Influence of Infrared Drying on Drying Kinetics of Apple Slices Coated with Basil Seed and Xanthan Gums

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ABSTRACT
Edible coatings can guarantee the quality of agricultural products, and performance as a low oxygen barrier, carbon dioxide, and water vapor, allowing reducing water loss or controlling water adsorption. The objective of the current work was aimed to evaluate the effects of novel edible coatings based on basil seed and xanthan gums, and infrared (IR) drying efficiency of coated apple slices. Seven empirical thin-layer models were fitted to the moisture ratio data. It was found that Page model had the best fit to show the kinetic behavior and acceptably described the IR drying behavior of coated apple slices with the lowest mean square error (MSE), root mean square error (RMSE), mean absolute error (MAE), and standard error (SE) values and the highest correlation coefficient (r) value. The values of MSE, RMSE and MAE for all experiments were in the ranges of 0.00014–0.00058, 0.012–0.024 and 0.009–0.021, respectively. The average drying time of uncoated apple slices, coated by xanthan gum and coated by basil seed gum were 48.00, 60.22, and 84.78 min, respectively. The average effective moisture diffusivity (D_{eff}) of uncoated and coated apple slices with basil seed and xanthan gums increased from 1.70 × 10^{-9} m^2/s to 4.45 × 10^{-9} m^2/s with increasing IR lamp power from 150 W to 375 W.

KEYWORDS
Effective moisture diffusivity; moisture ratio; page model

Introduction
Edible coatings can guarantee the quality of agricultural products, and performance as a low oxygen barrier, carbon dioxide, and water vapor, allowing reducing water loss or controlling water adsorption. They applied to food slices prior to drying is a technology that can improve the nutritional and sensory qualities of dehydrated products. Polysaccharide edible coatings present low water vapor barrier; however, they present good gas barrier properties, such as oxygen barrier, and could be used to minimize oxidative reactions in food during drying, pointing out the potential of using edible coatings prior to convective drying, since it could reduce undesirable changes due to large time of exposure of the food to oxygen (Fakhouri et al., 2007; Garcia et al., 2014; Salehi, 2021; Silva et al., 2015). Garcia et al. (2014) reported that edible coating by pectin reduced vitamin C losses during convective drying of papaya slices, when compared to the uncoated samples, showing that the coating protected the samples against the oxidation of this biologically active compound. Basil plant (Ocimum basilicum L.) is the mucilaginous native plant and its seeds have a high content of mucilage (gums) with outstanding useful characteristics. Basil gum is a hydrocolloid that extracted from this plant seeds (Salehi, 2019; Salehi et al., 2015). Major properties of the basil seed gum as a novel source of gum has been recently reported by Salehi (2020a).

Apple represents the fourth most important horticultural crop for human nutrition in the world. Drying is one of the important preservation methods employed for storage of apple (Salehi, 2017). One of the ways to decrease the drying time is to supply heat by infrared (IR) radiation. IR methods could...
be used as substitution to the current drying methods for producing high-quality dried hydrocolloids. IR heating has many advantages including high heat transfer rate, short processing time, high efficiency (80–90%), lower energy consumption, lower energy costs, and improving final product quality (Aktaş et al., 2017; Salehi, 2020c; Salehi et al., 2016). Comparing convective and IR heating as means of drying pomegranate arils was studied by Briki et al. (2019). The authors reported that the minimum times required to reach 9% moisture (w/w) starting from 78% were 510 and 94 min for convective and IR drying, respectively. In addition, Łechtańska et al. (2015) examined the IR assisted hot air drying of green pepper. They reported about 38% decrease in drying time when compared to drying using hot air.

The objective of this study was to investigate the effect of IR drying on the drying kinetics, moisture content and effective moisture diffusivity (D_eff) of coated apple slices with basil seed and xanthan gums.

**Materials and Methods**

**Apple Slices Preparation**

Slices of apple (5 mm thickness) were prepared with the aid of a cutter and a steel-made cutting tool, which was cylindrical in shape and pointed on one of the sides. The initial moisture content of the apple slices was 86% (wet basis). Moisture content of apple slices was determined in a oven at 105°C for 5 h (AOAC, method no. 934.06).

**Gum Extraction**

Basil seeds were physically cleaned and all foreign materials were removed. Then, the pure basil seeds were immersed in water for 20 min at a seed/water portion of 1:20 at 25°C. In the next step, the gum was separated from the inflated seeds by passing the seeds through an extractor (Bellanzo BFP-1540 Juicer, China) with a rotating disc which scratched the mucilage layer on the seed surface. The initial moisture content of the basil seed gum was 99.4% (wet basis).

