



## Effect of osmotic dehydration on the freeze drying kinetics of apricots

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### Abstract

In this work, the influence of osmotic dehydration on freeze drying of apricots was investigated. Osmotic dehydration of apricots was carried out in two solutions (sucrose and date) at two different concentrations (30 and 50% w/w). Product quality was investigated using the following criteria: drying time, vitamin C and total sugars. Results showed that osmotic dehydration in date solution (30% w/w) gave the shortest drying time (3 h) and the best freeze drying kinetics. The vitamin C loss was 14% during osmotic dehydration and 7% during freeze drying. Total sugars increased by 57% during osmotic dehydration and 8% during freeze drying. Seven models were fitted to the experimental data. The best models were the following: Page model for apricots treated with date solution, Wang and Singh model for apricots treated with sucrose solution, and Verma *et al.* model for apricots without osmotic dehydration.

**Key words:** Osmotic dehydration, freeze drying, kinetics, dried apricots, sugars, date, concentration, quality, vitamin C, food enrichment, modelling.

### Introduction

Fruits are considered an important source of raw materials for the food, cosmetic and pharmaceutical industries. Apricot is very rich in vitamin A and could be used as a rich source of antioxidants. It has a recognised action in the prevention of cardiovascular diseases and cancer<sup>1-3</sup>. Dried apricots are high calorific products and considered rich in vitamins and minerals<sup>4</sup>.

Fresh fruits are perishable products due to their high water content. Many processes were used to preserve them. Osmotic dehydration has been largely used as a single process or combined with other processes<sup>5-7</sup>. Osmotic dehydration in sugar has two main advantages: it inhibits the activity of polyphenoloxidase and prevents volatile component loss during dehydration<sup>8</sup>.

Freeze drying is a sophisticated drying method. Freeze-dried products are considered of higher quality for the following reasons: quick reconstitution due to its porous structure and a good preservation of nutrients due to a low drying temperature. However, the main disadvantage is its high cost. Freeze drying is considered better than air drying mainly because heat sensitive compounds are less damaged, and the product can be rapidly reconstituted with water<sup>9</sup>. In order to avoid sulfitation, the osmodehydro freezing process of apricots was studied<sup>10</sup>. It consists of osmotic dehydration followed by air dehydration and then freezing.

The influence of pretreatment solutions on the drying of fruits has been studied by various researchers<sup>10-13</sup>. Pretreatments in specific solutions modify the final product composition, and the fruit is enriched as it possesses new functional properties suitable for different applications<sup>14</sup>. However, there is no information in the literature on treatments based on the use of date solutions for osmotic dehydration of fruits such as apricots.

The aim of this work was to study osmotic dehydration of apricots using date and sucrose solutions, to determine its influence on the freeze drying kinetics and the quality of the processed apricots based on the following criteria: drying time, vitamin C content and total sugars content, and determine the best mathematical model for the drying process.

### Materials and Methods

**Raw material:** Fresh apricot (var. Canino) was purchased from a local market in Batna, Algeria, and stored at 4°C. It was washed, pitted and cut into 10 mm cubes. Samples were blanched using steam at 100°C for 3 minutes in order to stop enzymatic browning reactions.

**Processing:** Date solution was prepared by heating 1 kg of dry dates (var. Mechdegla) in 5 litres of water at a temperature of 70°C for 1 hour, followed by a filtration with paper filters. Osmotic dehydration was conducted at 25°C for 2 hours with a rotation of 50 tours/minute in two solution types (sucrose and date) at two different concentrations, 30 and 50% (w/w). Fruit/solution ratio was 1:4. Processed samples were dried with paper towels and weighed every 15 minutes.

**Freeze drying:** Samples were frozen at -30°C for 24 h and freeze-dried using a Phywe Christ laboratory freeze dryer. Sublimation was carried out at 20°C and a pressure of 0.05 mbar. Each sample weighed 30 g. Samples were weighed every 30 minutes. A thermocouple pt100 was used to measure the temperature in the centre of the sample during freeze drying. Dried samples were cooled and then packed in polyethylene bags.

