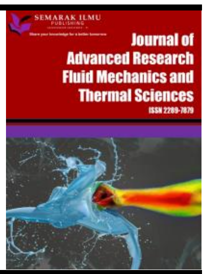
*Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 118, Issue 2 (2024) 47-61

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879




# Improve Drying Performance of Noodles using Hot Air Combined with Infrared Stimulation

Vinai Boonmunas[1], Praphanpong Somsila[1], Eakpoom Boonthum[2], Apinunt Namkhat[1], Umphisak Teeboonma[1,*]

[1] Department of Mechanical Engineering, Faculty of Engineering, Ubon Ratchathani University, Ubon Ratchathani Province, 34190, Thailand
[2] Department of Mechanical Engineering, Faculty of Industrial Technology, Pibulsongkram Rajabhat University, Phitsanulok Province, 65000, Thailand

**ARTICLE INFO**

***Article history:***
Received 16 January 2024
Received in revised form 26 May 2024
Accepted 5 June 2024
Available online 30 June 2024

***Keywords:***
Drying; hot air dryer; infrared; stimulation

**ABSTRACT**

Noodles are a product that has a large amount of consumption in Thailand. Therefore, it is important to extend the shelf life and increase the value of the noodles by drying. However, drying noodles has a relatively high energy consumption. For this reason, it is necessary to develop an energy-efficient drying process. Therefore, this research aims to study the drying of noodles using hot air combined with infrared stimulation. The drying performance was compared between the case with and without infrared stimulation. The experimental conditions were as follows: drying temperatures were 45, 50, and 55°C and hot air velocity were 1.0, 1.5, and 2.0 m/s. Criteria used to evaluate drying performance include drying rate and specific energy consumption. The study found that increasing in drying temperature and hot air velocity resulted in an increase in the drying rate and power of the dryer. Meanwhile, the specific energy consumption has decreased. It was also found that the drying efficiency of noodles using hot air combined with infrared stimulation was higher than the drying efficiency without infrared stimulation.

## 1. Introduction

Noodles are one of the noodle products that are widely and in large quantities consumed. Noodles are commonly found in noodle shops throughout Thailand and are the second most popular food consumed by consumers after rice. This is because noodles provide relatively high energy and are not very expensive. Noodles can also be used to cook many other types of food, such as stir-fried noodles, stir-fried soy sauce, crispy noodles and noodles, etc. Noodles have a white strand appearance because the main ingredients are flour and water. As a result, microorganisms can grow well, causing the noodles to spoil quickly and can be stored for no more than 3 days. Therefore, it is necessary to have a process to reduce the moisture content of the noodles with a drying process in order to remove water from the noodles in order to inhibit the growth of microorganisms. Drying with a dryer is therefore a good way to solve this problem. There are many methods of drying with

* *Corresponding author.*
*E-mail address: umphisak.t@ubu.ac.th*

https://doi.org/10.37934/arfmts.118.2.4761

dryers today, such as hot air drying from an electric heater, infrared drying, superheated steam drying, vacuum drying, heat pump drying and etc. It is well known that the drying process uses relatively high energy. However, there are researchers who have studied and tested drying techniques that have high energy efficiency along with obtaining quality products after drying as well, as detailed below. From previous research, related studies can be classified into 3 groups. The first group is that a single source of heat energy is studied for drying products consisting of A study of garlic drying with hot air studied its physical characteristics, hydration characteristics and the amount of allicin in garlic and drying rice noodles and noodles with a tunnel hot air dryer that has been developed to increase the length and dry the noodles in order to improve the quality to have good drying properties [1-3]. Moreover, there have also been studies on drying sweet potatoes, longan, and cantaloupe with hot air to study factors related to drying time and to be able to obtain quality dried products [4,5]. In addition, there are studies on various factors related to the drying process that correspond to the food quality of cooking, pressure or cooking time, etc [6]. There are also studies on the development of drying dynamics models, drying kinetics that can be used to predict drying behavior [7-9]. The development of hot air dryers for use in drying agricultural products for storage can produce different drying rates depending on the product [10,11]. Finally, infrared dryers are used for drying to focus on increasing energy efficiency [12,13].

The second group is a group of research that deals with the selection of two heat sources for drying, also known as hybrid drying. Researchers have studied the use of hot air and infrared, most of which are used together throughout the drying period and studied factors related to drying, such as drying temperature, hot air speed, and intensity of infrared radiation along with studying the physical properties of the product after drying as well [14-20]. In addition, there is a study of hot air drying combined with infrared in the periodic use of hot air and infrared and a comparison of the drying cases where hot air is used only, infrared alone is used and use together [21-23]. Furthermore, the drying kinetics of the product after drying using a hybrid dryer was analyzed [24,25]. The last group is the group that studies the use of more than two energy sources and compares the results. It was found that studies to compare several drying techniques including hot air drying, infrared drying, freeze drying, and high-voltage electric field drying (HVEF), microwave drying, vacuum drying and etc. Most of the produce used in drying is agricultural products such as ginger, nuts, cannabis, chives and brown rice with various factors varying in order to obtain quality products after drying [26-32]. Based on the results of the three groups, it can be concluded that the second and third groups had somewhat higher performance than the first group. But it is still possible to increase efficiency even more than at present by stimulating heat during the appropriate drying period.

From past studies, it has been found that there is still little improvement in the use of stimulation techniques in the range of reduced drying rates. Therefore, the objective of this research is to study the drying performance of noodles with hot air combined with infrared stimulation during the falling rate period by comparing the performance of the dryer between hot air drying and infrared stimulation drying.

## 2. Methodology

### *2.1 Experiment Setup*

Figure 1 shows a schematic diagram of the experimental equipment and the operation of the hot air dryer. The details of the components and working principles of the dryer can be described as follows.

