FREEZING CHARACTERISTICS OF PACKED SAMANI DATES

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ABSTRACT

Date fruits (phoenix dactylifera, L.) is playing an important role in the history of mankind ever since the birth of our planet. Freezing is one of the least time-consuming ways to preserve foods. It inhibits enzyme actions and microbial activity. The performance criteria for a successful freezing process are the freezing time and freezing rate. The present work was carried out to determine the behavior of dates during freezing characteristics of packed Samani dates with and without spikelet. Samples of dates were packed in tightly closed plastic pack and perforated pack. The objectives were to predict the freezing time under studied conditions. Only sound fruit without mechanical damage were used for the study. Samples of samani dates grows in Egypt, all at khalal stage (full size, crunchy and firm) Harvested fruits were packed in filed boxes and immediately transported to the Postharvest laboratory, Faculty of Agriculture, Alexandria University. Undamaged fruits were selected on the basis of size and color uniformity. Freezing curves for different treatments were established. Freezing curves consisted of three distinct stage, pre-cooling, freezing and sub-cooling stage storage for 2, 6 and 10 months beyond freezing and before thawing to test the effect of long storage periods on the final quality.

Key words: *Date fruits, freezing process, freezing rate.*

INTRODUCTION

Egypt is considered one of the largest date producing countries in the world and the date fruit is one of our important cash crops. The total cultivated area of all type of dates in Egypt exceeds 90292 feddan and the total female date palms are 12296563 with its estimated annual production over 1328468 tones, according to the latest statistics of (Bulletin of the Agriculture **(Statistics, 2013).**

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Date fruits (*phoenix dactylifera, L.*) have been an important harvest in arid and semiarid regions of the world since earliest times; they have always played a significant role in the economic and social lives of the people of these regions. Botanically the date fruit is a berry consisting of a single seed surrounded by a fibrous, parchment-like endocarp, a fleshy meso carp and the fruit skin (Exocarp). The fruit is attached to the spikelet by a perianth (calyx or cap), **(FAO, 1993).** There is scarce published data concerning Egyptian Samani date with regard to its freezing characteristics, which can be important for food industry in Egypt and for export. Therefore the main objective of this current study is to generate new experimental data on freezing of Samani dates with and without spikelet and packed in tightly closed and perforate packages. Investigate the effect of date treatments and packaging on freezing process.**More specific objectives are:**

1. To establish domestic freezing/time curves for Samani dates with and without attached spikelet using tightly closed and partially perforated packages in a freezing environment at -18 º C.
2. To predict initial and final freezing points.
3. To predict freezing rates (ºC / hr.) for the three freezing process stages.
4. To develop mathematical equations for the three freezing process stages.

2-REVIEW OF LITERTURE

2.1. Freezing processes

Freezing is one of the simplest and least time-consuming ways to preserve foods. Berries and cherries are best frozen soon after harvest. Peaches, plums and apples may need to fully ripen before freezing. Freezing does not sterilize food; the extreme cold simply retards growth of micro-organisms and slows down changes that affect quality or cause spoilage in food. Properly frozen fruits retain much of their fresh flavor and nutritive value. Their texture may be somewhat softer than fresh fruit. However, most fruits maintain high quality for 8 to 12 months at zero degrees ºF or below. Citrus fruits and citrus juices may be stored satisfactorily for 4 to 6 months (Kendall, 2011).

2.2. Prediction of freezing time

A number of models have been proposed in the literature to predict freezing times. The Plank equation has been used by several measures as the starting point, but since this equation does not include the times below and above the freezing stage itself, several attempts have been made to improve it by adding new terms and parameters, to make it suitable for the entire freezing process.**Pham (2014)** reported on a comprehensive presentation of several approaches for calculating freezing time starting with Planks̓ equation **(Plank, 1913).**

2.3. Analytical solutions for freezing time

For zero internal resistance, the rate of heat is governed by the convective heat transfer coefficient (h). Then the freezing time can be estimated as follows:

$$\theta = \frac{\rho V L_f}{hA\,(T_f - T_f)}$$

Pham (1986a) showed that Planks̓ solutions can be written in the following form for the three regular shapes:

$$\theta = \frac{\rho L_f R}{E_f\, h\,(T_f - T_m)} \quad 1 + \frac{Bi_f}{2}$$

$$Bi_f = \frac{hR}{K_f} \qquad\qquad E_f = \frac{AR}{V_f}$$

McNabb *et. al.* (1990 a,b) extended Planks̓ equation to multi-dimensional regular shapes. **Hossain *et. al.* (1992a)** presented McNabbs̓ solutions in the form of the shape factor E_f which represents the ratio of freezing time for the given shape to Planks̓ freezing time for the infinite slab. They calculated the value of Ef for finite slab and cylinder for freezing with sensible heat, they introduced Stefan number

$$Ste_f = \frac{c_f\,(T_f - T_m)}{L_f}$$

Mascheroni *et. al*. (1982) divided the total freezing process time in to precooling, from initial temperature of the product to freezing point, phase change and sub cooling to (final product center temperature) periods. The phase change time is calculated from Plank's equation.

$$\theta\ (\text{Plank}) = \frac{\rho L_f R}{E_f\, h (T_f - T_m)} \quad (1 + \frac{Bi_f}{2})$$

While the precooling and sub cooling are calculated from analytical expressions. Which assume uniform initial temperature and constant thermal properties for each period.

$$T_f = T \text{ precooling} + T \text{ plank} + T \text{ sub cooling}$$

Simpler methods were introduced by **pham (1984, 1986), (Ilicali and Saglam (1987)) and (Lacroix and Castaigne (1988)).**

