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Researgh article

Microwave Pretreatment of Sprouted Mung Beans Before Hot-Air and Infrared Drying Process

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Abstract

Sprouting enhances the nutritional and quality characteristics of mung beans (*Vigna radiata* L.). In this study, the impacts of infrared radiation and hot-air drying on microwave-pretreated mung bean sprouts were examined. The microwave process was performed for 0, 15, 30, 45, and 60 s before hot-air and infrared dehydration of sprouted mung beans. Microwave pretreatment decreased drying time of sprouted mung beans. Increasing the microwave pretreatment time from 0 to 60 s caused drying time of samples inside the hot-air dryer to decrease from 205 min to 130 min ($p<0.05$). Drying time of sprouts in the infrared dryer was significantly less than the hot-air dryer ($p<0.05$). Effective moisture diffusivity coefficient (D_{eff}) calculated by Fick's second law, varied in the range of 1.06×10^{-10} - 1.60×10^{-10} m^2s^{-1}, and 0.98×10^{-9} - 1.15×10^{-9} m^2s^{-1}, for hot-air and infrared dried samples, respectively. Experimental data for drying curves were fitted to various thin-layer equations, and the Midilli equation was best suited to explain drying kinetics of sprouted mung beans. Average rehydration ratio of dried sprouted mung beans in hot-air and infrared dryers were 262.55%, and 211.65%, respectively. Briefly, the microwave pretreatment (about 60 sec) and use of infrared dryer is appropriate drying technique for sprouted mung beans with faster mass transfer and shorter drying time.

Keywords: **Effective moisture Diffusivity coefficient, Microwave, Midilli equation, Mung bean, Rehydration.**

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1. Introduction

Microwave radiation has the ability to heat a material with dielectric properties. Material absorbs microwave energy and then converts it into heat [1]. Compared to the traditional heating process, microwave heating technology offers numerous advantages such as rapid heat transfer, non-contact heating, internal and volume heating, selective heating, uniform heating, cleanliness, pollution-free operation, and automated control [2]. Microwave drying can increase drying efficiency and reduce operating costs while maintaining high product quality [1]. Of all accessible pretreatment approaches for food products processing, use of microwaves is a promising technique [3-6]. The microwave pretreatment can facilitate mass transfer during drying and reduce drying time of fruits and vegetables [5-8]. Salehi et al. [9] used microwave pretreatment before the drying process to improve the quality attributes of dried sweet cherries. Their results showed that the moisture diffusivity, total phenolics, and antioxidant capacity of treated sweet cherries were higher than those of non-treated samples.

Mung bean (*Vigna radiata* L.) is a green legume rich in protein, oligosaccharides and fibers, high levels of phenolics, bioactive phytochemicals, flavonoids (vitexin and isovitexin), amino acids and antioxidants (regulating cholesterol levels and scavenging free radicals), and phytonutrients [10-12]. The boiled and sprouted mung beans are commonly used as a sprouted mung salad [10]. The results of Javed et al. [13] showed that the mung bean can be utilized in production of ready-to-eat therapeutic food due to its shelf-stability. Thus, it helps to mitigate the protein-energy malnutrition. Liu et al. [14] and Wan et al. [15] confirmed that the mung bean or its extract can be used as an appropriate candidate of natural antioxidant and phenolic compounds.

Sprouting a traditional method is used for reducing most of anti-nutritional factors in legumes. Sprouting enhances the nutritional and quality characteristics of mung beans [16, 17]. The sprouted mung beans are a good source of bioactive compounds with high antioxidant capacity [18, 19]. Dried sprouted grain powder is known to be an excellent source of nutrients for improving the quality and physicochemical properties of foods available throughout the year (such as noodles, pasta, bread, sausages, etc.) [16, 20-22]. Impacts of ultrasonic pretreatment and drying approaches on the drying kinetics and rehydration of sprouted mung beans were studied by Salehi [23]. The results demonstrated that the ultrasonic pretreatment increased the moisture diffusion capacity (higher moisture loss) and reduced the drying time of sprouted mung beans.

The use of microwaves shows many advantages. The most important aspect is shortening the time of the thermal process and reducing energy consumption and costs of the operation [1, 24]. No report on effects of microwave pretreatment on hot-air and infrared drying rate of sprouted mung beans was found. Hence, the present study aimed to determine the influence of microwave pretreatment and drying approaches on drying time, mass transfer kinetic, D_{eff}, and rehydration of sprouted mung beans. In addition, the moisture ratio changes of sprouted mung beans when dried were modeled.

