OSMOTIC DEHYDRATION FACILITATES SUBSEQUENT DRYING OF SLICED GARLIC

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Abstract
The goal of this study was to determine optimal conditions for osmotic dehydration used as a pretreatment for facilitating subsequent convective drying of sliced garlic. The pre-dehydration was performed using three concentrations 10, 15 or 20% sodium chloride at different temperatures 25, 35 or 45°C and followed by convective drying at 50 or 60°C.the solution to garlic ratio was 1:4 (w/w).The period of pretreatment lasted for 180 min. The pretreatment conditions found optimal were 15% salt at 35°C, which produced a water loss of 41.57% and a solids gain of 9.52%. . Results showed that increasing of drying temperature shortened the drying time for garlic slices non-pretreated and pretreated.Subsequent drying process times were thus reduced by factors of 2.25 and 1.31 respectively at 50°C and 60°C.Effective moisture diffusivity (Deff) values of pretreated garlic slices are greater than nonpretreated during the drying at all two temperatures. Deff increased with drying temperature for both pretreated and non-pretreated garlic slices. Deff values of non-pretreated and pretreated garlic slices ranged 1.34•10-10 to 2.34•10-10 m2/sec and 2.72.10-10 at 4.29.10-10 m2/s , respectively. Activation energy (Ea) of non-pretreated and pretreated garlic slices were obtained 39.92kJ/mol and 27.63 kJ/mol, respectively. Osmotic dehydration thus appears to be an interesting option for food industries seeking mean of reducing product drying times.

Keywords: Optimization, pretreatment, garlic, osmotic dehydration, convectivedrying

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1. INTRODUCTION

Garlic (*Allium sativum* L.) is one of the most common savory vegetables used in fine cuisine all over the world. Among allium species, *A.sativum* is currently second only to onion in crop production volume. In addition, garlic is a nutraceutical plant rich in phytonutrients, believed to help prevent a large number of diseases including cancer (Vemuri *et al*., 2017), cardiovascular disease (Siddiqui *et al*., 2017), obesity (Chen *et al*., 2014), hypercholesterolemia (Cheng *et al.*, 2013), type 2 diabetes (Naidu *et al.*, 2016), hypertension (Xiong *et al*., 2015) and gastrointestinal disorders (El-Ashmawy *et* al., 2016).
World production of garlic is more than 20 million tons, the largest amounts being produced in China, followed by India, Korea and the United States (Abano *et al.*, 2011). However, because of its relatively high moisture content (70% wet basis), fresh garlic cannot be stored on the longterm. At least 30% of the fresh crop is lost to spoilage by microorganisms (Pedraza Chaverrí *et al*., 2007). For this reason, garlic and its derivatives are sold mostly in dried forms. One of the most common of these is garlic powder, which is produced from dried pods or slices. Since about 2010, sliced garlic preserved by conventional drying has become popular. However, the quality of this product is influenced strongly by drying method and conditions (Fante *et al.*, 2013). This is stimulating research and development.