Although thawing is the opposite process of freezing, the earlier equations on freezing time prediction cannot be readily applied to thawing process.**Miguel, and Bengt, (2002)** studied the original Plank equation and its use in the development of food freezing rate predictions. A large number of methods to predict freezing and thawing times for foodstuffs have been proposed. Normally the original Plank equation has been used as the starting point, this equation does not include the times below and above the freezing stage itself, several attempts have been made to improve it by adding new terms and parameters, to make it suitable for the entire freezing process. In this study they reviewed and discussed Plank's equation and how it has been interpreted and modified by different scientists during the years is reviewed and discussed. They assessed as well several of these models, by comparing the values they predict with experimental freezing times available for the same experimental conditions. Two software programs were also included in the analyses. He developed software which follows the entire freezing process by a simple geometrical iterative approach**. Ilicali, and Icier, (2010)** studied Freezing time prediction for partially dried papaya puree as an infinite cylinder geometry. Dehydro-freezing which is the drying of foods to intermediate moisture content and subsequent freezing has the advantages of lowering the transportation costs due to reduced weight and improved texture. The available empirical equations for freezing time prediction. The experimental data on thermo-physical properties are for fresh produce. Some of these empirical equations were used to predict the freezing times of papaya puree as infinite cylinders with initial moisture contents ~52% to ~91%. **Resende, *et al.*, (2002)** studied air blast freezing of fruit pulp models in commercial boxes and the influence of preferential channels in the bed on freezing times. The freezing times of fruit pulp models packed and conditioned in multi-layered boxes were evaluated under conditions similar to those employed commercially. They stated that estimating the freezing time is a difficult practice due to the presence of significant voids in the boxes, of which influence may be analyzed by means of various methods. They used the models described in the literature for estimating freezing time and compared the results with experimental measurements of time/temperature data. They found that, the airflow through packages is a significant parameter for freezing time estimation. When the presence of preferential channels was considered, the predicted freezing time by the models was about 10% lower than the experimental values. The isotherms traced as a function of the location of the samples inside the boxes showed a displacement of the thermal center in relation to the geometric center of the product.

2.4. Freezing dates

Ahmed, (2011) reported that freezing of khalal dates by fast or slow freezing and thawing at room temperature led to gradual fruit color change from yellow in the khalal stage of Siwi, Samani and Amhat date cultivars to brown in rutab-like stage and from red in Hayani and Om-Al-Frakh at khalal to black after the ripening. The rapid color change of the treated fruits by slow or fast freezing take place with the beginning of thawing and continued gradually towards color of the natural rutab ripened on the palm. **Baloch, *et al*., (2011)** pointed out that streamline the production, and extend the availability period of freshly ripened Dhakki dates the prospects of storage of Doka (Khalal) stage at low temperature was investigated. The hardness, appearance and mold resistance of fruit were examined storing throughout. The Doka were stored at 10 ˚C, 0 ˚C, and -15 ˚C for one year. Subsequent performance for ripening/curing, quality, yield, and acceptability evaluated. The Dokas stored at 0˚C and -15 ˚C remained free from the infection during the study period, whereas those at 10˚C, mold-infected were found just after 3 months storage. The Doka sustained freezing stress effectively, and developed characteristics similar to the Dong (Rutab) from thawing by changing color from yellow to golden brown, and acquiring softer texture and sweeter taste. Leaving

Doka as frozen till required for further processing offers sound proposition to combact against unfavorable climatic conditions and monitors supply of fresh date during off-season.

3-MATERIALS AND METHODS

Samani dates fruits grown in Egypt; only sound fruits, at full colored yellow, without mechanical damage were used for the experimental study. The harvested fruits were immediately packed in filed boxes and transported to the postharvest laboratory at the Faculty of Agriculture, Alexandria University the fruits were inspected and stored with spikelets, undamaged fruits were selected on the basis of size and color uniformity. Selected fruits were washed with running water, wiped and then sorted for experimentation. Sound fruits were divided into two categories one with attached spikelets and the other with detached spikelets. Each category was divided into two equal groups one group was packed in a tightly closed plastic pack of 18*10*5 Cm. and the other was packed in a similar plastic pack with ventilation slots of 8% opening of the total surface area of the pack. The two packs contained equal numbers and weight of dates. The two packs were placed in a home freezer at -18 ± 0.5 º C.

Type T (copper - constantan) Thermocouple

probs were used to measure the lowest temperature point in the fruit flash thermal center (5 mm from the surface), and the freezing medium (air) temperature.

Data logger: was used for monitor temperature and transfer the data to a computer system (software) to store and demonstrate in temperature time graph

4-RESULTS AND DISCUSSION

In order to complete the freezing process of food material, the most appropriate thermal center of the material must be defined precisely. In case of dates, the thickness of an intact whole Samani dates is not uniform (figure 4-1). Therefore, the slowest cooling point must be defined to be a characteristic thermal point. In addition, as the freezing front advances towards the characteristic thermal center (CTC), soluble solids migrate towards the CTC causing an increase in soluble solids concentration areal accordingly a decrease in freezing point.

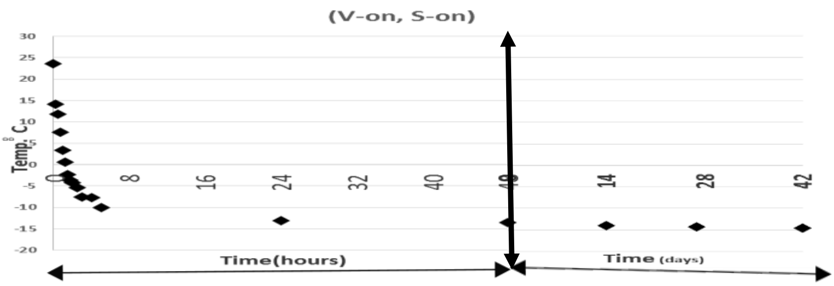

Figure (4-1): Total freezing process curve of Samani dates with spikelet on and with ventilation slots (V-on, S-on).

