Drying studies on peach and strawberry slices

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Drying experiments were carried out on peach and strawberry slices using a laboratory scale tray dryer with chamber dimension 30 cm × 30 cm × 20 cm at temperatures of 50, 60, and 70°C for air flow velocities of 0.18, 0.22, and 0.26 m/s. The experimental data were found to fit well with the Page thin-layer drying model. Transport of water during drying was described by Fick’s second law of diffusion and the diffusion coefficients were 3.99, 5.37, and $7 \times 10^{-10} \text{ m}^2 \text{ s}^{-1}$ for peach and 5.39, 7.41, and $8.59 \times 10^{-10} \text{ m}^2 \text{ s}^{-1}$ for strawberry. Activation energy was determined to be 25.92 kJ/mol for peach and 21.49 kJ/mol for strawberry using Arrhenius-type equation.

Subjects: Agriculture and Food; Drying Technology; Food Engineering

Keywords: peach; strawberry; drying kinetics; page equation; diffusion coefficient; activation energy

1. Introduction

Drying of fruits is an economical and effective preservation method practiced by our ancestors through the world. Some fruits are seasonal and are available in abundance during particular seasons of the year. According to the FAO report, one-third of the food supply for human consumption is being wasted (FAO, 2011). Post-harvest losses of fresh fruits and vegetables account to 24–40% in developing countries and 2–20% in developed countries (Sirivatanapa, 2006). This wastage can be drastically reduced by preservation. Dried fruits have number of applications similar to the fresh fruits. Some of the advantages are reduction in weight, volume, packaging, storage, and transportation costs.

In Oman, few varieties of fruits are cultivated and majority of the fresh fruits and vegetables are imported from other countries. Jabal Akhdar in Oman is a fertile ground where many of the fruits are cultivated. Some of the fruits are pomegranates, apricots, plums, peaches, and several varieties of pear (Anonymous, 2005). Wastage due to spoilage can lead to shortages and non-availability of certain types of...
It has been estimated that post-harvest losses of strawberry in Iran account to 35–40% (Baghkhandan, 2006). In the case of peaches, it was 30% in northern areas of Pakistan (Anjum & Awan, 2006).

Peach (Prunus persica) and strawberries (Fragaria ananassa) are fruits that are widely available across the world and are known for their delicacy and perishable nature. These fruits are seasonal and are available in abundance during particular seasons of the year. Peaches and strawberries found in stores in Oman are imported from other countries like South Africa, Australia, USA, and Egypt. They can be consumed fresh and in other forms such as, juice, jam, jelly, in yogurt, and bakery products (El-Beltagy, Gamea, & Essa, 2007).

In the drying process, excess moisture from food materials is removed which prevents the growth of micro-organism and its reproduction which causes decay. Sun drying is an easy and cheap method of drying practiced in tropical countries; however, its application for large-scale production is limited due to increased drying time, inappropriate weather, dust contamination, and non-uniform drying. Therefore, sun drying methods are replaced by mechanical drying for consistent product quality (Arora, Bharti, & Sehgal, 2006).

In food processing industry, drying of fruits consumes more time and energy. Fruits such as strawberries, grapes, and plums are naturally protected by a thin layer of wax cuticle which reduces the moisture diffusion through the fruits (Doymaz, 2008). Either the fruits are cut into slices before drying or it is treated chemically by dipping in chemical solutions such as, ethyl or methyl ester emulsions or alkali solutions of sodium hydroxide and potassium carbonate solutions to accelerate the drying process (Doymaz, 2008; Kingsly, Goyal, Manikantan, & Ilyas, 2007; Raouzeos & Saravacos, 1986; Sunjka & Raghavan, 2004).