Conventional hot air drying is a process of simultaneous heat and mass transfer followed by a change from the liquid phase to the vapor phase. In the case of convective drying of food products, long treatment times and attendant losses of functional and nutritional properties are major drawbacks (Thuwapanichayanan *et al*., 2014). For some foods, pre-treatment with osmotic dehydration has been used successfully to reduce the initial water content (N'Goran *et al*., 2012), to preserve texture and natural vegetable color (Chaguri *et al*., 2016), to inhibit enzymatic activity (Moreno *et al*., 2013), to improve retention of volatile aromas during drying (Heredia *et al*., 2012) and to shorten drying time (Costa Ribeiro *et al*., 2016). This technique is based on contacting the fresh product with concentrated solutions of salt or sugar, thus driving simultaneously two counter-current material transfers: a large transfer of water from the product to the solution and a smaller transfer of solute from the solution to the product (Junqueira *et al*., 2017). However, as the immersion time increases, so does the loss of bioactive molecules, nutrients and water-soluble vitamins from the food (Abraão *et al*., 2013, Araya-Farias*etal*., 2014). Many factors such as solution temperature, osmotic pressure and mass ratio and prior treatments (bleaching, ultrasound, pulsed electric field, etc.) have been found to influence the rate of diffusion during osmotic dehydration of semipermeable cell structures (N'Goran *et al*., 2012). Among the fruits and vegetables that appear to respond well to osmotic dehydration are potatoes (Goula *et al*., 2017), blue berries (Yu *et al*., 2018), egg plant (Junqueira *et al*., 2017), yacon (de Oliveira *et al*., 2016), mango (Jimenez-Hernandez *et al*., 2017), olives (Bonatsou *et al*., 2016), kiwi fruit (Traffano-Schiffo *et al*., 2017), pineapple (Silva *et al*., 2014), carrots (Singh *et al*., 2007) and onions (Sutarand and Gupta, 2007). Processes combining osmotic dehydration with subsequent drying have been modeled and optimized for operating conditions that minimize total processing time while preserving product quality. Fruits and vegetables that have been tested using this approach include quince (Dehghannya *et al*., 2017), pomegranate arils (Cano- Lamadrid *et al*., 2017), strawberries (Prosapio and Norton, 2017; Amami *et al*., 2017), pears (Costa Ribeiro *et al*., 2016), apples (Sabetghadam and Tavakolipour, 2015), mushrooms (Darvishi *et al*., 2018) and tomatoes (Souza *et al*., 2007). Drying of sliced garlic by processes that include osmotic dehydration has not been well studied. The main goal of this study was therefore to optimize a garlic drying process assisted by osmotic pre-dehydration.

2. MATERIALS AND METHODS

2.1. Materials

Garlic (*Allium sativum* L., El-Hamra variety) washarvested from Harrouche, a village in the Skikda province in eastern Algeria. The bulbs were stored in a dry place at room temperature (20°C) until use, then separated into pods, peeled and sliced uniformly to 2 mm thickness.
Sample moisture content was determined by drying in a vacuum oven (Binder DV53, Frankfurt, Germany) at 70°C for 24 h according to the Association of Official Analytical Chemists method (AOAC, 2010). The sample initial moisture content was 63± 0.5% (wet basis).

2.2 Osmotic dehydration treatment

Sliced garlic was first blanched in boiling water at 100°C for 30 seconds then plunged into ice water and then into 1% sodium meta-bisulfate solution for one second and finally rinsed immediately with distilled water. Samples were then subjected (or not in the case of controls, here in after called 'fresh') to osmotic dehydration in sodium chloride(NaCl) solutions at concentrations of 10%, 15% and 20% inErlenmeyer flasks (100 mL) covered with Parafilm™ to prevent evaporation, in a shaker-incubator (New Brunswick Innova™ 40, 230V,50 Hz) at 25°C, 35°C and 45°C. For all nine condition combinations, the solution to garlic ratio was 1:4 (w/w).
Slices were removed from the flasks at 5, 10, 15, 20, 25, 30, 40, 60, 90, 120, 150 and 180 min. Each slice was rinsed immediately with

distilled water, contacted with absorbent paper and weighed. Water loss (*WL*) and solids gain (*GS*) were expressed using equations (1) and (2):

$$WL = \frac{(M_0 - S_0) - (M_t - S_t)}{M_0} \times 100 \qquad \textbf{(1)}$$

$$GS = \frac{S_t - S_0}{S_0} \times 100 \qquad \textbf{(2)}$$

Where M0, Mt, S0 and St are respectively initial mass, final mass, initial dry mass and final dry mass of the sample.