2. Materials and methods

2.1. Sprouting process

Mung bean seeds were purchased at a market in Arak, Markazi Province, Iran. The seeds were manually cleaned and dust-free and then stored in a dry, cool place until needed. The seeds were washed and soaked in tap water at 25±1°C for 24 hours (seeds to water ratio 1:4, w/v) [16]. Soaked seeds were kept inside a polyethylene container covered with a clean kitchen towel and allowed to germinate for 72 hours in the dark at room temperature (25±1°C). The moisture content of mung beans was determined using an oven at 105°C for 5 hours (55L, Shimaz, Iran). In this study, the average moisture content of non-treated mung beans was 7.1% (wet basis).

2.2. Microwave pretreatment

To apply the microwave pretreatment on the germinated seeds, a microwave oven (Delmonti, Model; DL740, Italy) was used under atmospheric pressure (Figure 1). In this study, the impact of the microwave pretreatment time at 5 time intervals of 0, 15, 30, 45, and 60 s on the sprouted mung beans was studied.

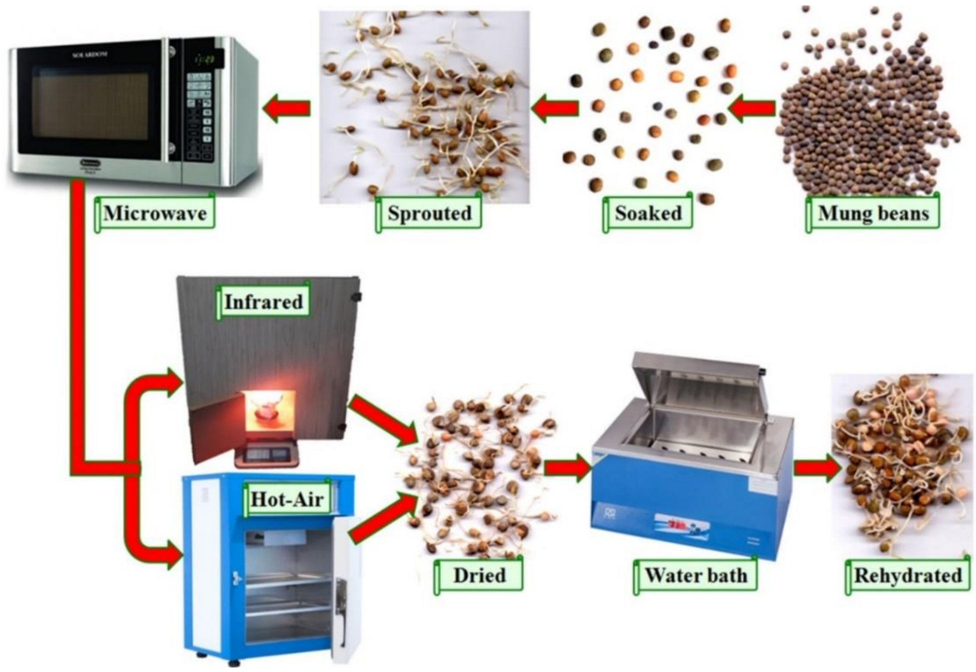

Fig. 1 Schematic of microwave pretreatment, hot-air and infrared drying, and rehydration process of sprouted mung beans.

2.3. Hot-air drying

After each treatment, the sprouted mung beans were dried in a convective hot-air oven (at 70±2°C, 55L, Shimaz, Iran) [25].

2.4. Infrared drying

In this research, an infrared dryer (length 440 mm, width 200 mm, and height 400 mm) with an infrared radiation source (250 W, near-infrared, Noor Lamp Company, Iran) was employed for drying germinated mung beans. In this dryer, the distance from the radiant lamp to the germinated seeds was 5 cm. Mass changes of samples were recorded by a Lutron GM-300p digital balance (sensitivity of ±0.01 g, Taiwan).

2.5. Drying kinetics

The sprouted mung beans drying kinetics are described using nine simplified drying equations (Approximation of diffusion, Henderson and Pabis, Logarithmic, Midilli, Newton, Page, Two-term, Verma, and Wang and Singh) [26, 27]. Regression analyses were performed to estimate model parameters using Matlab software (version R2012a).

2.6. Calculation of effective moisture diffusivity coefficient (D_{eff})

The D_{eff} values (m^2/s) of sprouted mung beans during drying process, at various hot-air and infrared drying conditions, were calculated pursuant to the method explained by Salehi et al. [9].

2.7. Rehydration

Rehydration tests were performed using a water-bath (R.J42, Pars Azma Co., Iran). The dried sprouted mung beans were weighed and placed in distilled water at 50°C for 30 minutes in a 250ml beaker. The researcher then drained the excess water for 30 seconds and reweighed the sample. The percent rehydration value of sprouted mung beans was determined as the rate of the mass of rehydrated sprouted mung beans to the dry mass of sprouted mung beans×100 [28].

