

*Research Article*

# Evaluation of Far-Infrared Drying on Some Quality Properties of Zucchini Slices: Influence of Operating Parameters

Fatemeh Jafari<sup>1</sup>, Kamyar Movagharnejad<sup>1\*</sup>, Ebrahim Sadeghi<sup>2</sup>

1. Faculty of Chemical Engineering, Babol Noshiravani University of Technology, Babol, Mazandaran, Iran

2. Department of Chemical Engineering, Shomal University, Amol, Mazandaran, Iran

(Received 2 May 2023, Received in revised form 7 June 2023, Accepted 4 July 2023)

## Abstract

This study aimed to estimate how sample thickness (3, 5, and 7 mm), air velocity (0.5, 1.25, and 2 ms<sup>-1</sup>), and infrared lamp power (1000, 1500, and 2000 W) affected the drying characteristics of zucchini slices in a far-infrared dryer. The design of drying tests, which illustrates the relation between input and output variables, was carried out by response surface methodology. Then, the effect of these independent factors on the moisture content (drying time), water activity, total phenolic content, potassium content and total color change was determined. To predict the responses, the most accurate mathematical models were selected using analysis of variance. The results revealed the drying time declined by decreasing the sample thickness and air velocity and increasing the infrared lamp power. Total phenolic content and potassium content had increased multifold after the drying process. An enhancement in sample thickness and infrared lamp power had a positive effect on both of these contents. The minimum and maximum values of total color change were 5.54 and 13.96, respectively. The dried zucchini produced by far-infrared drying is a high-value product that has the potential to be used in food and pharmaceutical industries or in the treatment of diseases as a booster meal.

**Keywords:** Infrared drying, Total phenolic content; Potassium content, Color characteristics, Response surface methodology, Zucchini.

### How to cite this article:

Jafari, F., Movagharnejad, K., & Sadeghi, E. (2023). Evaluation of Far-Infrared Drying on Some Quality Properties of Zucchini Slices: Influence of Operating Parameters. *Innov. Food Technol.*, 11(1), 47-59.

\* Corresponded author: K-movaghar@nit.ac.ir



## 1. Introduction

Zucchini (*Cucurbita pepo L.*) is a seasonal vegetable, which comprises numerous beneficial micronutrients like carotenoids, minerals (especially potassium), vitamin C, and phenolic compounds. It was utilized in traditional folk medicine for treating alleviate aches and colds, owing to its anti-carcinogenic, antioxidant/anti-radical, anti-inflammatory, antimicrobial, antiviral, and analgesic activities [1, 2]. Zucchini contains enzymatic and non-enzymatic antioxidant activities against the reactive oxygen species (ROS) buildup in the cells. ROS includes free radicals causing cellular injuries and initiating peroxidation of polyunsaturated fatty acids in biological membranes. Through enzymatic and non-enzymatic mechanisms, organisms defend themselves against the ROS destructive actions [3]. In addition, it has been demonstrated that it is useful for diabetes prevention and treatment because its potassium content is high and causes glucose tolerance improvement [4]. Nonetheless, zucchini is a highly perishable vegetable rotting quickly after being sliced, owing to firmness loss, decay, and browning, it has a limited shelf life of 1 to 2 days [5].

Of all the food preservation approaches, drying is still effectively and extensively utilized to prolong shelf life, preserve compounds, and enhance their bioavailability. Thus, Significantly less microbial degradation and spoiling occur [6]. Over the past few years, infrared radiation (IR) drying has become one of the incrementally common and novel approaches to obtain high-quality dried foodstuffs such as vegetables, fruits, rice, as well as other grains. Energy from infrared radiation is transferred from the heating source to the desired product. Therefore, heating the material is performed homogeneously and more rapidly while not heating the surrounding air. The heat produced in a layer beneath the surface is transferred to the material's center and surface. Convective heat transfer from the surface to the surrounding air directs the heat, though, moisture is transported from the substance's center to the surface. So, in layers close to the material's surface and in its other sections, respectively, mass and heat transfer occur countercurrent and concurrent [7]. In comparison to the usual methods, IR has several unique characteristics and advantages including the reduction in drying time, uniform heating, high heat transfer, high quality of the final products, and energy savings [8]. According to the previous studies, IR drying is quicker (needed less drying time) than vacuum drying, sun drying, hot-air drying, and freeze drying. This method has also found efficiency in maintaining the dried product's antioxidant activity and nutraceutical composition [9]. Yan, et al. [8] had applied freeze drying, hot-air drying, and IR radiation drying to dry bitter melon. Regarding bioactivities and physicochemical features, IR drying gave the best results. IR processing is one of the processing technologies that are compatible with the objective of developing the resource-saving and environment-friendly society like ener-

gy-wasting, time-consuming and environmental pollution. Merging IR with other drying approaches can give a synergistic effect. For example, IR-assisted vacuum drying can potentially enhance product quality and energy efficiency [10]. IR can be categorized into three wavelength ranges of near-IR (0.78–1.4  $\mu\text{m}$ ), mid-IR (1.4–3.0  $\mu\text{m}$ ), and far-IR (3.0–1000  $\mu\text{m}$ ). When the temperatures are below 400 °C, the long waves appear. IR processing is obtained by substances absorbing IR radiation. Generally, mid-IR and far-IR irradiation are absorbed by foodstuffs within the range of 2.5–100  $\mu\text{m}$ , due to the majority of food components like organic compounds (sugars, proteins, and lipids) and water absorb radiative energy in this area. Besides, it is commonly reported that IR radiation is absorbed by solid materials within a thin surface layer and the absorption on the surface is at long wavelengths. Thus, application of far-IR is more efficient in thin layer drying [11, 12].

Although the application of infrared drying has been investigated by several researchers [13-17], the information about the effect of sample thickness, air velocity, and IR lamp power on hydration (moisture content and water activity), nutritional (total phenolic content and potassium content), and optical (color changes) properties during zucchini IR drying is lacking. Finding a way to increase the high-value content of products that use in the food and pharmaceutical industries or disease treatment, and at the same time, be simple and affordable is important.

## 2. Materials and methods

### 2.1. Samples preparation

The raw zucchinis were chosen from a local bazaar in Babol, Iran. After purchase, the samples were washed, drained, and kept in the refrigerator at  $4 \pm 1$  °C for 24 h. Generally, the zucchini samples were chosen in the same sizes and uniform color. Before the drying process, the samples were located outside the refrigerator for almost 1 h to integrate with laboratory temperature and then divided into slices of 3, 5, and 7 mm and diameter of approximately 35 mm. A moisture analyzer (A&D, MX-50, Japan) was used to measure the initial moisture content. The drying tests were conducted until reaching a final moisture content of almost 8% wet basis (w.b.), which is in line with the value noted for the zucchini sample by Chayjan, et al. [18].

