Post-harvest Processing of Dates: Drying, Disinfestation and Storage

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Sustainable Pest Management in Date Palm: Current Status and Emerging Challenges

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Chapter 13
Post-harvest Processing of Dates: Drying, Disinfestation and Storage

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Abstract Progressive demand for better date quality led to the development of solar drying technology. Equilibrium relative humidity (ERH) and water activity (a_w) are the most reliable criteria indicating the ability to safely store dates. ERH <65 % at 26 °C serves as a critical limit for date storage at the commercial level and ensures resistance to deterioration by microflora. The relationship between MC and ERH for Medjool, Khadrawy, Zahidi and Deglet Noor is established based on different studies. A solar dryer employing mechanical distribution fans was successfully implemented to integrate thermal disinfestation technology. It is based on the principle of transfer of hot air through a tunnel containing 3 tonnes of dates exposed for 3 h at 50 °C. By employing thermal disinfestation technology to replace methyl bromide (MeBr) fumigation, no effect on the organoleptic properties of dates was observed, while complete mortality of insects and high disinfestation levels for all dry date cultivars were achieved. The technology is currently implemented in all Israeli date packing houses to replace the MeBr fumigation. Vapormate™ is a fumigant that contains 16.7 wt.% ethyl formate in liquid CO_2. It is registered in Israel to control date pests, such as Nitidulid beetles, at dosage of 420 g/m^3 for 12 h at temperatures above 24 °C, as an alternative to MeBr for dates stored in bulk. The storage atmosphere containing a concentration of 60–80 % CO_2 in a gas tight chamber was found to be effective in controlling pests and preserving the quality of dates and moisture content (MC) for 4.5 months storage period.

13.1 Introduction

Date palms are mainly grown in North Africa and the Middle East. The largest date production (about 90 %) is concentrated in the countries Algeria, Egypt, Oman, Saudi Arabia, Iran, Iraq, UAE, Sudan, Pakistan and Morocco. The world date production was 1.8 million tons during 1961 which gradually increased to 2.8 million

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tonnes during 1985 and nearly 8.0 million tonnes in 2012 (FAOSTAT 2012). Most of the harvested dates are locally consumed. Only during recent years the date palm has been introduced as modern plantations in Australia, South America and South Africa, USA and Israel (Zaid 2002).

Date fruit is oblong in shape with a single seed, and becomes sweet when ripe. Since the fruits are rich in carbohydrates and other nutrients, they are considered high energy food. The Food and Agriculture Organization (FAO) publication "Date Palm Cultivation" provides an update of the technical information included in the two earlier FAO books: "Dates Handling, Processing and Packaging" by Dowson and Aten (1962) and "Date Production and Protection" by Dowson (1982).

13.2 Date Varieties

Based on appearance and texture, dates can be primarily categorized into four types: Fresh (fruits are consumed immediately after harvesting, typical of the variety, Barhee); Wet (fruits mature and stored at low temperature under refrigeration, typical variety Hayany); semi-dry (typical varieties Medjool and Deglet Noor) and Dry (typical varieties Ameri, Thoory, Halawy, Khadrawy and Zahidi) (Dowson 1982; Glasner et al. 2002).

13.3 Treatments Before Storage

During maturation, dates pass through the following stages: Khalal stage (yellow or red colored physiologically mature dates with sweet taste bearing moisture content (MC) of 50–85 %, Rutab stage (moderately brown in color, bearing 30–45 % MC) and Tamar stage (dark brown to amber color, with 10–25 % MC). The later stage is also considered as nonperishable (Glasner et al. 2002).

Usually, over a period of several weeks, a number of pickings have to be made. In Saudi Arabia and California (USA), the growers mostly use several mechanized means (extension ladders, harvesting saddles or cat walk equipped mobile towers) to harvest the dates. High quality dates are harvested by hand, while others are harvested as whole bunches (Morton 1987).

Since tree nuts and dried fruits are relatively high value products and used as confectionary ingredients or as snack foods, their successful marketing requires strict quality control measures. All modern date handling practices are designed to meet the buyer's demands with definite quality standards. In order to maintain quality, the processing facilities must produce fruits with the same properties consistently (Glasner et al. 2002). Since dates are considered a dry to semi-dry commodity, drying to control their moisture content must be done before their storage in order to maintain high quality.

Generally, field pest population development does not take place during storage (Johnson 2004), but these are pre-harvest insect pests that continue to cause quality deterioration and damage by direct feeding on the fruit (Simmons and Nelson 1975). The existence of these pests causes phytosanitary constraints for processors and cause continuous quality deterioration, therefore, they are considered post-harvest pests.

Moreover, aflatoxin producing molds (*Aspergillus* spp.) can gain access at sites of feeding damage caused by the insect pests (Campbell et al. 2003). Therefore, preliminary disinfestation of fresh product is necessary before storage to reduce such damage. Among a number of devastating insect pests of stored dates, the Indian meal moth, *Plodia interpunctella* (Hübner) may be the most serious (Simmons and Nelson 1975). A number of date cultivars are also vulnerable to attack by nitidulid beetles. The prolonged storage of ripen dates may allow several generations of pre-existing nitidulid beetles to develop, which results in heavy infestation of stored dates.

