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Experimental Study on the Effect of Convective Drying of Potato Slices with Sequentially Reducing Temperature †

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Abstract: Solar convective drying is a method of dehydrating food that is gaining popularity in developing regions due to its low power consumption and shorter yield times compared to direct sun drying. Exposure of food items to high temperatures towards the end of drying results in color and shape deterioration, negatively affecting the product's market value. To alleviate this problem, we explored the impact of dehydrating potato slices using Convective Drying with reducing temperatures over the drying process. It was found that reducing the temperature in two steps during the drying process preserved 61% of the original color at the cost of a 23.8% increase in drying time, compared to constant temperature drying at 60 °C.

Keywords: convection; solar drying; drying time; potato drying; food systems; scorching; burning; food preservation; food drying

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1. Introduction

A total of 30% of the agricultural produce in developing countries is wasted as a post-harvest loss. While freezing food items is a globally adopted solution to prolong the shelf life of food, refrigeration is energy expensive and thereby eco-hazardous. Dehydration or drying is a more sustainable method of preserving fruits and vegetables to make food systems secure for a rapidly increasing global population.

Drying as a method of food preservation is particularly common in developing countries [1]. This is primarily due to its low operational cost. For this reason, the most popular method of dehydrating fruits and vegetables is Open Sun Drying. This method involves leaving food items in direct sunlight. The moisture present in the food is evaporated due to the vapor pressure difference created by solar heating [2]. Due to long drying times, the quality of nutritional and cosmetic quality of the product is inferior compared to more expensive methods [3]. Solar Convective Drying overcomes some of the shortcomings of Open Sun Drying. This method involves the use of solar thermal collectors to conduct drying at higher temperatures. This reduces the drying time as the moisture removal rate is relatively higher [4]. Due to short drying times and higher color retention, Solar Convective Drying is a more feasible method of dehydrating fruits and vegetables. It has been found that convective drying delivers better product quality at high temperatures [5]. Even so, scorching of food surface and poor color retention is a persistent problem with Convective drying [6].

In this work, we tested the effect of reducing the hot air temperature during the drying process to keep the surface temperatures at values that do not damage the food item.

2. Methodology

Potato slices 3 mm ± 0.5 mm thick, weighing 5 g ± 0.1 g, were used for the experiments. A 40 W centrifugal fan was used to blow air for convection. Airflow was measured with a hot wire anemometer calibrated against a manometer and static pressure. The surface temperature was measured with an infra-red thermometer which was calibrated against phase change points of water. Air temperature and Relative Humidity were measured with an XH-M452 module. Color retention was measured by conducting pixel thresholding of photographs of the potato slices. Figure 1 depicts the schematic of the equipment setup and instrumentation. The 1st experiment was conducted at a constant temperature of 40 °C. The 2nd experiment was conducted at a constant temperature of 60 °C. The 3rd experiment was started at 60 °C and when the surface temperature crossed 40 °C, the air temperature was dropped to 50 °C. Following this temperature reduction, when the surface temperature crossed 45 °C, the air temperature was dropped even further down to 40 °C. The measured parameters were the mass and surface temperature of drying slices.

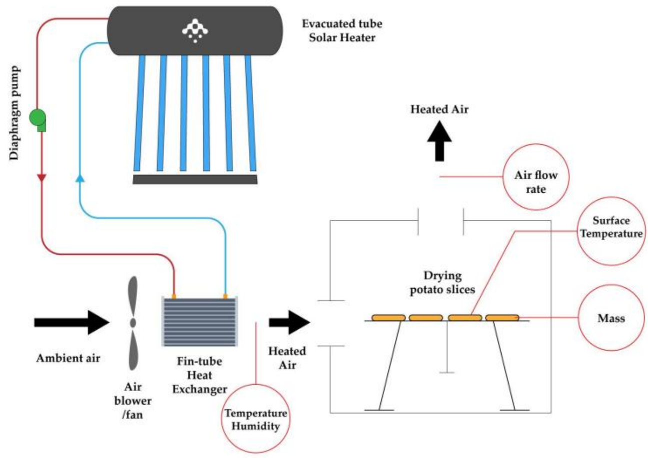

Figure 1. Solar evacuated tube based convection dryer with air flow, temperature, humidity and mass measurement.

3. Theoretical Model

Lewis' model of drying was used to theoretically calculate the rate of dehydration. The drying constant was iterated to fit the data closest to the experimental results to obtain the drying curve as shown in Figure 2.