### 2.2. Drying system and procedure

The drying experiments were performed using a laboratory-scale infrared dryer set-up, designed as a single tray. The infrared dryer's fundamental design entails a drying cham-

ber with interior measurements of 50\*30\*32 cm. Eight red glass lamps (Philips) with power of 250 W were contained in the dryer, within the far-IR radiation range mounted on the top of drying chamber. The lamps as radiators were located in two rows of four. The zucchini slices and radiators were within a distance of 12 cm. During drying, an anemometer was used to calculate the material temperature (StANDARD, St-3880, Hong Kong). An aluminum tray and an entrance door were used in the drying chamber for unloading and loading the tray. Several holes were made in the bottom of the dryer chamber so that the airflow could simply go into the drying chamber and leave via the fan located on the wall, the speed of which is variable and adjustable. A quartz glass was used to separate the infrared chamber from a section of the duct that contained an aluminum tray with zucchini slices. Such an arrangement ensures a uniform air flow over the zucchini slices. To achieve a stable temperature, the infrared dryer was permitted to operate for 1 to 1.5 h before the experiment. In the drying chamber, the slices were laid out on the tray uniformly. The loss of moisture was continuously recorded by a digital electronic balance (A&D, EK-6000i, Japan) with an accuracy of  $\pm 0.1$  g to obtain the drying curves. The digital electronic balance was linked to the PC to measure the weight loss in the zucchini slices at the specific time period. All slices were dried in the dryer until reaching the desired moisture content.

### 2.3. Response surface methodology and experimental design

Response Surface Methodology (RSM) and Box-Behnken design (BBD) utilized to examine the main effects of process variables on the reliant variables were considered as the response during the drying of zucchini slices. The sample thickness ( $X_1$ ), air velocity ( $X_2$ ), and IR lamp power ( $X_3$ ) were chosen as the independent variables. Table 1 presents the experimental parameters and BBD levels. Seventeen experimental tests were included in this design, with five center points (repeat tests).

Table 1. Experimental design of IR drying of zucchini

Independent variables (symbol), unit	Coded levels		
	-1	0	+1
Sample thickness ( $X_1$ ), mm	3	5	7
Air velocity ( $X_2$ ), m/s	0.5	1.25	2
Infrared power ( $X_3$ ), W	1000	1500	2000

Based on the experimental data, a multiple regression equation can be utilized for fitting the second-order polynomial equation as follows:

$$Y = b_0 + \sum_{j=1}^k b_j X_j + \sum_{j=1}^k b_{jj} X_j^2 + \sum_{i < j} \sum_{i,j} b_{ij} X_i X_j \quad (1)$$

Y denotes the predicted response,  $b_0$  shows the model intercept,  $b_j$ ,  $b_{jj}$ , and  $b_{ij}$  are the regression coefficients for the linear, quadratic, and interactive effects of the model, respectively. The independent variables are represented by  $x_i$  and  $x_j$ , and k is the total number of independent variables.

### 2.4. Water activity and moisture content

Using a water activity meter (NOVASINA, lab swift, Switzerland), the samples' water activity ( $a_w$ ) was determined at 25 °C. Each sample (about 1 g) was located in the sample cup. After equilibration, the values of  $a_w$  were registered. A Moisture Analyzer (A&D, MX-50, Japan) was utilized to determine the moisture content.

### 2.5. Total phenolic content determination

Using Folin – Ciocalteu method, the zucchini's total phenolic content were identified, as explained by Movagharnejad, et al. [19]. For this purpose, a volumetric flask was filled with 10 mL of distilled water, 0.5 mL of zucchini extract, and 0.25 mL of Folin – Ciocalteu's reagent. A 2 mL transfer of sodium carbonate solution (6% w/w) was made after 5 min. The resultant solution was mixed and kept for an hour at the ambient temperature in the darkness. A spectrophotometer was used to calculate the absorbance of the solutions at 750 nm in comparison to a reagent blank (with no extract). Taking into account the gallic acid standard curve, quantification was performed with  $r = 0.9999$ . The findings were presented as gallic acid equivalents (GAE), mg per 100 g of dry matter (dm). Note that all of the measurements have been replicated at least three times.

### 2.6. Potassium content determination

In order to extract potassium, the approach expressed by Hamada and El-Enany [20] was utilized. First, weighing of the samples was done (0.1 g), and then they were placed into a test tube. By adding 10 mL of 0.1mol L<sup>-1</sup> acid acetic glacial, the test tube was kept for 24 h in the laboratory. The samples were located in a bain-marie after 24 h, at 70 °C for 2 h. Filtering was performed by applying a Whatman No. 41 filter paper. The potassium content was determined through the flame photometer using the crude extract obtained. The device was calibrated with the standard solutions. With regard to the reading results and taking into account the standard curve with  $R^2 = 0.9999$ , quantification was performed. Potassium contents were displayed as mg per 100 g of dry matter (dm). At least three times, all the measurements were repeated.

## 2.7. Color characteristics measurement

What causes the color to change when drying is the chemical and biochemical responses. These reaction rates are heavily related to the processing parameters as well as the drying techniques. A Minolta Chroma Meter was used to measure the color amounts on the fresh (as the reference amount) and dried zucchini's surface at ambient temperature (24°C). The  $L^*$  color index lies between zero (complete blackness) and 100 (complete whiteness). Besides, the color index ranges for  $a^*$  and  $b^*$  are  $-a^*$  (greening) to  $+a^*$  (red-denning), and  $-b^*$  (bluing) to  $+b^*$  (yellowing), respectively [21]. Eq. (2) was followed to obtain the total color change:

$$\Delta E = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2} \quad (2)$$

The values related to the fresh zucchini are described by  $L_0^*$ ,  $a_0^*$ , and  $b_0^*$ .

The Chroma index (C) characterizes the purity or saturation of the color. The hue angle, which is explained as red-purple: 0°, yellow: 90°, bluish-green: 180°, and blue: 270°, represents the color tone. Plus, the whiteness index (WI) denotes the overall whiteness and the browning of the sample surface.

$$\text{Chroma } (C) = \sqrt{a^{*2} + b^{*2}} \quad (3)$$

$$\begin{cases} \text{Hue angle} = \tan^{-1}\left(\frac{b^*}{a^*}\right) & ; \text{when } a^* > 0 \text{ and } b^* > 0 \\ \text{Hue angle} = 180 + \tan^{-1}\left(\frac{b^*}{a^*}\right) & ; \text{when } a^* < 0 \text{ and } b^* > 0 \end{cases} \quad (4)$$

$$WI = 100 - \sqrt{[(100 - L^*)^2 + a^{*2} + b^{*2}]} \quad (5)$$

It is worth noting that at least three zucchini slices were utilized for maximum accuracy, to determine the color of each treatment.