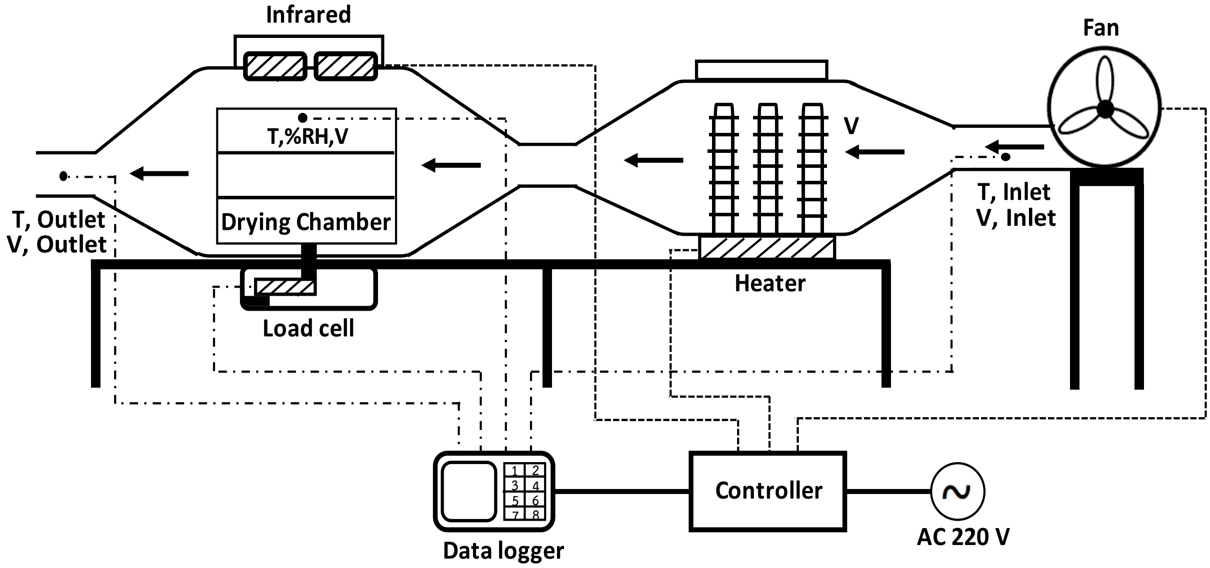



**Fig. 1.** Schematic diagram of the experimental equipment

The hot air dryer consists of 6 sets of 1,000 W fin heaters, 4 sets of 0.7 kW infrared heaters, 0.37 kW fan, 40 x 42 x 37 cm drying chamber, 4$^{th}$ of tray, load cell, data logger, measuring instrument and a set of equipment to control of the dryer.

The operation of the hot air dryer starts with outside air being drawn in by a fan at the inlet position. The air then flows through the heater to be heated. Hot air flows into the drying chamber and exits from the drying chamber at the outlet position. Infrared stimulation by radiating heat to the product inside the drying chamber. The air then flows out of the drying chamber at the outlet position, resulting in a decrease in the drying moisture proportion throughout the drying period. Additionally, the temperature control of the drying chamber is controlled using magnets that work together with the drying room temperature sensor to control the operation automatically. That is, when the temperature in the drying chamber reaches the set value, the magnets will cut off the heater/infrared system. Then, when the temperature in the drying room is lower than the set value, the magnets will resume operation as usual. The operation of the hot air dryer will continue repeatedly until the drying process ends.

### *2.2 Experimental Method*

The hot air dryer uses 2 systems of heat energy for drying: a heater system and an infrared system. Control the drying temperature by cutting off the heater's work with magnets and working together with the drying room temperature sensor. The experiment involved two drying systems: hot air drying and hot air drying and infrared stimulation techniques. Experiments were conducted at drying chamber temperature of 45, 50 and 55°C with hot air velocity in chamber of 1, 1.5 and 2 m/s, respectively. An experiment was conducted on drying noodles with a thickness of approximately 0.1 cm. and a length of approximately 27±2 cm. Noodle weight starts at 300 g per batch. Noodles had an average initial moisture content of 75.0%d.b., Drying was carried out until the final moisture content remained approximately 11.0%d.b., which is the moisture content of the product available in the market. Moisture content of noodle products was determined using the moisture determination method according to AOAC standards [33]. During the experiment, various values were measured and recorded, including temperature of the inlet and outlet air, temperature of the drying chamber, the ambient temperature, weight of product that changed throughout the drying process and the electrical energy consumption.

The experiment began with turning on the hot air dryer and adjusting the drying temperature and air velocity at the control unit according to the study conditions. Attach the thermocouple cable and load cell to the data logger and make adjustments to the measuring instruments. After that, run the hot air dryer until the system reaches steady state by considering the change in each variable specified. When the system reached steady state, the noodles were placed inside the drying chamber and the experiment was carried out until the noodles reached the final moisture content as specified, thus completing the experiment.

### *2.3 Analysis*

Analysis of experimental results includes moisture content, moisture ratio, drying rate and specific energy consumption. The details of the analysis of the results are as follows.

Moisture content, MC. Moisture content determination is carried out by preparing some products to dry in an electric oven at 103°C for 72 hours according to AOAC (2019) standards for use in determining dry weight. Then use the obtained values to calculate the moisture content at each time period as shown in Eq. (1) [2].

$$MC = \frac{w - d}{d} \tag{1}$$

where MC Dry basis moisture content at each time period (%d.b.) W Wet weight of product at each time period (g) d Dry weight of product at each time period (g).

Moisture ratio, MR. Changing in moisture content and drying time can be seen in Eq. (2) [11,21].

$$MR = \frac{M_t}{M_{in}} \tag{2}$$

where MR Moisture ratio (decimal) Mt moisture content at each time period (%d.b.) Min Initial moisture content (%d.b.).

Drying rate, DR, is a variable indicating the amount of moisture that can evaporate per unit of time. The relationship is as shown in Eq. (3) [4,11].

$$DR = \frac{\Delta w}{\Delta t} \tag{3}$$

where DR Drying rate (g/h) $\Delta$w water evaporates (g) $\Delta$t Time (h).

Specific energy consumption, SEC, is a value that represents the efficiency of energy use, which has a relationship as shown in Eq. (4) [5,24].

$$SEC = \frac{3.6E}{w_i - w_f} \tag{4}$$

where SEC Specific energy consumption (MJ/kg) $w_i$ Initial weight of product before drying (kg) $w_f$ Final weight of dried product (kg) E Electrical power (MJ).

Finding stimulation points using infrared starts with hot air drying, when the point of product moisture change is relatively small, the drying technique is changed from hot air to infrared drying. This will change the drying technique from considering the slope of the moisture change at any time compared to the difference in time as shown in Eq. (5).

$$Slope = \frac{\Delta M}{\Delta t} \tag{5}$$

where Slope value $\Delta$M different moisture content at any time (d.b.) $\Delta$t Time difference over any moisture content range. This research time is equal to 1 minute.