These beetles are strong flyers, capable of flying up to 4 km. The adult life span of Nitidulid beetles ranges from 6 to 12 months. They damage the ripening fruits by entering through the calyx end, and feeding on the date pulp starting on the palm, continue on mature fallen date fruits and even during storage. After the larvae hatch in the fruit, they feed and develop rapidly, contaminating the fruit with their molted skins and excretions. Usually, infestation by nitidulid beetles also provides entry points to the pathogens, which ultimately cause fermentation followed by rotting, and make the dates unmarketable (Blumberg 2008).

Since stored product pests reproduce during storage, repeated treatments are necessary to control the pests of stored dates particularly during long-term storage. Currently, fumigation is the main method of pest control in stored dates (Johnson 2004) that needs to be carried out immediately after the dates reach the packing stations.

In 2015, the fumigant methyl bromide (MeBr) will be withdrawn under the Montreal Protocol (MP) eliminating use of ozone depleting substances (UNEP 2006). MeBr has already been banned in Non-Article 5 countries. Therefore, a thermal disinfestation technology was developed as an alternative control measure to MeBr.

13.3.1 Solar Drying in Greenhouse

Amongst the preliminary actions must be taken into account for the safe storage of dates, the 'complete maturation' of all fruits is the significant one. Dates are known to ripen in stages at different times on the palm. The high quality dates are harvested by hand, and cutting off whole bunch for rest of the dates is a common practice. After harvesting, the drying process is carried out for semi-dry and dry cultivars (Navarro 2006).

In dates, the enzyme invertase converts disaccharide into glucose and fructose (monosaccharides), this enzymatic activity involved in converting the sugars, results in up to 90 % of the cellulose to break down by increasing the soluble pectin concentration that makes the fruit texture softer and juicier (Kanner et al. 1999). The activity of cellulase and polygalacturonase, level of glucose and fructose, relationship between water activity (a_w) [a_w; the proportion of water vapor pressure in a product to that of pure water the same temperature (Dowson and Aten 1962)] and moisture content (MC) are the main factors affecting the drying of date fruit.

Kanner et al. (1999) tested the enzymatic activities in Medjool cultivar. They observed that 0.65 a_w is safe for storage and effectively controls bacterial and mould growth with MC depending on the amount of sugars in the fruit. During an investigation dealing with the effect of sugar level on a_w and MC of Medjool date, it was found that dates absorbed more water at higher sugar levels for the same a_w value. At 0.75 a_w MC was 18 % and 20 % for dates containing 65 % reduced sugars and 24 % MC for dates containing 80 % reduced sugars (Kanner et al. 1999).

Due to difficulty of separating the dates one by one on the branches, incomplete ripen dates are harvested together with ripen dates. Those immature dates need to be separated from matured dates. In addition, sometimes, under unfavorable temperatures prevailing towards the end of the harvest season, ripening of dates on palms is not entirely completed; the maturation can be accomplished artificially by heat treatments. During those heat treatments, the temperature and time of exposure (at a particular temperature) are correlated and play an important role in the ripening of dates (Navarro 2006).

The temperature levels of 30 and 50 °C were required for maturation of Medjool dates in 156 and 21 h, respectively. The high temperature (55 °C) affected the date quality by causing a significant blistering (separation of skin from the fruit) and change in color of the fruit. The relationship between time and temperature for the maturation of dates can be expressed by an equation that describes the constant value (Navarro 2006):

$$K = T.\ln(t)$$

Where:

T = temperature (°C); t = time (hour)

With the calculated value (K) of 152.2 for ripening dates of Medjool cultivar (Navarro 2006) and based on the determination of maturation temperature the time required for the maturation of dates can be determined as follows:

$$\ln(t) = 2K / ((\Sigma(tmax) / n) + 30)$$

Where:

$\Sigma(tmax)/n$ = mean highest temperature within the maturation pallet on daily basis

For instance, when 40 °C is the mean highest daily temperature, then according to the equation, the maturation time for Medjool dates will be 77.4 h. This time (77.4 h) is the cumulative time period when the temperature of maturation is >30 °C.

Using solar energy for maturation, the dates placed in pallets are exposed to the solar heat and the energy requirements for field maturation can be determined by using the above equation. In the same regard, the use of shrink films to cover the trays containing immature Medjool dates in the field, gave excellent results (Navarro 2006). Moreover, leaving a ventilation window in the shrink film covering the date containing pallets prevents the condensation that further facilitates the ripening process. Since dates possess hygroscopic characteristics, they equilibrate the MC with the relative humidity of the ambient air by losing or gaining moisture from the outside environment through this ventilation window. This association can be expressed as equilibrium moisture content (EMC) or equilibrium relative humidity (ERH). EMC can be defined as the levels of MC in terms of ERH with which the product is in balanced position. While, ERH is the level of air RH surrounding the product with consistent MC on wet basis. The a_w helps in determining the intensity of infestation level caused by microorganisms. *Aspergillus restrictus* and a number of species of *Aspergillus glaucus* group can grow slowly at a_w of 0.65 or above. The water content may vary in different products having same a_w (Lacey et al. 1980) and generally commodities bearing high sugar content have higher MC than other stored products at the same a_w.

Immature dates possess less sugar content, hence results in an increased a_w. Therefore, dates with high MC before storage results in deterioration of fruits due to microflora activity. The a_w expresses the available water for metabolic activities under varying sugar concentrations (Kanner et al. 1999), therefore, a_w (or ERH) is a more practical parameter compared to the MC. Thus, a_w plays a significant role in decision making process for the storability of the produce. At 26 °C with 65 % RH drying dates to a MC below 21 % is not possible; e.g. Medjool dates exposed to air at 26 °C with 65 % RH can only be dried to a MC of 21 % (desorption) (Navarro 2006).