## 3. Results and discussion

### 3.1. Statistical analysis

Analysis of variance (ANOVA) was used to compute the significant effects of sample thickness, air velocity, and IR lamp power on each studied response, as well as fitting

second-order polynomial models to experimental data. ANOVA results for the response variables are summarized in Table 2. Therefore, to examine the model's adequacy and appropriateness, the coefficient of determination ( $R^2$ ), adj- $R^2$ , adeq precision, and, coefficient of variation (C.V. < 10%) were utilized. "Adeq Precision" determines the signal to noise ratio and makes a comparison on the predicted values range at design points to the average prediction error. A ratio higher than 4 is desirable. The variable impact value on the response is expressed by the F-value. The higher value denotes the variable's larger impact on the response. Model terms were measured with a confidence level of 95% by the P-value and employing Minitab Software version 18.1 (Minitab Inc. State College, City, PA, USA). While maintaining the model hierarchy, the not significant effects ( $P > 0.05$ ) were removed from the models.

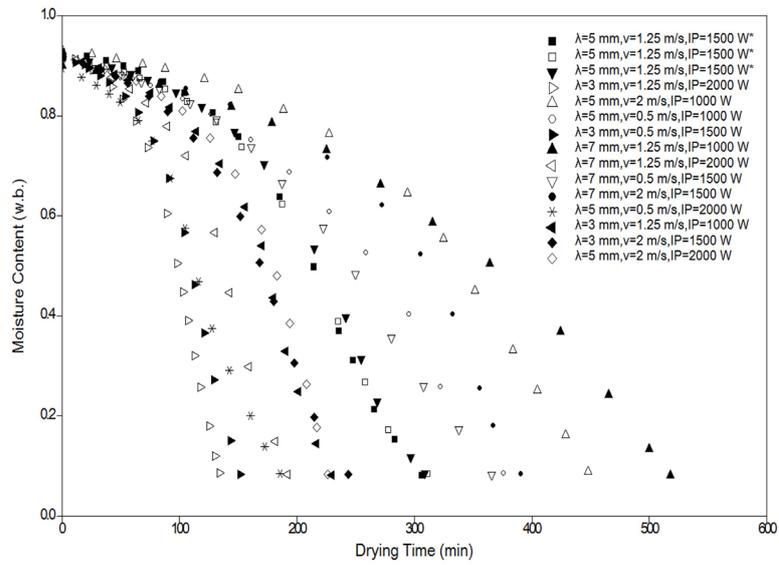
### 3.2. Water activity and moisture content

$a_w$  is the main factor to prevent or limit microbial growth. Generally, by reducing the  $a_w$  to the minimum level, biological and chemical deterioration happens at the minimum level. Thus, the food is preserved while curtailing the physicochemical alterations during storage [22]. The fresh samples had the  $a_w$  of 0.952, which was predictable, taking into account the exceedingly high moisture content of the zucchinis (91.7% on average). For various experimental conditions, the range of final water activity was 0.301–0.391. Based on the water activity and moisture content values obtained after different drying assays, the compatibility of all samples with good conservation was indicated. In addition, statistically significant differences were found in the water activity values for the various samples (ANOVA,  $P < 0.05$ ). Figure 1 depicts how the moisture content varies as a function of drying time under the various experimental circumstances. As drying time went on, the moisture content represented an exponential fall. The greater drying temperatures were achieved with a higher number of IR lamps within the drying chamber resulting in the shorter drying time caused by higher temperature differences between the sample and the drying medium. Comparing the drying data under different conditions disclosed that the drying time of zucchini samples was shorter at less thickness, higher infrared power, or lower air velocity (Figures 2A-C). The possible reason is that each noted item might increment the quantity of radiation absorbed by the zucchini surfaces. Hence, the higher drying rate during IR drying can be explained. There is a consistency between our results and those for drying pumpkin through infrared [16].

**Table 2** ANOVA results of experimental data and final equation presentation for the response parameters

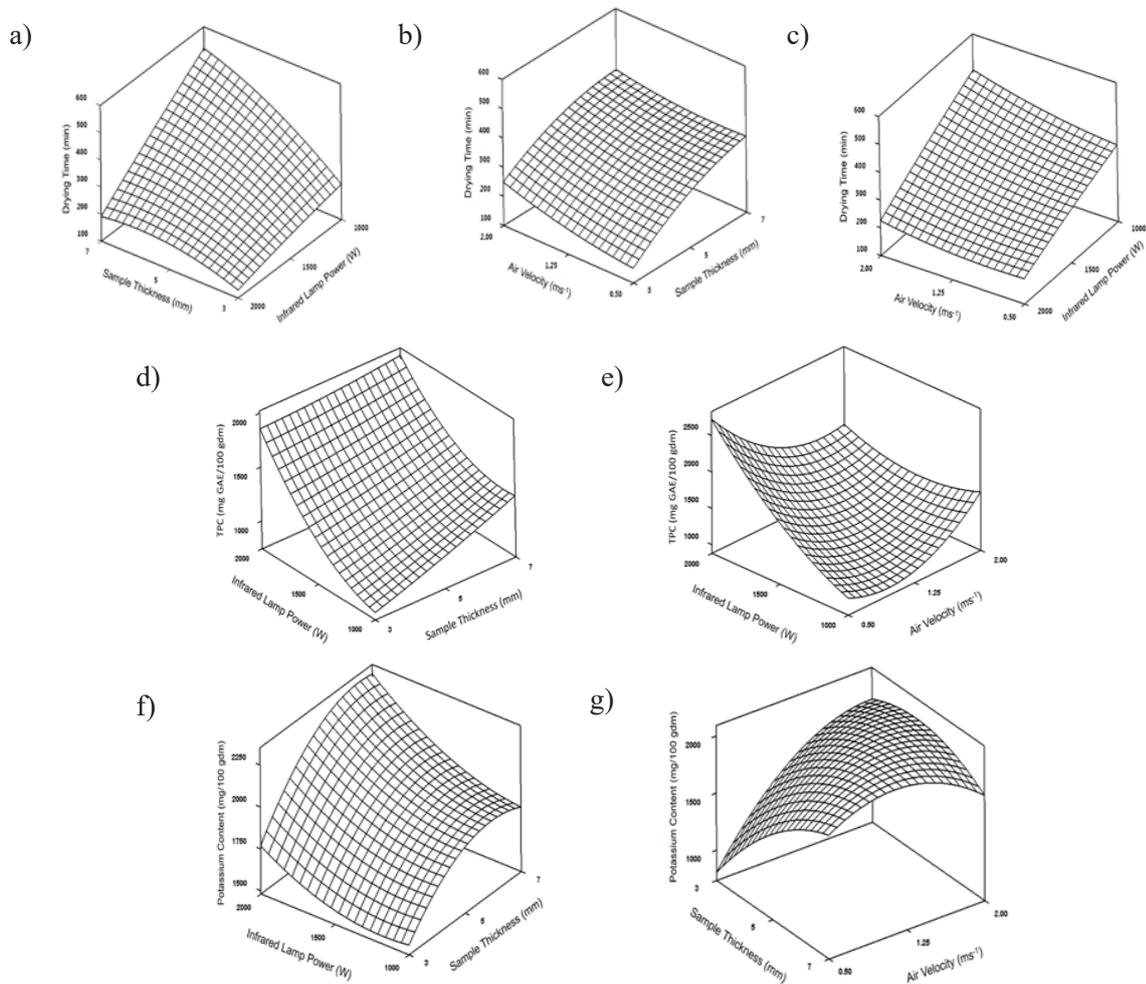
Response	TPC		K		$\Delta E$	
	(mg GAE/100 gdm)		(mg /100 gdm)		(-)	
Source	MS	F-val	MS $\times 10^{-7}$	F-val	MS	F-val
Linear	560533	274.5	198	63.7	27.8	373.2
$X_1$	178623	87.5	253	81.2	22.9	307.7
$X_2$	77640	37.9	263	84.5	6.9	93.3
$X_3$	1425516	698.1	79	25.4	53.5	718.7
Square	254790	124.8	109	35.1	1.0	13.8
$X_1 X_1$	1695	0.8 <sup>ns</sup>	94	30.2	1.9	25.9
$X_2 X_2$	544207	266.5	202	64.9	1.3	17.6
$X_3 X_3$	174474	85.4	28	9.1	0.03	0.5 <sup>ns</sup>
2-way Interaction	211858	103.8	111	35.5	2.6	34.6
$X_1 X_2$	10931	5.4 <sup>ns</sup>	325	104.5	0.3	3.4 <sup>ns</sup>
$X_1 X_3$	40260	19.7	1	0.3 <sup>ns</sup>	7.4	98.9
$X_2 X_3$	584384	286.2	5	1.8 <sup>ns</sup>	0.1	1.6 <sup>ns</sup>
Model	342394	167.7	139	44.8	10.5	140.6
LoF	3461	3.5 <sup>ns</sup>	4.6	2.3 <sup>ns</sup>	0.1	0.9 <sup>ns</sup>
Final equation considering stepping down "ns" parameters	TPC =293+131.5 $X_1$ -374 $X_2$ +0.18 $X_3$ +639.1 $X_2^2$ +8.14 $\times 10^{-4}$ $X_3^2$ -0.10 $X_1 X_3$ -1.02 $X_2 X_3$		$k^{-0.5}$ =0.05- 6.79 $\times 10^{-3}$ $X_1$ -0.02 $X_2$ +1 $\times 10^{-5}$ $X_3$ +3.73 $\times 10^{-4}$ $X_1^2$ + 3.9 $\times 10^{-3}$ $X_2^2$ -3.28 $\times 10^{-9}$ $X_3^2$ +1.9 $\times 10^{-3}$ $X_1 X_2$		$\Delta E$ = -2.98+4.77 $X_1$ +0.30 $X_2$ +1.11 $X_3$ -0.17 $X_1^2$ +0.99 $X_2^2$ -1.36 $\times 10^{-3}$ $X_1 X_3$	
$R^2$	0.9954		0.9829		0.9945	
Adj- $R^2$	0.9894		0.9610		0.9874	
Adeq precision	55.23		28.9		40.93	
C.V. (%)	2.95		2.32		3.04	

