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# The role of infrared waves in increasing the quality of food products

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**Abstract**

Infrared waves have found a special place in the food industry as one of the new sources of heat production. Infrared heating technology transfers large amounts of energy to the environment or material being processed in a short time. Also improves the quality of the product and makes the product produced by this method have a higher quality than the product produced by traditional methods. Applying modern methods of heating food achieves high-quality processed products and also reduces energy consumption. One of these methods is infrared heating, which can replace many other processes in the industry as an effective method in food processing. Infrared heating has many advantages over conventional heating in similar conditions, including reduced heating time, uniform heating, high heat transfer coefficient, reduced quality loss, significant energy savings, and environmental friendliness. This paper investigates heating using infrared radiation at temperatures of 55, 65, 75, and 85 °C, and its effect on pumpkin drying. The studied parameters include moisture ratio, drying rate, effective diffusion coefficient, and activation energy. According to the results, with increasing temperature from 55 to 85 °C, the drying time decreases by about 60%, and the effective diffusion coefficient has increased by 140%.

**Keywords:** heating; drying; infrared ray; pumpkin; food industry.

**Practical Application:** Infrared heating has many advantages over conventional heating in similar conditions, including reduced heating time, uniform heating, high heat transfer coefficient, reduced quality loss, significant energy savings, and environmental friendliness.

## 1 Introduction

The development of infrared technologies in the food and agriculture sectors as an alternative method is beneficial for the environment and reduces energy and water consumption (Skrzypiec & Gajewska, 2017). Recent advances in equipment for these waves also provide rapid and economical ways to produce food products with high nutritional and organoleptic value (Kipriyanov et al., 2021). Food heating is one of the most important stages of processing in the food industry, which greatly impacts the final quality and has a product (Khan et al., 2021). Increased demand for fresh and less processed foods over the past decade has led to increased attention to heat repair technologies (Zhou et al., 2018).

Heating is one of the important processes in processing and increasing the shelf life of food and includes heat transfer by conduction, convection and radiation methods (Oh et al., 2017). In conventional heating, heat is transferred to the surface of the food through conduction and convection, and the surface temperature rises to such an extent that heat is transferred into the food (Xi et al., 2019). In this way, overheating the surface of food products can cause physical and chemical changes in them. In recent years, researchers have been looking at technologies to minimize the exposure of food products to heat by controlling the temperature and process time (Ratseewo et al., 2020). New food processing technologies such as high-pressure processing (HPP), ohm heating, infrared heating, pulsed electric fields (PEF), microwaves, and cold plasma are among the technologies that have the potential to eliminate the use of heat treatment (Dias et al., 2021). The type of size and its physical condition determine the thermal process used to preserve physical, chemical, and organoleptic properties in food products (Sakare et al., 2020). Infrared radiation is part of electromagnetic radiation and is located in the area between visible and microwave wavelengths (Tezcan et al., 2021). The waves of this radiation are converted into heat after hitting the surface of the food. The shorter the wavelength of the radiation source, the higher the temperature produced. Reduces processing time, reduces energy costs, and prevents the ambient temperature of the equipment used (Shi et al., 2021). In addition to the ease of controlling this process, the wavelengths used in IR reach the desired temperature for food processing in the shortest time.

In general, food exposure to electromagnetic radiation leads to changes in food molecules' electronic, vibrational, and rotational states (Wen et al., 2020). The type of energy absorption mechanism depends on the wavelength of the radiation, so that

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the changes in the electronic, vibrational, and rotational modes are related to the wavelengths of the range $0.2 - 0.7\mu m$ (ultraviolet and visible), $2.5 - 100\mu m$ (far IR), and high $1000\mu m$ (microwave), respectively. Physical heating increases the movement of molecules, followed by an increase in internal energy and temperature in food. Water and organic compounds are the most important components of food that can absorb IR energy at wavelengths over $2.5\mu m$ (Wang et al., 2018).

Infrared heating is an efficient technology, and its characteristic features include high heating efficiency, short process time and fast heating speed, uniform heating, high heat transfer rate, low energy consumption, and direct heat penetration in the product (Rodrigues et al., 2021).