## 3. Results

Drying noodles with a hot air dryer that uses heater and infrared stimulation. The experimental conditions are drying with only hot air and using hot air and infrared stimulation techniques. The experiments were conducted at drying temperatures of 45, 50, and 55 °C and air velocity of 1, 1.5, and 2 m/s, respectively. The symbols in all figures include T describing the drying chamber temperature followed by a number representing each drying temperature in degrees Celsius and V describing the speed of the drying chamber hot air followed by each number representing the speed in meters per minute. The results are as follows:

Figure 2 shows the moisture content of the product in each experimental condition in the case of hot air drying. In all experimental conditions, the initial humidity of the noodles was equal to 75%d.b. It was found that the drying period starting from approximately 30-40 min in all experimental conditions had a constant moisture reduction rate proportional to time and a constant value as long as the movement of water to the surface of the noodles was balanced with moisture evaporates on the surface. This period is the constant rate period during which activated moisture is drawn from the noodles. Water moves from the inside to the surface of the noodles evenly, causing the surface to have a wet appearance. The temperature of the noodles is constant at the same temperature as the wet bulb temperature of the hot air. For moisture ratio in all experimental conditions, values ranged from 37-52 %d.b. This position is the end of the constant drying period and the beginning of the falling rate period. The drying period is a period in which the amount of water on the surface of the noodles decreases because the amount of water on the surface will evaporate. This is due to the movement of water from the inside to the surface being out of balance with water evaporate on surface and it is the period with the longest period of any drying period. From the above, the said point was chosen as the point of infrared stimulation. From the beginning of the drying period, hot air from an electric heater was used until the end of constant rate period. After the constant rate period ended, the use of infrared during the falling rate period until the drying process was completed without hot air being turned on. Therefore, it could be said that it is the point where the drying conditions are changed from hot air drying to infrared drying with the feature of infrared that can create molecular vibrations to generate heat and has a lower electrical power than an electric heater as well.

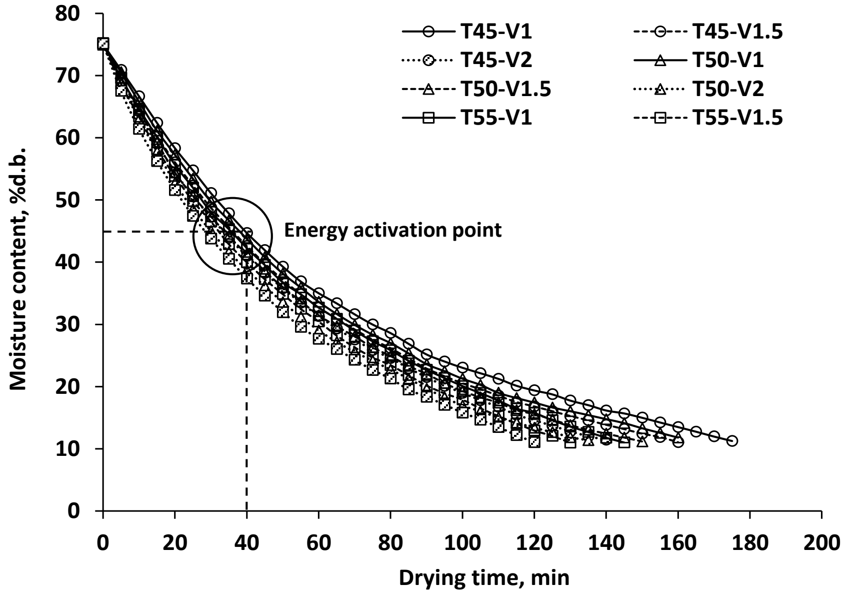



**Fig. 2.** Product moisture content in each condition of hot air drying

Figure 3 shows the product moisture content in both the hot air drying and infrared stimulation drying at the drying temperature of 45°C in each experimental condition. From the data for the case of hot air drying, it was found that the shortest drying time was 140 minutes at an air velocity of 2 m/s and longest drying time was 175 minutes under the condition of air velocity of 1 m/s. For the case of infrared stimulated, it was found that the shortest drying time was 90 minutes at air velocity of 2 m/s and the longest drying time was 105 minutes at air velocity of 1 m/s. It was found that the drying time decreased with infrared stimulation, the average of all experimental conditions at the drying temperature of 45°C was 61.70 minutes. Similarly, the drying temperature of 50°C is shown in Figure 4. It was found that in the case of hot air drying, the shortest and longest drying times were 135 minutes and 160 minutes within the conditions of air velocity of 2 m/s and 1 m/s, respectively. In the case of infrared stimulation, the shortest and longest drying times were 80 minutes and 95 minutes at air velocity of 2 m/s and 1 m/s, respectively [15]. It was found that the drying time decreased with infrared stimulation, the average of all experimental conditions at the drying temperature of 50°C was 61.70 minutes. Figure 5 is for the drying temperature of 55°C. It was found that in the case of hot air drying, the shortest and longest drying times were 120 minutes and 145 minutes at air velocity of 2 m/s and 1 m/s, respectively. In the case of infrared stimulation, the shortest and longest drying times were 75 minutes and 85 minutes at air velocity of 2 m/s and 1 m/s, respectively. It was also found that the drying time decreased with infrared stimulation, the average of all experimental conditions at the drying temperature of 55°C was 51.70 minutes, which is consistent with [7,24].

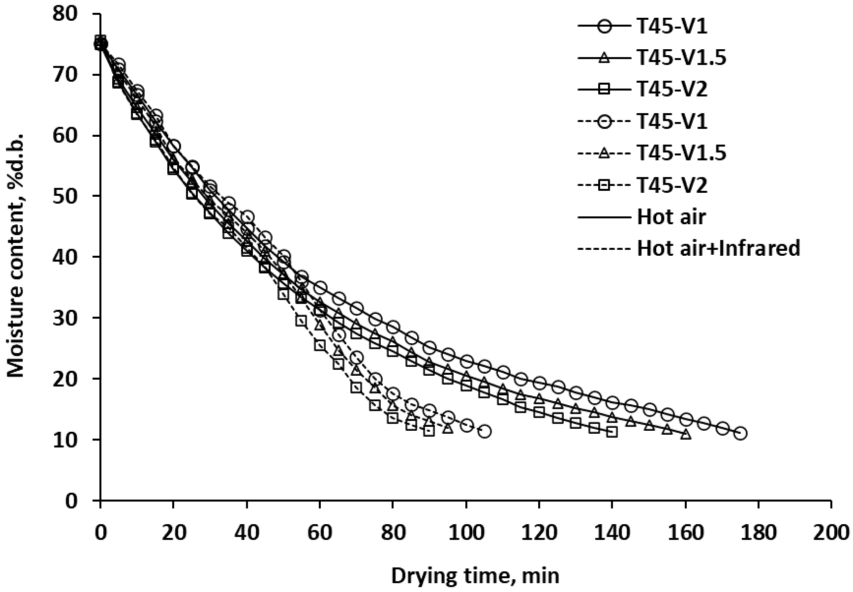



**Fig. 3.** Product moisture content in hot air and infrared stimulation drying at drying temperature was 45 °C in each experimental condition