TPC: Total phenolic content; K: Potassium content;  $\Delta E$  : Color change; MS: Mean square; LoF: Lack of fit



**Fig 1.** Drying curves of zucchini at different experimental conditions ( $\lambda$ ,  $v$  and IP are indicative the thickness of samples, air velocity and infrared power, respectively).

\* Due to the drying times of the repeat tests being close, only one has been shown among the five. The drying time for other repeat tests was 310.43,308.48,309.77, and 300.37.



**Fig 2.** Response surface plots of (a) – (c) drying time, (d) and (e) TPC, (e) and (f) potassium content at different drying conditions

### 3.3. Total phenolic content

Phenolic compounds' hydroxyl groups can play a direct role in antioxidant action as they make good electron donors. Additionally, they stimulate occasionally the synthesis of endogenous antioxidant molecules in the cell. According to numerous reports and research, in biological systems, phenolic compounds not only prevent the burden of oxidative disease but also exhibit peroxide decomposition, free radical inhibition, oxygen scavenging, or metal inactivation [23, 24]. Thus, it's a vital issue to maintain the phenolic content while drying. The average total phenolic compounds found in fresh zucchinis was 379.6 [mg GAE/100 gdm], which was various from the values presented in the former studies [25]. These differences were correlated pos-

itively with the growing zone and cultivar and the type of solvent extraction. Figure 3a illustrates the TPC values for each treatment. Based on the results, the dried zucchini slices' TPCs were different from 794.1 to 2721.3 [mg GAE/100 gdm]. It can be observed the TPC related to dried samples compared with fresh zucchini slices was increased by 109.2–616.9%. Several studies also indicated that the samples dried through infrared contained more phenols in comparison to the fresh samples [15, 26]. These results are justified as follows infrared drying can boost the phenolic compounds' extraction ratio by higher intermolecular interaction. Plus, it might be on the ground that the interconversion of phenolic compounds can speed up through infrared drying and undetectable compounds change into detectable ones [14].

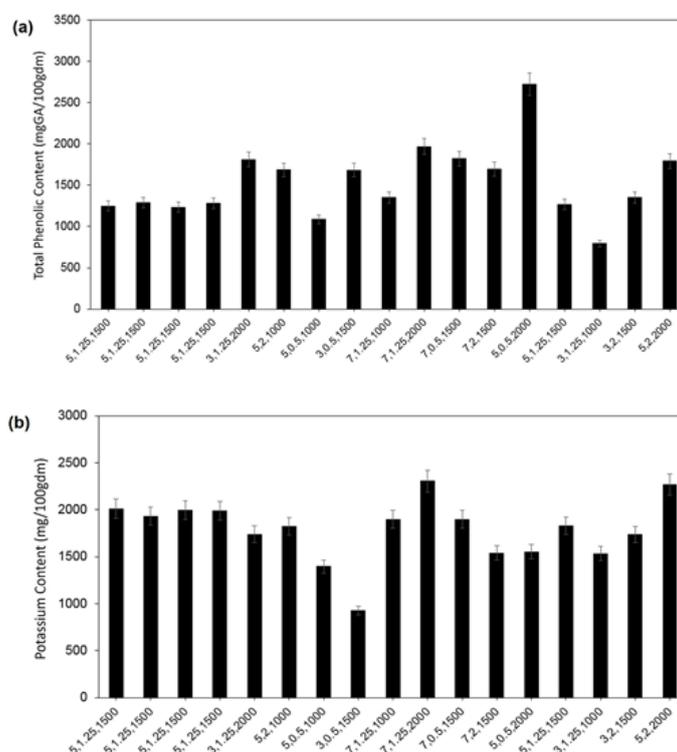


Fig 3. Bar chart of a) TPC and b) potassium content at different drying conditions

\* First, second, and third numbers in the horizontal axis for each bar present sample thickness (mm), air velocity (ms<sup>-1</sup>), and infrared lamp power (W), respectively.