2.8. Statistical analysis

The sprouted mung beans drying tests were performed with a 2×5×3 factorial design (dryer type, microwave treatment time, and three replicates) in a fully randomized design. Means were also compared with p-value<0.05 using Duncan’s multiple range test (using the SAS 9.1, USA).

3. Results and Discussion

3.1. Drying time

In this study, the final moisture content of dried sprouted mung beans was 0.30±0.07 (dry basis). Enhancing air temperature in the presence of infrared radiation improved the drying rate [29]. The analysis of variance results showed that the dryer type (hot-air and infrared), microwave time, and its interactions, have significant effects on the drying duration of sprouted mung beans ($p<0.01$) (Table 1). The impact of microwave pretreatment time and dryer type on sprouted mung beans drying duration is presented in Figure 2. The drying time of samples dried in infrared dryer was much shorter than the samples dried in hot-air dryer at all conditions ($p<0.05$). The average drying time of sprouted mung beans dried in hot-air and infrared dryers were 171.0 and 22.0 min, respectively. The drying duration of sprouted mung beans was shortened by increasing the microwave pretreatment time. As the microwave pretreatment time increased from 0 to 60 seconds, the drying time of sprouted mung beans in the hot-air dryer decreased from 205 min to 130 min ($p<0.05$). Besides, by increasing the microwave pretreatment time from 0 to 60 s, the drying time of samples inside the infrared dryer, decreased from 23.0 min to 21.0 min ($p>0.05$).

Table .1 Analysis of variance for drying time of sprouted mung beans.

Sources of changes	df	Sum of squares	Mean square	P
Dryer (D)	1	166508	166508	0.000
Microwave time (M)	4	5600	1400	0.000
D × M	4	4830	1208	0.000
Error	20	1226	61	
Total	29	178164		

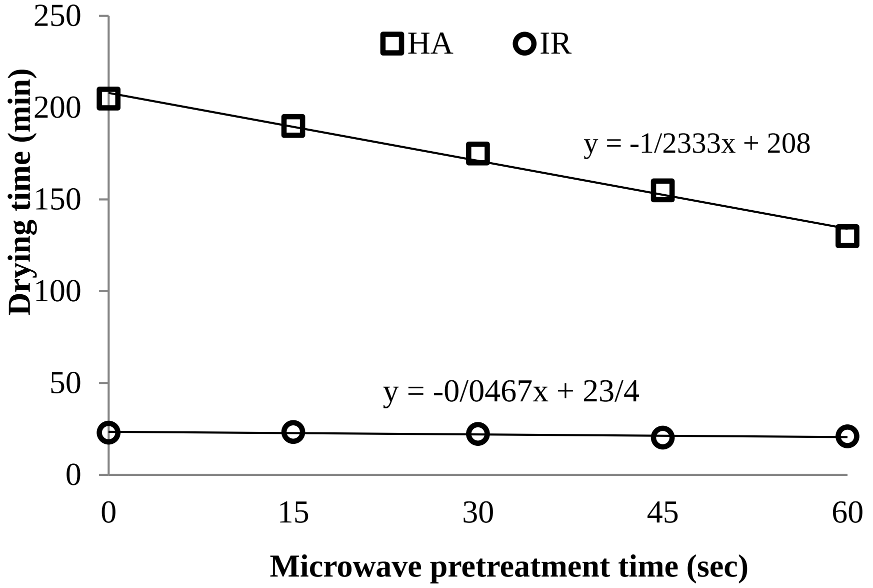

Fig. 2 Effect of microwave pretreatment on drying time of sprouted mung beans (HA=Hot-air dryer; IR=Infrared dryer).

The interaction between microwaves and materials occurs through the generation of dipoles within the material and changes in their orientation. This unique feature allows simultaneous heating throughout the body resulting in fast and uniform temperature elevation [1, 2]. The impacts of microwave time on the moisture content changes (dry basis) of sprouted mung beans when dried in the hot-air and infrared dryers are shown in Figures 3 and 4, respectively. As seen in these figures, the application of microwave has increased the rate of moisture removal from sprouted mung beans and, as a result, it increased the drying rate of the samples. Sarjerao et al. [30] used a tray dryer and a vacuum dryer to dry the sprouted mung beans. Their results confirmed that the dehydration duration in the vacuum dryer was 21.05% shorter than the drying duration in the tray dryer at 50°C.