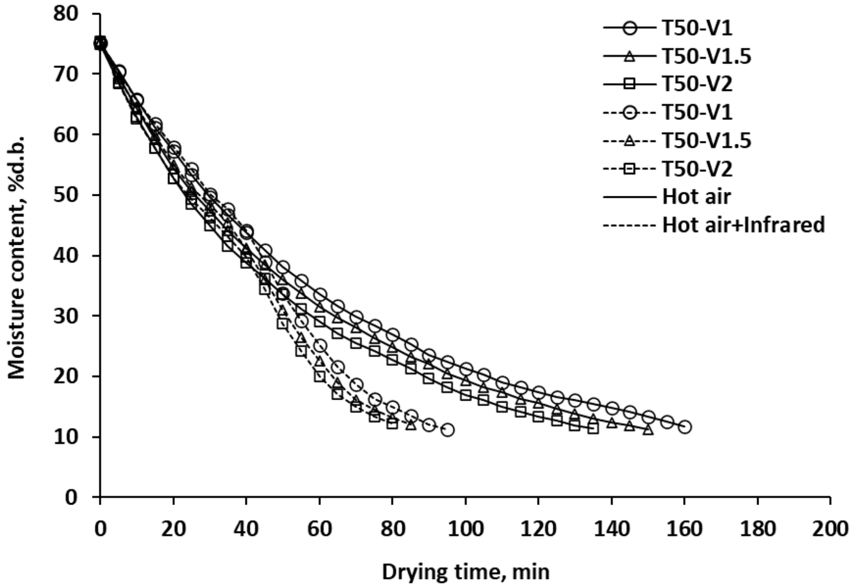



**Fig. 4.** Product moisture content in hot air and infrared stimulation drying at drying temperature was 50°C in each experimental condition

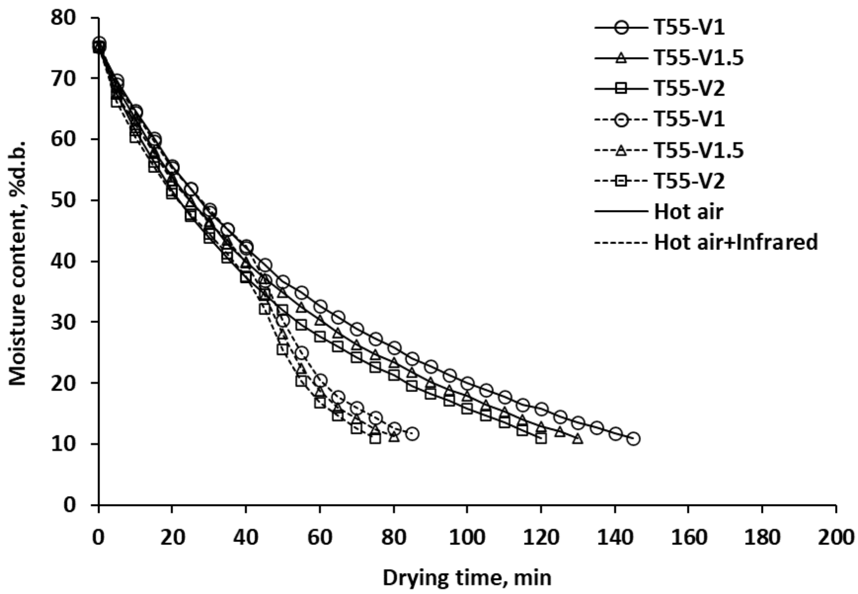



**Fig. 5.** Product moisture content in hot air and infrared stimulation drying at drying temperature was 55 °C in each experimental condition

Figure 6, Figure 7 and Figure 8 shown moisture ratios of the products in the hot air drying and infrared stimulation drying at drying temperature of 45, 50, and 55°C in each experimental condition, respectively. It was found that the moisture decreased rapidly during the first 40 minutes in the case of hot air drying and the first 35 minutes in the case of infrared-activated drying. Thereafter, the moisture ratio decreased slowly and similarly temperature of product increased with increasing drying time [17]. It was found that in the case of infrared stimulation, drying time was shorter than hot air drying with the same drying temperature and air velocity in all experimental conditions. Because infrared stimulation can penetrate through product surface layer, part of the radiation energy was absorbed by product and causes the product molecules to vibrate and convert into heat energy. Therefore, the water in the molecule will be heated and spread to the surface of the product, causing the moisture in the noodles to decrease more quickly than in the case of drying with hot air. It was also found that an increase in the drying temperature and air velocity resulted in a shortened drying time. It was found that in the case of increasing the drying temperature and hot air velocity, the temperature difference between product and hot air increased [20]. As a result, the heat transfer rate increases, causing the amount of moisture evaporation from the product to be increased. The same is true of hot air velocity, that is an increase in hot air velocity causes an increase in the convection coefficient. This causes the heat transfer value to increase as a result, the moisture ratio decreases in a faster drying time. Compare the moisture ratio in the case of hot air drying and infrared stimulation drying. It was found that the drying time to reach the final moisture content of the noodles at 11 %d.b. in the case of infrared stimulation drying was greater than hot air drying in all experimental conditions, with an average of 58.33 minutes. The percentage of drying time reduced compared to hot air drying in all experimental conditions was 39.93%.

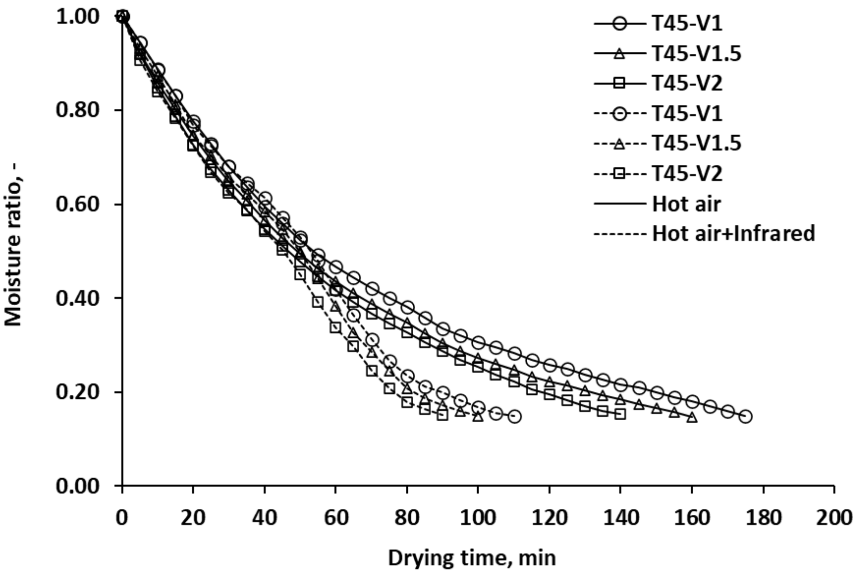



**Fig. 6.** Moisture ratios of the products in the hot air drying and infrared stimulation drying at drying temperature of 45°C in each experimental condition