The findings revealed that TPC of dried zucchini incremented by 17.5% from sample thickness of 3 to 7 mm and increased by 40.7% when the IR lamp power was raised from 1000 to 2000 W (Figure 2d). Since the used radiations are in the range of far-infrared, these rays are active biologically and transfer heat to the material center evenly while not degrading the surface constituent molecules. Far-IR radiation probably can cleave covalent bonds and liberate antioxidants like flavonoids, tannin, carotene, ascorbate, polyphenols, or flavoprotein from repeating polymers [27]. Moreover, the TPC values declined an enhancement of air

velocity from 0.5 to 1.25 ms<sup>-1</sup> and increased afterward (Figure 2e). The air velocity effect was lower compared to the other two parameters. Vega-Gálvez, et al. [28] reported this trend in air velocity to assess the dried-rehydrated sample of apples. The maximum quantity of TPC happened at 5 mm, 0.5 ms<sup>-1</sup>, and 2000 W, which can be justified by the dominance of the interaction effect of air velocity and IR lamp power over the main effect of sample thickness at higher powers

The ANOVA results in Table 2 confirmed a great correlation between the predicted and observed values. These results

showed that interaction of the sample thickness and IR lamp power ( $X_1 X_3$ ) had no significant effect on TPC.

### 3.4. Potassium content

Fresh zucchini had a potassium content of 470.6 [mg/100 gdm]. Similar to the TPC, a considerable difference was found between the studies on potassium [29] and the empirical values. Nonetheless, the natural changes can justify this difference in values due to these factors like soil, harvest time, and ripening degree. Figure 3b illustrates the values of potassium for each treatment. To the obtained results, the dried zucchini slices had the potassium content of 924 to 2366.7 [mg/100 gdm]. Hence, the potassium content for the slices dried in the infrared dryer was highly increased by 96.3 to 402.9% in comparison to the fresh sample, which is remarkable. Although the known about bioavailability potassium through dietary source is little, it has been assessed that almost 85 to 90% of dietary potassium is absorbed by the body [4, 7, 30]. Arslan and Özcan [31] compared the mineral contents of rosemary leaves using three methods, sun drying, oven drying, and microwave oven drying adopted in their work that one of them was potassium content. The mineral compositions of dried basil of all three drying methods were higher than the fresh sample.

As shown in Figure 2f, the increase in IR lamp power and sample thickness affected the content of potassium in zucchini samples. It should be noted that when the sample thickness changes from 3 to 5 mm, the amount of this effect will be considerable compared to the change in thickness from 5 to 7 mm (26.4% vs. 1.77%). Furthermore, with raising air velocity from 0.5 to 1.25  $\text{ms}^{-1}$ , the potassium content increased by 32.6% and then decreased by 2.5% (Figure 2g). The results revealed that there is a connection between the operating parameters and the experimental data so that the maximum quantity of potassium content happened in the 7 mm, 1.25  $\text{ms}^{-1}$ , and 2000 W.

The results obtained from ANOVA imply the accurateness of the model for the potassium content. The interaction of the sample thickness and IR lamp power ( $X_1 X_3$ ) and air velocity and IR lamp power ( $X_2 X_3$ ) had a not significant effect on potassium content (Table 2).

### 3.5. Color characteristics

The surface color parameters of the dried zucchini under various drying conditions were measured and summarized in Table 3. The sample thickness, air velocity, and IR lamp power affected the  $L^*$  values significantly ( $P < 0.05$ ). The  $L^*$  value represents the lightness of zucchini slices, indicating a reduction of 4.49% by increasing the thickness. The reason for this outcome may be that in thicker slices, non-enzymatic browning reactions such as the Maillard

reaction occur more intensely than in thinner slices [32]. Moreover, the value of  $L^*$  was reduced by 6.63% and 2.46% with decreasing IR lamp power and increasing air velocity, respectively, because the drying time had been longer (Figures 4 (a) and (b)). The decrement in the  $L^*$  value demonstrates that the color of the dried sample tends to darken. These were in agreement with the results of Supmoon and Noomhorm [33], Kurozawa, et al. [34], and Kaveh, et al. [35]. As illustrated in Figures 4 (c) – (f), the values of  $a^*$  and  $b^*$  increased when the sample thickness and air velocity increased and the IR lamp power decreased leading to the longer drying time. The fresh zucchini carried a negative  $a^*$  value, however, all the dried samples carried a positive  $a^*$  value indicating that the greenness of fresh zucchini altered to redness with the drying operation. The loss of greenness may be relevant to degrading chlorophylls to pheophytins. The form of chlorophylls that is magnesium-free detects as pheophytins. Chlorophyll is assumed to undergo acid-catalyzed transformation into pheophytin during its degradation because of cellular acids [36]. Similar observations for the  $b^*$  index were recorded by Wang, et al. [13] while infrared drying of shitake mushroom's gill. Also, Kręcisiz, et al. [37] were reported that  $b^*$  values of courgette after impregnation and after drying in different conditions (freeze drying, convection drying, and vacuum drying) decreased.

Based on Figure 5, at low air velocity (0.5  $\text{ms}^{-1}$ ), declining the IR lamp power and raising the sample thickness increased the drying time, and therefore the  $\Delta E$  increased. It was observed that a rise in air velocity led to a greater intensity in this trend. In the study of the linear term effect of the main parameters, it was indicated that by decreasing the thickness of the sample from 7 to 3 mm, air velocity from 2 to 0.5  $\text{ms}^{-1}$ , and incrementing the IR lamp power from 1000 to 2000 W, the  $\Delta E$  parameter decreased by 32.8%, 18.32%, and 44.61%, respectively. It is clear that the  $\Delta E$  value by increasing air velocity from 0.5 to 1.25 is less than 1.25 to 2  $\text{ms}^{-1}$ . Amini, et al. [17] examined the impacts of parameters like IR lamp power, mucilage thickness, the distance between mucilage and lamp surface on drying kinetics, as well as color scales of basil seed mucilage (BSM) within an infrared dryer system. They reported that the BSM color scales were affected by the drying circumstance. The increased IR radiation power positively affected the  $\Delta E$  index, which diminished from 13.04 to 11.5, when the IR radiation power incremented from 150 to 375 W.

The minimum and maximum values of  $\Delta E$  obtained as 5.54 at 3 mm, 1.25  $\text{ms}^{-1}$ , and 2000 W, and 13.96 at 7 mm, 1.25  $\text{ms}^{-1}$ , and 1000 W. According to the ANOVA results in Table 2, the linear term all of the parameters and interaction of the sample thickness and IR lamp power ( $X_1 X_3$ ), and the second power of sample thickness and air velocity ( $X_1 X_1$  and  $X_2 X_2$ ) significantly affected the  $\Delta E$ .