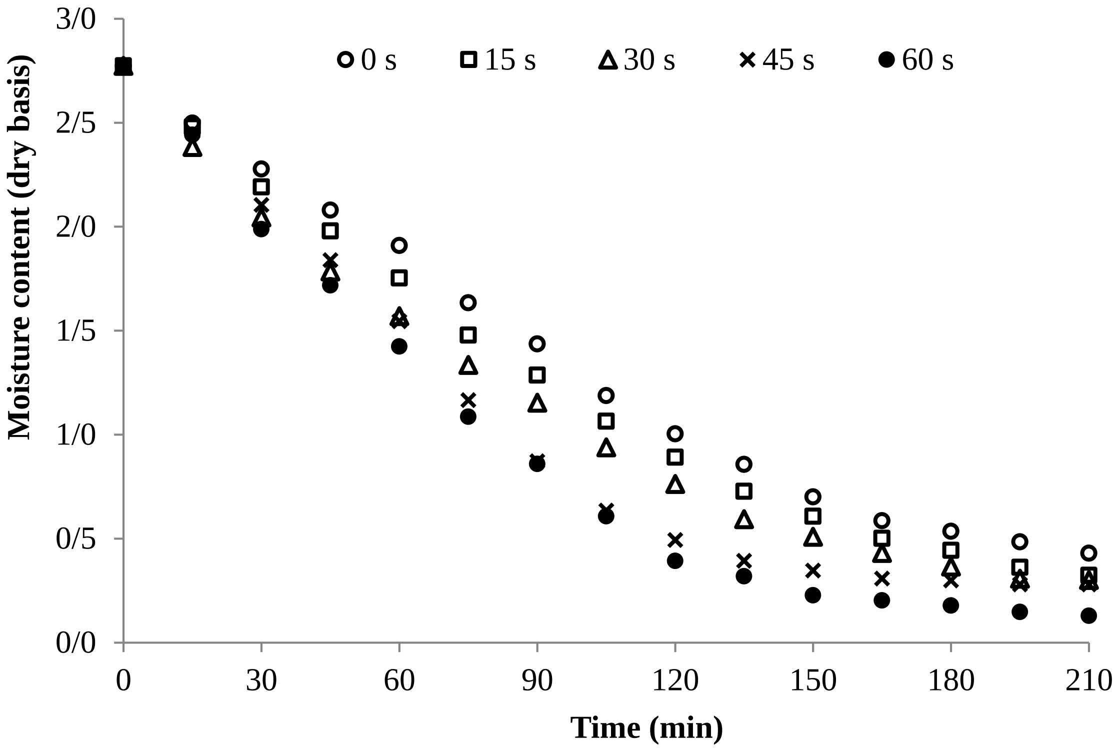

Fig. 3 Moisture content changes of sprouted mung beans when dried in the hot-air dryer

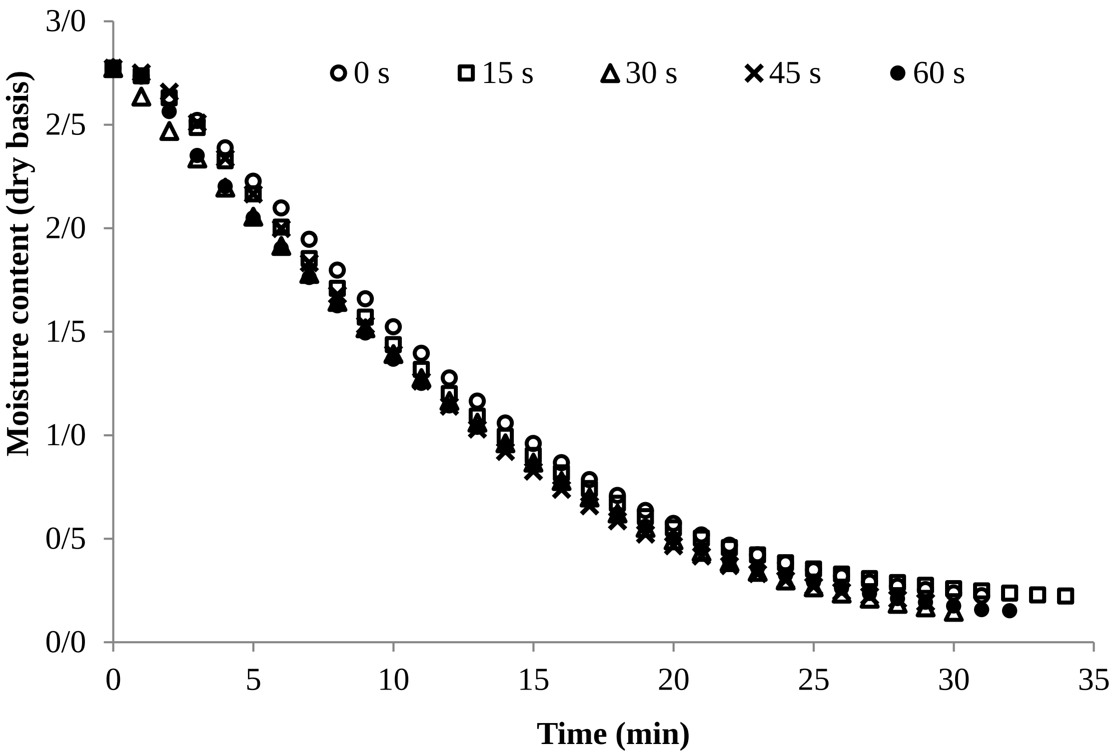

Fig. 4 Moisture content changes of sprouted mung beans when dried in the infrared dryer