Drying of solids involves both heat transfer and mass transfer phenomena (Gatea, 2011; Jabeen, Aijaz, & Gul, 2015). Yilbas, Hussain, and Dincer (2003) formulated a closed-form solution for the temperature distribution inside the solid slab-type substrate due to convective boundary condition. Moisture transport in food materials is found to vary due to its physical and pore structure. The drying curves from the laboratory experiments under controlled conditions give essential information on moisture transport and calculation of diffusion coefficient (Saravacos & Maroulis, 2001). Fick’s second law of diffusivity has been used by many researches to describe moisture diffusion in food materials such as strawberry, grapes, jujube, rambutan, and papad (Azzouz, Guizani, Jomaa, & Belghith, 2002; Chen et al., 2015; Doymaz, 2008; Math, Velu, Nagender, & Rao, 2004; Rahman, Wahid, & Rahman, 2015). Activation energy, energy required for removing moisture has also been reported by researches using Arrhenius-type relationship. The value of activation energy for papad was determined to be 45 kJ/mol (Math et al., 2004). In the case of green mango and half-ripe mango, the values ranged from 11.4 to 22.3 kJ/mol and 8.7 to 9.3 kJ/mol depending on the air flow velocities (Corzo, Bracho, & Alvarez, 2008). In another study by Doymaz and Ismail (2011), activation energy was determined to be 49.17 kJ/mol for alkali emulsion pre-treated sweet cherries. Recent study by Rahman et al. (2015) with rambutan determined the activation energy to be 24.99 kJ/mol. The objective of this study was to determine the diffusivity coefficient and activation energy for peach and strawberry slices during hot air drying in laboratory scale tray dryer.

2. Materials and methods

2.1. Sample preparation

Fresh peaches and strawberries were purchased from the local market. The fruits were thoroughly washed using tap water to remove dust and contaminants. The fruits were then cut into slices of 3 ± 0.2 mm. The peach samples weighed 4.1 ± 0.67 g and strawberry samples weighed 3.54 ± 0.38 g. Fresh samples were used for the experiments.
2.2. Experimental procedure

The samples were carefully placed in the custom-made tray dryer with chamber dimensions 30 cm × 30 cm × 20 cm supplied by Deepthi Engineering, India. The samples were weighed every hour until it reached equilibrium weight. Experiments were conducted at temperatures of 50, 60, and 70°C at a constant air flow velocity of 0.18, 0.22, and 0.26 m/s. Schematic diagram of the tray dryer used in the experiments is shown in Figure 1. Experiments were done in triplicate for consistency of the results.

2.3. Drying modeling

2.3.1. Data analysis

The moisture ratio (MR) of the fruits was determined using the following relation:

\[
MR = \frac{M_t - M_{eq}}{M_i - M_{eq}}
\]

(1)

where \(M_t\), \(M_{eq}\), and \(M_i\) are moisture content at time \(t\) (kg/kg), equilibrium moisture content (kg/kg), initial moisture content (kg/kg). Since the relative humidity of the drying air in the tray dryer fluctuated, correct value of \(M_{eq}\) could not be estimated; therefore, the equation was simplified to,

\[
MR = \frac{M_t}{M_i}
\]

(2)

Since \(M_{eq}\) is small compared to \(M_i\) and \(M_t\), the error involved in the simplification is negligible (Diamante & Munro, 1993). The drying curves were fitted using Page MR thin-layer drying model that is widely used for food and biological materials. These models are generally derived by simplifying the series solution of Fick’s second law. Page’s equation is given as follows:

\[
MR = \exp\left(-Kt^N\right)
\]

(3)

where \(K\) is the drying constant (1/h), \(t\) is the time in hours, \(N\) is the product constant giving the degree of nonlinearity of the drying curve.
2.3.2. Apparent diffusion coefficient

The change in moisture concentration in one dimension can be represented by Fick’s second law of diffusion (Crank, 1975).

\[ \frac{\partial M}{\partial t} = D_a \frac{\partial^2 M}{\partial x^2} \]  

(4)