Table 3. Color parameters values for fresh and dried zucchini slices

Run No.	Sample thickness (mm)	Air velocity (m/s)	IR lamp power (W)	L*	a*	b*	ΔE	c*	Hue angle (deg)	WI
Fresh sample	-	-	-	76.15	1.35	37.5	-	32.23	92.40	59.91
1	5	1.25	1500	72	3.71	38.27	8.93	38.45	84.46	52.44
2	5	1.25	1500	71.25	3.81	38.05	9.21	38.24	84.28	52.16
3	5	1.25	1500	71.95	3.75	38.32	9.01	38.50	84.41	52.36
4	5	1.25	1500	71.80	3.75	38.51	9.21	38.69	84.44	52.12
5	3	1.25	2000	75.76	3.07	35.52	5.54	35.65	85.06	56.89
6	5	2	1000	67.56	4.49	40.82	13.50	41.07	83.72	47.67
7	5	0.5	1000	70.80	4.21	40.32	11.20	40.54	84.04	50.04
8	3	0.5	1500	74.61	3.14	36.03	6.10	36.17	85.02	55.81
9	7	1.25	1000	67.29	4.75	41.1	13.96	41.37	83.41	47.26
10	7	1.25	2000	74.01	3.23	36.05	6.35	36.19	84.88	55.44
11	7	0.5	1500	70.92	4.00	38.6	9.85	38.81	84.08	51.51
12	7	2	1500	70.26	4.13	39.88	11.12	40.09	84.09	50.08
13	5	0.5	2000	74.20	3.20	35.76	6.10	35.90	84.89	55.79
14	5	1.25	1500	72	3.59	37.78	8.53	37.95	84.57	52.84
15	3	1.25	1000	73.10	3.42	37.45	7.72	37.61	84.78	53.76
16	3	2	1500	72.30	3.58	37.78	8.38	37.95	84.59	53.02
17	5	2	2000	73.25	3.42	37.5	7.70	37.66	84.79	53.81

L\*: Lightness ; a\* : Greening/reddening; b\*: Yellowing/bluing; ΔE: Total color change; c\* : Chroma; WI: Whiteness index

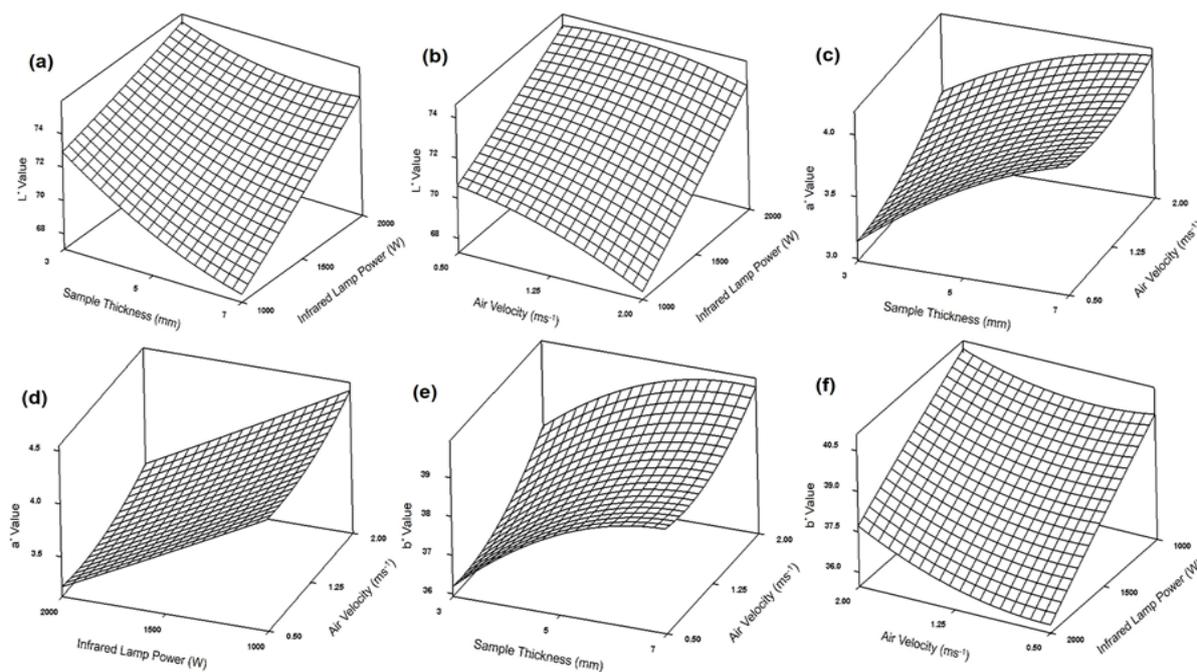


Fig 4. Response surface plots of color parameters at different drying conditions. (a) and (b) L\* values, (c) and (d) a\* values, (e) and (f) b\* values

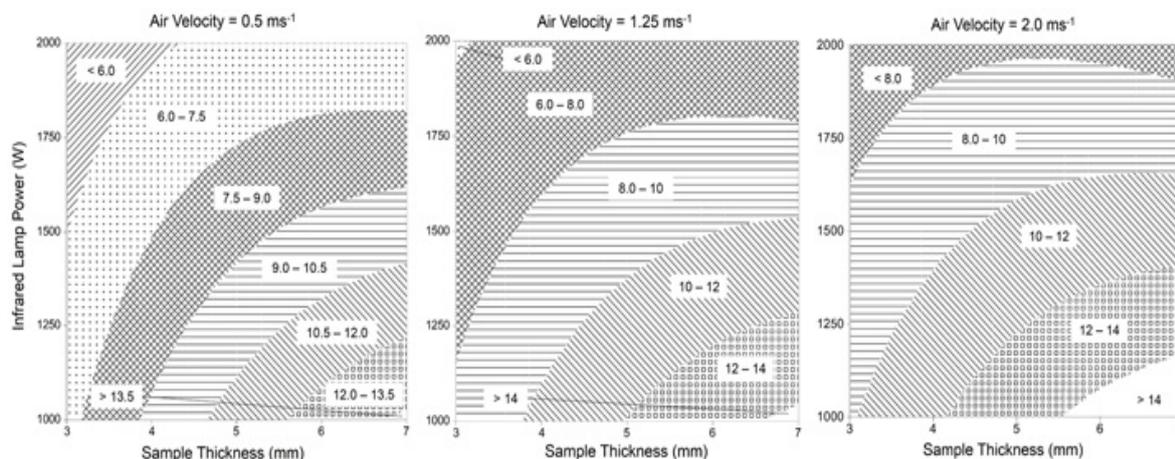


Fig 5. Contour plots of color change at different drying conditions

The experimental data revealed an increase in  $c^*$  values of dried samples during drying in all the conditions, and there were largely similar to the  $b^*$  values while the hue angle diminished. For both characteristics, the main parameters were effective independently. The hue angle of fresh zucchini was  $92.40^\circ$ , which represents a color in the yellow/green region ( $90^\circ < \text{hue angle} < 180^\circ$ ). After drying, the hue angle was in the range of  $83.41\text{--}85.06^\circ$ , which means being in the yellow/orange region (hue angle  $< 90^\circ$ ). Similar behavior was reported by Icier, et al. [38]. They stated that in evaluating both drying methods (carbon fiber-assisted cabin drying and infrared drying), Chroma value increased, and hue angle decreased compared to fresh sample. Eventually, a significant reduction in WI was observed in all the dried samples indicating that the final products are brown compared to the fresh ones.