**Table 1.** Thin-layer semi-theoretical drying models.

| No. | Model name          | Model equation                       | References |
|-----|---------------------|--------------------------------------|------------|
| 1   | Lewis               | $MR = \exp(-kt)$                     | 11         |
| 2   | Page                | $MR = \exp(-kt^n)$                   | 18         |
| 3   | Henderson and Pabis | $MR = a \exp(-kt)$                   | 30         |
| 4   | Wang and Singh      | $MR = 1 + at + bt^2$                 | 31         |
| 5   | Logarithmic         | $MR = a \exp(-kt) + c$               | 30         |
| 6   | Two-term            | $MR = a \exp(-k_0t) + b \exp(-k_1t)$ | 4          |
| 7   | Verma <i>et al.</i> | $MR = a \exp(-kt) + (1-a) \exp(-gt)$ | 32         |

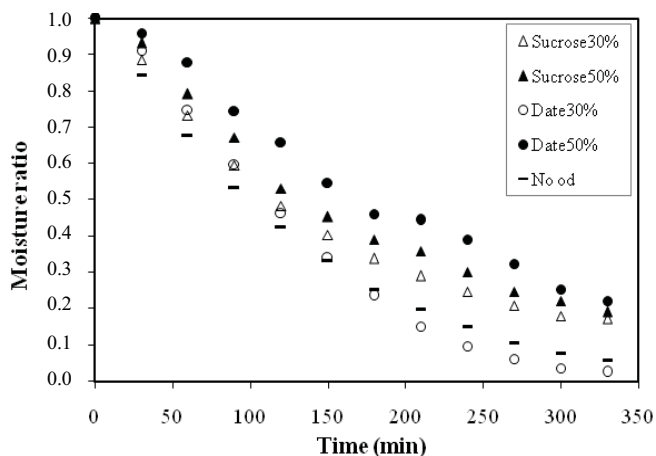
**Analysis:** Total sugars and vitamin C measurements were carried out at three stages: fresh, osmotic dehydrated and freeze-dried apricots. Dry matter and initial moisture content were determined according to AOAC methods<sup>15</sup>. Vitamin C content was quantitatively determined using the modified 2,6-dichlorophenolindophenol (DIP) method<sup>16</sup>. Total sugars were extracted using the phenol method<sup>17</sup>. All measurements were performed in triplicate.

**Modelling:** Thin layer drying models can be divided into three categories: theoretical, semi-theoretical and empirical. Theoretical and semi-theoretical models are commonly used to describe drying kinetics of agricultural products<sup>11,18-20</sup>. Each of the previous models was successfully used to model a specific food product such as grape, plum, apricot, barley and tea. In the current study, seven models were used to fit the freeze drying kinetics of apricots (Table 1), where  $MR = (M - M_e)/(M_0 - M_e)$ , MR moisture ratio, M moisture content at time t (kg water/kg DM),  $M_0$  initial moisture content (kg water/kg DM),  $M_e$  equilibrium moisture content (kg water/kg DM), a, b, c, g, n, k,  $k_0$ ,  $k_1$  model constants.  $M_e$  is relatively small compared to M and  $M_0$ <sup>21</sup>. Hence, the MR value could be simplified to  $MR = M/M_0$ .

The regression analysis was performed using the Statistica computer program and was based on the Quasi-Newton algorithm. The best model was chosen based on the following two criteria: the highest coefficient of determination ( $R^2$ ) and the least reduced chi-square ( $\chi^2$ )<sup>4</sup>.

## Results and Discussion

**Osmotic dehydration and drying kinetics:** The initial moisture content of apricot was 88.4% (w/w) and dry matter 11.6% (w/w).



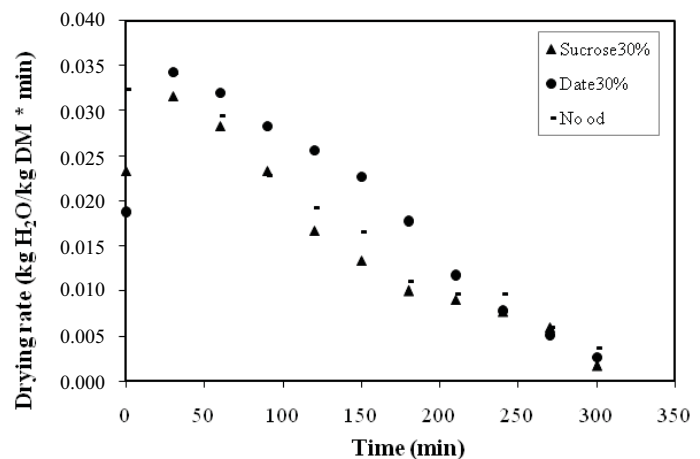
**Figure 1.** Moisture ratio of osmotic and non-osmotic dehydrated apricot cubes during freeze drying.