The activity of cellulase enzyme is determined by a_w of the fruit; at 0.87 a_w, which is typical for the Khalal stage, when progressed to Rutab stage with decreasing a_w, the enzymatic activity also decreased and stopped at 0.63 a_w (Kanner et al. 1999).

Elastic and soft texture dates are more in demand, therefore, fresh dates having MC 24–26 %, can be preserved after packing in cold storage. The growth of microbial agents like mold, bacteria and yeast is also inhibited in dates having ERH less than 65 %. In order to prevent ripening fruit from over drying on trees, they must be harvested when they have sufficient water content (Navarro 2006). Each cultivar has its own capacity of binding water, Figs. 13.1, 13.2, and 13.3 show this relationship between MC and ERH for date cultivars Khadrawy, Zahidi and Deglet Noor, respectively (Rindner et al. 2001; Navarro 2006).

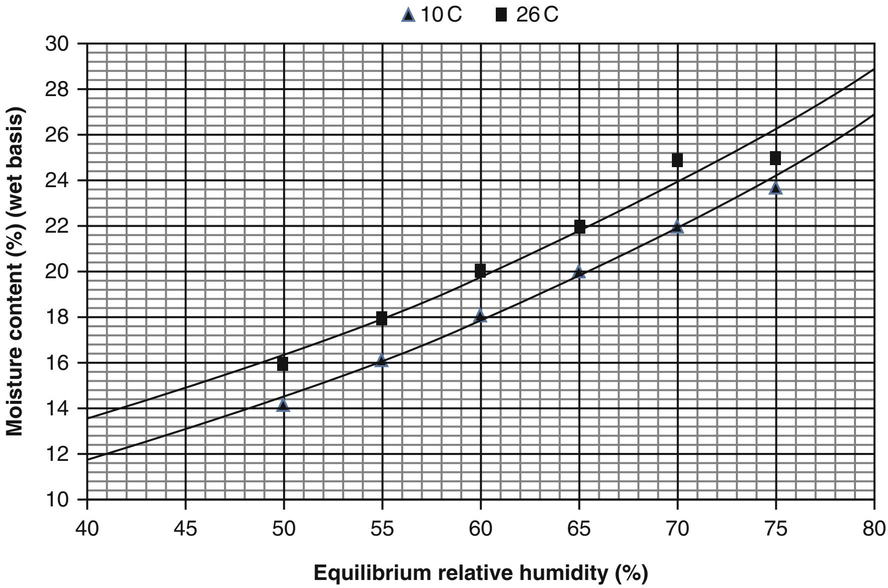

Fig. 13.1 Equilibrium relative humidity of Khadrawy date variety at different levels of relative humidity (50, 55, 60, 65 and 75 %) and at 26 and 10 °C (Rindner et al. 2001; with permission)

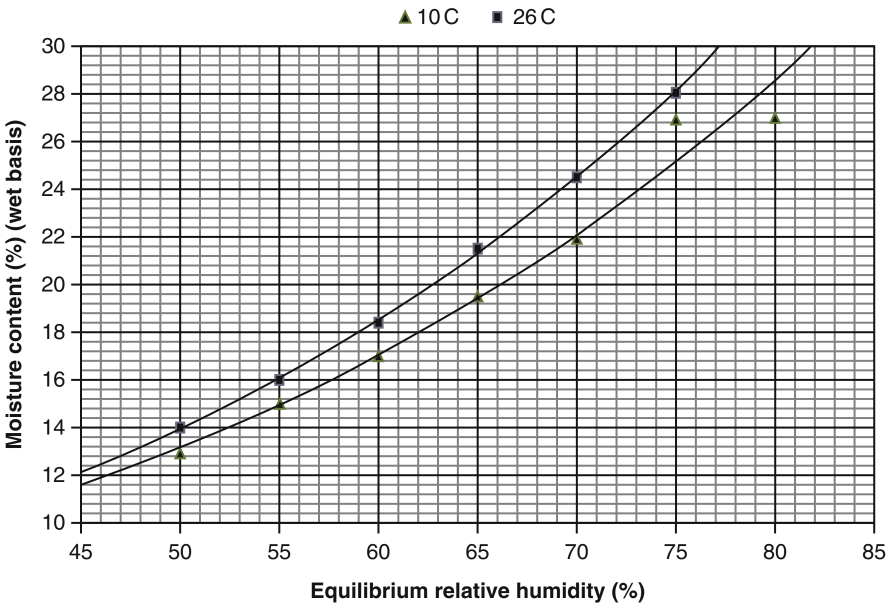

Fig. 13.2 Equilibrium relative humidity of Zahidi date variety at different levels of relative humidity (50, 55, 60, 65 and 75 %) and at 26 and 10 °C (Rindner et al. 2001; with permission)