#### 4. Conclusion

In the current study, the effects of sample thickness, air velocity, and IR lamp power were characterized on moisture content, total phenolic content, potassium content, total color change. Furthermore, the water activity was examined. The operating parameters significantly influenced drying time. A decrease in the air velocity and sample thickness and an increase in IR lamp power reduced the drying time. The TPC and potassium content increased by 109.2–616.9% and 96.3–402.9%, respectively, compared to fresh samples. Raising the sample thickness and IR lamp power increased both responses, but the effect of air velocity, before and after the midpoint ( $1.25 \text{ ms}^{-1}$ ) was different for each. Increased drying time led to increased  $\Delta E$  values.  $L^*$ ,  $a^*$ ,  $b^*$ ,  $c^*$ , hue angle, and WI indexes were also measured. Due to the selected parameters from the analysis of variance ( $F$ ,  $\text{adj-}$ ,  $\text{adeq}$  precision, and C.V.), the most suitable mathematical model

was presented for the infrared drying of zucchini slices.

#### Acknowledgments

This work was supported by the Babol Noshirvani University of Technology [BNUT/370675/98].

#### Conflict of interest

The authors declare that there is no conflict of interest.

#### References

- [1] USDA (United States Department of Agriculture), FoodData Central. URL <https://fdc.nal.usda.gov/fdc-app.html#/food-details/169291/nutrients>.
- [2] Martínez-Valdivieso D, Font R, Fernández-Bedmar Z, Merinas-Amo T, Gómez P, Alonso-Moraga Á, & Río-Celestino D (2017). Role of zucchini and its distinctive components in the modulation of degenerative processes: genotoxicity, anti-genotoxicity, cytotoxicity and apoptotic effects. *Nutrients*, 9, 755.
- [3] El-Sahar E-SG, Sopeah HR, & Almujaaydil MS (2020). Study the Effect of Different Levels of Zucchini (*Cucurbita pepo* L.) on the Biological Indicators for the Prevention of Cardiovascular Disease in Rats Fed High-Fat Diets. *Food Nutr. Sci.*, 11, 63–81.
- [4] He FJ, & MacGregor GA (2008). Beneficial effects of potassium on human health. *Physiol. plant.*, 133, 725–735.
- [5] drying systems on fresh-cut zucchini (*Cucurbita pepo*). *Innov. Food Sci. Emerg. Technol.*, 11, 361–368.

- [6] Yao L, Fan L, & Duan Z (2020). Effect of different pre-treatments followed by hot-air and far-infrared drying on the bioactive compounds, physicochemical property and microstructure of mango slices. *Food Chem.*, 305, 125477.
- [7] Jafari F, Movagharnejad K, & Sadeghi E (2020). Infrared drying effects on the quality of eggplant slices and process optimization using response surface methodology. *Food Chem.*, 333, 127423.
- [8] Yan J-K, Wu L-X, Qiao Z-R, Cai W-D, & Ma H (2019). Effect of different drying methods on the product quality and bioactive polysaccharides of bitter gourd (*Momordica charantia* L.) slices. *Food Chem.*, 271, 588-596.
- [9] Sakare P, Prasad N, Thombare N, Singh R, & Sharma SC (2020). Infrared Drying of Food Materials: Recent Advances. *Food Eng. Rev.*, 12, 381-398.
- [10] Ghaboos SHH, Ardabili SMS, Kashaninejad M, Asadi G, & Aalami M (2016). Combined infrared-vacuum drying of pumpkin slices. *J. Food Sci. Technol.*, 53, 2380-2388.
- [11] Lao Y, Zhang M, Chitrakar B, Bhandari B, & Fan D (2019). Efficient plant foods processing based on infrared heating. *Food Rev. Int.*, 35, 640-663.
- [12] Krishnamurthy K, Khurana HK, Soojin J, Irudayaraj J, & Demirci A (2008). Infrared heating in food processing: an overview. *Compr. Rev. Food Sci. Food Saf.*, 7, 2-13.
- [13] Wang Q, Li S, Han X, Ni Y, Zhao D, & Hao J (2019). Quality evaluation and drying kinetics of shitake mushrooms dried by hot air, infrared and intermittent microwave-assisted drying methods. *LWT- Food Sci. Technol.*, 107, 236-242.
- [14] Sui Y, Yang J, Ye Q, Li H, & Wang H (2014). Infrared, convective, and sequential infrared and convective drying of wine grape pomace. *Dry. Technol.*, 32, 686-694.
- [15] Adak N, Heybeli N, & Ertekin C (2017). Infrared drying of strawberry. *Food Chem.*, 219, 109-116.
- [16] Sadeghi E, Movagharnejad K, & Haghghi Asl A (2019). Mathematical modeling of infrared radiation thin-layer drying of pumpkin samples under natural and forced convection. *J. Food Process. Preserv.*, 43, e14229.
- [17] Amini G, Salehi F, & Rasouli M (2021). Color changes and drying kinetics modeling of basil seed mucilage during infrared drying process. *Inf. Process. Agric.*, 9, 397-405.
- [18] Chayjan RA, Dibagar N, & Alaei B (2017). Drying characteristics of zucchini slices under periodic infrared-microwave vacuum conditions. *Heat Mass Transf.*, 53, 3473-3485.
- [19] Movagharnejad K, Vahdatkhoram F, & Nanvakenari S (2018). Optimization of microwave and infrared drying process of nettle leaves using design of experiments. *J. Therm. Anal. Calorim.*, 135, 1677-1685.
- [20] Hamada, A. M., & El-Enany, A. E. (1994). Effect of NaCl salinity on growth, pigment and mineral element contents, and gas exchange of broad bean and pea plants. *Biol. Plant.*, 36, 75-81.
- [21] Maskan M (2001). Kinetics of colour change of kiwi-fruits during hot air and microwave drying. *J. Food Eng.*, 48, 169-175.
- [22] Tunckal C, & Doymaz İ (2020). Performance analysis and mathematical modelling of banana slices in a heat pump drying system. *Renew. Energy.*, 150, 918-923.
- [23] Méndez-Lagunas L, Rodríguez-Ramírez J, Cruz-Gracida M, Sandoval-Torres S, & Barriada-Bernal G (2017). Convective drying kinetics of strawberry (*Fragaria ananassa*): Effects on antioxidant activity, anthocyanins and total phenolic content. *Food Chem.*, 230, 174-181.
- [24] Aryal S, Baniya MK, Danekhu K, Kunwar P, Gurung R, & Koirala N (2019). Total phenolic content, flavonoid content and antioxidant potential of wild vegetables from Western Nepal. *Plants*, 8, 96.
- [25] Eissa HA, Barih GF, Ibrahim AA, Moawad RK, & Ali HS (2013). The Effect of Different Drying Methods on the Nutrients and Non-nutrients Composition of zucchini (green squash) rings. *J. Appl. Sci. Res.*, 9, 5380-5389.
- [26] Onwude DI, Hashim N, Abdan K, Janius R, & Chen G (2019). The effectiveness of combined infrared and hot-air drying strategies for sweet potato. *J. Food Eng.*, 241, 75-87.
- [27] Lee S-C, Jeong S-M, Kim S-Y, Park H-R, Nam K, & Ahn D (2006). Effect of far-infrared radiation and heat treatment on the antioxidant activity of water extracts from peanut hulls. *Food Chem.*, 94, 489-493.
- [28] Vega-Gálvez A, Ah-Hen K, Chacana M, Vergara J, Martínez-Monzó J, García-Segovia P, Lemus-Mondaca R, & Di Scala K (2012). Effect of temperature and air velocity on drying kinetics, antioxidant capacity, total phenolic content, colour, texture and microstructure of apple (var. Granny Smith) slices. *Food Chem.*, 132, 51-59.
- [29] de Castro NT, de Alencar ER, Zandonadi RP, Han H, Raposo A, Ariza-Montes A, Araya-Castillo L, & Botelho RBA (2021). Influence of Cooking Method on the Nutritional Quality of Organic and Conventional Brazilian Vegetables: A Study on Sodium, Potassium, and Carotenoids. *Foods* 10, 1782.