2.3. Convective drying

Convective drying experiment was performed in a conventional drying oven (MEMMERT model UF750, Germany) at 50°Cor 60°C and air flow rate of2m/s. Slices dehydrated under the conditions found optimal(15% NaCl and 35°C) were used. Sample weight loss during drying was measured at 10 min intervals. The drying process was stopped when the moisture content was stable, which was at about 9 ± 0.2%. The moisture ratio (MR) of garlic slices was calculated using equation (3):

$$MR = \frac{M_t - M_e}{M_0 - M_t} \qquad \textbf{(3)}$$

Where *Mt* is moisture content at time *t*, *M0* is the initial moisture content and *Me* is the equilibrium moisture content (all in kg water per kg dry matter).

For longer drying periods, equation (4) was used.

$$MR = \frac{M_t}{M_0} \qquad \textbf{(4)}$$

The drying rate (DR) was calculated using equation (5):

$$DR = \frac{M_t - M_{t+\Delta t}}{\Delta_t} \qquad \textbf{(5)}$$

Where, *Mt* + Δ*t* is the moisture content (kg water per kg dry matter) at *t* + Δ*t* and *t* is the time in min.

Determination of effective diffusivity

Fick's second law was used to determine the coefficient of diffusivity according to the method of Sacilikand Unal (2005).

$$\frac{\delta M}{\delta t} = D_{eff} \nabla^2 M \qquad \textbf{(6)}$$

$$MR = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 D_{eff}}{4L^2} t\right) \qquad \textbf{(7)}$$

$$\ln MR = ln\frac{8}{\pi^2} - \frac{\pi^2 D_{eff}}{4L^2} t \qquad \textbf{(8)}$$

Where, Deff is the effective diffusivity in m2/s, MR is the moisture ratio (kg water per kg dry matter) at time *t* and L2is the half-thickness of the sample slab (m).