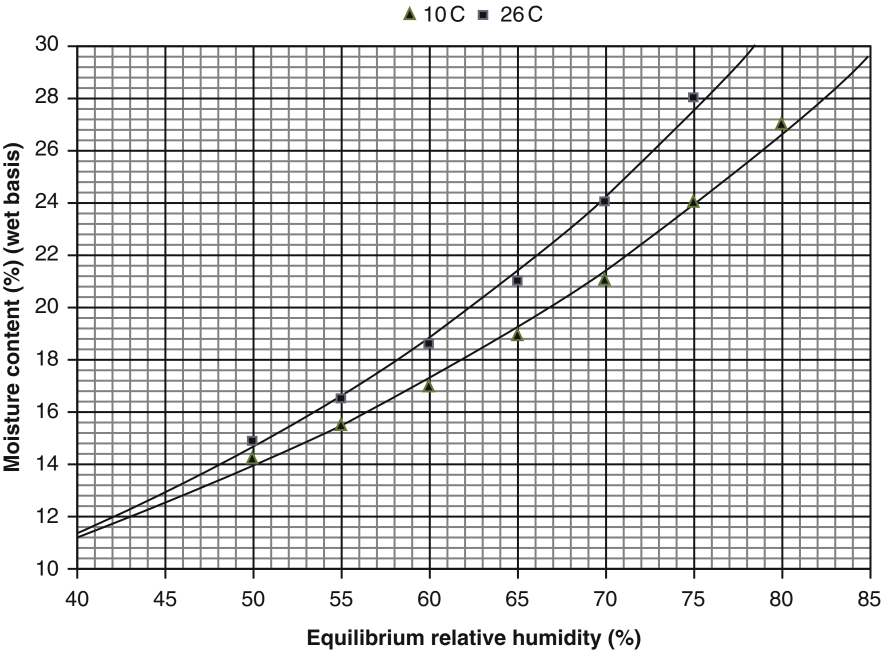

Fig. 13.3 Equilibrium relative humidity of Deglet Noor date variety at different levels of relative humidity (50, 55, 60, 65 and 75 %) and at 26 and 10 °C (Rindner et al. 2001; with permission)

Under climatic conditions where sunshine is adequate and ambient humidity is low, harvested dates may be dried outdoors as a whole date or cut into two halves.

Solar and mechanical drying methods are also used to dry the dates. In conventional sun drying method, date trays are directly exposed to sun radiations in the open. Although, this is a low cost method but the dust deposition by wind on the dates diminish their shine, quality and visual appearance. Additionally, washing done to remove the adhered dust on dates not only causes blistering (separation of skin from the pulp) but also exposes the fruits to insects, especially Nitidulid spp., and finally, if the grower cannot measure a_w, it is difficult to avoid over drying that would substantially lower the fruit quality. As an alternate to this conventional drying method, date pallets covered with shrink film exposed to sun radiation at a height up to 2 m is a very useful method that also allows aeration and avoid condensation. Such solar dryers are very simple and useful since drying is possible close to the date orchard where electrical power is not accessible. Navarro (2006) indicates average MC of sun dried pallets at 65 % ERH, which reveals that when dates are positioned at the top of dryer it takes about 7 days for dates with values of about 76 % ERH to reach 65 % while at the bottom layer it takes 8 days (Navarro et al. 2000).

The mechanical drying method is hot air flow through a tunnel to avoid the change in color and texture deterioration of dried fruits and nuts, where moderate temperature (35–55 °C) is required for drying process. In Israel, for drying Medjool dates, the recommended temperature is to maintain at 45 °C to avoid the blistering effect. Mechanical drying is the fastest and most accurate of all the above mentioned methods. It takes approximately 2 days for the dates to reach their desired ERH but it is also the most energy cost effective method. In this method, dates are placed on trays in one layer. After drying is completed by mechanical means the dates need to be packed into boxes manually which is time consuming and costly.

In the Jordan Valley of Israel, the hybrid solar-mechanical drying method was developed and successfully implemented taking advantage of the hot climatic conditions including adequate sunshine and low atmospheric humidity suitable for drying of harvested dates. In this method, the dates were placed in trays (in one layer containing 3 kg) or in PVC holed boxes (containing 12–14 kg) on pallets 2 m high. The principle in this method is making the hot air flow through the dates which are covered with polyethylene liner that makes the hot air scatter inside the tunnel. At the end of each tunnel, a fan sucks and circulates the hot air entering the tunnel. The average airflow must be 1.4–2.1 m/s on the surface of the dates or fan airflow rate at 12,600 m^3/h (Navarro et al. 2000). In 2003 the drying facility was a greenhouse converted to a solar dryer that measured 10 m wide × 40 m long × 3 m high covered with polyethylene, prepared specially for commercial drying of dates on a large scale (Navarro et al. 2004a). The greenhouse was designed in such a way that up to 12 stacked rows of dates were placed parallel across the greenhouse and drying ducts were formed by covering side and top with polyethylene liners. Ten pallets were positioned in each row, arranged in five pallets lengthwise and two pallets across. Every pallet (2.1 m high) bears trays stacked 20 layers high with 5 trays (40 × 60 × 10 cm high) per layer, in this way every pallet holds 100 trays. Each tray contained 3 kg Medjool dates, in a single layer. Therefore, a standard drying duct consisted of ten pallets (every pallet holds 300 kg fruit) containing 3 tonnes dates. The drying process was controlled using less energy than conventional drying based on LPG or using electricity as an energy source.

13.3.2 Thermal Disinfestation Method: Principles and Practices

The conventional method for disinfestation of raw dates is based on fumigation and is most suited for small fumigation chambers. Dates received at the packing stations are first fumigated, then cold stored, dried and re-stored. Methyl bromide (MeBr) treatments are useful to limit insect infestation in dates particularly when the drying facility is small. It is important to mention that storing the dates at low temperatures kills the insects inside the fruit. Fumigation using MeBr before storage improves quality.

