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Scientific Research

Application of hot-air, infrared, and microwave methods for drying ground of chickpea sprouts

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ABSTRACT

The sprouting process includes changes in nutritional, biochemical, and sensory characteristics that improve chickpea quality and increase its digestibility. Various products such as Falafel are made from ground and dried chickpea sprouts. Therefore, in this research, the use of hot air (70°C), infrared (250 W), and microwave (220 W) methods for drying ground chickpea sprouts was investigated and modeled. The drying time of the samples in the infrared dryer was shorter than the other two dryers. The average drying time of the samples in the hot air, infrared and microwave dryers was 63.3, 26.7, and 156.7 min, respectively. In this research, the effective moisture diffusivity coefficient of ground chickpea sprouts in hot air, infrared and microwave dryers was determined to be 4.99×10^{-9} m^2s^{-1}, 17.95×10^{-9} m^2s^{-1}, and 1.59×10^{-9} m^2s^{-1}, respectively. To study the drying kinetics of ground chickpea sprouts, Wang and Singh, Henderson and Pabis, Approximation of diffusion, Page, Newton, Midilli, and Logarithmic mathematical models were fitted to the experimental data. Finally, when modeling the drying process of this product, Midilli's mathematical model with four parameters was chosen as the best model due to its minimal error.

1. Introduction

Legumes rank second after cereals as an essential food source around the world, and in developing countries, a significant part of people's dietary protein comes from various legumes such as peas, green peas, mung beans, soybeans, beans, and lentils. The protein content of legumes (20-50%) is relatively higher compared to cereals and other starchy crops and roots [1, 2]. Chickpea (*Cicer arietinum* L.) is widely grown in tropical, subtropical and temperate regions and is the third most important crop (after soybean and bean) of the legume family in the world [1, 3, 4]. Pea seeds are a good source of protein, carbohydrates, fiber, vitamins, and minerals (P, Mg, Ca, Fe, K) and vitamins such as niacin, thiamin, riboflavin, B vitamins, and β-carotene [1].

The germination process includes changes in nutritional, biochemical and sensory characteristics that improve the quality of legumes. This process is used in the processing of legumes to improve their nutritional quality, as it improves digestibility. Also, during this process, the amount of phenolic compounds and antioxidant capacity of the product increases [5-9].

For the processing and drying of each product, it is necessary to use the best drying method in optimal conditions so that the least quality loss is created in the desired product and the operation is performed in the shortest time [10, 11]. The most common method of drying agricultural products is the use of hot-air flow and displacement heat transfer method, which includes the simultaneous transfer of mass and heat in the product. Hot-air drying, despite its advantages such as the ability to accurately control temperature and process conditions, has disadvantages such as long process time and product quality loss, compared to other modern methods [12].

One of the ways to reduce the drying time and improve the quality of the dried product is to use infrared rays. The use of infrared radiation increases the drying speed, maintains the quality of the final product and reduces the costs of the production process due to the reduction of energy consumption [13]. Nachaisin et al. (2015) used a combined infrared-hot air method for drying instant germinated brown rice. Based on the results reported in this research, the use of infrared radiation led to an increase in the drying speed and thus a decrease in the drying time. Energy consumption decreased with the increase of radiation intensity [14].

Microwaves are a fast and effective heating source that directly affects the entire food material, thereby accelerating the physicochemical reactions and the drying rate, resulting in the production of a high quality dried product [15]. The results of reports related to various studies show that the use of microwave pretreatment causes less damage to the nutritional compounds in plants [16]. Bualuang et al. (2017) investigated the effect of microwave drying on the quality of germinated corn. The results of this research showed that drying with microwaves (power 300 W) leads to maintaining the nutritional value and increasing the antioxidant activity of dried germinated corn [17].

Ground chickpea sprouts are used as the main ingredient in falafel [4, 18]. Investigating and using new methods such as infrared reduces the drying time of agricultural products. Therefore, in this research, the use of hot-air, infrared, and microwave methods for drying ground of chickpea sprouts was investigated and modeled.

2. Materials and methods

2-1- Ground of chickpea sprouts preparation

To perform this research, packaged chickpeas were obtained from Sahar Company (Hamedan). After washing, the chickpeas were soaked in water at 25°C for 24 h. In the following, their excess water was completely removed and chickpeas were sprouted in a container covered with a thin towel for 24 h at 25°C (the water of the samples was changed every 6 h). Meat grinder (MK-G20NR, National, Japan) was used to grind the sprouted chickpeas.