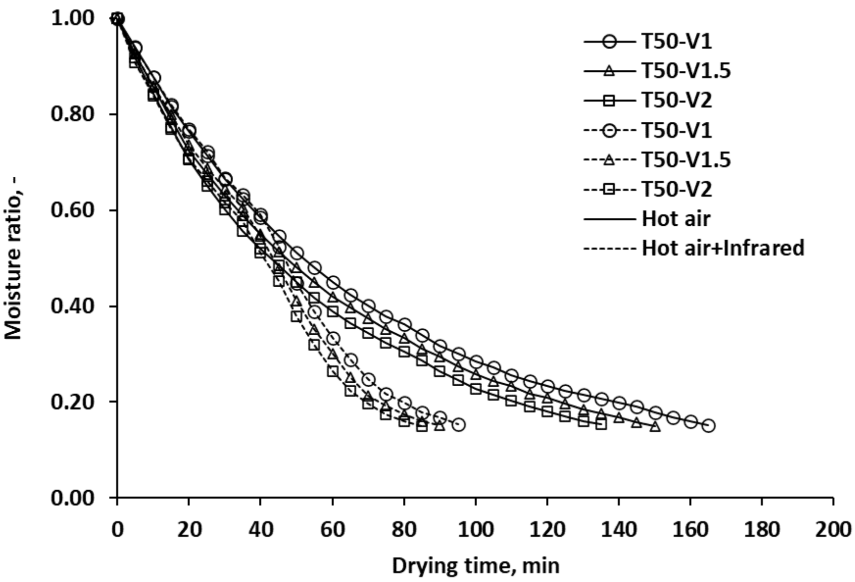



**Fig. 7.** Moisture ratios of the products in the hot air drying and infrared stimulation drying at drying temperature of 50°C in each experimental condition

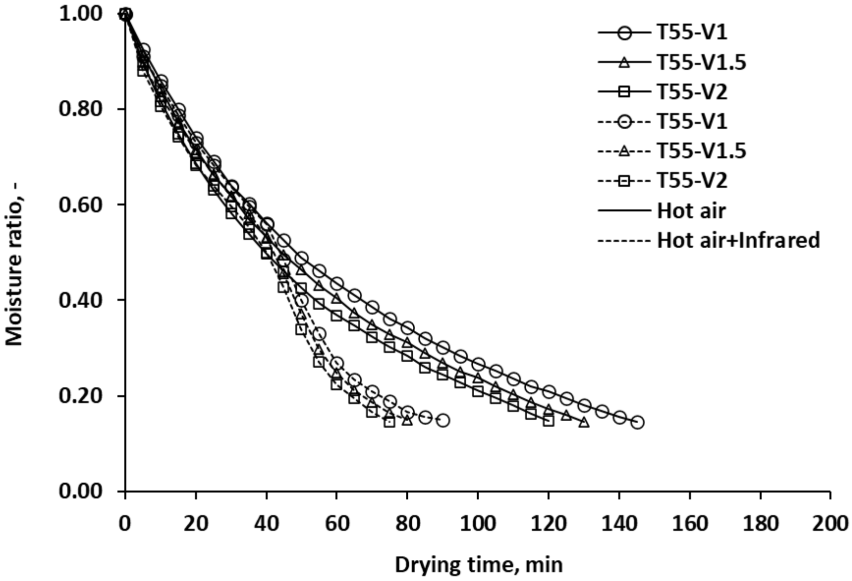



**Fig. 8.** Moisture ratios of the products in the hot air drying and infrared stimulation drying at drying temperature of 55°C in each experimental condition

Figure 9 shown the drying rate of the product in each experimental condition. It was found that the drying rate of noodles in the case of infrared stimulation drying was higher than hot air drying in all experimental conditions, with an average of 29.16 g/h or 64.50% of all experimental conditions in the case of hot air drying, which is consistent with [21]. It was also found that the highest drying rate occurred in the case of infrared stimulation drying at drying temperature of 55°C and a hot air velocity of 2 m/s was 88 g/h. The lowest drying rate occurred in the hot air drying at drying temperature of 45°C and a hot air velocity of 1 m/s was 36.87 g/h. Adding infrared stimulation to the noodle drying process can increase the drying rate more than hot air drying. This can be explained by the same reason as Figure 3 to Figure 8 by the ability to stimulate water molecules to vibrate to generate heat and accelerate the evaporation of water from the product quickly [11,12]. As a result, the drying rate has clearly increased.

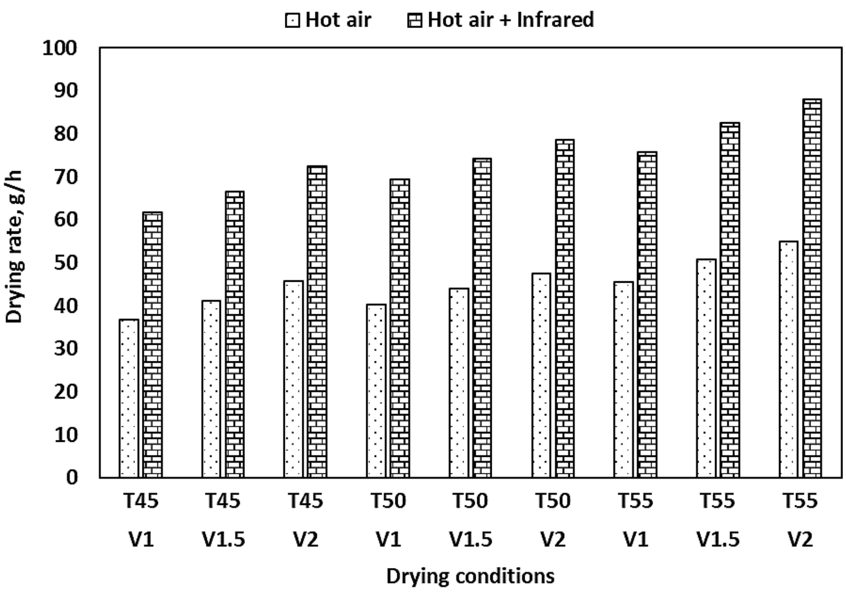



**Fig. 9.** Drying rate in each experimental condition

Figure 10 shows the dryer power in each experimental condition. It was found that the electrical power of the dryer in the case of drying with infrared stimulation was higher than in the case of hot air drying in all experimental conditions, with an average of 1.55 kW or 21.10% of all experimental conditions in hot air drying. In addition, it was found that in the case of hot air drying, when considering the hot air velocity to be constant for every 10% increase in the average drying air temperature, the dryer power increased on average to 4.25 kW. Considering that the drying temperature remains constant for every 50% increase in hot air speed, the dryer power increases on average by 0.02%. For the case of drying with infrared stimulation, considering that the hot air velocity is constant for every 10% increase in the average drying temperature, the average dryer power increase is 3.09 kW. Considering that the drying temperature remains constant for every 50% increase in hot air speed, the dryer power increases on average by 0.01%. The above data shows that the dryer with infrared stimulation and the increase in the drying air temperature had a greater effect on power than the increase in the hot air velocity.