For Samani dates, the CTC was estimated to be at a bout 5mm from the surface. Thermocouple probe was positioned at 5 mm from surface at the largest diameter of dates. It has been declared by Pham (1984) that any point within a food material in a freezing medium is exposed to three phenomenal stages during the freezing process.

- The first stage is the precooling phase, in which, the material is cooled down from an initial temperature (T_i) to an initial freezing point (T_{if}). Only sensible heat is extracted from the material.
- The second stage is the change-of-state phase or the ice formation phase, in which, free water in the food material is transformed into ice crystals. In this phase extracted heat includes latent heat for crystallization in addition to sensible heat for reducing material temperature from an initial freezing temperature (T_{if}) to a final freezing temperature (T_{ff}).
- The third stage is the solid phase, in which the whole material becomes completely solid and only sensible heat is extracted and sub-cooling occurs beyond the final freezing point (T_{ff}) approaching the freezing medium temperature.

Figures (4-1 and 4-2) show two freezing curves of samani dates under two different treatments as obtained experimentally during freezing process. This carves reveal the differences in freezing behavior ventilated and non-ventilated dates. the freezing process slow at boxes without ventilations slots.

The experimental results exhibit clearly the three distinct stages. During the first stage only sensible heat is removed from water content. The rate of heat removal is controlled by the thermal properties of the unfrozen phase.

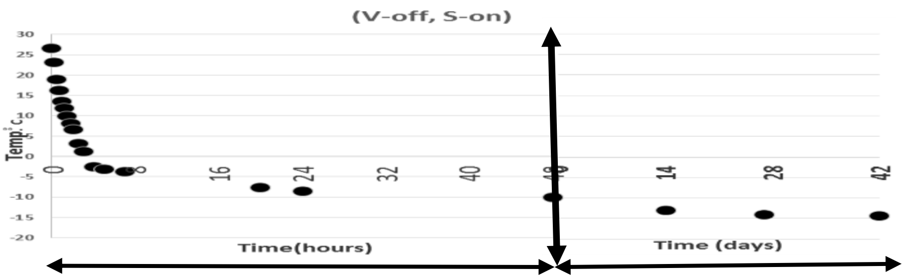

Figure (4-2): Total freezing process curve of Samani dates with spikelet on and without ventilation slots (V-off, S-on).

During the second stage, two forms of heat are being removed and transferred to the freezing medium, sensible heat from the dry matter and unfrozen water in addition to latent heat of crystallization. The amount of heat to be removed for full crystallization phase must be the same for all tested freezing conditions. The difference is the rates of crystal formation, or the total time each case requires to remove heat out to complete crystallization.

The Stefan number $Ste_f = \frac{c_f (T_f - T_m)}{L_f}$ measures the ratio of the sensible heat for cooling to the latent heat for crystallization. The third stage is the solid stage, where all free water has been crystallized, and only sensible heat is conducted at a rate dependent on the thermal properties of the frozen phase the potential temperature difference between the traced point in the material and the freezing medium, and the resistance to heat transfer expressed by different treatments. In this stage, temperature at the measured point for all experiments converges to about -15°C after about 44 days, from the beginning of the process. Experimental date of temperature / time histories for the two treatment are given in table (4-1). For generalization of the data, a dimensionless temperature ratio TR is introduced as:

$$TR = \frac{T_\theta - T_m}{(T_i - T_m)}$$

Figures (4-3 and 4-4) demonstrate the relation between TR and Ө for all treatments. The dates are given in table (4-2). For materials which exhibit a broken cooling curve, it is suggested that the first slowest cooling point established experimentally in the curve to be considered the initial freezing point. This was defined to occur at the first deflection of temperature decrease between the pre-cooling stage and freezing stage. The final freezing temperature was defined at the second deflection between the freezing phase and sub cooling. The second deflection was not explicit. The initial and final freezing points were estimated graphically by plotting TR versus time on a semi-log paper. The first deflection in the curve was considered to be equivalent to the initial freezing point. The second deflection was not too clear but considered the final freezing point.

Table (4-1): The temperatures and freezing time

Temp. ˚C / Time (hour)	**V-on, S-on**	**V-off, S-on**
0	23.6	26.6
0.25	14.2	23.2
0.5	11.8	18.9
0.75	7.6	16.3
1	3.3	13.6
1.25	0.6	11.8
1.5	-2.3	9.9
1.75	-3.7	8.1
2	-4.3	6.6
2.5	-5.4	3.2
3	-7.6	1.2
4	-7.7	-2.5
5	-10	-3.1
24	-13.1	-8.6
48	-13.6	-10.1
336	-14	-13
648	-14.3	-14.1
1008	-14.6	-14.3

Table (4-2): The temperature ratio and freezing time

Temp. ˚C / Time (hour)	**V-on, S-on**	**V-off, S-on**
0	**1**	**1**
0.25	0.717949	0.927739
0.5	0.662005	0.827506
0.75	0.564103	0.7669
1	0.463869	0.703963
1.25	0.400932	0.662005
1.5	0.333333	0.617716
1.75	0.300699	0.575758
2	0.286713	0.540793
2.5	0.284382	0.461538
3	0.20979	0.414918
4	0.207459	0.328671
5	0.153846	0.314685
24	0.081585	0.18648
48	0.06993	0.151515
336	0.060606	0.083916
648	0.053613	0.058275
1008	0.04662	0.053613