3.2. Effective moisture diffusivity coefficient (D_{eff})

In constant power microwave drying, as the moisture content in the material decreases, its ability to absorb microwaves decreases [24]. The impacts of microwave pretreatment time and dryer type on the D_{eff} values of sprouted mung beans are presented in Figure 5. The D_{eff} values of the samples dried with the infrared dryer were considerably higher than those of the sprouts dried with the hot-air dryer ($p<0.05$). The average D_{eff} values of sprouted mung beans when dried in hot-air dryer increased from 1.06×10^{-10} m^2s^{-1} to 1.60×10^{-10} m^2s^{-1} when the microwave pretreatment time was increased from 0 to 60 s ($p>0.05$). In addition, the average D_{eff} values of sprouted mung beans when dried in infrared dryer increased from 0.98×10^{-9} m^2s^{-1} to 1.15×10^{-9} m^2s^{-1} when the microwave pretreatment time was increased from 0 to 60 s ($p<0.05$). These data lie within the common range of 10^{-11}-10^{-9} m^2/s for other grains. Rafiee et al. [31] used a hot-air dryer (at 35-70°C) for drying wheat (Tajan). The results indicated that the D_{eff} values for the whole wheat ranged from 2.3×10^{-11} m^2/s to 1.1×10^{-10} m^2/s, and it was enhanced when the temperature of the dry air increased. The results of Sarjerao et al. [30] indicated that the D_{eff} values for vacuum-dried sprouted mung beans was more than tray dryer at all condition. As well, the D_{eff} values for tray and vacuum dryers were reported between 3.98×10^{-11} m^2s^{-1} and 7.35×10^{-11} m^2s^{-1}, and 4.50×10^{-11} m^2s^{-1}, and 7.892×10^{-11} m^2s^{-1}, respectively. Manikantan et al. [27] used a tray dryer (at 50–80°C, for 24-48 h) for drying sprouted wheat grains. Their results indicated that the D_{eff} values of sprouted wheat grains (at 48h drying period) increased from 1.9×10^{-9} m^2 s^{-1} to 2.6×10^{-9} m^2 s^{-1} with an increase in dryer temperature from 50 to 80°C. In another study, Shingare and Thorat [22] used a fluidized bed dryer to dry sprouted wheat grains. They reported D_{eff} values for sprouted wheat grains when dried in a fluidized bed dryer ranging from 7.3×10^{-10} m^2 s^{-1} to 30.4×10^{-10} m^2 s^{-1}.

