration rate. Aleid et *al.* [74], compared dates packed in MAP in varying CO_2 concentrations with dates packed in paperboard carton (control). MAP in high CO_2 (up to 20%) retarded date ripening and maintained the quality and firmness of dates better than the control. Hunter color of dates values were stable in MAP samples, especially to day 9, though decreased at day 18 and day 27 but were still significantly higher than the control. High CO_2 MAP has also shown to be effective in eliminating insects in stored dates [73].

Al-Redhaiman [75], also reported that storage under high CO_2 atmosphere extended the shelf life of Barhi date fruits. Shelf life of Barhi dates stored at 0°C was 26 weeks under 20% CO_2, 17 weeks under 5% and 10% CO_2, and about 7 weeks under normal air condition [34]. Storage under high CO_2 was shown to reduce decay and weight loss, while maintaining color, firmness, sensory quality, soluble solids, total sugar content, and total tannins, which are the principal antioxidants in dates.

In addition, high CO_2 atmosphere was shown to delay the degradation of caffeoyl-shikimic acid, which is one of the major phenolic compounds in dates [34].

Achour [76], studied the effect of MAP in combination with vacuum on Deglet Nour dates and dates stuffed with almond paste. Dates were packaged in amorphous PET wrap (APET) and the package was injected with 10 or 15% of a gas mixture of 20% CO_2 + 80% N_2 and stored at 20,30, and 40°C. The results showed that both vacuum and MAP reduced dehydration of dates. Shelf life of fresh dates packaged in APET with modified atmosphere stored at 20 ◦C was increased to 9 months from 3.8 months in normal air conditions [34].

The respiration rate of dates is very low: <5 mg CO_2 kg/hr at 20°C (68 ◦F) at the Khalal stage, and <2 mg/kg/hr at the Rutab and Tamar stages [77]. Ethylene production of dates is also very low: <0.1μl/kg/hr at Khalal stage and none at Rutab and Tamar stages [78]. Dates beyond Kimri and Khalal stages are not sensitive to chilling injury [77]. Yahia [79], reported that dates may require postharvest ripening if picked early. Soft and semi-dry cultivars need to be dehydrated to eliminate excess moisture if they will not be consumed immediately [77]. Hydration is used to soften the texture of hard-type cultivars [77].

Kaderand Hussein [52], suggested that dates should not be mixed with onions, garlic, potatoes, apples, or other commodities with strong odors that can be adsorbed by the dates.

Date fruit quality loss resulting from pathological and physiological deterioration increases with increasing moisture content and storage temperature [78]. Storing dates at low temperatures is the most important way of maintaining quality: because it minimizes loss of color, flavor, and textural quality; delays development of sugar spotting, incidence of molds and yeasts, and insect infestation; and prevents development of syrupiness (due to conversion of sucrose into reducing sugars) and souring of excessively moist dates [77]. Khalal dates should be stored at 0°C and 85–95% RH to reduce water loss, delay ripening to the Rutab stage, and maintain their textural and flavor quality [52]. In order to reduce moisture loss and improve shelf life, packaging in moisture-barrier plastic bags or use of plastic liner in the box is helpful [77].

Optimal temperature for Tamar dates is 0 ˚C for 6–12 months, depending on cultivar (semi-soft dates, like Deglet Nour and Halawy, have longer storage-life than soft dates, like Medjhool and Barhee) [77]. For extended storage, the use of temperatures below the highest freezing temperature of –15.7°C is recommended. Dates with 20% or lower moisture can be kept at –18 ◦C for more than one year, at 0 ◦C for one year, at 4 ◦C for 8 months, or at 20 ◦C for one month; RH should be kept at 65–75% for all cases [52].

There is a continuing trend toward increased precision in temperature and RH management to provide the optimum environment for fresh produce during cooling, storage, and transport; precision temperature control and management tools, including time–temperature monitors, are becoming more common in cooling/storage facilities and during transportation and shipping [80].

Dates are non-climacteric with relatively low respiration rate: <25 ml/kg/hr for Khalal stage dates, and <5ml CO_2/kg/hr for Rutab and Tamar stage dates kept at 20°C [36]. The respiration rates increase with higher moisture content and temperatures. Ethylene production rate of dates is also very low at 20 ◦C, i.e.,<0.5 µl/kg/hr for Khalal stage, and <0.1 µl/kg/hr for Rutab and Tamar stage dates [79].