**Coating of Apple Slices**

Xanthan and basil seed gums were used to coat the fresh apple slices. A 0.6% (w/w) xanthan and basil seed gums solution were prepared at 25°C and then apple slices were immersed for 1 min in this aqueous solution.

**IR Drying**

The coated apple slices were dried in an IR dryer (figure 1). The distance of apple slices from IR lamp surface was equal 10 cm. The influence of IR radiation power at three levels 150, 250 and 375 W, and drying time (min) on drying kinetics of apple slices was examined. The weight changes of apple slices were measured using a LutronGM-300p digital balance (Taiwan, sensitivity of ±0.01 gr). In this study, the digital balance was placed under the IR dryer and samples were placed on its surface. Also, the weigh change data were transferred continually (every 1 min) to the computer.

**Experimental Design**

In this study the effects of drying parameters, including infrared radiation power (at three levels of 150, 250 and 375 W) and coating type (at three levels of uncoated, coated by xanthan gum and coated by basil seed gum) on the drying kinetics, moisture content and effective moisture diffusivity of apple slices were investigated.
**Statistical Analysis**

Statistical analysis of data was done in a factorial design by analysis of variance (ANOVA) using SAS 9.1 statistical software. Significant difference between data means were determined using Duncan’s multiple range test at $\alpha = 0.05$ level, and it was performed to establish the impact of coating type and IR radiation power on drying kinetics of apple slices. All measurements were done in triplicate.

**Drying Kinetics**

Numerical modeling is one of the appropriate methods for describing the drying kinetics of agricultural products (Salehi, 2020b). In order to numerical modeling the drying kinetic behavior of coated apple slices, 7 commonly used thin-layer models including Quadratic (Eq. 1), Page (Eq. 2), Newton (Eq. 3), Midilli (Eq. 4), Logarithmic (Eq. 5), Verma (Eq. 6) and Two term (Eq. 7) were examined (Akpinar and Bicer, 2005; Doymaz, 2011).

\[ MR = a + bx + cx^2 \]  
\[ MR = \exp(-ktn) \]  
\[ MR = \exp(-kt) \]  
\[ MR = a\exp(-ktn) + bt \]  
\[ MR = a\exp(-kt) + c \]  
\[ MR = a\exp(-kt) + (1 - a)\exp(-gt) \]  
\[ MR = a\exp(-k0tn) + b\exp(-k1t) \]

Where MR and t are moisture ratio and drying time, respectively. Also $a$, $b$, $c$, $k$, $n$, and $g$ are coefficients of models. In these models, dimensionless moisture ratio (MR) were defined as equation 8:

\[ MR = \frac{M_t - M_e}{M_0 - M_e} \]  

![Figure 1. Schematic of infrared drying of coated apple slices.](image-url)
Where $M_t$ is moisture content of the sample (gr water/gr dry matter) at time $t$; $M_e$ and $M_0$ are equilibrium and initial moisture content (gr water/gr dry matter), respectively. In equation (8), since $M_e \geq M_t$ and $M_e \geq M_0$, the value of $M_e$ is negligible and the equation was simplified to $M_t/M_0$ (Salehi et al., 2017).

Nonlinear regression analysis (based predictive control algorithm) was done using Curve Expert software (Version 1.34, Hyams, D. G., Microsoft Corporation) to evaluate equations parameters. Mean square error (MSE), root mean square error (RMSE), mean absolute error (MAE), standard error (SE), and correlation coefficient ($r$) values were calculated using equations 9 to 13 to evaluate the accuracy of models (Bahramparvar et al., 2014). It is noted that the highest $r$-value (closer to one) and the lowest $MSE$, $RMSE$, $MAE$, and $SE$ values (closer to zero) represent the best model (good fitting).

\[
MSE = \frac{\sum_{i=1}^{N} (O_i - T_i)^2}{N} 
\]  
(9)

\[
RMSE = \sqrt{\frac{\sum_{i=1}^{N} (O_i - T_i)^2}{N}}
\]  
(10)

\[
MAE = \frac{1}{N} \sum_{i=1}^{N} |O_i - T_i|
\]  
(11)

\[
SE = \frac{\sigma}{\sqrt{N}}
\]  
(12)

\[
r = 1 - \frac{\sum_{i=1}^{N} |O_i - T_i|^2}{\sum_{i=1}^{N} |O_i - T_m|^2}
\]  
(13)