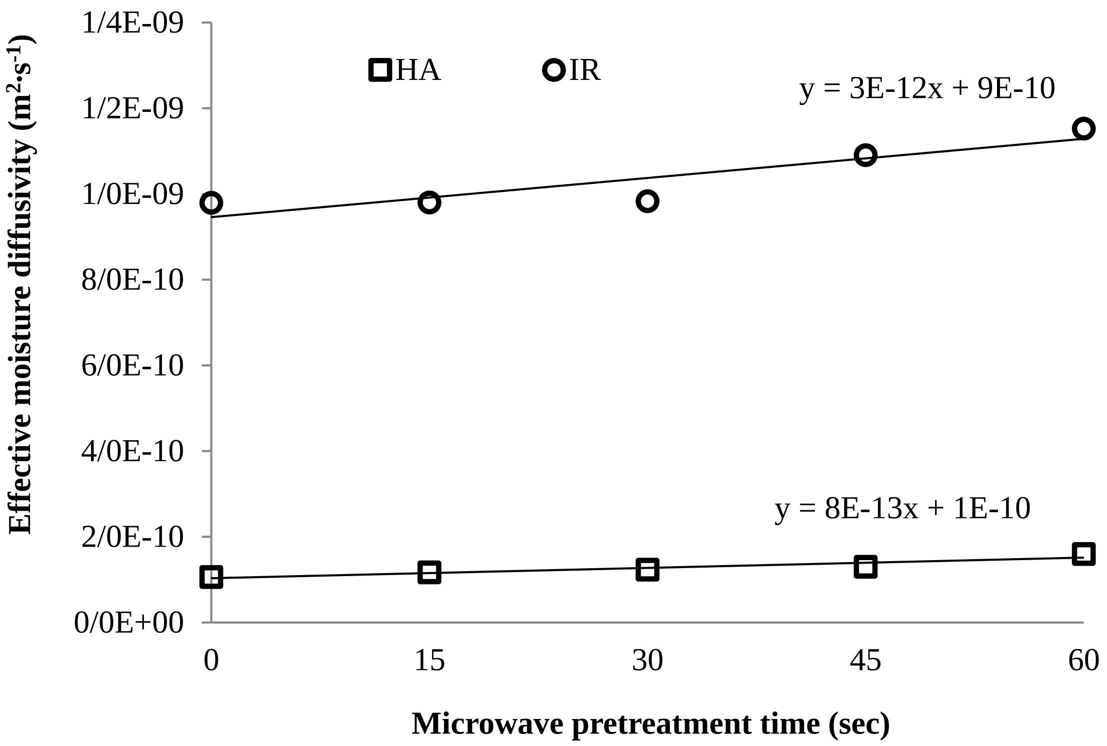

Fig. 5 Effect of microwave pretreatment on effective water diffusivity coefficient of sprouted mung beans (HA=Hot-air dryer; IR=Infrared dryer**).**

3.3. Kinetics modelling

The drying behavior of sprouted mung beans in hot-air and infrared dryers was fitted with the Midilli model. Combining the highest r value with the lowest sum of squares for error (SSE) and root mean squared error (RMSE) values establishes a satisfactory agreement between the actual data and the correlations. This model presented a good fit with the maximum r-value (greater than 0.998) and the minimum SSE, and RMSE values (less than 0.0053 and 0.0219, respectively) for all conditions. The calculated constant coefficients of the Midilli equation including a, k, n, and b are shown in Table 2. The values of SSE, RMSE, and r values for all conditions ranged from 0.0004 to 0.0053, 0.0036 to 0.0219, and 0.998 to 0.999, respectively. Figure 6 shows a comparison of the experimental results (microwave time = 30 s, infrared dryer used) and fitted moisture ratio data using the Midilli equation. The results demonstrate that the Midilli equation is suitable for describing the drying rate of sprouted mung beans under different drying conditions. The results of Salehi [23] indicated that Midilli was the appropriately fitted equation for sprouted mung beans drying in the hot-air and infrared dryers.

Table.2 The constants and coefficients of the Midilli model

Dryer type	Microwave time (sec)	a	k	n	b	Sum of squared error (SSE)	Correlation coefficient (r)	Root mean square error (RMSE)
Hot-air dryer	0	0.9951	0.0060	0.8803	-0.0045	0.0022	0.9990	0.0141
	15	0.9887	-0.0005	1.2211	-0.0039	0.0015	0.9993	0.0114
	30	0.9864	0.0043	1.2280	0.0000	0.0027	0.9989	0.0157
	45	0.9818	0.0012	1.5397	0.0005	0.0025	0.9990	0.0147
	60	0.9815	0.0019	1.4573	0.0002	0.0042	0.9985	0.0194
Infrared dryer	0	1.0103	-0.0199	1.2566	-0.0403	0.0017	0.9995	0.0075
	15	1.0026	0.0301	1.3617	0.0010	0.0005	0.9998	0.0041
	30	1.0047	0.0186	1.2197	-0.0273	0.0007	0.9996	0.0046
	45	1.0147	0.0357	1.3973	0.0016	0.0008	0.9995	0.0052
	60	1.0021	0.0372	1.2703	-0.0005	0.0012	0.9997	0.0063