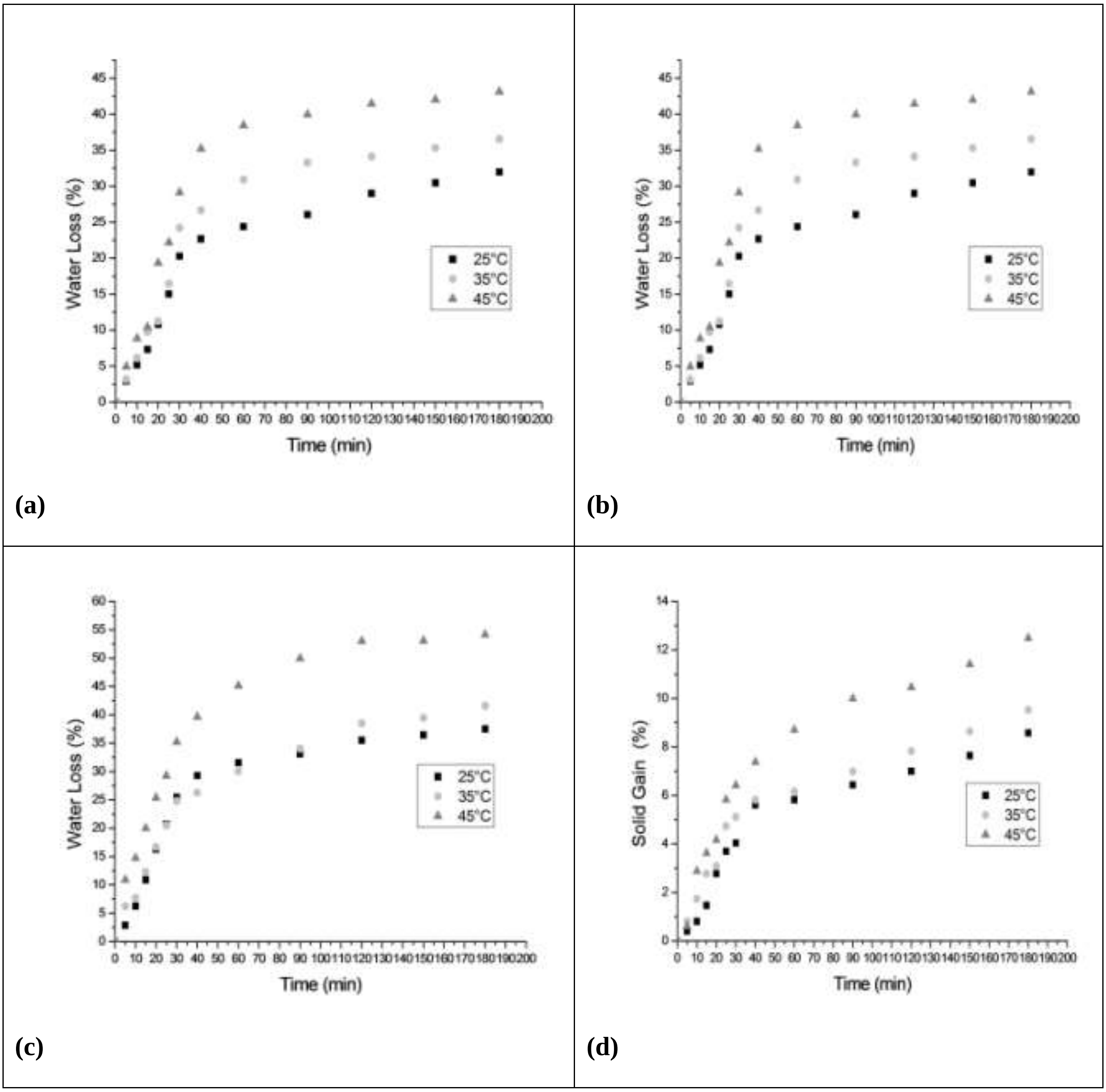
2.4. Statistical analysis

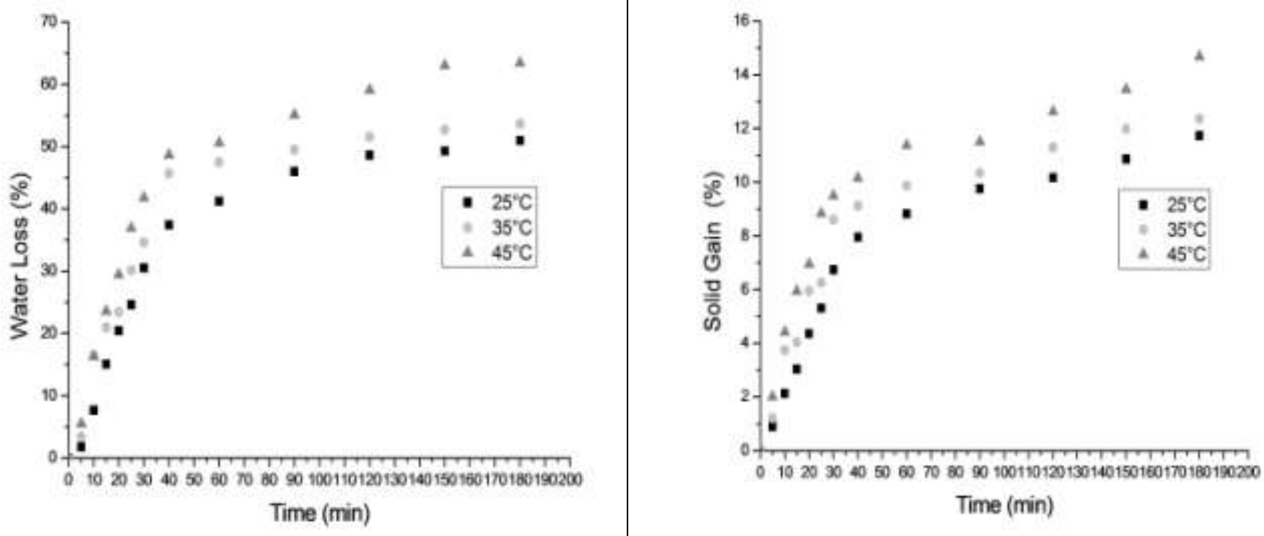
Analysis of variance (ANOVA) was performed using the General Linear Models procedure (GLM) provided in SigmaPlot\SPW11 software version 11.0(2008). Experiments were performed in triplicate and the means of the three data sets are shown. Means were separated by least significant difference according to Duncan's multiple ranges.