Dietary processes can affect food in whole or in part. Numerous physical, chemical, and microbiological changes may also occur in the food during production, storage, and storage. These factors cause physical changes such as color and texture (Antigo et al., 2018). They can also cause unwanted reactions such as the breakdown of nutrients. So having a good drying method would be a good choice for storing valuable food. Drying provides a means of storing food in safe and stable conditions, as it reduces water activity (Salehi & Satorabi, 2021). Many older methods of heating, including airflow drying, vacuum drying, and freeze-drying, reduce the drying rate during the descent drying phase. Prolonged drying time at higher relative temperatures during the decreasing drying speed period causes improper temperature degradation of the final product. The term drying refers to the removal of moisture from materials (Cardoso et al., 2021). This method is the most common and widely used method in terms of energy consumption for food storage, which is associated with many changes, especially in solid particles, pastes, long sheets, clots, or solutions. Air drying is an old food preservation process in which the solid to be dried is exposed to constant moving air, which causes moisture to evaporate (Taghinezhad et al., 2021).

Drying reduces the risk of contamination by reducing the water activity of food products, prolongs their shelf life, and reduces the cost of storage and transportation (Yousefi et al., 2013). Therefore, it is necessary to study and find a suitable method for drying pumpkins that produces a high-quality product (Mirzaei et al., 2021). Today, infrared radiation is used as a continuous or intermittent source of thermal energy to improve quality and save energy. Infrared radiation has many advantages over conventional heating methods, and the quality of the dried product in this method is higher. Also, in this method of heating, the processing time is shorter, and the amount of energy consumption is less (Nowak & Lewicki, 2004). Like other drying methods, infrared drying is due to the pressure difference between inside and outside the product, which is the driving force of moisture transfer. In infrared dryers, heat is generated inside the material and concentrated in the points where there is more moisture, and increasing the moisture pressure, causes the diffusion of moisture from those points to the outer layers; therefore, in this drying method, it seems that the problems related to hardening of the shell and preventing more moisture from leaving can be reduced (Doymaz, 2012).

## 2 Material and methods

In this section, explanations about the use of infrared waves in the food industry, cooking food by infrared waves, drying by infrared waves, drying using a combination of infrared and hot air, preparation of samples, method of determining the effective emission coefficient, and method of determining the amount of activation energy are provided, respectively.

### *2.1 Use of infrared waves in the food industry*

As one of the modern and reliable sources of heat, infrared waves have opened $0.78 - 1000\mu m$ their place in many industries. Infrared heating technology transfers a large amount of energy in a short time, and due to the type of heat transfer in this method, cracking is expected, and fracture due to tensile stress is reduced. Infrared heating has many advantages over traditional heating methods, including reduced uniform heating time, reduced product quality, usability in many cases, simplicity and low volume of tools and equipment, and a significant reduction in energy consumption. This technology has been widely used in various food industry processes such as drying, cooking, frying, enzyme deactivation, pathogen inactivation, sterilization, and pasteurization. Infrared or infrared waves (wavelengths) are part of electromagnetic radiation between visible waves.

### *2.2 Cooking food by infrared waves*

IR radiation is an efficient method in cooking food, both for cooking the product's surface parts and the central parts. Reduction of cooking time in this method is due to effective heat transfer to the surface compared to heating by convection or convection method, and lower weight of food in this method causes high water content in the central part during cooking, which leads to improved product quality during maintenance. IR cooking for the processed meat section has received special attention because the use of the convection method can cause surface damage, overheating, oxidation, low efficiency, and high energy costs. So far, many examples of cooking and heating food have been provided by the FIR method, such as drying fruits and vegetables, roasting coffee, baking bread and biscuits, heating fish and pork. Rapid surface heating by this method can be used to cook and heat food while preserving aroma, taste, aromatic compounds, and acceptable quality characteristics.

### *2.3 Drying by infrared waves*

The oldest method of drying food is to expose it to sunlight, which aims to reduce water activity and increase shelf life. Drying also increases food shelf life by repairing enzyme activation and destroying microorganisms. Infrared heating has advantages over the convection method, so that in this method, high heat transfer coefficient, short process time, and energy cost are low.

Drying using a combination of cryopreservation and infrared. Freeze drying is one of the best ways to dry high-cost food. Therefore, the use of infrared waves by removing part of the moisture content before freezing can reduce process time, reduce costs and increase the quality of food products.

### 2.4 Drying using a combination of infrared and hot air

In all food-related industrial units, drying is one of the most important processes because, in most stages of food production, at least one stage of drying is seen. Drying refers to the process of reducing the moisture content of a material until it reaches a dry product, which is done in different ways. Drying materials using heat sources is the most important and common drying method. In the drying process, the main goal is to use the minimum thermal energy to extract the maximum amount of moisture, taking into account the product's final quality. Based on this, various methods for drying were invented and introduced, including drying materials using infrared waves. Infrared waves emitted from any source carry energy that is transmitted from the source to the body without the need for an interface and then cause food molecules to vibrate and heat up.

