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Original research

Study on the quality characteristics of cooked faba beans as affected by microwave treatment

Fakhreddin Salehi [a, *], Sara Ghazvineh [a], Mostafa Amiri [a]

[a] *Department of Food Science and Technology, Faculty of Food Industry, Bu-Ali Sina University, Hamedan, Iran*

ABSTRACT

Conventional heat treatment methods are very time-consuming, but microwave pretreatment (MPT) is more and more widely used because it is faster than other methods and can considerably reduce processing time. Faba beans are an important nutrient-rich legume, especially rich in high levels of lysine-rich proteins, complex carbohydrates, fiber, non-nutrient secondary metabolites, and bioactive compounds. The current study aimed to investigate the influence of the MPT process (220 W for 0, 20, 40, and 60 s) on the mass transfer kinetics, drying time, and effective moisture diffusivity of fresh faba beans. Also, the effect of MPT on textural properties and sensory attributes of cooked faba beans was studied. By using the microwave, the rate of water extraction from fresh faba beans, and thus their dehydration rate, can be increased. With increasing the duration of MPT from 0 to 60 s, the drying time of fresh faba beans decreased from 263 min to 167 min ($p<0.05$). The Page model best fitted the drying kinetic of fresh faba beans with a coefficient of determination ($r>0.9945$. When the MPT process time was extended from 0 to 60 s, the rehydration ratio of dried faba beans (after cooking) increased meaningfully from 233.4% to 270.0% ($p<0.05$). The minimum and maximum crust hardness and texture firmness values were for the untreated and treated samples for 60 s, respectively. The MPT increased the sensory acceptance of the cooked faba beans and the highest appearance, odor, texture, flavor, and overall acceptance was for the 60 s treated faba beans.

Keywords: Moisture diffusivity; Page model; Rehydration ratio; Sensory attributes; Textural properties.

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1. Introduction

Plant proteins are becoming more popular as better options than animal proteins due to their high nutritional values, functional properties, and health benefits (Li et al., 2024). Faba bean (*Vicia faba* L.) is a plant from the legume family that, like many legumes, its protein consists of two fractions: albumin and globulin. Its high contents of digestible protein and starch are the reason for its widespread use (Maleki et al., 2018; Dhull et al., 2022; Salehi et al., 2024a). Recently, there has been increasing interest in the health and nutritional benefits of faba beans, leading to the development of a range of biomolecule-fortified foods with enhanced functionality and nutritional values (Dhull et al., 2022; Salehi et al., 2024a). Several bioactive phytochemicals have been identified in faba bean, including phenolic compounds, flavonoids, lignans, and terpenoids (Dhull et al., 2022). Total phenolic content in faba bean pod extract of different varieties were in the range of 4.8 to 13 mg gallic acid equivalent/g (Valente et al., 2018).

Different drying methods for drying faba beans have been studied by various researchers. For example, Maleki et al. (2018) investigated the effect of temperature (55-75 °C) and hot-air velocity (1-2 m/s) on the qualitative and sensory properties of faba beans. Their findings confirmed that the shortest drying time was at 75 °C. In another study, Karimi Arpanahi et al. (2017) investigated the impact of drying techniques (sun-drying and shade-drying) on the quality of faba bean seeds cultivar Shami. The results of this research confirmed that the faba bean seeds' quality was higher in the shade-drying than in the sun-drying. Salehi et al. (2024a) studied on the impacts of ultrasonic pretreatment on the textural properties and sensory attributes of dried and cooked faba beans. Their results showed that the ultrasonic pretreatment increased the sensory acceptance of the cooked faba beans and the highest appearance,

*Corresponding author.
E-mail address: *F.Salehi@basu.ac.ir* (F. Salehi).
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odor, texture, flavor, and overall acceptance were for the 10 min sonicated faba beans.