3. RESULTS AND DISCUSSION

3.1. Osmotic dehydration

The water losses and solids gains (equations 1 and 2) measured for sliced garlic pretreated by osmotic dehydration at different temperatures and salt concentrations are shown in Figure 1. The largest gain of solids (i.e. salt) was14.67%, which was obtained after 120 minutes of immersion in 20% NaCl, while the smallest gain was 8.69%, which was obtained after immersion for the same length of time in 10% NaCl. These two treatments also produced the largest and smallest water losses, respectively 63.44% and 31.97%. These experiments also showed that these losses and gains were faster during the initial phase of the osmotic dehydration, which corroborates results reported by Dermesonlouoglou *et al*. (2018) for Goji berries. Junqueira *et al*. (2017) also showed that the initial rates of dehydration and solids gain are faster. This is not surprising since the concentration differential and hence the mass transfer driving force between the fruit and the hypertonic solution are greatest at this point. The pattern of change during the 2 hours of treatment is thus logarithmic, in most cases reaching a plateau representing maximal loss or gain. Prolonging the immersion time nevertheless further decreases the water fraction while increasing the solids content of sliced garlic (Dermesonlouoglou *et al*., 2018). The accumulation of salt eventually slows down the water loss considerably (Souza *et al*., 2007, Junqueira *et al*., 2017). This has been reported also for osmotic dehydration of sliced green banana (Chaguri*et al*., 2016) and eggplant (Junqueira *et al*., 2017). It is also apparent in Figure 1 that the final water loss and solids gain are greatest at the highest salt concentration and temperature. In other words, both the initial osmotic pressure and the thermal energy of the solution drive the transfer of water from inside the garlic into the surrounding medium (Souza *et al*., 2016; Dehghannya *et al*., 2017).





(e) **(f)**

Fig. 01: Kinetics of water loss (WL) and solid gain (SG) of garlic slices during (a) the osmotic dehydration

(a)water loss concentration 10%, **(b)** solid gain concentration 10%,**(c)** water loss concentration 15%, **(d)** solid gain concentration 15%, **(e)**water loss concentration 20%, **(f)** solid gain concentration 20%.

Salt concentration affects the solids gain significantly, suggesting that salt penetrates the tissues and possibly the cell membranes of sliced garlic (Chaguri *et al*., 2016; de Oliveira *et al*., 2016; Amami *et al*., 2017; Prosapio and Norton, 2017; Prosapio *et al*., 2017). It is likely that polymers surrounding plant cell walls (and possibly the walls themselves) swell in water and that the cell membranes are water-permeable or become so under these conditions (Akbarian *et al*., 2014).

The increase in wall and membrane permeability could allow salt penetration to increase and thereby lead to structural changes (Junqueira *et al*., 2017). It is also possible that at increased osmotic pressure, the viscosity of the salt solution is lower and the external resistance to mass transfer at the garlic tissue surface is lower, thus facilitating water transfer (Amami *et al*., 2017).

Regardless, it has been proven that soaking sliced garlic in NaCl solution increases moisture mobility within the tissue, which increases water mass transfer to the soaking solution, thus increasing water loss from the sample and therefore sample dry matter content even without salt absorption, as long as the water does not carry dissolved substances outward (Al-Harahsheh *et al*.,2009). It is believed that sodium and chloride ions permeate the plant tissue during soaking and re-associate as NaCl crystallizes inside cells, thus counteracting tissue shrinkage and maintaining or increasing moisture mobility within the sample and enhancing mass transfer and thus the dehydration process (Dehghannya *et al*.,2017).