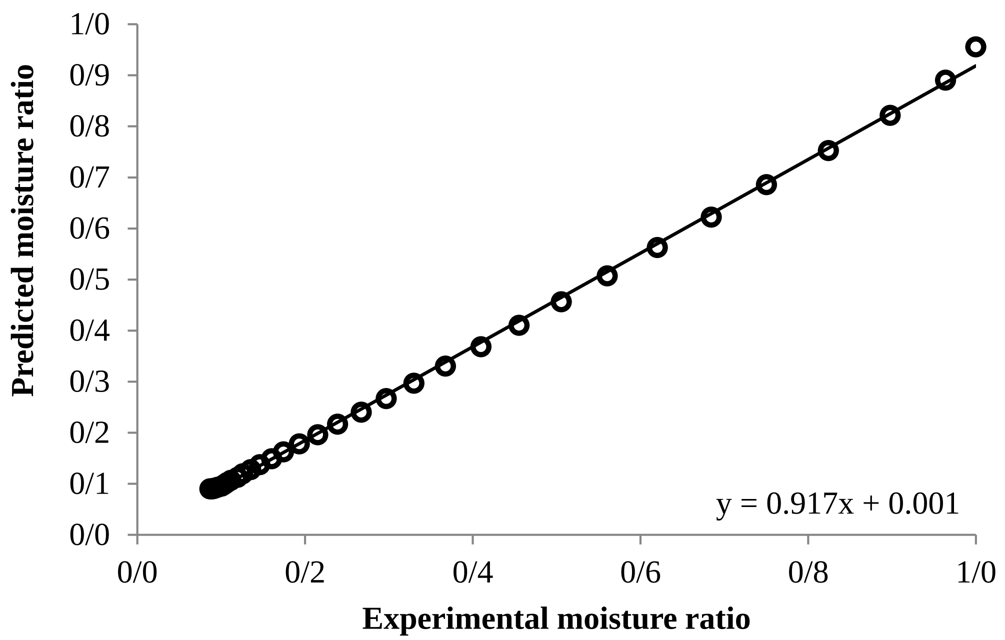

Fig. 6 Evaluation of fitted values by Midilli model with experimental data of moisture ratio (microwave pretreatment time=30 s and at infrared dryer).

3.4. Rehydration

The analysis of variance results confirmed that the drying method (hot-air and infrared), microwave time, and their interaction had a significant influence on the rehydration rate of dried sprouted mung beans ($p<0.01$) (Table 3). The impacts of microwave pretreatment and drying approaches on the rehydration ratio of dried sprouted mung beans are shown in Figure 7. The rehydration rate of dried sprouted mung beans in hot-air and infrared dryers increased when the microwave pretreatment time was increased. Furthermore, the rehydration rate of the pretreated hot-air-dried sprouted mung beans was considerably higher than that of the infrared dried sprouted mung beans ($p<0.05$). This problem may be due to the small shrinkage, large volume, and porous structure of the hot-air dried sprouts, resulting in greater water diffusion within the dried mung bean cells and a more rehydration rate [23]. The mean rehydration rate of dried sprouted mung beans in the hot-air dryer enhanced from 254.85% to 273.72% as the microwave pretreatment time was increased from 0 to 60 seconds ($p<0.05$). In addition, the average rehydration ratio of dried sprouted mung beans in infrared dryer increased from 187.60% to 222.48% when the microwave pretreatment time was increased from 0 to 60 seconds ($p<0.05$). Salehi [23] reported that the rehydration ratio of dried sprouted mung beans in hot-air and infrared dryers increased when the ultrasound pretreatment time was increased.

Table. 3 Analysis of variance for rehydration of dried sprouted mung beans in hot-air and infrared dryers.

Sources of changes	df	Sum of squares	Mean square	P
Dryer (D)	1	19431.5	19431.5	0.000
Microwave time (M)	4	2531.8	633.0	0.000
D × M	4	621.1	155.3	0.000
Error	20	305.0	15.3	
Total	29	22889.4		