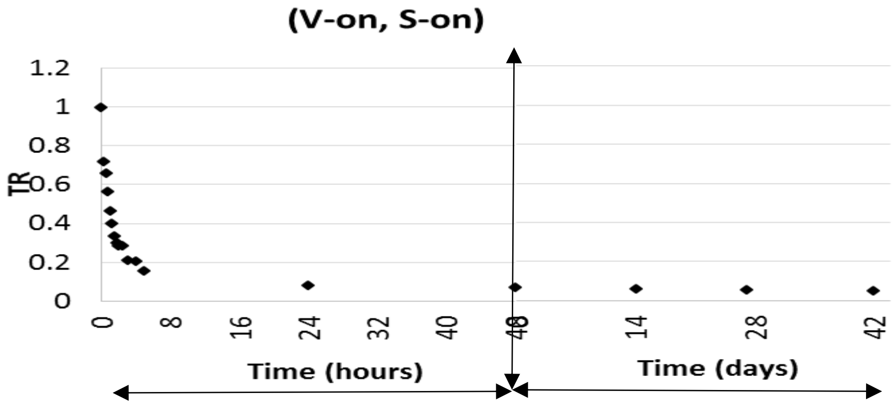

Figure (4-3): Freezing curve of Samani dates with spikelet on and ventilation slots (V-on, S-on).

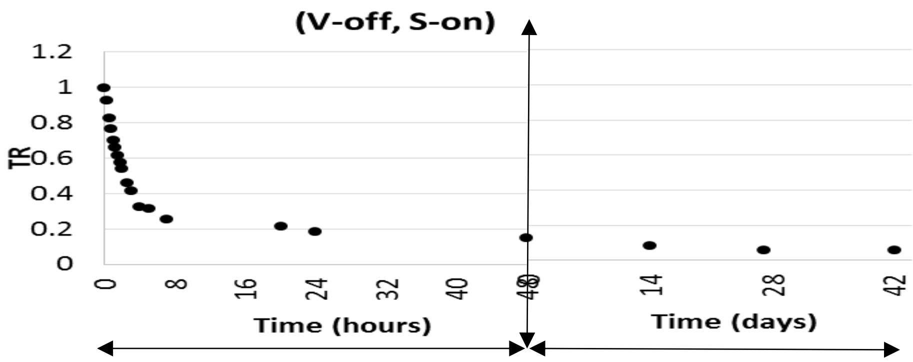

Figure (4-4): Freezing curve of Samani dates with spiklet on without ventilation slots (Voff, S-on).

4.2.1 <u>Initial freezing point</u>

The first deflection in the curves were found to be as follows:

For the (V-on, S-on) treatment,

$$\frac{T_{if} - (-18)}{23.6 - (-18)} = 0.37$$

$$T_{if} = -3.85°C$$

For the (V-off, S-on) Treatment

$$\frac{T_{if} - (-18)}{26.3 - (-18)} = 0.35$$

$$T_{if} = -2.5\ °C$$

The slight differences in the initial freezing temperatures may be attributed to the slight differences in concentrations of soluble solids accumulated at this point for the different treatments. The differences in concentration is due to the concentration gradients established within each date for each treatment, as a result of the cooling rate.

As the temperature continues to decrease, the formation of ice crystals increases and a portion of ice separates from the solution causing the concentration of the solutes in the remaining solution to increase causing a further depression in freezing point. Thus, it is evident that during the freezing process, the ice and water fractions at the frozen point depend totally on temperature.

4.2.2 <u>Final freezing point</u>

In food materials, there exist free and bound water. Bound water does not freeze even at very low temperatures. Therefore the final freezing point may be defined as the temperature at which all free water is crystalized ending the freezing stage (crystal formation). The final freezing temperature of samani dates at 5 mm radial depth was detected from the freezing curves at the second deflection in the freezing curve between the crystal formation stage and the complete solid stage, beyond which no further crystallization occurs.

The results show that the final freezing temperature

- For (V-on, S-on) case, the final freezing temperature (-7.5°C) occurs after about 2.5 hours beyond precooling.
- For (V-off, S-on) the final freezing temperature (-7.7°C) occurs after about 16 hours beyond precooling.

Beyond the final freezing point, it is considered that the whole part of material is solid and any decrease in the temperature is due to heat transfer by conduction from the specified point in the material through a thickness to the surface and to the freezing medium.

In all treatments, date temperature converged to about (-15°C) after about 44 days (1.46 months)

Table (4 –3) gives the temperature reduction, the time elapsed and the overall rate of temperature reduction for each stage of the freezing process as detected from the experimental freezing data.

Table (4-3): Times, Temperature differences and cooling rates for the three stages of deference treatment

Treatment	Pre-cooling			Freezing			Sub-cooling			Total		
	Time (hrs.)	ΔT(°C)	Rate (°C/ hr.)	Time (hrs.)	ΔT°C	Rate (°C/hr.)	Time (hrs.)	ΔT(°C)	Rate (°C/ hr.)	Time (hrs.)	ΔT(°C)	Rate (°C/ hr.)
V-on , S-on	1.67	19.8	16.41	2.5	3.7	1.48	21.1	5.5	0.261	25.27	36.6	1.450
V-off , S-on	4.0	23.8	7.53	16	5.2	0.32	291	5.3	0.018	311	39.3	0.126

Generally, the quality of the frozen products is largely dependent on the rate of freezing (Ramaswany and Tung, 1984). The faster the rate of freezing the better the final quality is. Freezing rates are mainly affected by four factors:

- The temperature difference between the product and the cooling medium.
- The modes of heat transfer to, from and within the product,
- The size of the product and type of package containing the product, and
- The thermal properties of the product

4.2.3) <u>For Samani date freezing rate:</u>

In this study, three distinct stages have been defined and experimentally recognized for freezing process as unfrozen, freezing and frozen. Each of the two first stages is bounded by two temperatures. The unfrozen stage is bounded by the Samani initial temperature (T_i) and the initial freezing temperature (T_{if}). The freezing stage is bounded by the initial freezing temperature (T_{if}) and the final freezing temperature (T_{ff}). The frozen stage starts at the final freezing temperature and is limited by the cooling medium temperature (T_m).