Assuming the slice is a slab of infinite extent Newman’s solution is (Newman, 1931),

\[ \frac{M_t}{M_i} = \frac{8}{\pi^2} \left[ \exp \left( -\frac{\pi^2 D_a t}{4 h^2} \right) + \frac{1}{9} \exp \left( -\frac{9\pi^2 D_a t}{4 h^2} \right) + \frac{1}{25} \exp \left( -\frac{12\pi^2 D_a t}{4 h^2} \right) + \ldots \right] \]  

(5)

Neglecting the higher order terms in the above equation gives,

\[ \frac{M_t}{M_i} = \frac{8}{\pi^2} \exp \left( -\frac{\pi^2 D_a t}{4 h^2} \right) \]  

(6)

which on arrangement gives,

\[- \ln \left( \frac{\pi^2 M_t}{8 M_i} \right) = \frac{\pi^2 D_a t}{4 h^2} \]  

(7)

where \( D_a \) is the diffusion coefficient in \( m^2/s \), \( t \) in seconds, and \( h \) in meters is the thickness of the sample being dried.

2.3.3. Activation energy

The effect of temperature on the apparent diffusion coefficient was assumed to follow an Arrhenius-type relationship (Geankoplis, 1972; Math et al., 2004; Rice & Gamble, 1989). The equation is given as,

\[ D_a = D_0 \exp \left( -\frac{E}{RT} \right) \]  

(8)

where \( D_0 \) is the frequency factor (min\(^{-1}\)), \( E \) is the activation energy (J/mol), \( R \) is the universal gas constant (8.314 J/mol K), and \( T \) is the absolute temperature (K). A graph was plotted between \( \ln(D_a) \) and \( 1/T \) and activation energy was obtained from the slope and the intercept being equal to \( \ln D_0 \).

3. Results and discussion

3.1. Effect of drying temperature on peach and strawberry

Initial moisture content of the peach and strawberries was observed to be 6.51 ± 0.93 and 9.73 ± 0.88 kg water/kg dry basis, respectively. The moisture content of peach and strawberry decreased throughout the drying period. The drying data were used to calculate the non-dimensional MR. Plot of the MR for peach and strawberry at 50, 60, and 70°C with air flow velocity of 0.18 m/s is shown in Figure 2(a) and (b). Similarly, the results for peach and strawberry dried with air velocity of 0.22 and 0.26 m/s are presented in Figure 3(a) and (b).

Plots satisfactorily describe the drying behavior over the MR range (0 ≤ MR ≤ 1.0), a range that represents the bulk of the drying process. It can be seen from the Figures 2 and 3 that the samples archived equilibrium moisture content. The drying rate increases with increase in air flow velocity and temperature. Deviation of some experimental data is due to experimental anomaly. As the time progresses, the moisture from interior of the fruit slices diffuse slowly to the surface. Drying at higher temperature produces a larger driving force for mass transfer. Mass transfer is further accelerated by the process of convection in the drying chamber. It has also been reported that the higher drying temperatures provided a larger water vapor pressure deficit or the difference between the saturated water vapor pressure and partial pressure of water vapor in air at a given temperature, which is one
of the driving forces for drying (Prabhanjan, Ramaswamy, & Raghavan, 1995). Similar behavior was observed by Jaya and Das (2003). The drying rate of peach was less compared to strawberry. This is because the moisture removal from peach was slower due to the dense nature of the fruit as compared to strawberry.

### 3.2. Empirical modeling

To describe the drying behavior of peach and strawberry undergoing drying process, Page’s equation is used. Figure 4(a) and (b) shows the data fitted according to Page’s equation for peach and strawberry. The exponential curve was linearized to determine drying constant and product constant. Drying constant is influenced by the characteristics of the material, air flow conditions, and the temperature (El-Beltagy et al., 2007; Singh, Sharma, Bawa, & Saxena, 2008). Table 1 gives the drying parameters obtained using Page’s equation for the experimental data. Scatter in the data can be due to experimental anomaly.