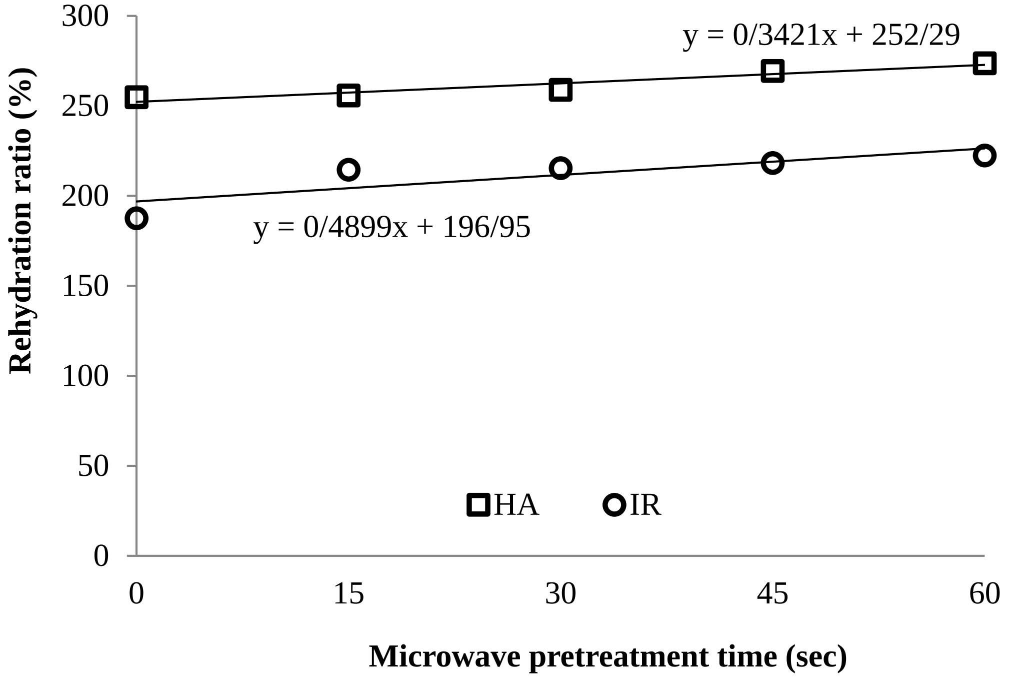

Fig. 7 Effect of microwave pretreatment on rehydration of dried sprouted mung beans (HA=Hot-air dryer; IR=Infrared dryer).

4. Conclusion

In this study, the impacts of microwave pretreatment and drying approach on the thin layer dehydration properties of sprouted mung beans were examined. The drying time of samples dried with an infrared dryer was considerably shorter than that of sprouts dried with a hot-air dryer ($p<0.05$). The average D_{eff} values of sprouted mung beans when dried in the hot-air and infrared dryers enhanced when the microwave pretreatment duration was increased from 0 to 60 s. The average D_{eff} values of sprouted mung beans when dried in hot-air and infrared dryers were 1.28×10^{-10} m^2s^{-1}, and 1.04×10^{-9} m^2s^{-1}, respectively. The drying behavior of sprouted mung beans was fitted using the Midilli equation. This formula showed a good fit with the maximum r-value (greater than 0.998), and the minimum SSE and RMSE values (less than 0.0053 and 0.0219, respectively) for all conditions compared to other models. The rehydration rate of pretreated and hot-air dried sprouts was considerably higher than that of infrared dried sprouts ($p<0.05$). The study’s findings confirmed that microwave pretreatment improved the mass transfer rate of sprouted mung beans when dried in hot-air and infrared dryers.

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مقاله پژوهشی

پیش‌تیمار ماش جوانه‌زده با مایکروویو قبل از فرآیند خشک‌کردن با هوای گرم و فروسرخ

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چکیده

جوانه زدن ویژگی‌های تغذیه‌ای و کیفی ماش (*Vigna radiata* L.) را افزایش می‌دهد. در این مطالعه اثرات خشک‌کردن با تابش فروسرخ و هوای داغ بر جوانه‌های ماش پیش‌تیمار شده با مایکروویو مورد بررسی قرار گرفت. فرآیند مایکروویو برای، ۱۵، ۳۰، ۴۵ و ۶۰ ثانیه قبل از خشک‌کردن ماش جوانه‌زده در هوای گرم و فروسرخ انجام شد. پیش‌تیمار مایکروویو مدت زمان خشک شدن ماش جوانه‌زده را کاهش داد. افزایش زمان پیش‌تیمار مایکروویو از ۰ به ۶۰ ثانیه باعث شد زمان خشک شدن نمونه‌ها در داخل خشک‌کن هوای گرم از ۲۰۵ دقیقه به ۱۳۰ دقیقه کاهش یابد ($p<0.05$). زمان خشک شدن جوانه‌ها در خشک‌کن فروسرخ به‌طور معنی‌داری کمتر از خشک‌کن هوای گرم بود ($p<0.05$). ضریب نفوذ مؤثر رطوبت محاسبه شده توسط قانون دوم فیک، برای نمونه‌های خشک‌شده توسط هوای گرم و فروسرخ به ترتیب در محدوده $1.60\times10^{-10}\ m^2s^{-1}$-$1.06\times10^{-10}\ m^2s^{-1}$ و $1.15\times10^{-9}\ m^2s^{-1}$-$0.98\times10^{-9}\ m^2s^{-1}$ متغیر بود. داده‌های آزمایشگاهی برای منحنی‌های خشک‌کردن با معادلات لایه‌نازک مختلف برازش داده شدند و معادله میدیلی برای توضیح سینتیک خشک‌کردن ماش جوانه‌زده مناسب‌تر بود. متوسط آبگیری مجدد ماش جوانه‌زده خشک‌شده در خشک‌کن‌های هوای گرم و فروسرخ به ترتیب ۲۶۲/۵۵٪ و ۲۱۱/۶۵٪ بود. در مجموع، پیش‌تیمار مایکروویو (حدود ۶۰ ثانیه) و استفاده از خشک‌کن فروسرخ، روش خشک‌کردن مناسب برای ماش جوانه‌زده با انتقال جرم سریع‌تر و زمان خشک‌کردن کوتاه‌تر است.

واژه‌های کلیدی: **آبگیری مجدد، ضریب نفوذ مؤثر رطوبت، ماش، مایکروویو، معادله میدیلی.**

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