For pre-cooling, freezing and Sub-cooling:

Pre-cooling rate = $1/\theta_p$ $[(T_i - T_{if})]$

Freezing rate = $1/\theta_f$ $[(T_{if} - T_{ff})]$

Sub-cooling rate = $1/\theta_s$ $[(T_{ff} - T_s)]$

Total process rate = $1/\theta_T$ $[(T_i - T_s)]$

Cooling Rate Shown in table (4-4)

Table (4 –4): Cooling Rate Array

Treatment	Pre-cooling Rate °C/hr	Freezing Rate °C/hr	Sub-cooling Rate °C/hr	Total
V-on , S-on	16.41	1.48	0.261	1.450
V-off , S-on	7.53	0.32	0.018	0.126

Linger and Beveflo (2001) suggested 3 groups of freezing rates concerning the quality of the frozen products:

1- Fast freezing (rate is > 5 C°/hr.)
2- Moderately fast (rate is from 1 to 5 C°/hr.)
3- Slow freezing (rate is < 1 C°/hr.)

Based on Linger's classification of freezing rates and its relation to quality, the freezing rates of the four treatments from table (4-2) are:

- For (V on – S on), freezing rate = 1.48 C°/hr. (moderate)
- For (V off – S on), freezing rate = 0.32 C°/hr. (slow)

4.3 Measures of performance:

4.3.1 Dimensions of samani dates:

It is noticed that the thickness of the pulp is irregular around the peripheral and along the axis. Based on measurements of the thickness of several date fruits, the minimum thickness (an average of several measurements, as a reference to the thermal center was found to be 5 mm.

- The initial temperature of experimented dates is the room temperature (23.6 to 26.6°c).
- Temperature of freezing medium is (-18°C).
- The initial freezing temperature was considered to be the temperature at the first deflection of the freezing curve after

precooling stage. The final freezing temperature was considered to be the second deflection in the freezing curve.

- The surface heat transfer coefficient (h) and the thermal peroperties of samani dates (k , Cp) were estimated based on Hobani and Al-Askar (2000).

4.3.2 Estimation of thermal properties of Samani dates

No thermal properties of Samani dates were traced in the literature. Thus thermal properties of Samani were estimated based mainly on the experimental measurements obtained by Hobani and Al-Askar (2000). On Khadary and Sufary dates. Adjustments were done to estimate thermal properties for unfrozen Samani at a moisture content of 67% (wb) and in a temperature range above freezing and below 26°C for unfrozen stage.

Pulp cross-sectional area = $\pi ((R_o^2 - R_i^2) = 6.91$ cm^2

Volume of a date pulp = $\pi ((R_o^2 - R_i^2) L = 6.91 * 5.1 = 35.24$ cm^2

Average weight of pulp = 24.71 gram = 0.0247 Kg

Density of pulp = 0.7 gram/ cm^3

Surface area of heat transfer (A) = $\pi D l = \pi(3.16 * 5.1) = 50.63$ cm^2 =0.00506 m^2

The adjusted values of thermal conductivity (k), specific heat (Cp) and thermal diffusivity for Samani are given in the following. Latent heat of samani moisture is 335 kJ/ kg water.

A) For unfrozen:

k_u at 67 % (wb) and 25°C = 0.558 KJ/ m °C s

k_u at 67 % (wb) and 0°C = 0.4 KJ/ m °C s

k_u (mean) 67 % (wb) and 0°C to 25°C = (0.558 + 0.4) /2

= 0.48 KJ/ m °C s

Cp_u at 67 % (wb) and 25°C = 4 KJ/ kg °C

B) For frozen:

According to Charm (1971),

k_f =2.75 k_u,

Cp_f = 0.5 $Cp_u k_f$ = 2.75*(0.48) = 1.32 KJ/ m °C s

Cp_f = 0.5*(4.0) = 2.0 KJ/ kg°C s

The specific heat of frozen samani dates was estimated using data given by Hobani (2000)

4.3.3 <u>Estimation of surface heat transfer coefficient of samany date</u>

According to Fricke and Becker (2002). The value of (h) was estimated using the following equation:

$$h = \frac{m * c_P}{A * \Delta\theta} \ln \left(\frac{T_1 - T_m}{T_2 - T_m}\right)$$

A) <u>For unfrozen stage</u>

V-on, S-on

$$\mathrm{h} = \frac{(0.0247)*(4)}{(0.00506)*(0.75)} \ln\left(\frac{14.2-(-18)}{0.6-(-18)}\right) = 19.526 * 0.549 = 10.72 \text{ kj/m}^2{}^\circ\text{C hr}$$

V-off, S-on

$$\mathrm{h} = \frac{(0.0247)*(4)}{(0.00506)*(2.25)} \ln\left(\frac{23.2-(-18)}{3.2-(-18)}\right) = 8.78 * 0.664 = 5.83 \text{ kj/m}^2{}^\circ\text{C hr}$$

<u>For frozen stage:</u>

Von, S-on

$$\mathrm{h} = \frac{0.0247*2.15}{0.00506*21.1} \ln\left(\frac{-7.5-(-18)}{-13-(-18)}\right) = (0.5) * (0.742) = 0.371 \text{ kj/m}^2{}^\circ\text{C hr}$$

<u>V-off, S-on</u>

$$\mathrm{h} = \frac{0.0247*2.15}{0.00506*291} \ln\left(\frac{-8-(-18)}{-13-(-18)}\right) = (0.0361) * (0.693) = 0.025 \text{ kj/m}^2{}^\circ\text{C hr}$$

The total freezing process time:

Pham (1984) suggested three stages of freezing process; Precooling time, phase change time and sub-cooling time.