2-2- Drying by hot-air

To dry the ground of chickpea sprouts, the samples were poured into aluminum containers as a thin-layer and then placed in a fan oven (Shimaz, Iran) at 70°C. The weight changes of the samples during drying until reaching a constant weight were recorded every 5 min by a digital balance (GM-300p, Lutron, Taiwan) with an accuracy of ± 0.01 g.

2-3- Drying by infrared

In this research, an infrared dryer with a power of 250 W was used to dry the ground of chickpea sprouts, and the distance between the samples and the surface of the lamp was considered to be 7 cm. The weight changes of the samples during drying were recorded every 5 min by a digital balance with an accuracy of ± 0.01 g.

2-4- Drying by microwave

In order to dry the ground of chickpea sprouts with a microwave, a household microwave device with a power of 220 W (20% of the main power of the device) was used. In this dryer, the weight changes of the samples during drying were recorded every 5 min by a digital balance with an accuracy of ± 0.01 g.

2-5- Calculate the moisture ratio parameter

The moisture ratio (MR) parameter can make the data obtained from the drying process uniform. Having the initial moisture content of the product and reducing its weight, the parameter of the moisture ratio when the product dries is calculated by equation 1 [19].

(1)

$$MR = \frac{M_t - M_e}{M_0 - M_e}$$

In this equation, MR: moisture ratio (dimensionless), M_t the moisture content on a dry basis at any time t (g water/g dry matter), M_0 the initial moisture content on a dry basis and M_e the equilibrium moisture content (g water/g dry matter). For long drying times, M_e values are very small compared to M_0 and M_t values; Therefore, the equation of moisture ratio during drying can be simplified as equation 2, and there is no need to measure the equilibrium moisture to calculate the moisture ratio [20].

(2)

$$MR = \frac{M_t}{M_o}$$

2-6- Calculate the effective moisture diffusivity coefficient

Throughout the drying process, diffusion is the dominant phenomenon of moisture transfer from the center of the sample to the surface, so in this study, the mass transfer space was considered as a flat plate (thin layer) and moisture removal was calculated based on Fick's second law, according to equation 3 [21].

(3)

$$MR = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp(-(2n+1)^2 \frac{\pi^2 D_{eff} t}{4L^2})$$

In this equation, L is half the thickness of the layer (in meters), n is the number of terms considered from the equation, t is the drying time (s) and D_{eff} is the effective diffusion coefficient (m^2s^{-1}). In a common way, the first term of this series was considered and the above equation was obtained as a simple equation 4 and the effective moisture diffusivity coefficient was obtained through this equation and slope calculation.

(4)

$$MR = \frac{m_t - m_e}{m_0 - m_e} = \frac{8}{\pi^2} \exp\left[\frac{-\pi^2 D_{eff} t}{4L^2}\right]$$

By taking the natural logarithm of the sides of equation 4, equation 5 is obtained:

(5)

$$\ln MR = Ln \frac{8}{\pi^2} + \left(-\frac{\pi^2 D_{eff} t}{4L^2}\right)$$

Then, the effective moisture diffusivity coefficient was calculated through the slope of the natural logarithm of the experimental data moisture ratio (LnMR) against the drying time and using equation 6.

(6)

$$Slope = \frac{\pi^2 D_{eff}}{4L^2}$$

In this equation, Slope is the slope of the line.

2-7- Kinetic modeling

By using mathematical models, it is possible to achieve a better understanding of the drying process as a function of various variables by spending less time and money. In this study, in order to investigate the kinetics and predict the drying process of ground of chickpea sprouts, kinetic modeling was done with the help of experimental data and using different experimental drying models. Wang and Singh, Henderson and Pabis, Approximation of diffusion, Page, Newton, Midilli, and Logarithmic equations [21] were selected and analyzed to model the drying process and choose the best kinetic model. In order to model the experimental data of drying and obtain the constants of the models, MATLAB software version R2012a was used.

2-8- Statistic analysis

Drying tests were performed in three repetitions and Duncan's multi-range test was used at the 95% confidence level to compare the average of the observed responses. The results obtained from this research were analyzed using SPSS version 21 software. Excel (2007) program was also used to draw charts.