A good agreement was found between the experimental data and fitted lines with the $R^2$ values between 0.89 and 0.99. From Table 1 it can be seen that the $K$ values tend to increase with temperature. As the drying temperature is increased, the moisture driving forces due to heat and mass transfer increase. However, for air velocity of 0.22 m/s the $K$ values are lower for strawberry compared to peach this discrepancy may have been caused due to the variation in the sample thickness. Strawberries tend to dry faster compared to peaches due to less moisture content.
3.3. Diffusion coefficient

The diffusion coefficient values were determined using Equation (7). The values were found to be 3.99, 5.37, and $7 \times 10^{-10}$ m$^2$/s at 50, 60, and 70°C for peach and 5.39, 7.41, and $8.59 \times 10^{-10}$ m$^2$/s for strawberry. Values are reported to vary between $4.52$ and $9.63 \times 10^{-10}$ m$^2$/s for strawberries at 60 to 85°C and $4.95 \times 10^{-10}$ to $1.09 \times 10^{-10}$ m$^2$/s for untreated strawberries over the temperature range of 50–65°C (Akpinar & Bicer, 2006). The values can be seen to increase with increase in temperature of drying. The increase was greater for strawberry than for peach denoting higher diffusion rate in strawberry. Similar trend was also observed by other researches with other food materials.

3.4. Activation energy

Activation energy is the amount of energy required for removing moisture from the materials. It was determined using Equation (8) and the graphic representation is presented in Figure 5. The activation energy values were found to be 25.92 kJ/mol for peach and 21.49 kJ/mol for strawberry. The value for peach can be seen to be higher which implies higher energy requirement for water diffusivity. This can be attributed to the more dense texture of peach which requires more energy for diffusing trapped moisture from inside. The values obtained are in close agreement with reported values by other researches for other fruits such as apricot fruit 33.78 kJ/mol (Mirzaee, Rafiee, Keyhani, & Djomeh, 2009), Üryani plum 21.32 kJ/mol (Sacilik, Elicin, & Unal, 2006), figs. 40.95 kJ/mol (Xanthopoulos, Yanniotis, & Lambrinos, 2009) and mango slices 37.99 kJ/mol (Akoy, 2014).
Figure 4. Linearized curve of Page’s equation at 50°C for drying of (a) peach at air velocity 0.18 m/s and (b) strawberry at air velocity 0.26 m/s.

![Figure 4: Linearized curve of Page’s equation at 50°C](image)

(a) $y = 1.0393x - 1.0101$

$R^2 = 0.9923$

(b) $y = 1.2341x - 0.7623$

$R^2 = 0.9956$

Figure 5. Arrhenius-type relationship between diffusivity and reciprocal of absolute temperature.

![Figure 5: Arrhenius-type relationship](image)
4. Conclusion
Drying experiments were successfully conducted on peach and strawberry slices in a laboratory scale tray dryer at 50, 60, and 70°C for three different air flow velocities. It was found the increase in temperature decreased significantly the drying time of the fruits. Page model was used to describe the drying characteristics of peach and strawberry. The diffusion coefficient was determined to be 3.99, 5.37, and $7 \times 10^{-10}$ m$^2$ s$^{-1}$ for peach and 5.39, 7.41, and $8.59 \times 10^{-10}$ m$^2$ s$^{-1}$ for strawberry. In the temperature range 50–70°C, diffusivity was found to be higher for strawberry. The activation energies were estimated to be 25.92 kJ/mol for peach and 21.49 kJ/mol for strawberry, respectively.

Table 1. Page equation parameters evaluated at various temperatures and air velocity

<table>
<thead>
<tr>
<th>Fruits</th>
<th>Air velocity (m/s)</th>
<th>Temperature (°C)</th>
<th>Page's parameter</th>
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<tr>
<td></td>
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<td>$K$ (h$^{-1}$)</td>
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<td>Peach</td>
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Competing interests
The authors declare no competing interest.

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