Infrared waves have properties that its usage in drying agricultural products, reducing energy consumption, reducing drying time, and increasing the quality of the final product, so its use in recent years with advances in the type of infrared sources red is on the rise. In the combined method of hot air infrared drying, heat transfer takes place simultaneously through hot air flow and infrared radiation. In this way, combined infrared dryers of hot air have the advantages of both individual methods and usually reduce the drying time and increase the quality of the final product. With the invention of each new method, its effect on the drying process of different products should be studied. This method is very fast compared to the separate methods of infrared drying and hot air drying and has advantages such as high-efficiency heat transfer and improving the quality of the dried product. Also, during the drying process with the combined method, the temperature of the food is kept almost low, and thus the quality of heat-sensitive products is prevented from declining, so this method can be used as an alternative method for drying sensitive products heat was considered.

### 2.5 Preparation of samples

The samples were taken out of the refrigerator and kept at room temperature (23 °C) before the test. The samples were converted into sheets 5 mm thick. The initial humidity of the pumpkin samples was determined in an oven at 100 °C for 48 hours.

In order to perform the experiments, an infrared dryer with the ability to control the power of radiation was used. Only infrared radiation and air convection flow were drying agents in this device. The samples were placed on an insulated tray and exposed to radiation from one side. A thermocouple measured the center temperature of the samples. During the experiment, the weight of the samples was measured every 10 seconds with an accuracy of 0.001 g. The aforementioned infrared dryer was turned on one hour before each test to reach a stable level. The experiments were performed at temperatures of 55, 65, 75, and 85 °C. These temperatures were adjusted by selecting the appropriate radiation power.

### 2.6 Method of determining the effective emission coefficient

Due to the decreasing rate of drying, internal resistance to mass transfer (moisture) is observed. Fick's diffusion equation analyzes the drying process at a declining rate. The mentioned equation is in the form of (Equation 1) (Barton, 1975).

$$MR = \frac{8}{\pi^2}\exp\left(-\frac{\pi^2 D_{eff}\,t}{4L^2}\right) \tag{1}$$

In this equation, "$D_{eff}$" represents the effective diffusion coefficient ($m^2/s$), "t" drying time (s), and "L" is half the thickness of the blade-shaped specimens (m).

### 2.7 Method of determining the amount of activation energy

According to the Arrhenius relation, the dependence of $D_{eff}$ on temperature can be expressed as (Equation 2) (Simal et al., 1996).

$$D_{eff} = D_0\exp\left(-\frac{E_a}{R(T+273.15)}\right) \tag{2}$$

In this equation, "$D_0$" represents the fixed Arrhenius ($m^2/s$), "$E_a$" activation energy (kJ/mol), "T" drying temperature (°C), and "R" is the global constant of gases.

## 3 Results and discussion

In this section, the results related to the determination of moisture ratio, drying rate, effective diffusion coefficient, and activation energy are presented, respectively.

### 3.1 Determining the moisture ratio

The graph of changes in the humidity ratio with the drying time of the samples at temperatures of 55 to 85 °C is shown in (Figure 1). As the drying temperature increases, the moisture content decreases at a certain time. As the results show, with increasing temperature from 55 to 85 °C, the drying time decreases by about 60%. At higher temperatures, the drying process takes less time due to the faster removal of moisture. This reduction in drying time, which occurs as a result of rising temperatures, maybe due to increased water vapor pressure inside the pumpkin slices, which increases moisture migration.