3- Results and discussion

3-1- Investigating the mass transfer kinetics

Figure 1 shows the drying time of ground of chickpea sprouts in three hot-air, infrared, and microwave dryers. As can be seen in this figure, the drying time of the samples in the infrared dryer is less than the other two dryers. Considering that the high powers of the microwave device cause the product to burn, therefore, in this study, the power of the microwave was set to 220 W for drying the ground of chickpea sprouts, so the drying time of the product in this dryer increased compared to the hot-air dryer. Figure 2 shows moisture removal rate from ground of chickpea sprouts during drying in three hot-air, infrared, and microwave dryers. This figure shows that moisture removal rate from the samples placed in the infrared dryer is higher than the other two dryers. Najib et al. (2022) reported the drying time of two varieties of lentils in a combined microwave-assisted infrared dryer depending on the power of the system in the range of 5.5 to 100 minutes, which decreased with the increase of microwave and infrared power [22]. In a research, Aghajani et al. (2023) investigated the effect of hot oven drying temperature and time on weight loss, total phenolic compounds, and antioxidant properties of mint leaves and optimized them with the response surface method. Their results showed that with increasing drying time and temperature, the weight loss and phenolic compounds of the whole mint leaf increased and drying time has a greater effect on the changes of these two parameters compared to drying temperature [23].

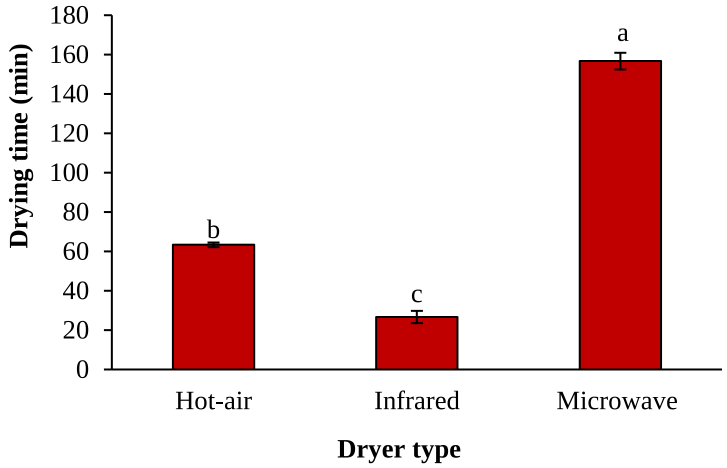

Fig 1- Drying time of ground chickpea sprouts at different dryers. Means with different superscripts differ significantly ($p<0.05$).

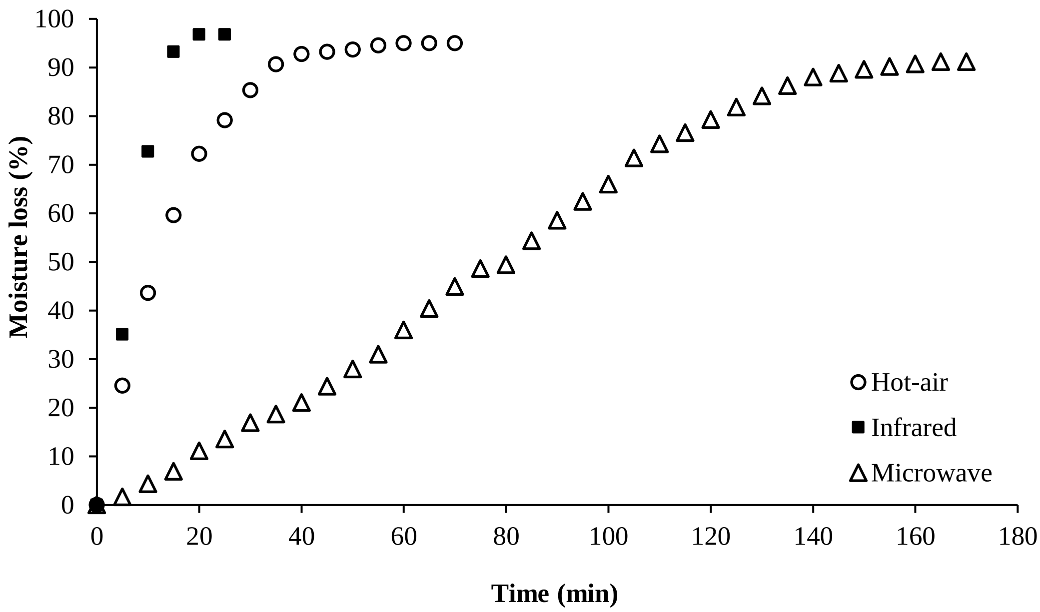

Fig 2- Moisture loss rate of ground chickpea sprouts during drying at different dryers.