The effect of two solutions (sucrose and date) at two concentrations (30 and 50%: suc30, suc50, dat30, dat50 and No od) on the drying kinetics of apricots was studied. Fig. 1 shows the drying curves of osmotically dehydrated apricot cubes with different solutions as well as samples that did not undergo any pretreatment. The sample osmotically dehydrated with date solution at 30% gave the fastest drying curve, followed by the sample that was not subject to osmotic

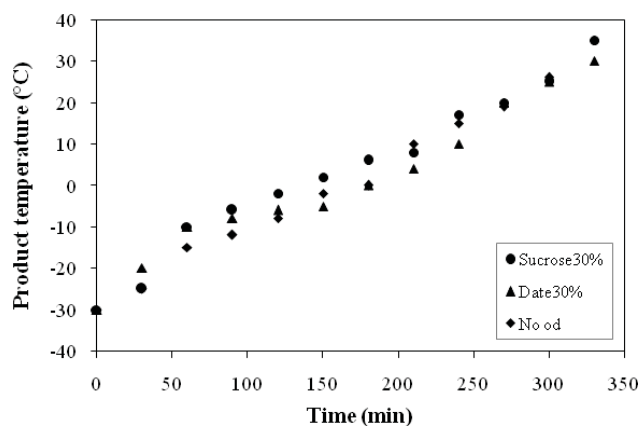
dehydration. The samples treated with solution at 30% gave better results than samples treated with solutions at 50%. In fact, a high concentration creates a layer on the sample surface which decreases water migration through the surface of the sample<sup>5</sup>. Mass transfer during osmosis depends on variables such as concentration, temperature and solute type of the dehydration solution<sup>22</sup>. Previous studies reported that osmotically pretreated fruits increase resistance to water movement during air drying<sup>23,24</sup>. However, little is known on freeze drying of porous products.

To analyse the rate of drying for different treatments, the three best freeze drying curves (corresponding to osmotic dehydration with sucrose at 30%, osmotic dehydration with date at 30% and no osmotic dehydration) are presented in Fig. 2. The curves show the presence of two drying periods. The first period corresponds to heating samples from initial temperature to the drying temperature, followed by the falling rate period. In fact, previous research with hot air drying of fruits such as apricots and grapes did not allow the constant-rate period to be observed<sup>25,26</sup>. However, another research<sup>6</sup> showed that during solar and artificial air drying of fruits such as plums, apricots and figs two drying rate periods were evident, one almost constant and a second falling rate period. It is observed that the drying rate curve of the samples treated with date solution at 30% was higher than for samples treated with other solutions.

Fig. 3 compares the evolution of temperature in the apricot centre during freeze drying for the three best freeze drying curves (corresponding to osmotic dehydration with sucrose at 30%, osmotic dehydration with date at 30% and no osmotic dehydration). Initial sample temperature was -30°C, which increases during the freeze drying process. When all the ice is sublimated, sample temperature reaches 0°C. Fig. 3 shows that pretreatment



**Figure 2.** Freeze drying rate vs. time for apricots pretreated in date (30%), sucrose (30%), and without treatment.



**Figure 3.** Apricot inner temperature during freeze drying. Samples pretreated in date (30%), sucrose (30%) and without treatment.

does not have an effect on sample temperature. According to the literature<sup>27</sup>, drying in the constant drying rate period is greatly affected by the air flow. However, at the falling rate period, drying is controlled by diffusion, and internal product temperature was not influenced by osmotic dehydration.

Freeze drying duration was determined for samples with a final moisture content of 1.5 (kg water/kg DM). The shortest time was 180 minutes, corresponding to samples pretreated with date solution at 30%, and the longest time corresponded to samples pretreated with date solution at 50% (Table 2). We can deduce that osmotic dehydration has an effect on freeze drying duration. However, concentration has a greater effect. Thus, for the identical solution, e.g., date solution, it has the shortest drying time at low concentration yet the longest drying time at high concentration. This is because osmotic dehydration is a surface-dominated process. So, at higher concentration, sugars penetrate to a greater depth, which prevents water diffusion<sup>5</sup>. On the other hand, freeze-dried samples without pretreatment need a drying time of 190 minutes. This value is the second best value following the date solution samples at 30%. Hence, osmotic dehydration improves freeze drying duration when used with a specific solution such as date solution at low concentration (30%).