The effect of temperature on water loss (31.97%, 53.64% and 63.44% respectively at 25°C, 35°C and 45°C) and on solids gain could be due to salt ions modifying the dielectric characteristics and therefore the uniformity of the heating of the product (Dehghannya *et al*., 2017). It is well known that higher temperatures increase cell membrane permeability (Amami *et al*., 2017) perhaps by swelling alone, which would facilitate mass transfer. Other investigators have shown that higher temperatures favor water flow from the fruit to the soaking medium (Nono *et al*., 2001, Khoyi and Hesari, 2007, Azoubel and Murr., 2004). At 45°C, sliced garlic appears to undergo changes in physical properties such as color. These might indicate changes in cell wall and membrane structures leading to losses of selectivity, increased permeability and uptake of solutes (Amami *et* al., 2017).

Based primarily on color, osmotic dehydration of sliced garlic appeared to be optimal at 15% NaCl and 35□C. Under these conditions, water loss reached 41.57% and solids gain reached 9.52%, which were the best results to be carried forward to the drying process.

3.2 Moisture ratio and drying rate

The kinetics of drying of untreated and pretreated garlic slices at 50°C and 60°C are shown in Figures 2 and 3. The drying process is characterized by a progressive decrease in moisture content over time at both temperatures. During initial drying, the free water at the garlic slice surface evaporates quickly (Kaushal and Sharma, 2014). This explains the noticeable steepness of the first portion of the curve. However, as drying progresses, water must move from the inside of the plant tissue to the surface, which depends on liquid diffusion, capillary movement and surface diffusion and slows down the water evaporation rate (Kaushal and Sharma, 2014).

The times required to dry fresh garlic slices from the initial (63 ± 0.2%) to final (9 ± 1%) moisture content at 50°C and 60°C are 510 min and 210 min respectively (Figure 3). For osmosis-dehydrated garlic slices, these times are shortened to220 min and 160 min (Figure 2), since a considerable portion of the water has already been removed. A thin layer of salt formed on the surface of the pre-dehydrated slices could lead to changes in intracellular tissue structure as the effects of osmotic pressure and drying are combined (Amami *et al.*, 2017). This could have some effect on product quality. Our results corroborate those reported by Amami *et al.* (2017) for strawberries.

Based on measurement of moisture ratio of the sliced garlic during the drying process, partial dehydration by osmosis slightly increased the water loss.

Dehydration induces component saturation, leading to an increase in cohesive forces between water molecules and solutes and consequently decreasing molecular mobility. The interactions of water with other components are important factors to consider not only in process control, but also in terms of the stability and quality of the final product (Sette e*t al*.,2016). This, has been observed in dried figs pretreated by osmotic dehydration (Şahin and Öztürk, 2016).

The present results confirm that warmer air enhances considerably the kinetics of drying of sliced garlic, whether pre-dehydrated or not, since both the vapor pressure and the diffusion of water must increase with temperature (Chen *et al*., 2017). This has been observed with peas (Şahin and Öztürk, 2016) and greens (Kek*et al*., 2013) subjected to osmotic dehydration followed by convective drying. If this were not so, one would have to examine the possibility that the dehydration process somehow formed a watertight barrier at the surface of the product.

The average drying rates (in kg of water per kg dry matter per min, calculated using equation 4) at 60°C and 50°C are respectively 4.7·10-3 and 1.57·10-3 for fresh sliced garlic and 5.79·10-4 and 1.93·10-4 for pre-dehydrated product. The differences between fresh and pre-dehydrated may reflect increased internal resistance to mass transfer due to solute (salt) uptake, as has been observed for the drying of papaya (El-Aouar *et al.*, 2003). The pre-dehydration may also have increased the drying rate and hence water diffusivity. These trends can be explained in terms of the physical chemistry of water binding and changes in garlic cell structure caused by solids gain (Cano-Lamadrid *et al*., 2017; Dermesonlouoglou *et al*., 2018).