Agricultural products will spoil quickly if they are not processed and stored under proper conditions. The processing of these products creates a variety of food products that consumers are likely to purchase and consume. Drying is a technique to extend the shelf-life of agricultural products, and several drying methods have been proposed (Khodadadi et al., 2017; Salehi, 2023). Microwave ovens are one of the most common household appliances today, and using a microwave to heat or reheat food has become an essential part of preparing food at home. Compared with traditional heating methods, microwave heating has many advantages, including energy savings, shortening cooking and heating times, improving product uniformity, and creating unique microstructures and properties. Heating by microwave energy is greatly affected by the moisture content of the food (Clark et al., 2000; Aydar et al., 2022; Salehi et al., 2024b). Microwave dryers utilize high frequency electromagnetic waves as a heating source to generate energy, which is then converted rapidly into heat energy inside the food products (Qin et al., 2020; Yu et al., 2021). Bualuang et al. (2017) investigated the effect of microwave drying on the quality of germinated corn and found that drying by microwave (power=300 W) could preserve the nutritional value and enhance the antioxidant activity of dried germinated corn. Akbarian Meymand et al. (2015) reported that the antimicrobial properties of dried Hindi roots nutmeg were improved by using microwave pretreatment (MPT).

Cooking has been used as the most common processing method in home preparation of faba beans. Different heat processing methods for cooking faba beans have been studied by various researchers. For example, the effect of cooking, autoclaving, and germination on nutritional quality of faba beans was examined by Khalil and Mansour (1995). Their results showed that stachyose, phytic acid, tannins, trypsin inhibitor, vicine, and haemagglutinin activity were significantly decreased after the heat processing. Also, the heat processing increased the contents of leucine, threonine, and histidine. In another study, the effects of soaking, boiling and autoclaving on the phenolic contents and antioxidant activities of faba beans were studied by Siah et al. (2014). Their findings show that the boiling is a better method in retaining active compounds in beans than autoclaving.

Faba beans can be eaten dried, roasted, cooked, or canned (Dhull et al., 2022; Salehi et al., 2024a). This research aimed to investigate the impact of MPT on the drying time, mass transfer rate, and effective moisture diffusivity (Deff) of fresh faba beans. Furthermore, the influence of MPT on the textural properties and sensory attributes of cooked faba beans was studied.

2. Material and Methods

2.1. Preparation of faba beans

Faba bean pods were prepared from Hamedan city (Hamedan province, Iran), with medium size and uniform shape. The faba beans were removed from the pods and stored in the refrigerator (at 6 °C).

2.2. Microwave pretreatment

The fresh faba beans were treated in a microwave oven (Gplus, Model; GMW-M425S.MIS00, Goldiran Industries Co., Iran) for 0, 20, 40, and 60 s at low power (220W).

2.3. Drying process

After MPT, the faba beans were removed from the microwave. The faba beans were then dehydrated in a temperature-controlled oven (K.M 55, Pars Azma Co., Iran), where a drying temperature of 70 °C was used.

2.4. Cooking process

After the drying process, to cook the dried faba beans, they were placed in glass beakers (250 ml) containing distilled water that was inside a water bath (R.J42, Pars Azma, Iran). The cooking process was carried out for 3 h at a temperature of 90°C (Fig. 1).

2.5. Drying kinetic

The drying kinetic of fresh faba beans during drying was studied and modeled following the procedure explained by Salehi et al. (2024b), using 7 simplified drying equations (Approximation of diffusion, Henderson and Pabis, Logarithmic, Midilli, Newton, Page, and Wang and Singh) and Matlab software (version R2012a).

2.6. Calculation of Moisture Diffusivity

The effective moisture diffusivity coefficient (D_{eff}) of fresh faba beans during drying was estimated following the procedure described by Salehi et al. (2024b).

2.7. Rehydration ratio

The rehydration ratio was determined by immersing dried samples in distilled water at a specified rehydration temperature (90°C) for 3 h (after cooking). The rehydration ratio was defined as the ratio of the weight of rehydrated faba beans to the dry weight of the faba beans (Salehi et al., 2024a).

2.8. Textural properties

A texture analyzer (Santam, STM-5, Iran) was used to evaluate the crust hardness (hull) and texture firmness of the cooked faba beans. The puncture test was performed using a cylindrical probe with a diameter of 2.5 mm and a penetration speed of 1 mm/s (Salehi et al., 2024a).

2.9. Sensory evaluation

The cooked faba beans were subjected to a sensory test using 20 panelists. Each attribute was scored based on its intensity scaled on a 9-point hedonic scale (1 = disliked extremely; 5 = neither liked or disliked; 9 = liked very extremely) for appearance, odor, texture, flavor, and overall acceptance of cooked faba beans (Salehi et al., 2024a).