**Modelling of drying curves:** Moisture content of the best three drying curves corresponding to the following pretreatments (sucrose 30%, date 30% and No od) were fitted to seven models. Non-linear regression was performed using Statistica software to obtain models parameters. The results are summarised in Table 3. The coefficient of determination ( $R^2$ ) for the three solutions is greater than 0.97. Page model fitted best the experimental data of apricot samples pretreated with date solution with a coefficient of determination of 0.9988 and a reduced chi-square of 0.000331. Wang and Singh model fitted best the experimental data of apricot

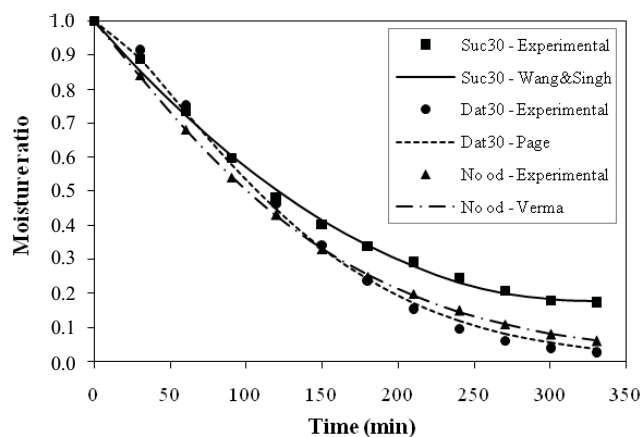
**Table 2.** Freeze drying time of osmotic dehydrated apricots in different solutions.

| Solution | Concentration (% w/w) | Freeze drying time (min.) |
|----------|-----------------------|---------------------------|
| Sucrose  | 30                    | 245                       |
| Sucrose  | 50                    | 280                       |
| Date     | 30                    | 180                       |
| Date     | 50                    | 315                       |
| No od    | -                     | 190                       |

samples pretreated with sucrose solution with a coefficient of determination of 0.9985 and a reduced chi-square of 0.000266, and Verma *et al.* model fitted best the experimental data of untreated apricot samples with a coefficient of determination of 0.9999 and a reduced chi-square of 0.000013. Similar parameters during air drying of apricots were identified<sup>4</sup>.

Table 3 shows that the best results were obtained for untreated samples. Indeed, the drying models did not take into account the effect of osmotic dehydration. Fig. 4 shows experimental data with the predicted results for apricots subject to three different treatments. Therefore, we conclude that Page, Wang and Singh and Verma *et al.* models are well suited to predicting the freeze drying curves of apricots.

The effect of osmotic dehydration and freeze drying on apricot quality was based on measuring the changes of vitamin C and total sugars of samples at three stages of the process: fresh sample, after osmotic dehydration and after freeze drying. Apricot cubes pretreated with date solution at a concentration of 30% were used for the analysis. The amount of vitamin C in fresh apricot (FA) has a mean value of 14 mg/100 g, the amount of vitamin C decreased to a value of 12 mg/100 g after osmotic dehydration (OD), which represents a loss of 14% during this operation. After freeze drying (FD), the amount of vitamin C decreased to 11 mg/100 g, showing a loss of 7% (Table 4). These process losses were in the same range as those obtained by other authors<sup>10, 28</sup>. Therefore, the combined treatment (osmotic dehydration and freeze drying) represented a total loss of 21% in vitamin C in the apricot samples. Total sugars in fresh apricots (FA) had a mean value of 7.4 mg/100 g. After osmotic dehydration (OD), total sugars increased to 11.6 mg/100 g, which represented an increase of 57% over the initial value. During osmotic dehydration, sugars (sucrose, glucose, fructose, etc.) infused inside sample tissues, causing an increase in its sugar concentration. After freeze drying (FD), total sugars value was estimated to be 12.2 mg/100 g, which represented an increase of 8% (Table 4). Sugars increased probably due to the thickening of the cell walls after osmotic dehydration and freeze drying as a result of the adsorption of sugar or other polysaccharides<sup>12, 29</sup>. We noticed that the freeze drying process had a better effect on apricot quality than osmotic dehydration, since it caused less damage to vitamin C and less increase in total sugars.



**Figure 4.** Experimental and predicted moisture ratio of apricot cubes during freeze drying. Samples pretreated in date (30%), sucrose (30%), and without treatment.