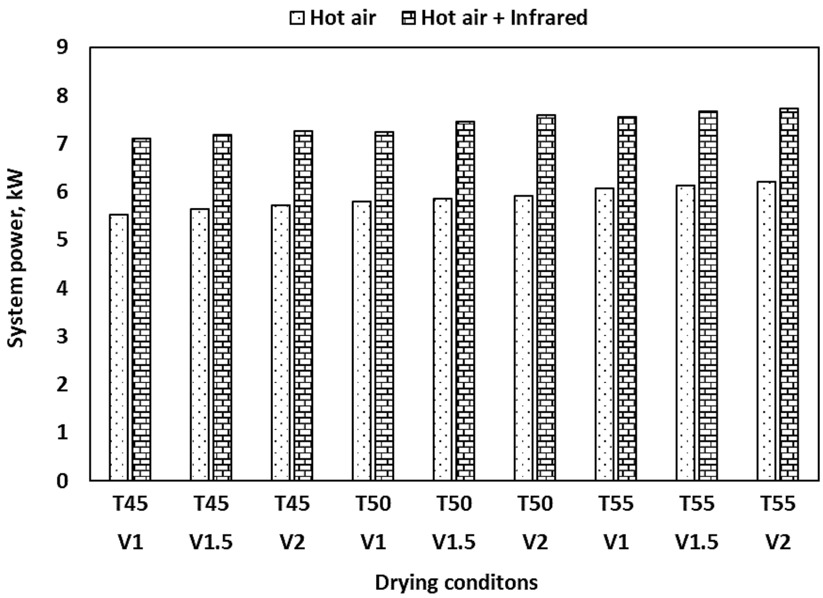


**Fig. 10.** Electrical power at each experiment conditions

Figure 11 shows the specific energy consumption in each experimental condition. The lower specific energy consumption indicates that the drying process with this dryer has a high level of energy efficiency. It was found that the lowest specific energy consumption occurred on infrared stimulation drying at drying air temperature of 55°C and a hot air velocity of 2 m/s, equal to 24.55 MJ/kg. If we consider only the electrical power as shown in Figure 10, it would be found that in this condition the dryer has the highest power consumption. However, at this condition it was found that the shortest drying time was used. Considering the same water evaporation from the product, the short drying time condition results in the lowest specific energy consumption, which is consistent with [5,10,12]. Additionally, it was found that the specific energy consumption in hot air drying was between 31.42 - 46.87 MJ/kg and infrared stimulation drying was between 24.55 - 35.02 MJ/kg. In all experimental conditions, it was found that specific energy consumption of infrared stimulation drying was higher than hot air drying.

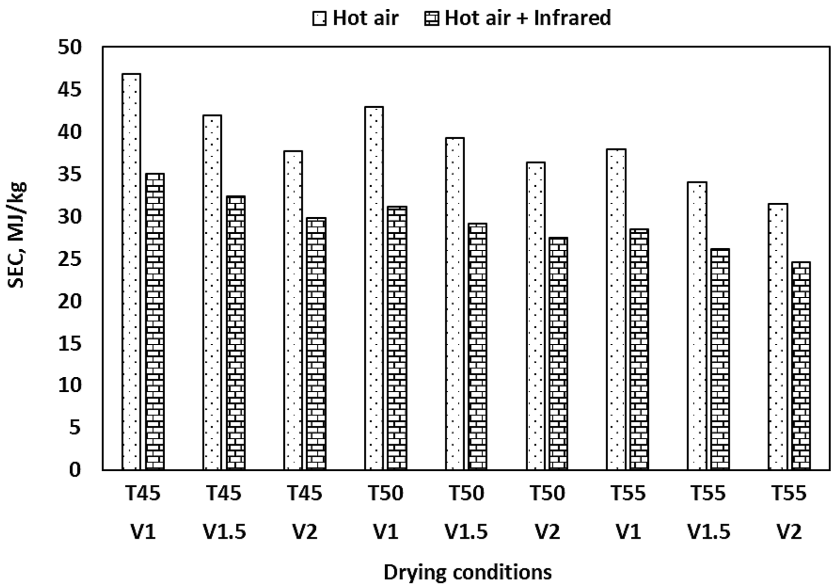



**Fig. 11.** Specific energy consumption at each experiment conditions

Table 1 presents an overview of the dryer performance analysis in the case of hot air drying. The average from the beginning of the experiment until the end of the experiment was found to be at a temperature of 55°C and an air velocity of 2 m/s the drying rate was 55 g/h. It is also the condition that gives the lowest specific energy consumption. Table 2 presents an overview of the dryer performance analysis in the case of drying with infrared stimulation. The average from the beginning of the experiment until the end of the experiment was found to be at a temperature of 55°C and an air velocity of 2 m/s the drying rate was 88 g/h. It is also the condition that gives the lowest specific energy consumption. When comparing the overall data of the dryer performance analysis in the case of hot air drying with infrared stimulation, it was found that the drying with infrared stimulation had a performance higher than hot air drying. It has a higher drying rate and lower specific energy consumption.

**Table 1**
Performance analysis in the case of drying with hot air

| Description | Conditions | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | T45 V1 | T45 V1.5 | T45 V2 | T50 V1 | T50 V1.5 | T50 V2 | T55 V1 | T55 V1.5 | T55 V2 |
| Initial weight, g | 300 | 300 | 300 | 300 | 300 | 300 | 300 | 300 | 300 |
| Initial moisture content, %d.b. | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 |
| Final moisture content, %d.b. | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 |
| Drying time, h | 2.98 | 2.67 | 2.40 | 2.73 | 2.50 | 2.32 | 2.42 | 2.17 | 2.00 |
| Drying rate, g/h | 36.87 | 41.25 | 45.83 | 40.24 | 44.00 | 47.48 | 45.52 | 50.77 | 55.00 |
| Energy consumption, kWh | 1.43 | 1.28 | 1.15 | 1.31 | 1.20 | 1.11 | 1.16 | 1.04 | 0.96 |
| Specific energy consumption, MJ/kg | 46.87 | 41.89 | 37.70 | 42.94 | 39.27 | 36.39 | 37.96 | 34.04 | 31.42 |

**Table 2**
Performance analysis in the case of drying with infrared stimulation

| Description | Conditions | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | T45 V1 | T45 V1.5 | T45 V2 | T50 V1 | T50 V1.5 | T50 V2 | T55 V1 | T55 V1.5 | T55 V2 |
| Initial weight, g | 300 | 300 | 300 | 300 | 300 | 300 | 300 | 300 | 300 |
| Initial moisture content, %d.b. | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 |
| Final moisture content, %d.b. | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 |
| Drying time, h | 1.78 | 1.65 | 1.52 | 1.58 | 1.48 | 1.40 | 1.45 | 1.33 | 1.25 |
| Drying rate, g/h | 61.68 | 66.67 | 72.53 | 69.47 | 74.16 | 78.57 | 75.86 | 82.50 | 88.00 |
| Energy consumption, kWh | 1.07 | 0.99 | 0.91 | 0.95 | 0.89 | 0.84 | 0.87 | 0.80 | 0.75 |
| Specific energy consumption, MJ/kg | 35.02 | 32.40 | 29.78 | 31.09 | 29.13 | 27.49 | 28.47 | 26.18 | 24.55 |