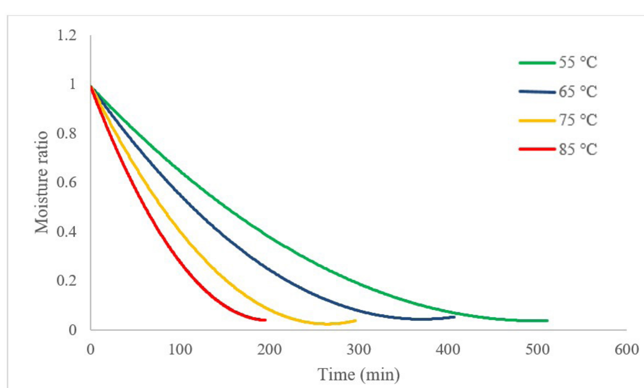


**Figure 1**. Changes in moisture ratio with time.

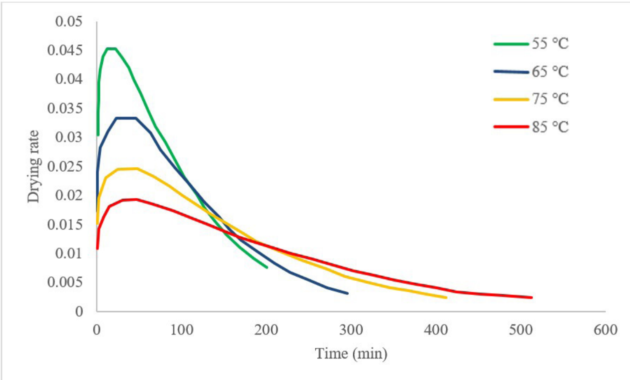


**Figure 2**. Changes in drying rate with time.

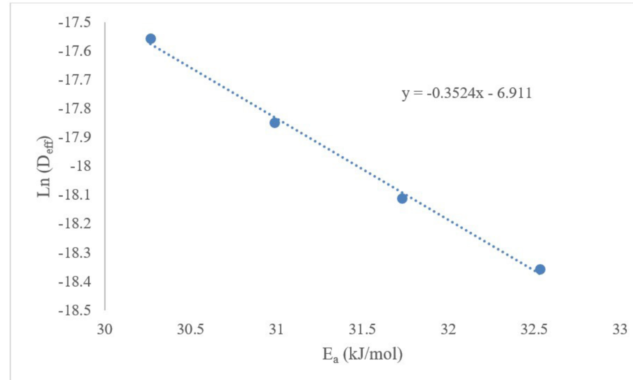


**Figure 4**. Determination of activation energy ($E_a$) based on the changes in $D_{eff}$ with temperature.

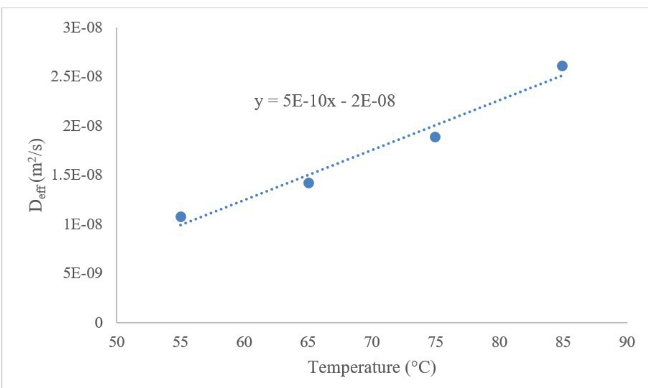


**Figure 3**. The drying temperature affects changes in effective diffusion coefficient ($D_{eff}$).

### *3.2 Determining the drying rate*

(Figure 2) shows the changes in drying speed versus drying time at the test temperatures. According to the Figure2, drying speed is initially high and gradually decreases during the process. The drying process of the parts takes place at a constant speed, and the process takes place at a decreasing speed, and it is only at the beginning of the drying time that the speed is increased. This time is about 6% of the total drying process time.

### *3.3 Determining the effective diffusion coefficient*

Based on (Equation 1), the effective diffusion coefficient of moisture of the pumpkin cuts during drying at different temperatures of 55 to 85 °C infrared rays was determined, the results of which are shown in (Figure 3). As the temperature increases, the value of $D_{eff}$ increases. According to the results, it was found that with increasing temperature from 55 to 85 °C, the amount of $D_{eff}$ increased from $1.1 \times 10^{-8}$ m²/sto $2.64 \times 10^{-8}$ m²/s, and has increased by 140%.

### *3.4 Determining the activation energy*

The amount of activation energy obtained for pumpkin slices, using (Equation 2), is equal to 30.27 kJ/mol. Activation energy values are shown in (Figure 4).

## 4 Conclusion

Infrared processes have high efficiency and many environmental and economic benefits compared to conventional thermal processes, so in the food processing industry, the tendency to heat by infrared radiation has increased over the past few years. The results showed that increasing the temperature reduces the drying time and drying rate and also increases the effective diffusion coefficient. In general, due to the problems of conventional heating and the many applications of infrared heating in the food industry, it is expected that this technology can be a suitable alternative or complement to conventional thermal processes.

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