Where $O_i$ is the $i^{th}$ actual value, $T_i$ is the $i^{th}$ predicted value, $N$ is the number of data, $\sigma$ is the standard deviation, and $T_m$ is given by:

\[
T_m = \frac{\sum_{i=1}^{N} O_i}{N}
\]  
(14)

**Calculation of Moisture Diffusivity ($D_{eff}$)**

Fick’s second law of diffusion can be used to describe the thin layer drying of agricultural products at falling rate period (Sacilik, 2007). According to this law, moisture ratio for different geometries including cylinder, slab and sphere is defined as equation 15:

\[
\frac{\partial MR}{\partial t} = D_{eff} \nabla^2 MR
\]  
(15)

Analytical solution of this equation for infinite slab geometry and with assuming a constant moisture distribution, one dimensional moisture, negligible shrinkage, and negligible external resistance used to predict moisture diffusion in samples (Doymaz, 2011; Onwude et al., 2018). The dimensionless
moisture content values were calculated with the equilibrium moisture content determined by dynamic equilibrium data of samples. It is given as equation 16:

\[
MR = \frac{8}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{(2n+1)^2} \exp\left(-\frac{\pi^2 D_{\text{eff}} t}{4L^2}\right) 
\]  

(16)

Where \(t\) is the drying time (s), \(D_{\text{eff}}\) is the effective moisture diffusivity (m\(^2\)/s); \(L\) is half-thickness of apple slices which is equal to 0.25 \times 10^{-2} \text{ m} in this study.

For long drying process period, Eq. (16) can be further simplified to:

\[
MR = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 D_{\text{eff}} t}{4L^2}\right) 
\]  

(17)

Hence, a logarithmic form was introduced as follows:

\[
\ln MR = \ln\left(\frac{8}{\pi^2}\right) - \frac{\pi^2 D_{\text{eff}} t}{4L^2}
\]  

(18)

The \(D_{\text{eff}}\) was calculated through Eq. (18) by using the method of slopes. From Eq. 18, a plot of experimental drying data in terms of \(\ln MR\) versus time gives a straight line with a slope (K) of:

\[
\text{Slope}(K) = -\frac{\pi^2 D_{\text{eff}}}{4L^2}
\]  

(19)

### Results and Discussion

#### Drying Time

Symmetrical temperature sharing by IR improved final product quality (Baeghbal et al., 2019). Statistical analysis of experimental results (data) demonstrated that the coating type (uncoated, coated by xanthan gum and coated by basil seed gum) and IR power, have a significant effect on the evolution of drying time of apple slices (\(p < .01\)) (table 1). The effects of coating type and IR radiation power on the moisture content (%) of apple slices are shown in figure 2. The average drying time of uncoated apple slices, coated by xanthan gum and coated by basil seed gum were 48.00, 60.22 and 84.78 min, respectively. As expected, the moisture content decreased with increasing the power because of the increasing temperature and heat transfer gradient between the air and samples. The average drying times of coated apple slices with basil seed gum were 135.67, 69.00 and 49.67 min at 150, 250, and 375 W, respectively. With increasing IR intensity, due to the increase in samples temperature and increasing evaporation rate and the decrease in drying time, the specific energy for drying of coated apple slices decreases. The average drying time of coated apple slices with xanthan gum reduced from 90.67 to 39.33 min when the IR radiation power was increased from 150 to 375 W. The effect of IR pretreatment on low humidity air drying of apple slices was investigated by Shewale and Hebar (2017). They observed that the pretreatment with IR waves decreased the drying time approximately 23 and 17% in low-humidity air and hot air drying, respectively.

| Sources of changes | Degrees of freedom | Sum of squares | Mean square | F       | P       |
|--------------------|--------------------|----------------|-------------|---------|---------|
| Coating type       | 2                  | 6314.9         | 3157.4      | 30.11   | 0.000   |
| Power              | 2                  | 17613.6        | 8806.8      | 83.99   | 0.000   |
| Coating type × Power | 4                  | 1930.2         | 482.6       | 4.60    | 0.010   |
| Error              | 18                 | 1887.3         | 104.9       |         |         |
| Total              | 26                 |                |             |         |         |

Table 1. Results of analysis of variance for drying time parameters of coated apple slices.
Numerical Modeling