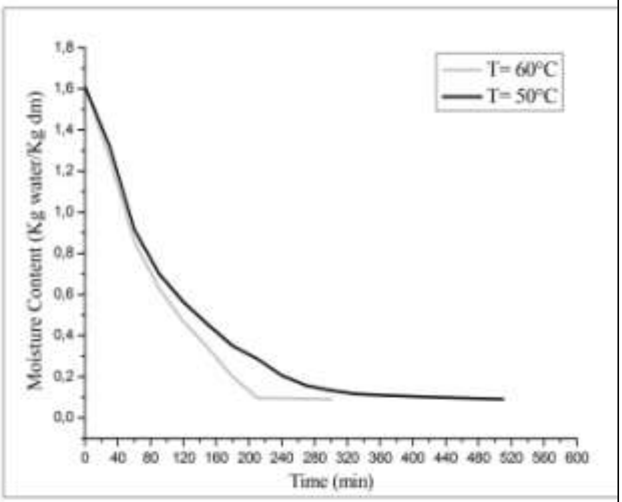


Fig.02: Moisture content as a function of drying time for pretreated garlic slices.

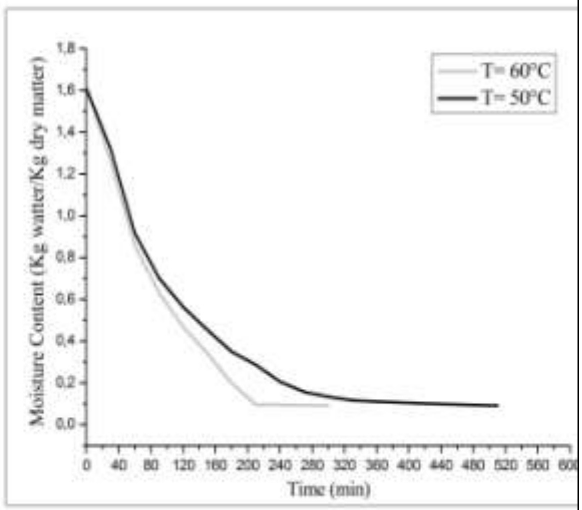


Fig. 3: Moisture content of pre-dehydrated sliced garlic as a function of drying time.

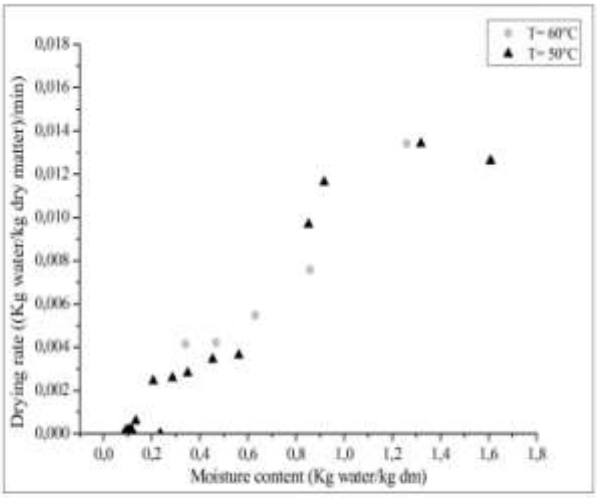


Fig. 4: Rate of drying of fresh sliced garlic as a function of moisture content

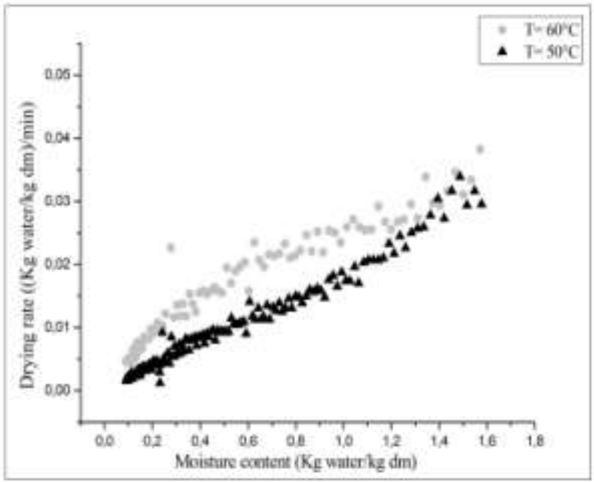


Fig. 5: Rate of drying of pre-dehydrated sliced garlic as a function of moisture content.