2-3- Results of effective moisture diffusivity coefficient calculation

Figure 3 shows the trend of changes in the natural logarithm of the moisture ratio (LnMR) with respect to the drying time of ground of chickpea sprouts in three hot-air, infrared, and microwave dryers. The slope of these lines was used to calculate the effective moisture diffusivity coefficient.

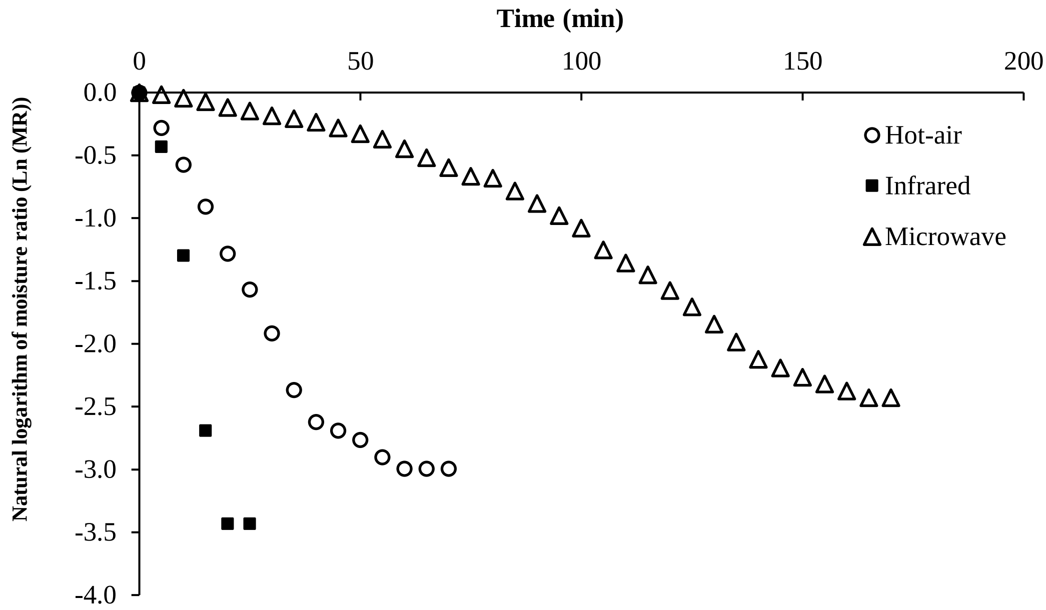

Fig 3- Variations of the natural logarithm of moisture ratio (Ln (MR)) values versus drying time of ground chickpea sprouts at different dryers.

As can be seen in Figure 4, the effective moisture diffusivity coefficient of ground of chickpea sprouts in the infrared dryer is higher than the other two dryers. In this research, the effective moisture diffusivity coefficient values for ground of chickpea sprouts in hot-air, infrared, and microwave dryers were equal to 4.99×10^{-9} m^2s^{-1}, 17.95×10^{-9} m^2s^{-1}, and 1.59×10^{-9} m^2s^{-1} respectively. Taheri et al. (2020) studied the drying kinetics of red lentil seeds by combined microwave-fluidised bed dryer. Taking into account the second law of Fick's diffusion in one direction in a sphere with convective boundary conditions, as well as the negligible external resistance against mass transfer, these researchers reported the effective moisture diffusivity coefficient of lentil seeds to be equal 0.44×10^{-10} m^2s^{-1} for hot-air (at 50°C) and 3.06×10^{-10} m^2s^{-1} for the combined method [24].