$$MR(t) = e^{-kt} \tag{1}$$

$$m(t) = m_w(t) + m_d \tag{2}$$

where

$$m_w(t) = (MR)(m_i), \tag{3}$$

$$m_d = (m_i)(1 - MR_i) \tag{4}$$

$$k = drying\ constant,\ MR = Moisture\ Ratio,\ t = time,\ m(t) = mass, \tag{5}$$

$$m_w(t) = water\ mass,\ m_d = dry\ mass, \tag{6}$$

$$m_i = initial\ mass,\ MR_i = initial\ Moisture\ Ratio \tag{7}$$

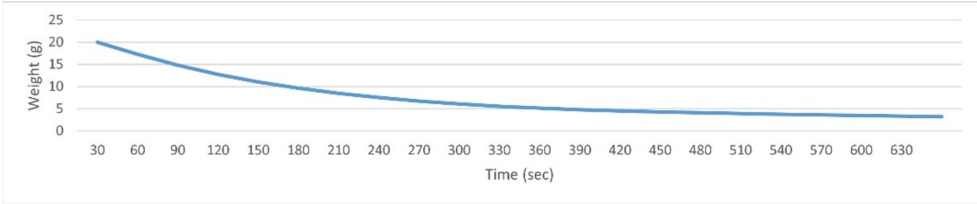

Figure 2. Drying rate predicted by theoretical model for Convective Drying at 60 °C.

4. Results

Table 1 shows that Experiment-2 delivered the fastest drying time and Experiment-3 delivered the highest color retention. Figure 3 shows the plot of mass and surface temperature over the drying period for Experiment-1. Figure 4 shows the plots for Experiment-2 and Figure 5 shows the drying rate and surface temperatures over time for Experiment-3.

Table 1. Experimental parameters and results.

No.	Inlet Temperature (°C)	Air Speed (m/s)	Initial Mass (g)	Final Mass (g)	Drying Time (min)	Color Retention (%)
1	40	1	20	5.1	33	44.9
2	60	1	20	3.9	21	41.2
3	60–50–40	1	20	4.6	26	61.0

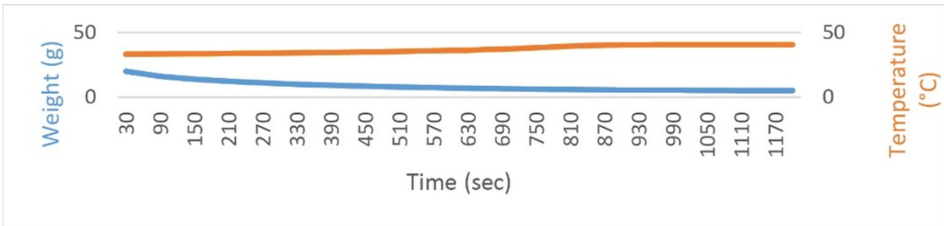

Figure 3. Graphical results for Constant temperature convection at 40 °C.

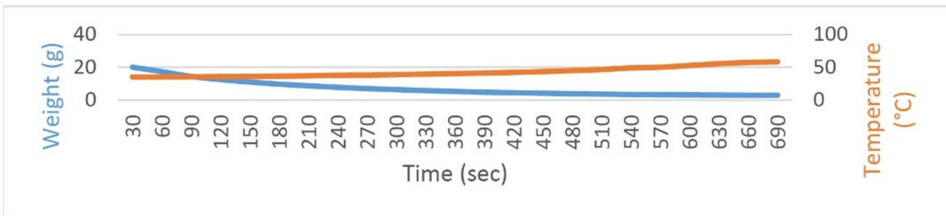

Figure 4. Graphical results for Constant temperature convection at 60 °C.

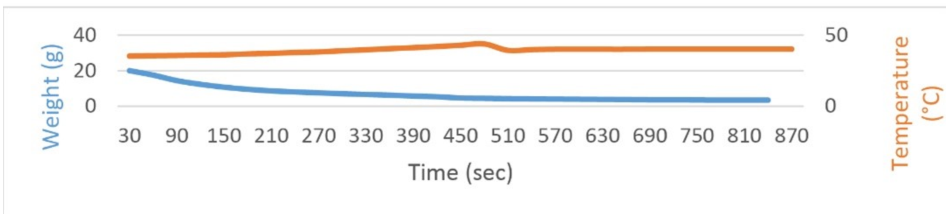

Figure 5. Graphical results for step-reduction in temperature by 10 °C.

5. Conclusions

5.1. Drying Rate

- The drying rate was found to observe an exponential decay for all experiments. This is due to the rate of evaporation at the surface being higher towards the beginning and reducing over time. The moisture that is removed further through the drying process is located further away from the surface.
- For step-reduction of temperature done in Experiment—3, it was found that the slope of the drying rate reduces on each temperature reduction step.

5.2. Surface Temperature

- The surface temperature was found to exponentially converge to the temperature of the hot air. This is because the moisture at the surface acts as a phase-change coolant that depletes over time. Thus, the rate of evaporative cooling at the surface approaches zero as the drying process continues.
- For Experiment—3, the temperature curve was identical to that obtained with constant temperature drying at 60 °C for the first 210 seconds. The slope of the curve reduced to zero as the temperature change became linear after the first step-reduction. The second step-reduction caused a sudden drop in temperature following which it approached and stagnated at 40 °C.

Overall, the surface temperature remained below 45 °C throughout the drying process with a 23.8% increase in drying time over constant temperature drying at 60 °C. Reducing the temperature in two steps resulted in 19.8% higher color retention and thereby improved cosmetic product quality. This makes the product much more suitable to compete with dried snacks made with eco-hazardous and energy-inefficient methods.

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