It is also noted that the drying rate decreased as the drying process progressed, and in the case of pre-dehydrated sliced garlic dried at 50°C, it had an almost linear relationship with water content (Figure 4). At 60°C, the decrease appears to accelerate as the moisture content decreases, at least in the case of pre-dehydrated slices, for which data were more abundant. In the case of fresh garlic slices, the drying rate dropped as the moisture content decreased, although based on the data obtained, it is difficult to say at what point this occurred (Figure 5). In general, the drying rate appears to be proportional to the moisture content of the food, that is, highest at the beginning of the process when the moisture content is high, and it appears to stay higher for longer at the higher drying temperature. A higher drying air temperature likely decreases the moisture ratio faster by transferring more heat to the vegetable and thereby accelerating moisture migration (Kaushal and Sharma, 2014). Similar observations have been reported for drying of strawberries (Amami *et al.*, 2017). Again, if this were not so, one would have to expect that somehow a barrier had formed inside the tissue or at the surface.

Effective moisture diffusivity (Deff)

The Deff is one of the most significant factors in drying kinetics and is dependent on product characteristics. This parameter encompasses all possible mechanisms of moisture movement in the foodstuffs including liquid, vapor, surface diffusion, capillary and hydrostatic flows (Dehghannya *et al*., 2017). The effective moisture diffusivity was calculated using Fick's second law (equation 7). The values obtained at 50°C and 60°Cranged respectively from 1.34·10-10 to 2.34·10-10 m2/sec for fresh slices and 2.72**.**10-10 at 4.29**.**10-10 m2/s for pre-dehydrated slices.

Regardless of product pretreatment and drying temperature, Deff increased as the moisture content decreased. The coefficients of determination were greater than 0.99 in both cases. The values obtained in this study are within in the range of 10−12 to 10−8 m2/s for drying food materials (Zielinska, 2016). The higher effective diffusivity for pre-dehydrated slices indicates that their mass transfer efficiency was superior.

When the osmotic dehydration is begun, a high osmotic pressure gradient exists between the slices and the immersion solution. Salt forces its way into the vegetable product, causing damage to cell walls and possibly to cell membranes. As these structures breakdown, the diffusion of water within the plant tissue becomes easier and the effective water diffusivity increases (Souza *et al*., 2007). In addition, the higher the temperature, the higher the Deff values, since the thermal activity of water molecules is increased, speeding up the transfer of water from the inside to the surface of the matrix (Amami *et al*., 2017).

Activation energy (Ea)

The activation energy estimated from the Arrhenius equation is the amount of energy required to remove moisture from the material. The values were 39.92kJ/mol and 27.63 kJ/mol respectively for fresh and pre-dehydrated sliced garlic. The Ea values obtained in this study are consistent with the range of 12.7kJ/mol to 110 kJ/mol reported for various foods (Doymaz, 2011). The lower values for the pre-dehydrated slices at the same air temperature means that this product can absorb a greater proportion of the input energy available, thus increasing the rate of heat and mass transfer and decreasing the drying time.

4. CONCLUSION

Study of the kinetics of osmotic dehydration of sliced garlic showed that 15% sodium chloride at 35°C was optimal in terms of water loss, solids gain and product color. This pre-dehydration allows a decrease in drying time and final moisture content. Although the time required to obtain dried garlic slices by convection was shorter at 60°C, assisting drying at 50°C by osmotic dehydration gave a better final product. In addition, this allowed an increase in effective water diffusivity. Finally, these results are relevant to the food processing industry since they allow a better understanding of the physical processes involved and could lead to reductions in cost and improvements in the quality of the product.

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