## 4. Conclusions

This research studied the enhancement of the drying performance of noodles with hot air combined with infrared stimulation by comparing the dryer performance between the drying with hot air and the drying with hot air combined with infrared stimulation. Noodles were the test sample. It was found that drying with infrared stimulation increases the drying rate. The drying rate of noodles in the case of drying with infrared stimulation was higher than in the case of hot air drying in all experimental conditions, with an average of 29.16 g/h or accounting for 64.50% of all experimental conditions. The reduces the specific energy consumption more than drying with hot air. It was also found that increasing the drying temperature and hot air velocity had the same effect on the drying rate and specific energy consumption.

## Acknowledgement
Thank you to the Department of Mechanical Engineering, Faculty of Engineering, Ubon Ratchathani University for supporting funds and equipment for this research.

## References
[1] Guo, Xiaojing, Qidong Hao, Xuguang Qiao, Meng Li, Zhichang Qiu, Zhenjia Zheng, and Bin Zhang. "An evaluation of different pretreatment methods of hot-air drying of garlic: Drying characteristics, energy consumption and quality properties." *LWT* 180 (2023): 114685. https://doi.org/10.1016/j.lwt.2023.114685

[2] Wang, Zhenhua, Yingquan Zhang, Bo Zhang, Fuguang Yang, Xiaolei Yu, Bo Zhao, and Yimin Wei. "Analysis on energy consumption of drying process for dried Chinese noodles." *Applied Thermal Engineering* 110 (2017): 941-948. https://doi.org/10.1016/j.applthermaleng.2016.08.225

[3] Meng, Linghan, Xuyang Sun, Yan Zhang, and Xiaozhi Tang. "Effects of high temperature and high relative humidity drying on moisture distribution, starch microstructure and cooking characteristics of extruded whole buckwheat noodles." *Journal of Future Foods* 4, no. 2 (2024): 159-166. https://doi.org/10.1016/j.jfutfo.2023.06.007

[4] Ju, Hao-Yu, Shi-Hao Zhao, A. S. Mujumdar, Xiao-Ming Fang, Zhen-Jiang Gao, Zhi-An Zheng, and Hong-Wei Xiao. "Energy efficient improvements in hot air drying by controlling relative humidity based on Weibull and Bi-Di models." *Food and Bioproducts Processing* 111 (2018): 20-29. https://doi.org/10.1016/j.fbp.2018.06.002

[5] Zadhossein, Safoura, Yousef Abbaspour-Gilandeh, Mohammad Kaveh, Mohammad Nadimi, and Jitendra Paliwal. "Comparison of the energy and exergy parameters in cantaloupe (Cucurbita maxima) drying using hot air." *Smart Agricultural Technology* 4 (2023): 100198. https://doi.org/10.1016/j.atech.2023.100198

[6] Laopoolkit, Pattra, and Prisana Suwannaporn. "Effect of pretreatments and vacuum drying on instant dried pork process optimization." *Meat Science* 88, no. 3 (2011): 553-558. https://doi.org/10.1016/j.meatsci.2011.02.011

[7] Kim, Si-Yoen, Ui-Chan Jeong, Hye-In Ju, Seho Jeong, and Dong-Un Lee. "Effect of pulsed electric field pretreatment on mass transfer during hot air drying: Drying and rehydration properties of sweet potato." *Innovative Food Science & Emerging Technologies* 89 (2023): 103449. https://doi.org/10.1016/j.ifset.2023.103449

[8] Ponkham, Kamon, Naret Meeso, Somchart Soponronnarit, and Sirithon Siriamornpun. "Modeling of combined far-infrared radiation and air drying of a ring shaped-pineapple with/without shrinkage." *Food and Bioproducts Processing* 90, no. 2 (2012): 155-164. https://doi.org/10.1016/j.fbp.2011.02.008

[9] Wei, Shuo, Weijun Xie, Zhaohui Zheng, Liuyang Ren, and Deyong Yang. "Numerical study on drying uniformity of bulk corn kernels during radio frequency-assisted hot air drying." *Biosystems Engineering* 227 (2023): 117-129. https://doi.org/10.1016/j.biosystemseng.2023.01.020

[10] Chen, Chang, Ragab Khir, Yi Shen, Xingzhu Wu, Rentang Zhang, Xiangyu Cao, Franz Niederholzer, and Zhongli Pan. "Energy consumption and product quality of off-ground harvested almonds under hot air column drying." *LWT* 138 (2021): 110768. https://doi.org/10.1016/j.lwt.2020.110768

[11] Gaikwad, Pratik S., C. K. Sunil, Aditi Negi, and Akash Pare. "Effect of microwave assisted hot-air drying temperatures on drying kinetics of dried black gram papad (Indian snack food): Drying characteristics of black gram papad." *Applied Food Research* 2, no. 2 (2022): 100144. https://doi.org/10.1016/j.afres.2022.100144

[12] Zhang, Dongyan, Dan Huang, Yixiao Zhang, Yijun Lu, Shuai Huang, Guiliang Gong, and Lijun Li. "Ultrasonic assisted far infrared drying characteristics and energy consumption of ginger slices." *Ultrasonics Sonochemistry* 92 (2023): 106287. https://doi.org/10.1016/j.ultsonch.2022.106287

[13] Wang, Xule, Yabin Feng, Cunshan Zhou, Yanhui Sun, Bengang Wu, Abu ElGasim A. Yagoub, and Elmuez Alsir A. Aboagarib. "Effect of vacuum and ethanol pretreatment on infrared-hot air drying of scallion (Allium fistulosum)." *Food Chemistry* 295 (2019): 432-440. https://doi.org/10.1016/j.foodchem.2019.05.145

[14] Geng, Zhihua, Hui Wang, Mehdi Torki, Mohsen Beigi, Lichun Zhu, Xiao Huang, Xuhai Yang, and Bin Hu. "Thermodynamically analysis and optimization of potato drying in a combined infrared/convective dryer." *Case Studies in Thermal Engineering* 42 (2023): 102671. https://doi.org/10.1016/j.csite.2022.102671

[15] Zhang, Yue, Guangfei Zhu, Xingyi Li, Yu Zhao, Dengwen Lei, Guoqiang Ding, Kingsly Ambrose, and Yanhong Liu. "Combined medium-and short-wave infrared and hot air impingement drying of sponge gourd (Luffa cylindrical) slices." *Journal of Food Engineering* 284 (2020): 110043. https://doi.org/10.1016/j.jfoodeng.2020.110043