In order to estimate drying kinetics of food products, numerous empirical models have been used by researchers. In this study, 7 thin-layer equations (Quadratic, Page, Newton, Midilli, Logarithmic, Verma and Two term) were selected and fitted to experimental data to choose the best and most suitable equation. The model with the highest r value and the lowest MSE, RMSE, MAE and SE values was selected as the best suitable model describing the IR drying processes of uncoated and coated apple slices. It was found that Page model has the best fit to show the kinetic behavior. The estimated parameters (fitting data) of the Page model including drying constants, k and n, are tabulated in Table 2 along with corresponding statistical data (MSE, RMSE, MAE, SE, and r) for all experiments conditions. The values of MSE, RMSE, and MAE for all experiments were in the ranges of 0.00014–0.00058, 0.012–0.024, and 0.009–0.021, respectively. Also, the values of r and SE for all experiments were in the ranges of 0.996–0.999 and 0.013–0.025, respectively. This model has been proved for other IR dried products such as apple (Zhu and Pan, 2009), apple pomace (Sun et al., 2007), mushroom (Salehi et al., 2017), banana (Pekke et al., 2013) and onion (Sharma et al., 2005).

Figure 3 shows comparison of fitted moisture ratio data by Page model with experimental results. These results indicate that Page model is appropriate in describing drying characteristics of uncoated and coated apple slices with basil seed and xanthan gums under the various IR drying conditions.
Table 2. Model constants of the page model for all experimental data.

| Coating type | Power (W) | k     | n | MSE     | RMSE    | MAE    | SE   | r     |
|--------------|-----------|-------|---|---------|---------|--------|------|-------|
| Uncoated     | 150       | 0.0147| 1.2163 | 0.00058 | 0.0241  | 0.0211 | 0.025 | 0.996 |
|              | 250       | 0.0233| 1.3976 | 0.00027 | 0.0165  | 0.0140 | 0.017 | 0.998 |
|              | 375       | 0.0304| 1.3437 | 0.00033 | 0.0181  | 0.0143 | 0.019 | 0.998 |
| Xanthan      | 150       | 0.0111| 1.2481 | 0.00014 | 0.0120  | 0.0088 | 0.013 | 0.999 |
|              | 250       | 0.0160| 1.3181 | 0.00039 | 0.0197  | 0.0156 | 0.021 | 0.997 |
|              | 375       | 0.0288| 1.2627 | 0.00036 | 0.0188  | 0.0151 | 0.021 | 0.997 |
| Basil        | 150       | 0.0100| 1.1725 | 0.00034 | 0.0186  | 0.0160 | 0.019 | 0.998 |
|              | 250       | 0.0191| 1.2038 | 0.00038 | 0.0195  | 0.0165 | 0.020 | 0.997 |
|              | 375       | 0.0270| 1.2027 | 0.00048 | 0.0220  | 0.0187 | 0.023 | 0.997 |

Figure 3. Comparison of fitted data by page model with experimental results.

**Moisture Diffusivity**

Effect of IR drying systems on the $D_{eff}$ of some fruits and vegetables was studied (Salehi, 2020c). The $D_{eff}$ values lie within in range of $10^{-8}$ to $10^{-10}$ m$^2$/s for fruits and vegetables in this dryer. The $D_{eff}$ values are determined by plotting experimental drying data in terms of lnMR versus time. The values of $D_{eff}$ at different condition drying of uncoated and coated apple slices obtained by using Eq. (19) and calculated values are shown in table 3. The results of such fitting gave a average regression coefficient of 0.93 indicating that the quality of such fitting was satisfactory. The $D_{eff}$ values of coated apple slices with basil seed gum and xanthan gum were ranged from $1.30 \times 10^{-9}$ to $3.47 \times 10^{-9}$ m$^2$/s and $1.74 \times 10^{-9}$ to $4.20 \times 10^{-9}$ m$^2$/s, respectively. $D_{eff}$ values increased with increasing IR radiation power because of the rapid movement of water at high temperatures (Doyraz, 2011). The average $D_{eff}$ increased from $1.70 \times 10^{-9}$ m$^2$/s to $4.45 \times 10^{-9}$ m$^2$/s with increasing lamp power from 150 W to 375 W. These $D_{eff}$ values are comparable with the reported values of $1.00 \times 10^{-8}$ to $3.72 \times 10^{-8}$ m$^2$/s for dried quince in IR system (Mehrnia et al., 2017) and $0.87 \times 10^{-9}$ to $2.64 \times 10^{-9}$ m$^2$/s for dried pomegranate arils in IR system (Briki et al., 2019).
Conclusions