In all date cultivars, field infestations of Nitidulid beetles serve as source to carry the infestation into storage. Recently, the fumigant MeBr controlled this problem successfully. MeBr; however, has been phased out since January 2005 under the Montreal Protocol for developed countries (Non-Article 5), and will be phased out for the developing countries (Article 5) by 2015, excluding treatments before shipment and quarantine (TEAP and MB 2003). Instead of using fumigants, heat treatment is now considered the most efficient way of controlling nitidulid beetles in stored dates.

According to Fields (1992), exposure to temperatures of 50 °C for 1 h or more is effective in controlling stored product insects. Target temperatures in the range of 50–60 °C are standard temperatures for heat treatments (Imholte and Imholte-Tauscher 1999). During actual field treatment, at a commercial drying facility distribution of heat is uneven and because of the differences in the specific heat of the materials, the composition and thickness of their mass where insects harbor, some areas of the fruit cannot receive the target temperatures or do not get treated for the required time to attain complete mortality (Roesli et al. 2003).

Exposure to 49 °C for 4–20 min was needed to obtain 90 % mortality of adult Nitidulids, depending upon the relative humidity, as reported through laboratory observations made by Lindgren and Vincent (1953) on dried fruits. Under controlled conditions the adults of *Carpophilus hemipterus* (L.), the dried fruit beetle, exhibited tolerance towards heat and took times ranging from 25 to 60 min to achieve complete mortality of the target insect pest (Al-Azawi et al. 1984). In stored dates, heat treatment at 60 °C for 33 min was required for the control of all the developmental stages of *Cadra cautella* Walker (Al-Azawi et al. 1983). For dates, the feasible temperature lies in the range of 45 and 55 °C, and temperatures beyond 60 °C may exert undesirable drying effect, blistering of fruit and even biochemical changes in the fruit. Treatment at lower temperatures would take extended periods to attain complete mortality of the pest.

Finkelman et al. (2006) observed the temperature effect (four temperatures 45, 50, 55 and 55 °C) on the mortality and disinfestation levels of *C. hemipterus* mobile stages under laboratory conditions. The target temperatures were employed for 2 h at feeding sites and 100 % mortality of *C. hemipterus* larvae was observed at 50 °C, with maximum number of larvae left (92.3 %) the commodity (disinfestation).

However, some previous findings revealed <90 % disinfestation when dates were fumigated with MeBr (Donahaye et al. 1991, 1992). Promising results were also recorded in controlling adults and larvae of *C. hemipterus* when exposed at 50 °C in a commercial drying facility (Finkelman et al. 2006).

On a commercial scale, natural infestations were examined by inserting the infested dates into drying ducts where infestations were examined after 3 h of exposure to heated air (50 °C). To achieve the desired temperature for controlling stored pests of dates, the exposure period of 1–2 h was required. Since these semi-commercial trials provided similar level of disinfestation as with the MeBr fumigation, the drying facility was considered a promising alternative for controlling stored dates infestation. The thermal disinfestation strategy also satisfied the needs of processors for disinfestation of Medjool date cultivar (Finkelman et al. 2006). In this case, after the initial disinfestation, at 50 °C the drying time at 45 °C can be extended up to few days depending on the initial MC of dates. After heat treatment for disinfestations of dates, they are dried and then stored either as cold or at ambient temperatures depending on the MC and cultivar of the dates. The thermal disinfestation in combination with drying technology was examined at a commercial drying facility with the highest disinfestations observed at 50 °C while most of the date verities get dried between 45 and 50 °C (Navarro et al. 2003). The development of commercial heat disinfestation application using solar dryers in Israel is the outcome of above findings (Navarro et al. 2004a, b; Finkelman et al. 2006). Additional investigation was needed to explore the employment of heat treatment for the other date cultivars. For this purpose, trials were conducted on Deglet Noor in branches (Navarro et al. 2009). In this study involving thermal disinfestation process of Deglet Noor dates, the results from both laboratory and field tests were encouraging. In commercial scale trials, the use of Dolev type crates (containing 100–150 kg dates in branches) indicated the successful application of increased temperature (50 °C) to Deglet Noor dates in branches. Furthermore, no change in the color of branches and dates was observed both in laboratory and field trials. The heat treatment of Zahidi and Halawy cultivars in bulk using Dolev type crates (containing 200–250 kg) has also been tested. During these trials, in contrast to Medjool cultivar with amount of 3 tons per tunnel, the total amount of dates used for Zahidi and Halawy cultivar was approximately 1,600 kg per tunnel. However, it was found that at the bottom side of the tunnel the bulk of dates took an additional 2 h to attain the target temperature (50 °C) compared to the rest of tunnel sections where hot air with an average speed of 1–1.7 m/s raised the date's temperature up to 55 °C in half an hour. The RH measured in this trial reached equilibrium at 20–25 % gradually at both ends of the tunnel, affecting the MC of dates (Navarro et al. 2010).