[16] Ershadfarkar, Mahsa, Saeed Dadashi, Jalal Dehghannya, and Maryam Khakbaz Heshmati. "Effect of combined convective hot air and far-infrared radiation on physic-chemical aspects of black raspberry powder produced by foam mat method." *Heliyon* 9, no. 8 (2023). https://doi.org/10.1016/j.heliyon.2023.e19166

[17] Rashid, Muhammad Tayyab, Kunlun Liu, Mushtaque Ahmed Jatoi, Bushra Safdar, Dingyang Lv, and Dengzhong Wei. "Developing ultrasound-assisted hot-air and infrared drying technology for sweet potatoes." *Ultrasonics Sonochemistry* 86 (2022): 106047. https://doi.org/10.1016/j.ultsonch.2022.106047

[18] Bagheri, Hadi, Mahdi Kashaninejad, Aman M. Ziaiifar, and Mehran Aalami. "Novel hybridized infrared-hot air method for roasting of peanut kernels." *Innovative Food Science & Emerging Technologies* 37 (2016): 106-114. https://doi.org/10.1016/j.ifset.2016.08.014

[19] Nuthong, Paradorn, Aree Achariyaviriya, Kodkwan Namsanguan, and Siva Achariyaviriya. "Kinetics and modeling of whole longan with combined infrared and hot air." *Journal of Food Engineering* 102, no. 3 (2011): 233-239. https://doi.org/10.1016/j.jfoodeng.2010.08.024

[20] Onwude, Daniel I., Norhashila Hashim, Khalina Abdan, Rimfiel Janius, Guangnan Chen, and Chandan Kumar. "Modelling of coupled heat and mass transfer for combined infrared and hot-air drying of sweet potato." *Journal of Food Engineering* 228 (2018): 12-24. https://doi.org/10.1016/j.jfoodeng.2018.02.006

[21] Jeevarathinam, G., R. Pandiselvam, T. Pandiarajan, P. Preetha, M. Balakrishnan, V. Thirupathi, and Anjineyulu Kothakota. "Infrared assisted hot air dryer for turmeric slices: Effect on drying rate and quality parameters." *LWT* 144 (2021): 111258. https://doi.org/10.1016/j.lwt.2021.111258

[22] Onwude, Daniel I., Norhashila Hashim, Khalina Abdan, Rimfiel Janius, and Guangnan Chen. "The effectiveness of combined infrared and hot-air drying strategies for sweet potato." *Journal of Food Engineering* 241 (2019): 75-87. https://doi.org/10.1016/j.jfoodeng.2018.08.008

[23] Chen, Qinqin, Jinfeng Bi, Xinye Wu, Jianyong Yi, Linyan Zhou, and Yuhan Zhou. "Drying kinetics and quality attributes of jujube (Zizyphus jujuba Miller) slices dried by hot-air and short-and medium-wave infrared radiation." *LWT-Food Science and Technology* 64, no. 2 (2015): 759-766. https://doi.org/10.1016/j.lwt.2015.06.071

[24] EL-Mesery, Hany S., Reham M. Kamel, and Ramy Z. Emara. "Influence of infrared intensity and air temperature on energy consumption and physical quality of dried apple using hybrid dryer." *Case Studies in Thermal Engineering* 27 (2021): 101365. https://doi.org/10.1016/j.csite.2021.101365

[25] Guo, Yiting, Bengang Wu, Xiuyu Guo, Fangfang Ding, Zhongli Pan, and Haile Ma. "Effects of power ultrasound enhancement on infrared drying of carrot slices: Moisture migration and quality characterizations." *LWT* 126 (2020): 109312. https://doi.org/10.1016/j.lwt.2020.109312

[26] Ren, Zifei, Xiaojie Yu, Abu ElGasim A. Yagoub, Olugbenga Abiola Fakayode, Haile Ma, Yanhui Sun, and Cunshan Zhou. "Combinative effect of cutting orientation and drying techniques (hot air, vacuum, freeze and catalytic infrared drying) on the physicochemical properties of ginger (Zingiber officinale Roscoe)." *LWT* 144 (2021): 111238. https://doi.org/10.1016/j.lwt.2021.111238

[27] Chen, Chang, Ivan Wongso, Daniel Putnam, Ragab Khir, and Zhongli Pan. "Effect of hot air and infrared drying on the retention of cannabidiol and terpenes in industrial hemp (Cannabis sativa L.)." *Industrial Crops and Products* 172 (2021): 114051. https://doi.org/10.1016/j.indcrop.2021.114051

[28] Sriariyakul, Weera, Thanit Swasdisevi, Sakamon Devahastin, and Somchart Soponronnarit. "Drying of aloe vera puree using hot air in combination with far-infrared radiation and high-voltage electric field: Drying kinetics, energy consumption and product quality evaluation." *Food and Bioproducts Processing* 100 (2016): 391-400. https://doi.org/10.1016/j.fbp.2016.08.012

[29] Venkitasamy, Chandrasekar, Maria T. Brandl, Bini Wang, Tara H. McHugh, Ruihong Zhang, and Zhongli Pan. "Drying and decontamination of raw pistachios with sequential infrared drying, tempering and hot air drying." *International Journal of Food Microbiology* 246 (2017): 85-91. https://doi.org/10.1016/j.ijfoodmicro.2017.02.005

[30] Gu, Chen, Haile Ma, Jamila Akter Tuly, Lina Guo, Xueli Zhang, Dandan Liu, Ningning Ouyang, Xuan Luo, and Yanqin Shan. "Effects of catalytic infrared drying in combination with hot air drying and freeze drying on the drying characteristics and product quality of chives." *LWT* 161 (2022): 113363. https://doi.org/10.1016/j.lwt.2022.113363

[31] Ding, Chao, Ragab Khir, Zhongli Pan, Delilah F. Wood, Chandrasekar Venkitasamy, Kang Tu, Hamed El-Mashad, and Jose Berrios. "Influence of infrared drying on storage characteristics of brown rice." *Food Chemistry* 264 (2018): 149-156. https://doi.org/10.1016/j.foodchem.2018.05.042

[32] Nudar, J., Mukta Roy, and Shafaet Ahmed. "Combined osmotic pretreatment and hot air drying: Evaluation of drying kinetics and quality parameters of adajamir (Citrus assamensis)." *Heliyon* 9, no. 9 (2023). https://doi.org/10.1016/j.heliyon.2023.e19545

[33] AOAC. *Official Methods of Analysis of the Association of Official Analytical Chemists: Official Methods of Analysis of AOAC International*. 21st Edition, AOAC, Washington DC, 2019.