- [30] Kowey, P.R. (2002). The Role of Potassium. In: Lobo, R.A., Crosignani, P.G., Paoletti, R., & Bruschi, F. (Eds). *Women's Health and Menopause* (1st ed., pp. 151-157). Boston, MA: Springer.
- [31] Arslan D, & Özcan MM (2008). Evaluation of drying methods with respect to drying kinetics, mineral content and colour characteristics of rosemary leaves. *Energy Convers. Manag.*, 49, 1258-1264.
- [32] Wu B, Guo Y, Wang J, Pan Z, & Ma H (2018). Effect of thickness on non-fried potato chips subjected to infrared radiation blanching and drying. *J. Food Eng.*, 237, 249-255.
- [33] Supmoon N, & Noomhorm A (2013). Influence of combined hot air impingement and infrared drying on drying kinetics and physical properties of potato chips. *Dry. Technol.*, 31, 24-31.
- [34] Kurozawa, L. E., Azoubel, P. M., MURR, F. E. X., & Park, K. J (2012). Drying kinetic of fresh and osmotically dehydrated mushroom (*Agaricus blazei*). *J. Food Process Eng.*, 35, 295-313.
- [35] Kaveh M, Abbaspour-Gilandeh Y, Taghinezhad E, Witrowa-Rajchert D, & Nowacka M (2021). The Quality of Infrared Rotary Dried Terebinth (*Pistacia atlantica* L.)-Optimization and Prediction Approach Using Response Surface Methodology. *Molecules*, 26, 1999.
- [36] MacDougall D (2002). *Colour in food: improving quality (1th ed.)*. Cambridge, UK: Woodhead Publishing.
- [37] Kręcisz M, Stępień B, Paślawska M, Popłoński J, & Dulak K (2021). Physicochemical and quality properties of dried courgette slices: Impact of vacuum impregnation and drying methods. *Molecules*, 26, 4597.
- [38] Icier F, Ozmen D, Cevik M, & Cokgezme OF (2021). Drying of licorice root by novel radiative methods. *J. Food Process. Preserv.*, 45, e15214.

## مقاله پژوهشی

ارزیابی خشک کردن مادون قرمز دور بر روی خواص کیفی برش های کدو سبز:  
تأثیر پارامترهای عملیاتیفاطمه جعفری<sup>۱</sup>، کامیار موقرنژاد<sup>۲\*</sup>، ابراهیم صادقی<sup>۲</sup>

۱. دانشکده مهندسی شیمی، دانشگاه صنعتی نوشیروانی بابل، بابل، مازندران، ایران

۲. دپارتمان مهندسی شیمی، دانشگاه شمال، آمل، مازندران، ایران

(تاریخ ارسال: ۱۴۰۲/۰۲/۱۲، تاریخ آخرین بازنگری: ۱۴۰۲/۰۳/۱۷، تاریخ پذیرش: ۱۴۰۲/۰۴/۱۳)

## چکیده

این تحقیق با هدف ارزیابی چگونگی تأثیر ضخامت نمونه (۳، ۵ و ۷ mm)، سرعت هوا (۰/۵، ۱/۲۵ و ۲ ms<sup>-1</sup>)، و توان لامپ مادون قرمز (۱۰۰۰، ۱۵۰۰ و ۲۰۰۰ W) بر ویژگی‌های خشک کردن برش‌های کدو سبز در خشک‌کن مادون قرمز دور انجام شد. طراحی آزمایش‌های خشک کردن، که رابطه بین متغیرهای ورودی و خروجی را نشان می‌دهد، با روش سطح پاسخ انجام شد. سپس تأثیر این عوامل مستقل بر میزان رطوبت (زمان خشک شدن)، فعالیت آبی، محتوای فنولی کل، محتوای پتاسیم و رنگ تعیین شد. برای پیش‌بینی پاسخ‌ها، دقیق‌ترین مدل‌های ریاضی با استفاده از تحلیل واریانس انتخاب شدند. نتایج نشان داد که زمان خشک شدن با کاهش ضخامت نمونه و سرعت هوا و افزایش قدرت لامپ مادون قرمز کاهش یافت. محتوای فنولی کل و محتوای پتاسیم پس از فرآیند خشک کردن چندین برابر افزایش یافت. افزایش ضخامت نمونه و قدرت لامپ مادون قرمز تأثیر مثبتی بر هر دوی این مقادیر داشت. حداقل و حداکثر مقدار کل تغییر رنگ به ترتیب ۵/۵۴ و ۱۳/۹۶ بود. کدو سبز خشک تولید شده با استفاده از خشک کردن مادون قرمز دور، محصولی با ارزش است که قابلیت استفاده در صنایع غذایی و دارویی و یا در درمان بیماری‌ها را به عنوان یک وعده غذایی تقویتی دارد.

واژگان کلیدی: خشک کردن مادون قرمز، محتوای فنولی کل، محتوای پتاسیم، مشخصات رنگ، روش سطح پاسخ، کدو سبز.