Based on these findings, the successful development of protocols using thermal treatment with regard to dates' bulk resistance to hot air and its uneven distribution in bulk dates, lead to further expansion of this technology to other cultivars like Khadrawy, Halawy, Zahidi, Derhi and Ameri. The technology involves transferring the hot air through a tunnel to the dates placed in factory boxes (12 kg). Field trials were carried out by disinfesting dates in a commercial chamber made for these cultivars to test even distribution of hot air and its effect on the quality of dates. For this purpose, the bulk of dates wrapped into 13 layers pallets were placed in boxes (each weighing 12 kg) inside the tunnel, and each tunnel contained 3,120 kg of dates in total. In boxes where the airflow through the bulk of dates was at the rate of 1.4 m/s, target temperature (50 °C) was achieved within 3 h, while at higher airflow the same temperature level was achieved within 1–2 h of heating. The temperature increase at this rate successfully disinfested the dates with no changes in their color and taste, however a slight reduction in MC (1–2 %) of dates was observed. Therefore, it is recommended that for date cultivars like Deglet Noor, the exposure period should not be longer than 3 h after attaining the target temperature for disinfestation, and some preliminary trials have also revealed that this exposure time is safe to retain the optimum MC of the dates (Navarro et al. 2009).

Finkelman et al. (2006) reported that under laboratory conditions the optimal temperature for date disinfestation was 50 °C achieved in 2 h. However, for successful disinfestations in packing houses and in order to let the temperature distribute uniformly in the disinfestation dryer, the exposure time was extended to 3 h (Navarro et al. 2003, 2004a, b). During these investigations, the actual environmental factor (temperature or low humidity) conferring mortality to *C. hemipterus* could not be identified, but it was seen that adults of *C. hemipterus* were more sensitive to high temperatures compared to its larvae (Navarro et al. 1989).

During some other investigations, the effect of thermal treatment on 1 day old eggs of *C. hemipterus* tested at 50 °C for 3 h exposure revealed that not a single viable egg was there after 48 and 72 h of treatment (Navarro et al. 2013). According to some studies, insects have metabolically adapted thermally challenging environments. Among a number of findings, it was seen that insect elicit heat shock proteins which provide resistance against heat (Fields 1992). However, further studies are required to investigate the thermotolerance impact on these proteins.

Dates that are brought to the packing houses exhibit varying levels of humidity e.g. the cultivar Deglet Noor when brought to packing house might be very dry (approximately 40 % RH) compared to the Medjool cultivar which in most cases contains approximately 85 % RH when harvested (Kanner et al. 1999). The possible impact of relative humidity levels in interaction with temperatures on the storing dates tested against *C. hemipterus* larvae revealed that highest larval mortalities were observed at 50 °C than at 29 °C with all tested humidity regimes (15, 65 and 95 % RH). In order to predict larval mortality in relation to the exposure duration (min) and relative humidity (%), a stepwise regression model analysis exhibited that the exposure parameter significantly affected the larval mortality [$F_{(1,70)} = 289.168$, $P < 0.01$]. In a multiple step regression performed for short exposure times (up to 30 min) humidity was identified as a significant variable [$F_{(2,33)} = 50.793$, $P < 0.01$] (Navarro et al. 2013). In a related study, the exposure time of 30 min completely killed all the developmental stages of *C. hemipterus* at 50 °C and 70 % RH (Al-Azawi et al. 1984).

13.3.2.1 Environmental Aspects of Thermal Disinfestation and Drying

Thermal disinfestation technology may be applied based either on liquid petroleum gas (LPG), diesel oil, solar energy or combined energy. All of the above mentioned disinfestation methods have different impacts on the environment. Nevertheless, the choice of method is influenced by its economic feasibility and its impact on the environment (e.g. external costs). The environmental impact of the energy used in different disinfestation methods is evaluated on the basis of their carbon footprint calculation. *Carbon footprint* is “a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product” (Wiedmann and Minx 2008).

Carbon footprint serves as a common denominator that allows comparison between similar products of different processes that are generated and involved in global warming. This concept has become popular in recent years and is used for comparison. In contrast to life cycle analysis (LCA) which compares the entire environmental impacts, is actually a more complicated analysis for different products that might skip the concept of the common denominator of a product influencing the environment, and since the carbon footprint is popular, and has the potential to increase the green environmental awareness of consumers (Weidema et al. 2008).

13.3.3 Ethyl Formate Mixed with CO_2

Ethyl formate (EF) is an effective alternative to conventional fumigants and is commercially available under different brand names. EF is a natural component found in apples, honey, orange juice, wine and pears, and commonly used as an artificial fragrance, synthetic flavor in food industry and more importantly as a food additive it is registered as GRAS (Generally Regarded As Safe). A commercial product of EF contains a mixture of 16.7 % ethyl formate and 83.3 % carbon dioxide (w/w) (Ryan and Bishop 2003). The incorporation of CO_2 reduces its inflammability of the EF and their combination enhances the speed of kill the target insects (Haritos et al. 2006). Laboratory and field studies carried out to investigate its fumigant properties against insect pests of stored commodities and dried fruits are reported (Muthu et al. 1984). The laboratory bioassays performed against *C. maculatus* Murray and *C. hemipterus* depicted 100 % mortality of exposed insects when the fumigant was applied at the rate of 420 mg/L for 12 h at 30 °C. The treatment also removed 69.6 % infestation of *Carpophilus* spp. from stored dates (Donahaye et al. 1992). The product effectiveness (at 420 g/m^3) as larvicide and disinfestant was investigated for the exposure period of 12 h at five different temperature levels (16, 18, 24, 26 and 28 °C). The highest larval disinfestation >88 % was observed at 26 and 28 °C, while the complete larval mortality was achieved at temperatures ranging from 18 to 28 °C. In the same way, the fumigant applied at the same rate killed all the exposed eggs of *C. hemipterus* at 12 h exposure at both exposure temperatures i.e. 24 and 30 °C (Donahaye et al. 1992).