The total freezing process time is the summation of the three stage as follows:

$$\theta_{f\,p} = \theta_p + \theta_f + \theta_s$$

The thermal conductivity of the date in the pre-cooling stage, where dates contain unfrozen water, is much lower than the thermal conductivity of the totally frozen stage (solid stage). In the freezing stage latent heat of crystallization is being extracted in addition to sensible heat as defined by Ste No. Pre-cooling time (θ_p) is considered to be the time necessary to reduce initial temperature of raw date to the initial freezing time. The freezing time (θ_f) is the time between the initial freezing temperature and the final freezing temperature at which most of the free water is crystalized. Table (4 – 1) gives the three phase times and the total time for each treatment.

4.3.4 The Total freezing process time

- In case of (V-on, S-on), cooling medium is indirect contact with dates. If heat is considered to transfer radially and axially, the presence of spikelets may be considered a partial resistance to axial heat transfer. Pre-cooling time in this case is 1.67 hours, the freezing time is 2.5 hours and sub-cooling time to reach (-13°C) is 21.1 hours. The total freezing process time is:

$$\Theta_{FPT} = 1.67 + 2.5 + 21.1 = 25.27 \text{ hours}$$

- The (V-off, S-on) case is expected to be the most resistant to heat transfer. Pre-cooling time is 4 hours, freezing time is 16 hours and sub-cooling time to reach -13°C is 291 hours. The total freezing process time is:

$$\Theta_{FPT} = 4 + 16 + 291 = 311 \text{ hour}$$

4.4 Mathematical expressions of freezing process time

Due to the limitations to Plank's equation (1913) in estimating freezing time, researches have focused upon development of improved semi-analytical/ empirical cooling and freezing time estimation methods which account for precooling and sub-cooling time, non-constant thermal properties, and phase change over a range of temperatures.

Pham (1984) suggested three stages of freezing process; Precooling time, phase change time and sub-cooling time.

Data used for estimating total freezing time using Pham's equations shown in table (4-5)

Table (4 –5): Data used for estimating total freezing time using Pham's equations

Treatment	Contact	Product state	h (kj/m²°c hr)	K (kj/m°c hr)	Cp (kj/kg°c)
V-on , S-on	+	Unfrozen	10.72	0.48	4
V-off , S-on	-	Unfrozen	5.83	0.48	4
V-on , S-on	+	frozen	0.371	1.32	2
V-off , S-on	-	frozen	0.025	1.32	2

According to Pham (2014) the total freezing time is estimated using the following equation:

$$t_f = \left[1 + 0.41\, R_T^{0.5}\ \left(1 - e^{-Bi_f}\right)\right] t_{fp_1}$$

Table (4 –6): Total freezing time by an experimental and by Pham's equations

Treatment	Total freezing time by an experimental (hrs.)	Total freezing time by Pham's equations (hrs.)
V-on , S-on	25.27	28.42
V-off , S-on	311	148.34

Table (4 – 6) explains the very differences in cooling rates among the four treatments and among the three stages of each. It shows a cooling rate array of (Treatments × Stages). In order to explain the differences.
Table (4 – 7) gives experimental values of (T_i, T_{if}, T_{tf} and T_s)for treatments. It was noticed that the first deflection was obvious for all treatments, while the second deflection was not as obvious. slowest cooling point is considered to be the final freezing point.
It can be seen that according to Linger' s classification the freezing treatments
(V-on, S-on) belong to the second class (rate 1 to 5 C̊/ hr.), moderately fast freezing. The freezing treatments (V-off, S-on) belong to the slow freezing rate.
Samani freezing process curves for the temperature treatments (T vs Θ) exhibit broken cooling curves. This phenomena is more obvious when a dimensionless temperature ratio

$$(TR = \frac{T - T_m}{T_i - T_m})$$

Is plotted versus time on a semi-log paper. This graphical method was employed for estimating the initial freezing temperature and the final freezing temperature, as well as estimating the stage process time. The first defection at which the slowest cooling point experimentally established, is considered to be the initial freezing point. The second deflection, at which the second

Table (4 –7): Experimental values at (T_i, T_{if}, T_{ff} and T_s)

Treatment	T_i	T_{if}	T_{ff}	T_s
V-on , S-off	24.9	-3.0	-5.1	-13
V-on , S-on	23.6	-3.4	-7.5	-13
V-off , S-off	26.6	-3.4	-7.7	-13
V-off , S-on	26.3	-3.8	-7.7	-13
Average	25.35	-3.4	-7.0	-13

4.5 Empirical Expressions of Freezing Process Stages

Analytical expressions which relate the temperature as a function of time and position in freezing process have been approached by several researchers. Most of these researchers dealt with food material as regular engineering shapes (slab, cylinder or sphere) to simplify and generalize the mathematical equations. Plank's equation for freezing and modifications. Don't describe accurately the freezing process of irregular shapes of food materials.

Empirical equations, developed by regression analysis using experimental data are thought to be more specific and could be more accurate, to describe the freezing process of irregular shapes of food materials.

For generalization of the expressions, a transformation of temperatures in a dimensionless value was used as follows:

$$TR = \frac{T_\theta - T_m}{T_i - T_m}$$

The temperature ratios of the four treatments are given in table (4–2) appendix A, and plotted for the three stages separately in figures (4-3) and (4-4) versus time.