2.10. Statistical analysis

All the experimental determinations were repeated three times in parallel to obtain the average values. The experimental data were calculated as standard deviation using Microsoft Excel 2007 software, analyzed by ANOVA using SPSS 21.0 software, and analyzed by Duncan's Multiple Significant Difference Analysis, with $p<0.05$ indicating a significant difference.

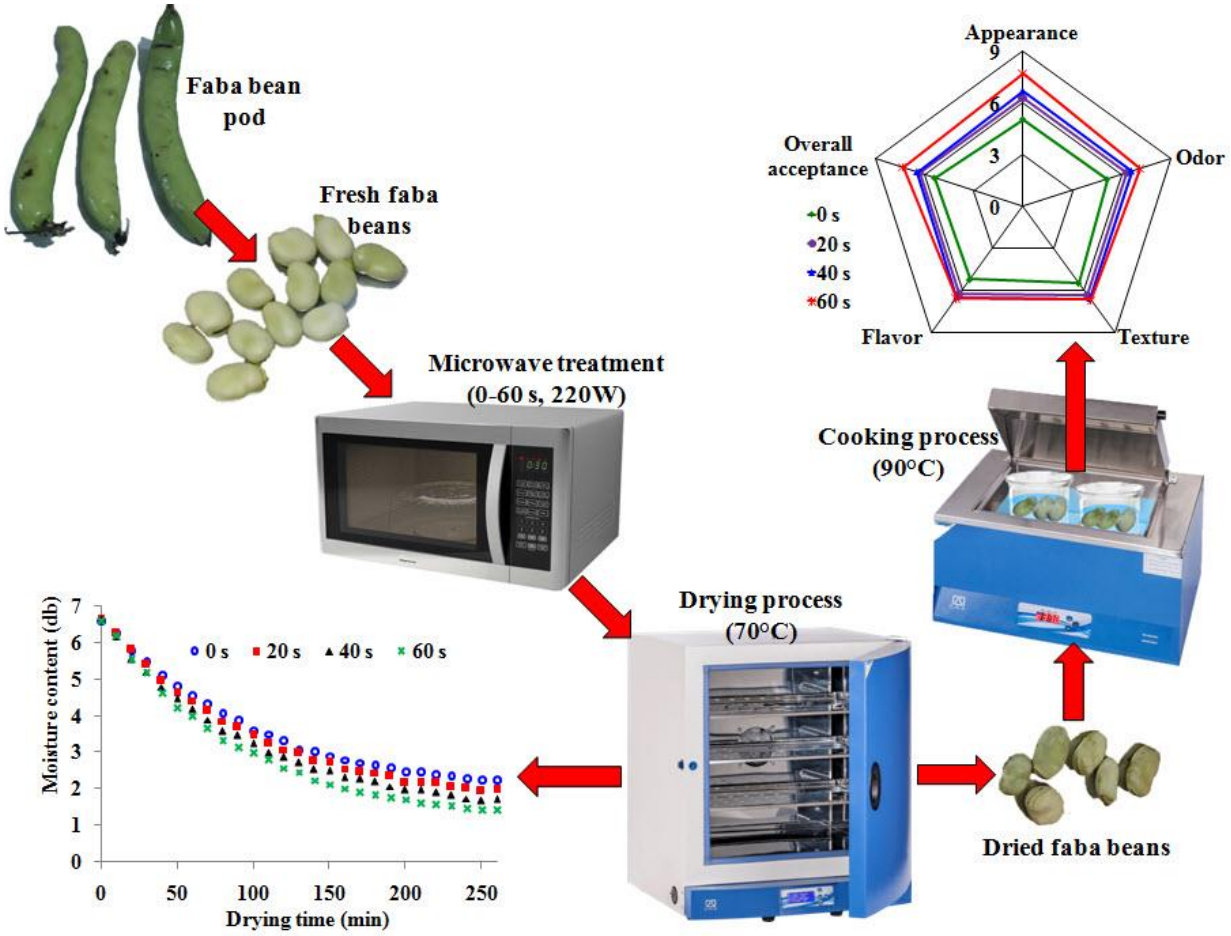

Fig. 1. Schematic of microwave pretreatment, hot-air drying, and cooking process of faba beans.