In this study, the influence of coating type (uncoated, coated by xanthan gum and coated by basil seed gum) and IR radiation power on the drying kinetics of apple slices were studied. The coating type and IR lamp power influenced the drying time of coated apple slices. The average drying times of coated apple slices with basil seed gum were 135.67, 69.00 and 49.67 min at 150, 250 and 375 W, respectively. The drying characteristics were satisfactorily described by Page model with the highest $r$ value (greater than 0.996) and the lowest MSE, RMSE, MAE and SE values (a good fit). The $D_{\text{eff}}$ values of coated apple slices with basil seed gum and xanthan gum were ranged from $1.30 \times 10^{-9}$ to $3.47 \times 10^{-9}$ m$^2$/s and $1.74 \times 10^{-9}$ to $4.20 \times 10^{-9}$ m$^2$/s, respectively. In addition, the average $D_{\text{eff}}$ of uncoated and coated apple slices with basil seed and xanthan gums increased with increasing IR lamp power.

List Of Symbols

| Symbol   | Description                                      |
|----------|--------------------------------------------------|
| $D_0$    | Pre-exponential factor (m$^2$/s)                 |
| $D_{\text{eff}}$ | Effective moisture diffusivity (m$^2$/s)             |
| $k$      | Drying rate constants in models (1/s)            |
| $K$      | Slope                                           |
| $L$      | Half slab thickness of the samples (m)           |
| $M_i$    | Initial moisture content (kg water/kg dry matter) |
| $M_e$    | Equilibrium moisture content (kg water/kg dry matter) |
| $M_t$    | Moisture content at time t (kg water/kg dry matter) |
| $n$      | Number of constants                              |
| $N$      | Number of observations                           |
| $r$      | Correlation coefficient                          |
| $t$      | Drying time (min)                                |

Disclosure Statement

We have no conflict of interest to declare.

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References

Akpinar, E.K., and Y. Bicer. 2005. Modelling of the drying of eggplants in thin-layers. Int J Food Sci Tech 40(3):273–281.

doi: 10.1111/j.1365-2621.2004.00886.x.

Aktaş, M., A. Sözen, A. Amini, and A. Khanlari. 2017. Experimental analysis and CFD simulation of infrared apricot dryer with heat recovery. Drying Technol 35(6):766–783.

doi: 10.1080/07373937.2016.1212871.
Baegbali, V., M. Niakousari, M.O. Ngadi, and M. Hadi Eskandari. 2019. Combined ultrasound and infrared assisted conductive hydro-drying of apple slices. Drying Technol 37(14):1793–1805. doi: 10.1080/07373937.2018.1539745.

Bahramparvar, M., F. Salehi, and S. Razavi. 2014. Predicting total acceptance of ice cream using artificial neural network. J Food Process. Preserv 38(3):1080–1088. doi: 10.1111/jfps.12066.

Briki, S., B. Zitouni, B. Bechaa, and M. Amiali. 2019. Comparison of convective and infrared heating as means of drying pomegranate arils (Punica granatum L.). Heat Mass Transfer 55(11):3189–3199. doi: 10.1007/s00231-019-02644-8.

Doymaz, I. 2011. Drying of eggplant slices in thin layers at different air temperatures. J Food Process. Preserv 35(2):280–289. doi: 10.1111/j.1745-4549.2009.00454.x.

Fakhouri, F.M., L.C.B. Fontes, P.V.D. Gonçalves, M. Milanez, C.R. Steel, C. J., and F.P. Collares-Queiroz. 2007. Filmes e coberturas comestíveis compostas à base de amidos nativos e gelatina na conservação e aceitação sensorial de uvas Crimson. Food Sci Techno 27(2):369–375. doi: 10.1590/S0101-20612007000200027.

Garcia, C.C., L.C. Caetano, K. De Souza Silva, and M.A. Mauro. 2014. Influence of Edible Coating on the Drying and Quality of Papaya (Carica papaya). Food Bioprocess Tech 7(10):2828–2839. doi: 10.1007/s11947-014-1350-6.

Lechtańska, J.M., J. Szadzińska, and S.J. Kowalski. 2015. Microwave- and infrared-assisted convective drying of green pepper: Quality and energy considerations. Chem Eng Process 98(155–164):155–164. doi: 10.1016/j.cep.2015.10.001.