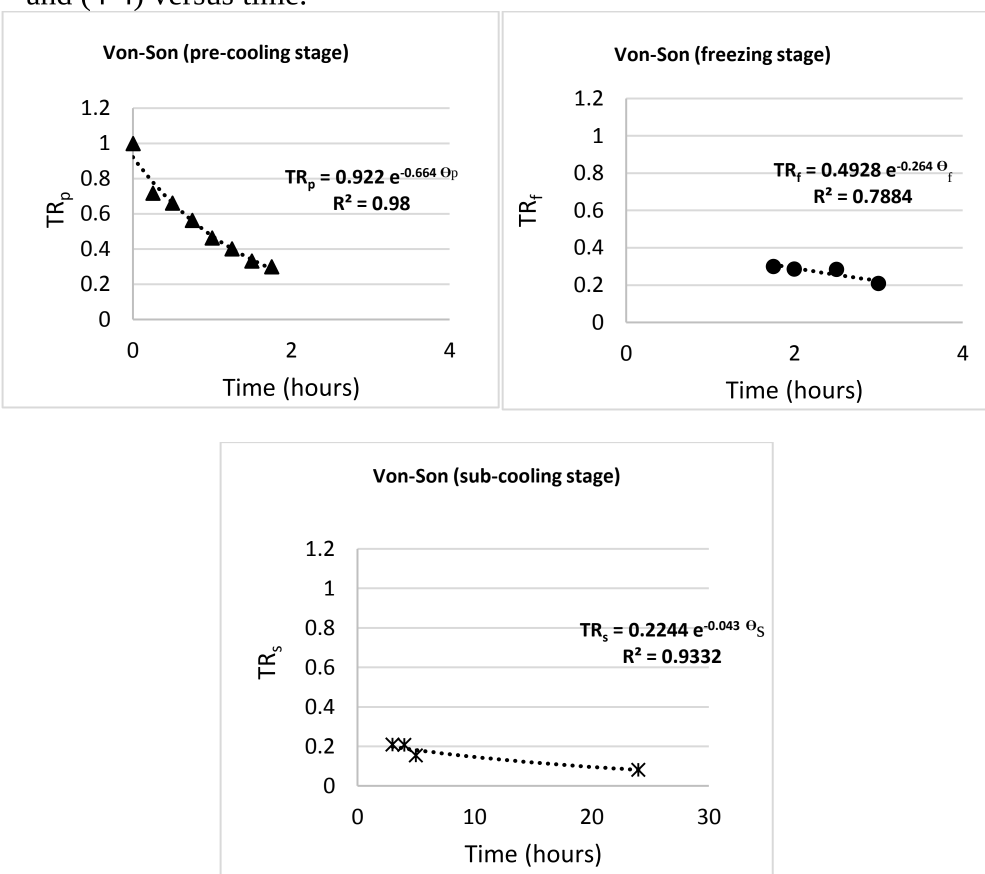

Figure (4 – 5): Prediction of cooling curves based on empirical results (V-on, S-on).

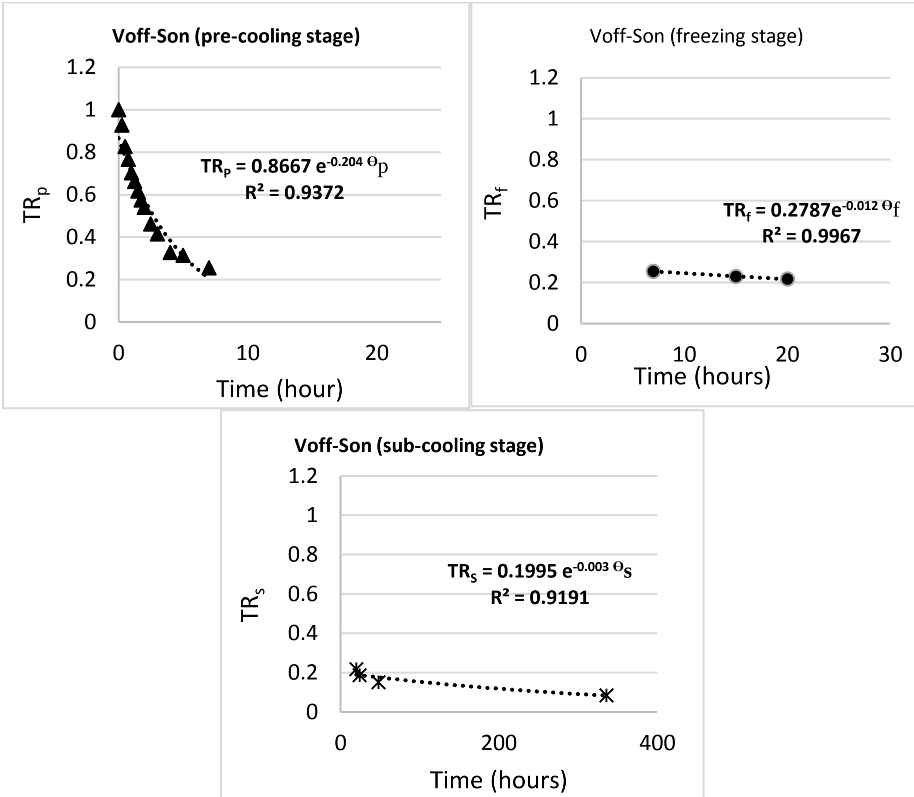

Figure (4 – 6): Prediction of cooling curves based on empirical results (V-off, S-on).

- **<u>For pre-cooling stage</u>**

$$TR_p = \frac{TP\,(\theta_p) - T_m}{T_{iP} - T_m} = a_p\, e^{-k\,p\,\Theta_p}$$

- **<u>For freezing stage:</u>**

$$TR_f = \frac{T\,(\theta_f\,) - (T_m\,)}{T_{i\,f} - (T_m)} = a_f\, e^{-k\,f\,\theta_f}$$

- **<u>For sub-cooling stage:</u>**

$$TR_s = \frac{T\,(\theta_s\,) - (T_m\,)}{T_{ff} - (T_m)} = a_s\, e^{-ks\,\theta_s}$$

The values of cooling constants (K), (a) for all stages and for all treatments are given in table (4-7)

Table (4 – 7): The values of cooling constants (a, K), (R^2) for all stages and for all treatments

Treatment	Pre-cooling			Freezing			Sub-cooling		
	a_p	K_p	R_p^2	a_f	K_f	R_f^2	a_s	K_s	R_s^2
V on – S on	0.922	0.664	0.986	0.443	0.264	0.788	0.224	0.043	0.933
V off – S on	0.867	0.204	0.937	0.279	0.012	0.997	0.199	0.003	0.919

- For direct contact with air and with spikelet on (V-on, S-on) heat is supposedly transferred only radially.