3. Results and Discussion

3.1. Drying time

Traditional heat treatment methods are very time-consuming, but MPT is faster than other pretreatments, significantly reducing the treatment time, and is becoming common. This reduction in heating time can be attributed to the thermal and non-thermal effects of microwave heating on the destruction of cells being more significant than other heat treatment methods (Liu et al., 2020; Salehi et al., 2023). The effect of MPT duration on the weight loss of fresh faba beans during drying in the hot-air dryer is illustrated in Fig. 2. Based on the drying curves, it was observed that microwave-treated faba beans dried more quickly than untreated faba beans. As expected, the drying rate increased as the extension of processing time increased. As can be seen from this figure, the use of MPT enhanced the rate of water extraction from fresh faba beans, resulting in an enhanced drying rate of the samples.

The MPT leads to the accumulation of water on the surface of food products, and the hot air generated by the dryer can remove the water from the surface of the food (Heydari et al., 2020). The influence of MPT duration on the drying time of fresh faba beans is illustrated in Fig. 3. According to ANOVA results, MPT time has a significant influence on the drying time of fresh faba beans ($p<0.05$). The drying time of fresh faba beans was shortened by extending the treatment time. When the MPT time was prolonged from 0 to 60 s, the drying time of fresh faba beans reduced from 263 min to 167 min ($p<0.05$). Consistent with the findings of this study, Motevali et al. (2012) confirmed that the drying time of pomegranate arils was meaningfully decreased by using the MPT (100 W and 200 W).

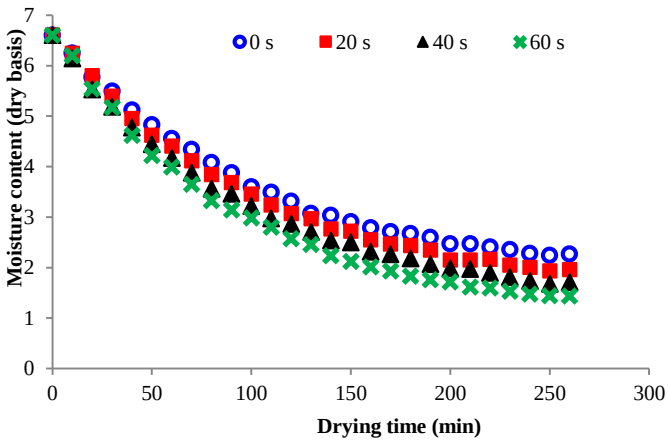

Fig. 2. Impact of microwave pretreatment time (0-60 s) on moisture loss of fresh faba beans during drying.

Table 1. The constants and coefficients of the Page model ($MR=\exp(-kt^n)$)

Microwave treatment time	k	n	Sum of squared error	Coefficient of determination	Root mean squared error
0 s	0.0185	0.7618	0.0118	0.9945	0.0217
20 s	0.0181	0.7764	0.0102	0.9955	0.0202
40 s	0.0142	0.8386	0.0068	0.9973	0.0165
60 s	0.0154	0.8449	0.0071	0.9975	0.0166

Where, the MR is moisture ratio, and the k and n are coefficients of the Page model (dimensionless).

The Page equation demonstrated a good fit with the highest r-value (>0.9945) and the lowest sum of squared error (SSE), and root mean squared error (RMSE) values (<0.0118 and <0.0217, respectively). The estimated constant parameters for the Page equation including k and n are detailed in Table 1 along with corresponding statistical error values (SSE, r, and RMSE). The SSE, r, and RMSE values for all pretreatments ranged from 0.0068 to 0.0118, 0.9945 to 0.9975, and 0.0165 to 0.0217, respectively.

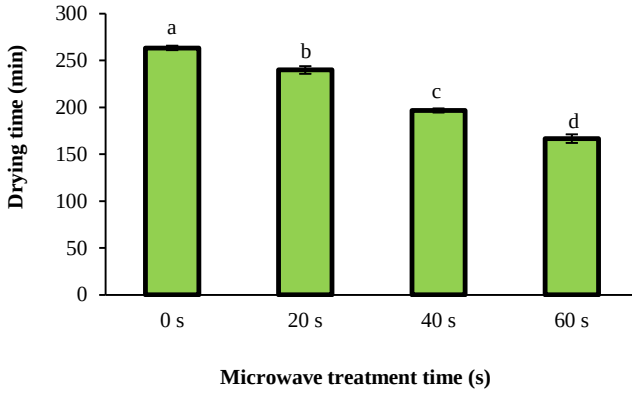

Fig. 3. Impact of microwave pretreatment on drying time of fresh faba beans. Different lowercase letters represent significant differences ($p<0.05$).