Mehría, M.A., A. Bashiti, and F. Salehi. 2017. Experimental and modeling investigation of mass transfer during infrared drying of Quince. Iran Food Sci Techno Res J 12(6):758–766.

Onwude, D.I., N. Hashim, K. Abdan, R. Janius, and G. Chen. 2018. Modelling the mid-infrared drying of sweet potato: Kinetics, mass and heat transfer parameters, and energy consumption. Heat Mass Transfer 54(10):2917–2933. doi: 10.1007/s00231-018-2338-y.

Pekke, M.A., Z. Pan, G.G. Atungulu, G. Smith, and J.F. Thompson. 2013. Drying characteristics and quality of bananas under infrared radiation heating. Int J Agri Biol Eng 6(3):58–70.

Sacilik, K. 2007. Effect of drying methods on thin-layer drying characteristics of hull-less seed pumpkin (Cucurbita pepo L.) J Food Eng 79(1)(23–30): doi: 10.1016/j.jfoodeng.2006.01.023.

Salehi, F. 2017. Rheological and physical properties and quality of the new formulation of apple cake with wild sage seed gum (Salvia macroisphion). J Food Meas Charact 11(4):2006–2012. doi: 10.1016/s1169-017-9583-5.

Salehi, F. 2019. Improvement of gluten-free bread and cake properties using natural hydrocolloids: A review. Food Sci Nutri 7(11):3391–3402. doi: 10.1002/fsn3.1245.

Salehi, F. 2020a. Effect of common and new gums on the quality, physical, and textural properties of bakery products: A review. J Texture Stud 51(2):361–370. doi: 10.1111/jtxs.12482.

Salehi, F. 2020b. Recent advances in the modeling and predicting quality parameters of fruits and vegetables during postharvest storage: A review. Int J Fruit Sci 20(3):506–520. doi: 10.1080/15538362.2019.1653810.

Salehi, F. 2020c. Recent applications and potential of infrared dryer systems for drying various agricultural products: A review. Int. J. Fruit Sci 20(3):586–602. doi: 10.1080/15538362.2019.1616243.

Salehi, F. 2021. Effect of coatings made by new hydrocolloids on the oil uptake during deep-fat frying: A review. J Food Process Preserv: Early View 44(11):1–12. doi: 10.1111/jfpp.14879.

Salehi, F., M. Kashaninejad, E. Akbari, S.M. Sobhani, and F. Asadi. 2016. Potential of sponge cake making using infrared-hot air dried carrot. J Food Technol Sci 47(1):34–39. doi: 10.1111/jfts.12165.

Salehi, F., M. Kashaninejad, and A. Jafarianlari. 2017. Drying kinetics and characteristics of combined infrared-vacuum drying of button mushroom slices. Heat Mass Transfer 53(5):1751–1759. doi: 10.1007/s00231-016-1931-1.

Salehi, F., M. Kashaninejad, A. Tadayyon, and F. Arabameri. 2015. Modeling of extraction process of crude polysaccharides from Basil seeds (Ocimum basilicum L.) as affected by process variables. J Food Sci Technol 52(8):5220–5227. doi: 10.1007/s13197-014-1614-1.

Sharma, G., R. Verma, and P. Pathare. 2005. Mathematical modeling of infrared radiation thin layer drying of onion slices. J Food Eng 71(3):282–286. doi: 10.1016/j.jfoodeng.2005.02.010.

Shewale, S.R., and H.U. Hebar. 2017. Effect of infrared pretreatment on low-humidity air drying of apple slices. Drying Technol 35(4):490–499. doi: 10.1080/07373937.2016.1190935.

Silva, K.S., C.C. Garcia, L.R. Amado, and M.A. Mauro. 2015. Effects of edible coatings on convective drying and characteristics of the dried pineapple. Food Bioprocess Tech 8(7):1465–1475. doi: 10.1007/s11947-015-1495-y.

Sun, J., X. Hu, G. Zhao, J. Wu, Z. Wang, F. Chen, and X. Liao. 2007. Characteristics of thin-layer infrared drying of apple pomace with and without hot air pre-drying. Food Sci Technol Int 13(2):91–97. doi: 10.1177/108203107078525.

Zhu, Y., and Z. Pan. 2009. Processing and quality characteristics of apple slices under simultaneous infrared dry-blanching and dehydration with continuous heating. J Food Eng 90(4):441–452. doi: 10.1016/j.jfoodeng.2008.07.015.