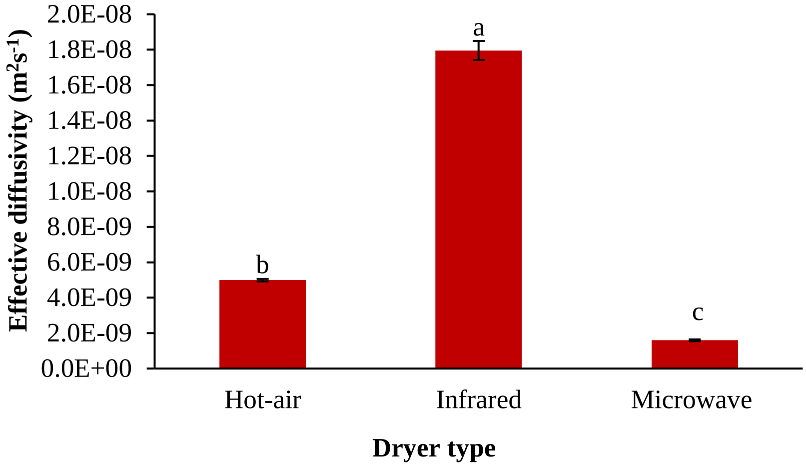

Fig 4- Effective moisture diffusivity values (D_{eff}) of ground chickpea sprouts at different dryers. Means with different superscripts differ significantly ($p<0.05$).

3-3- Selection of the best kinetic model

By calculating the value of the moisture ratio for all the studied treatments during the drying process of ground of chickpea sprouts and fitting the points obtained by drawing the moisture ratio -time diagrams, using Wang and Singh, Henderson and Pabis, Approximation of diffusion, Page, Newton, Midilli, and Logarithmic models, the results were analyzed for each model. Table 1 shows the sum of squared error (SSE), correlation coefficient (r), and root mean square error (RMSE), as well as the coefficients of these models. In this table, MR is moisture ratio, t is time (min), and n, k, b, l, c, and a are constants of these models. The best model should have the highest value of correlation coefficient and minimum error values. The results showed that the best model with the highest fit, according to the mentioned conditions, regarding the drying process of ground of chickpea sprouts, is the Midilli model.

Table 1- The statistical parameters obtained in order to verify the fit of each mathematical model to the observed data during drying of ground chickpea sprouts (hot-air drying data)

Model number	Model name	Model equation	Model constants	SSE	r	RMSE
1	Wang and Singh	$MR = 1 + at + bt^2$	a=-0.0402 b=0.0004	0.0483	0.9802	0.0609
2	Henderson and Pabis	$MR = a\exp(-kt)$	a=1.0080 k=0.0616	0.0051	0.9979	0.0198
3	Approximation of diffusion	$MR = a\exp(-kt) + (1-a)\exp(-kbt)$	a=-0.0293 k=0.7070 b=0.0889	0.0049	0.9980	0.0202
4	Page	$MR = \exp(-kt^n)$	k=0.0586 n=1.0150	0.0051	0.9979	0.0199
5	Newton	$MR = \exp(-kt)$	k=0.0612	0.0052	0.9979	0.0193

6	Midilli	$MR = a\exp(-kt^{n}) + bt$	a=0.9965 k=0446 n=1.1280 b=0.0006	0.0008	0.9997	0.0084
7	Logarithmic	$MR = a\exp(-kt) + c$	a=0.9954 k=0.0661 c=- 0.0219	0.0033	0.9986	0.0167

Considering the lower error resulting from the fitting of the experimental data with Midilli model and the greater fit of this equation with the experimental data during the drying kinetics study of ground of chickpea sprouts, the average coefficients of this model are reported in Table 2. In this research, the values of sum of squared error, correlation coefficient, and root mean square error were in the range of 0.0002 to 0.0199, 0.9951 to 0.9998, and 0.0084 to 0.0266, respectively.

Table 2- The constants and coefficients of the Midilli model

Dryer type	a	k	n	b	SSE	r	RMSE
Hot-air	0.9942	0.0355	1.1840	0.0006	0.0018	0.9993	0.0119
Infrared	0.9980	0.0268	1.6750	0.0004	0.0005	0.9997	0.0133
Microwave	0.9932	-0.0004	0.7920	-0.0084	0.0143	0.9972	0.0210

In order to validate the proposed Midilli model, the values of moisture ratio changes predicted by the Midilli model and the experimental moisture ratio values obtained are shown in Figure 5. As this figure shows, there is a good agreement between the experimental and model-predicted moisture ratios; Therefore, proposed Midilli model is suitable for predicting changes in moisture ratio of ground of chickpea sprouts during drying in hot-air, infrared, and microwave dryers. Ghaderi et al. (2011) reported that the Midilli model is the most suitable model for investigating the drying process of sour cherry in a microwave-vacuum dryer due to having the highest correlation coefficient and the lowest error [25].