**Table 3.** Statistical results of models for different solutions.

| Solution     | Model name                 | Model constants                                | R <sup>2</sup> | χ <sup>2</sup>  |
|--------------|----------------------------|--|----------------|-----------------|
| <b>Dat30</b> | <b>Page</b>                | <b>k = 0.0011; n = 1.3824</b>                  | <b>0.9988</b>  | <b>0.000331</b> |
| Dat30        | Wang and Singh             | a = -0.0054; b = 0.000007                      | 0.9961         | 0.001041        |
| Dat30        | Logarithmic                | a = 1.3178; k = 0.0051; c = -0.2629            | 0.9952         | 0.001439        |
| Dat30        | Henderson and Pabis        | a = 1.0982; k = 0.0081                         | 0.9850         | 0.004003        |
| Dat30        | Two-term                   | a = 0.5490; k0 = 0.0081; b = 0.5490; k1=0.0081 | 0.9850         | 0.005004        |
| Dat30        | Verma <i>et al.</i>        | a = 0.0261; k = 0.0074; g = 0.0074             | 0.9789         | 0.006266        |
| Dat30        | Newton                     | k = 0.0074                                     | 0.9788         | 0.005127        |
| <b>Suc30</b> | <b>Wang and Singh</b>      | <b>a = -0.0051; b = 0.000008</b>               | <b>0.9985</b>  | <b>0.000266</b> |
| Suc30        | Logarithmic                | a = 0.9937; k = 0.0064; c = 0.0355             | 0.9982         | 0.000359        |
| Suc30        | Henderson and Pabis        | a = 1.0218; k = 0.0059                         | 0.9979         | 0.000363        |
| Suc30        | Page                       | k = 0.0047; n = 1.0406                         | 0.9977         | 0.000399        |
| Suc30        | Newton                     | k = 0.0058                                     | 0.9975         | 0.000408        |
| Suc30        | Verma <i>et al.</i>        | a = 0.0364; k = 0.0057; g = 0.0058             | 0.9975         | 0.000498        |
| Suc30        | Two-term                   | a = 0.5229; k0 = 0.0058; b = 0.5229; k1=0.0059 | 0.9967         | 0.000736        |
| <b>No od</b> | <b>Verma <i>et al.</i></b> | <b>a = -1.3426; k = 0.0143; g = 0.0105</b>     | <b>0.9999</b>  | <b>0.000013</b> |
| No od        | Page                       | k = 0.0035; n = 1.1496                         | 0.9999         | 0.000014        |
| No od        | Logarithmic                | a = 1.1038; k = 0.0063; c = -0.0875            | 0.9995         | 0.000127        |
| No od        | Wang and Singh             | a = -0.0058; b = 0.000009                      | 0.9994         | 0.000124        |
| No od        | Henderson and Pabis        | a = 1.0356; k = 0.0077                         | 0.9978         | 0.000485        |
| No od        | Two-term                   | a = 0.5178; k0 = 0.0077; b = 0.5178; k1=0.0077 | 0.9978         | 0.000606        |
| No od        | Newton                     | k = 0.0074                                     | 0.9968         | 0.000631        |

**Table 4.** Vitamin C and total sugars composition of apricot.

| Parameter              | Apricot (var. Canino) |                |              |
|------------------------|-----------------------|----------------|--------------|
|                        | Fresh                 | Osmodehydrated | Freeze-dried |
| Vitamin C (mg/100g)    | 14 (±0.6)             | 12 (±0.1)      | 11 (±0.6)    |
| Total sugars (mg/100g) | 7.4 (±0.3)            | 11.6 (±0.4)    | 12.2 (±0.4)  |

The advantage of osmotic dehydration using date solution was the enrichment of apricot with sugars (sucrose, glucose, fructose) but also with other soluble vitamins and minerals that are contained in dates (Mg, Fe, etc...).

### Conclusions

Solution type and concentration of the osmotic pretreatment affected the freeze drying kinetics of apricots. Date solution gave better results than sucrose solution. A low concentration (30% w/w) was found to be better than a high concentration (50% w/w). Osmotic dehydration in date solution (30% w/w) gave the shortest drying time and the best freeze drying kinetics.

Apricot quality was evaluated based on vitamin C and total sugars criteria. Vitamin C loss did not exceed 21%, of which 14% occurred during osmotic dehydration and 7% during freeze drying. This showed that freeze drying has less damage on vitamin C, since the process occurred at low temperature. Osmotic dehydration enriched apricot samples in sugars by 57%. Freeze drying also increased total sugars by 8% due to the concentration of solubles in apricots.

Seven models were fitted to the dehydration data of apricot samples. Results showed a good agreement with the experimental data. The best models were the following: Page model for apricots treated with date solution, Wang and Singh model for apricots treated with sucrose solution and Verma *et al.* model for apricots without osmotic dehydration.

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