Semi-commercial trials using flexible fumigation chambers (9.5 m^3) and commercial trials employing rigid fumigation chambers (96.5 m^3) were also carried out. After treatment of naturally infested Halawy dates in a flexible chamber all the dates were completely disinfected from pest population, while 95 % beetles were found dead outside the fruits. In commercial rigid fumigation chamber, a complete disinfestation was observed at all the four locations and date samples from the same location were also free from insect contamination (Navarro et al. 1998). The product is now commercially registered as Vapormate™ and can be successfully used against the insect pests of stored grains, horticultural products and quarantine treatment of bananas in Australia and New Zealand (Krishna et al. 2002).

13.3.4 Controlled Atmosphere (CA) Storage of Dates

In Israel, as a general practice dates are stored at −18 °C, this storage temperature is particularly suitable for the soft fruit cultivars but at the same time it is also an energy consuming approach. Very limited research has been conducted regarding the influence of controlled atmospheres (CA) on quality of dates. Under laboratory conditions, Baloch et al. (2007) examined the stability of Dhakki dates stored in tinplate cans at 0.52–0.75 a_w under oxygen, air or nitrogen and 40 °C for the period of 4 months. They concluded that in order to maintain freshness of the produce with extended shelf life, Dhakki dates should be stored under inert atmosphere with a water activity close to 0.61 ± 0.01 a_w (corresponds to 24–25 % equilibrium MC). The water activity and storage atmosphere greatly affect the quality of Dhakki dates (darkening of fruit and other linked changes that deteriorate the fruit quality). Investigations showed that some quality parameters like darkening, pH and titratable acidity (is a simple measure of the amount of acid 'anions' in a juice) of dates were significantly reduced under the storage environment containing nitrogen and water activity of 0.52 a_w. The results revealed that oxygen free atmosphere and water activity ranging between 0.60 and 0.61 is best suited for the storage rendering enhanced shelf life of Dhakki dates (Baloch et al. 2007).

Stored dates under controlled atmosphere must be immediately marketed after exposure to air. The elevated CO_2 concentration significantly reduces the fungal growth (fungistatic), but when dates are exposed to ambient air, the fungal spores resume growth, especially under elevated humidity and temperature levels (Kader and Hussein 2009). Tamar dates under nitrogen packed conditions eliminates the possibility of insect infestation and darkening at Khalal stage (Kader and Hussein 2009). In case of Barhee dates, the storage temperature of 0 °C at 90–95 % RH in 20 % CO_2 enriched air successfully maintained the date quality up to 26 weeks compared to 7 weeks storage at ambient air (Kader and Hussein 2009). Some other studies have also shown that the factors like sugar formation and browning of dates responsible for shelf life are significantly delayed in the presence of CO_2 enriched environment in comparison with the storage at −18 °C (Navarro et al. 1988, 1992, 1995). Based on these findings, specially designed gastight plastic liners for CA storage of dates are used in Israel (Navarro et al. 1998), a flexible structure of 151 m^3 was used and tested for gas tightness using the pressure decay method (Annis et al. 1991; Navarro 1997).

Investigations conducted in Israel showed that in same size storage facilities, half-life pressure decay time (time elapse to half the pressure of a pressurized structure using pressurized air compared to ambient pressure) for less than 10 min was considered as critical, while for maintaining constant concentration of CO_2 a less gastight structures must be used (Fig. 13.4).

Usually, high glucose and fructose contents with very little or no sucrose are present in the soft fruit date cultivars, while sucrose content is high in firm and dry date cultivars. The sugar content in unripe fruit is sucrose which gets converted in the latter stages. During the latter stages of development, the activity of invertase

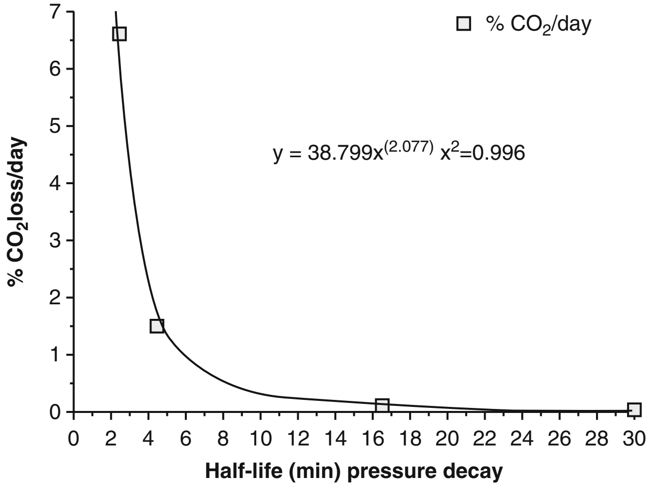

Fig. 13.4 Degree of gas tightness expressed in half-life (min) pressure decay and daily percentage carbon dioxide loss from the 151 m^3 capacity storage enclosure (Navarro et al. 1997)

was found to be the maximum in soft fruits compared to the dry date cultivars (Kanner et al. 1978). In ripe fruits of soft date cultivars which carry plenty of reducing sugars, a "caramel" like taste develops due to the non-enzymatic browning (Kanner 1967). The accumulation of sugar and changes in color determines the quality of dates during storage (Rygg 1956). During the storage period of 4.5 months no significant difference was observed in sugar formation and sloughing of peel on dates (Navarro et al. 1997). These results are in accordance with the previous studies performed for Halawy, Zahidi and Ameri cultivars stored under CO_2 enriched CA which revealed no adverse effect on increase in sugars, even after a long storage period of 8 months at ambient temperatures (Navarro et al. 1992, 1995).