Serrano [81], studied some physicochemical parameters related to ripening and their relationship with ethylene in dates (cv. Negros), which were harvested and classified into sixteen ripening stages according to their color, ranging from yellow-greenish to dark brown. Fruit firmness decreased through the different ripening stages, while the ripening index, expressed as the relation between soluble solids and acidity, increased; the greatest loss of fruit firmness correlated with the greatest increases in both polygalacturonase and $^{\beta}$galactosidase activities [36]. In early ripening stages, a small peak in ethylene production was detected, followed by a peak in respiration rate; with the plant hormone ethylene being responsible for changes in color, fruit firmness, total solids content and acidity [36].

Regarding response to ethylene, it has been reported that there was no effect of exposing Khalal stage yellow Barhee dates to 100 ppm ethylene for up to 48 hours at 20°C and 85–90% relative humidity [36].

However, Khalal stage dates may respond to ethylene action at higher temperatures (30–35 ◦C), which are more optimal for their ripening. Rutab and Tamar stage dates are not influenced by exposure to ethylene but can readily absorb the aroma of other products [36]. Thus, dates should not be stored with garlic, onion, potato, or other commodities with strong odor [52].

Heat treatment of dates at 60–70°C for 2 hours killed 100% of both the figmoth and the saw-toothed beetle, but resulted in a shiny appearance or glazing of the fruit [82]. Exposing dates to temperatures of 65–80°C for 30 min to 4 hours at high humidity controls insects [78]; however, this approach is not always very efficient for controlling insects in dates with high moisture content because high temperatures for prolonged periods may cause darkening and the appearance of a dull colour and loss of flavor [35].

Rafaeli et *al.* [87], described an effective, short-duration and inexpensive method using postharvest heating container. They found that the optimum temperature regime for maximum escape of beetles from the fruit was 55˚C for 2.5 hours attained at a rate of 1.8˚C/min.

Heated air at 50–55°C for 2–4 hours (from the time the fruit temperature reaches 50°C or higher) is effective for insect disinfestation [88], but the use of higher temperatures is not recommended because it makes the color of the dates darker Elhadi et *al.* [35]. Forced hot air is recommended to obtain faster and more uniform heating of the dates [35]. Cooling the dates to the desired storage temperature (0°C) soon after completion of the heat treatment reduces the intensity of color darkening [35]. Hussein et *al.* [84], reported that boiling water is more efficient in controlling insect infestation of dates than exposure to hot air at 70 ◦C. However, very hot water also increases sugar loss that can reach up to 20% [35].

Dates are very resistant to low temperature, and thus can significantly reduce insect infestation [78, 3]. Fig-moth larva could live for 85 days at 2–6 ◦C, but storage at 0°C can result in total mortality of the larva of the fig-moth and adult of the grain beetle after 15 and 27 days, respectively [82]. Thus, packed fumigated dates could be kept free of infestation at 4 ◦C for as long as 1 year [82]. Freezing at –18 ◦C or lower for at least 48 hr (from the time when the fruit temperature reaches –18°C or lower) is enough to kill all life stages of stored products insects [35].

Packing infested dates in polyethylene bags with 80–90% vacuum resulted in 100% mortality after two days [82]. A 4-hour exposure at 2.8% O_2 in N_2 at 26 ◦C resulted in over 80% of the initial nitidulid beetles populations to emigrate from the infested dried dates [93, 94]. Al-Azab [85], used a mixture of modified atmosphere (65% CO_2, 15% N_2 and 20% O_2) and found that an exposure for 24 hours at 34 ◦C and 65% relative humidity cause 100% mortality against the adults of *E. cautella*. El-Mohandes [86], found that 100% mortality was achieved after 36-hour exposure at CO_2 concentrations of 75% at 25°C and 55% relative humidity for the adults of Oryzaephilus surinamensis and Tribolium confusum. Moreover, application of CO_2 at concentrations of 75% with half dose of PH_3 at 28 ±2°C and 60 ±5% relative humidity caused 100% mortality, of both tested insects, after 6 hours of exposure [35].

CONCLUSION

Preserving the quality of the date from harvest to consumption poses major problems for national operators. Good conservation depends on both the condition of the fruit at harvest and the conditions of storage.

The control of the quality of the dates is largely conditioned by the homogeneity of their degree of maturity. The harvest period at the Tamar stage is an important factor as the Deglet-Nour date is a staggered mature fruit. To reduce the heterogeneity of the fruit batches used in our studies, we selected the most homogeneous fruits possible from the point of view of color and general external appearance. At the industrial level, an artificial maturation, which remains to be studied (heat input, humidification, etc.) would be wise to increase the homogeneity of the fruits.

Thermization, heat treatment is proposed as an alternative to fumigation. It is based on the use of heat to destroy the worm of the date -Myelois- at its different biological stages, including eggs and larvae.

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