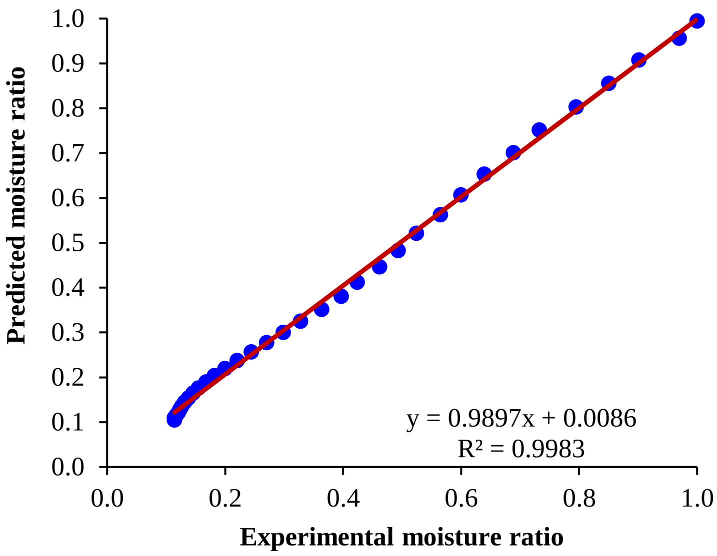

Fig 5- Comparison of fitted data by Midilli model with experimental results (microwave drying data).

4. Conclusion

In this research, the use of hot-air, infrared, and microwave methods for drying ground of chickpea sprouts was studied. The results of this research showed that the drying time of the samples in the infrared dryer is shorter than the other two dryers. Also, the effective moisture diffusivity coefficient and moisture removal rate from the samples in this dryer were higher than hot-air and microwave dryers. In general, due to the shorter drying time of ground of chickpea sprouts in the infrared dryer, it is recommended to use this type of dryer to dry this product and similar products. Also, in this research, different models were used to model the drying kinetics of ground of chickpea sprouts, and the Midilli model was chosen as the best model due to its lower error value.

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چکیده

فرآیند جوانه‌زنی شامل تغییراتی در ویژگی‌های تغذیه‌ای، بیوشیمیایی و حسی است که باعث بهبود کیفیت و افزایش قابلیت هضم نخود می‌شود. از جوانه‌های چرخ‌شده و خشک‌شده نخود برای تهیه محصولات مختلفی مانند فلافل استفاده می‌شود. لذا در این پژوهش استفاده از روش‌های هوای داغ (دمای ۷۰ درجه سلسیوس)، فروسرخ (توان ۲۵۰ وات) و مایکروویو (توان ۲۲۰ وات) برای خشک‌کردن جوانه‌های چرخ‌شده نخود بررسی و مدل‌سازی شد. زمان خشک شدن نمونه‌ها در خشک‌کن فروسرخ از دو خشک‌کن دیگر کمتر بود. متوسط زمان خشک شدن نمونه‌ها در خشک‌کن‌های هوای داغ، فروسرخ و مایکروویو به ترتیب برابر ٦۳/۳، ۲٦/۷ و ۱٥٦/۷ دقیقه بود. در این پژوهش، ضریب نفوذ مؤثر رطوبت برای جوانه‌های چرخ‌شده نخود در خشک‌کن‌های هوای داغ، فروسرخ و مایکروویو به ترتیب برابر $4.99\times10^{-9}\ m^2s^{-1}$، $17.95\times10^{-9}\ m^2s^{-1}$ و $1.59\times10^{-9}\ m^2s^{-1}$ به دست آمد. جهت بررسی سینتیک خشک شدن جوانه‌های چرخ‌شده نخود، مدل‌های ریاضی ونگ و سینگ، هندسون و پابیس، تقریب انتشار، پیج، نیوتن، میدیلی و لگاریتمی بر داده‌های تجربی برازش داده شدند. در نهایت، در مدل‌سازی فرآیند خشک‌کردن این محصول، مدل ریاضی میدیلی با چهار پارامتر به دلیل حداقل خطا به‌عنوان بهترین مدل انتخاب شد.