13.4 Post-harvest Handling and Storage

Investigations showed that exhale of gases from dates take place at very low rate, for instance, less than 5 mg and 2 mg CO_2 per kg/h of dates at 20 °C at Khalal, and Rutab and Tamar stage, respectively. Similarly, very low 0.1 µl/kg/h ethylene is produced at Khalal stage with no ethylene production during the Rutab and Tamar stages (Yahia 2004). The unripe dates picked at early stages require post-harvest ripening (Yahia 2004). During post-harvest handling, the soft and semi-dry cultivars are dehydrated to remove extra moisture, while hard or dry cultivars are hydrated to soften their texture. In addition to the storage environment, the date moisture plays a significant role in maintaining the quality of fruit which may be deteriorated by certain physiological and pathological disorders in case of increased MC of the stored dates (Yahia 2004; Baloch et al. 2007). The storage of dates at Khalal stage is carried out at 0 °C and 85–95 % RH to avoid the excessive water loss. These storage conditions are also helpful in retaining the flavor and quality parameters of Rutab cultivar (Kader and Hussein 2009). The packaging of dates in boxes lined with plastic or in moisture barrier plastic bags is also effective in preventing moisture loss and storing dates for extended periods.

Stored dates quality can also be maintained by storing at low temperatures as it postpones insect infestation, reduces the growth and incidence of yeasts and molds, prevents development of syrupiness (formed due to formation of reducing sugar from sucrose) and souring of highly moist dates (Kader and Hussein 2009). Tamar dates can be stored at optimum temperature of 0 °C for 6–12 months, which may vary among cultivars (soft dates, like Barhee and Hiani have reduced shelf life compared to the semi-soft dates, like Halawy and Deglet Noor). For long term storage, a temperature level of −15.7 °C and below is recommended. Dry date cultivars with 20 % or less MC can be kept for longer periods at higher temperatures. Kader and Hussein (2009) found that storage temperatures of −18 °C for more than 12 months, 0 °C for 12 months, 4 °C for 8 months, or 20 °C for 30 days all with 65–75 % RH did not affect the quality of dry dates during entire storage period. In addition to the optimum storage temperature and RH, post-harvest treatments like modified atmosphere packaging and edible coating can significantly contribute to increase the shelf life of dates and other fruits (Kader and Hussein 2009).

13.5 Future Research

Thermal disinfestation is considered as an effective alternative to MeBr fumigation, however, this method is limited to Medjool cultivar in trays of 3 kg and in boxes of 12 kg capacity for Halawy, Khadrawy, Zahidi, Ameri and Derei cultivars. This technology is applied in handling and drying of date cultivars in solar dryers, however, an additional research is required to elaborate the likelihood of other handling and drying methods for heat disinfestation of dates. Controlled atmosphere storage method may replace expensive cold storage of dates and further research would be needed to make this technology more cost-effective and broadly applicable.

13.6 Summary

The use of solar energy in shrink covered pallets for ripening of immature Medjool dates was proved to be a feasible option. Ripening times can be determined by applying the equations developed for Medjool dates. For marketing, the acceptable moisture limit for the dates is 65 % ERH at 26 °C, whereas, the length of storage period depends upon the actual ERH or a_w of the stored dates. Temperature plays a vital role in determining the ERH for each date cultivar. Hence, for each cultivar the ERH should specify for which particular temperature the isotherm is valid.

The most common approach for drying of dates is solar drying (spreading date trays in the open field) and mechanical drying. For drying of dates, a solar dryer was constructed by wrapping the shrink film around the pallets. Dates dry within about 7–8 days in pallet size solar dryers which have successfully replaced the traditional practices of spreading date trays in the field. A hybrid mechanical and solar dryer is also effectively used in the Jordan Valley of Israel. These dryers are cost effective as have an ability to integrate thermal disinfestation and drying of dates together thus save energy.

The drying process (at 45 °C) can be followed after thermal disinfestation at 50 °C, that was found as an alternative to MeBr treatment. This approach is used in already installed drying facility without any modification of the date handling trays for Medjool dates (3 kg) and factory boxes (12 kg) used for other date cultivars. As far as the disinfestation of dry dates (dates with MC suitable for storage) is concerned, the dates are exposed to 50 °C for 3 h after attaining the desired temperature during which time, moisture loss was found to be insignificant.

For bulk stored dates, another date treatment method registered in Israel is the use of fumigant Vapormate™. This fumigant has shown to be very successful in both controlling the nitidulid beetles and disinfesting the dates at dosage of 420 g/m^3 for 12 h at temperatures above 24 °C.

Storing dates under controlled atmospheres instead of cold storage is feasible, and requires a daily supply of 0.8 kg of CO_2 to maintain 60–80 % CO_2 concentration in a hermetic cube or a rigid sealed structure. The half-life pressure decay time not less than 10 min is also needed to avoid further loss of CO_2. The date storage in CA containing CO_2 has been found very effective in insect pest control and maintaining quality of dates during long term storage.

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