5-SUMARY AND CONCLUSION:

Freezing is one of the oldest and most widely used methods of food preservation, which allows preservation of taste, texture, and nutritional value in foods better than any other method. The freezing process is a combination of the beneficial effects of low temperatures at which microorganisms cannot grow, chemical reactions are reduced, and cellular metabolic reactions are delayed.

Freezing preservation retains the quality of agricultural products over long storage periods. As a method of long-term preservation for fruits and vegetables, freezing is generally regarded as superior to canning and dehydration, with respect to retention in sensory attributes and nutritive properties. The safety and nutrition quality of frozen products are emphasized when high quality raw materials are used, good manufacturing practices are employed in the preservation process, and the products are kept in accordance with specified temperatures.

Samples of frozen dates, were removed from the freezer after:

Two months, six months and ten months.

- **Conclusion**

1- Freezing of Khalal dates and thawing led to gradual fruit color change from yellow in the Khalal stage of Samani dates cultivars to brown in the rutab-like stage. The rapid color change of the treated fruit by freezing take place with the beginning of thawing and continued gradually towards color of the natural rutab ripened on the palm.

2- Find freezing/time curves for two different freezing treatments and thawing / time curves for two different treatments: 2, 6, and 10 months of storage at -18 ºC

3- Find initial and final freezing point for two different freezing conditions (treatments).
4- Find freezing rates (ºC / hr.) for two treatments
5- Develop mathematical equations for the three freezing process stages.

In the end:

It could be concluded that:

1- the postharvest freezing of Khalal date fruit induced the production of rutab-like stage.

2- The Khalal date fruit completely converted in to edible unstringing, soft and sweet rutab-like dates.

4-A box with ventilation slots is the best way for keeping because it allowed air in freezer to a cross between the date fruit, the date with spikelet best way for keeping good rutab-like induced by freezing allot of time

Finally we can say that freezing are safe natural and efficient application to enhance the indication of rutab-like stage from the Khalal stage.

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الملخص العربى

دراسة سلوك البلح السماني اثناء التجميد

منى علي محمود إبراهيم* ، عبد الحميد زكريا شكر و محمد أحمد صباح****

الهدف الرئيسي من هذة الدراسة: هو دراسة تأثير سلوك البلح وتاثير معاملات التعبئة والتغليف على عملية التجميد.

أهداف محددة:

١. إنشاء منحنيات التجميد / الوقت لأربعة معاملات مختلفه.
٢. التنبؤ نقطة التجمد الأولية والنهائية لأربعة معاملات مختلفة.
٣. التنبؤ بمعدلات التجمد (درجة مئوية / ساعة) لثلاث مراحل عملية التجميد.
٤. تطوير المعادلات الرياضية لثلاث مراحل عملية التجميد، لربط معدلات التبريد بزمن التجميد.
٥. مقارنة زمن التجميد الناتج من التجربة مع زمن التجميد الناتج من التعويض في معادلات حساب زمن التجميد (معادلات بلانك).

الطرق والمواد المستخدمة:

تم حصد الثمار ثم استخدمت فقط فاكهة سليمة دون اضرار ميكانيكية واستخدمت الثمار محل الدراسة مباشرة من دون اجراء اى معاملات عليها وقد تم استخدام عينات البلح السمانى الذى ينمو فى مصر وكلها فى مرحلة الخلال وكانت معباة فى صناديق الفواكه وتم رفعها ونقلها بعد الحصاد على الفور الى معمل فسيولوجيا التدوال بكلية الزراعة جامعة الاسكندرية ،

***طالبة دراسات عليا و ** أستاذ : قسم الهندسة الزراعية و النظم الحيوية – كلية الزراعة – جامعة الإسكندرية.**

وقد تم اختيار الثمار السليمة على اساس حجم ولون موحد واستبعاد التالفة وتم غسل الثمار المختارة بالمياه الجارية ثم جففت وتم فرزها لتجنب الثمار المعيبة ثم تقسيم الثمار السليمة الى فئتين واحدة مع الشماريخ واحدة مع الكبسولة وتم حفظ الثمار فى نوعين من علب الحفظ البلاستيكية (علب بفتحات تهوية وعلب بدون فتحات تهوية) ابعادها (5×10×18 cm) وكانت الفتحات تشغل ٨% من المساحة الكلية للعلبة.

وتم ايجاد الخصائص الطبيعية (وزن الثمرة ،وزن اللب،وزن البذور،طول الثمرة وقطرها) وزمن التجميد. كما تم تحديد ثلاث فترات تخزين لاجراء التجربة (شهرين - ستة اشهر – عشرة اشهر)

<u>الخلاصة:</u>

يمكن ان نلخص انه بعد الحصاد تجميد ثمار الخلال يسبب انتاج شبيه الرطب .اي ان ثمرة البلح الخلال تم تحويلها تماما الى ثمرة لينة وحلوة شبيهة الرطب. علب الحفظ بفتحات تهوية هي المثلى للحفاظ على الثمار لانها تسمح بمرور الهواء بين ثمار البلح داخل المجمد. حفظ البلح بالشماريخ من افضل طرق الحفظ لانتاج شبيه رطب جيد لوقت طويل بعد الاذابة. واخيرا يمكننا القول ان التجميد امن وطبيعي وذو كفاءة لتعزيز انتاج شبيه الرطب من مرحلة الخلال.