3.2. Kinetics modeling

Fig. 4 shows a comparison of the moisture ratio data fitted testing the Page equation with the experimental results (MPT time = 60 s). The results show that the Page equation is appropriate for describing the drying kinetics of fresh faba beans. In line with the findings of this research, the results of Maleki et al. (2018) research also showed that Page's model is appropriate for investigating and modeling the moisture loss data of faba beans.

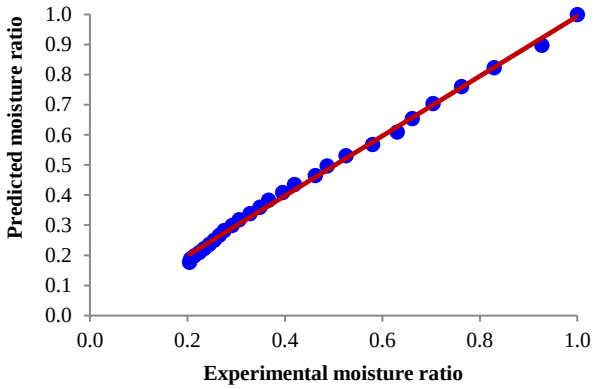

Fig. 4. Comparison of fitted data by Page model with experimental results of moisture ratio (microwave pretreatment time=60 s).

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

Compared with traditional heating methods, microwave irradiation can stimulate molecular movement and generate heat throughout the fabric through molecular friction from the inside to the outside, therefore the heating output is much higher (Yan et al., 2021). The impact of MPT on the D_{eff} values of fresh faba beans is shown in Fig. 5. The result evidence the improvement of mass transfer rate with MPT with higher moisture diffusivity (higher D_{eff} values). The average D_{eff} values of fresh faba beans during drying in the hot-air dryer meaningfully increased from 7.30×10^{-10} m^2s^{-1} to 9.98×10^{-10} m^2s^{-1} when the extension of MPT time was prolonged from 0 to 60 s ($p<0.05$). Salehi et al. (2024a) reported that the D_{eff} of fresh faba beans was significantly increased from 0.70×10^{-9} m^2s^{-1} to 1.05×10^{-9} m^2s^{-1} when the ultrasonic pretreatment time was extended from 0 to 15 min ($p<0.05$).

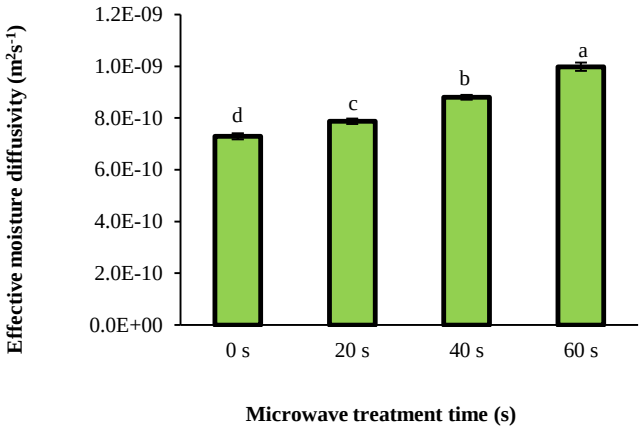

Fig. 5. Impact of microwave pretreatment on effective moisture diffusivity coefficient of fresh faba beans. Different lowercase letters represent significant differences ($p<0.05$).

3.4. Rehydration

The effect of MPT duration on the rehydration ratio (after cooking) of dried faba beans is displayed in Fig. 6. The rehydration ratio values of MPT faba beans for 40 s and 60 s were higher than those of untreated sample. This indicated that the combination of MPT and hot-air drying could decrease irreversible structural damage. Furthermore, the rehydration ratio increased along with MPT time. The mean rehydration ratio of dried faba beans after cooking meaningfully increased from 233.4% to 270.0% when the extension of MPT time was from 0 to 60 s ($p<0.05$). Jafari et al. (2019) reported that the rehydration ratio of air-dried potato sticks was improved by using MPT. Also, Salehi et al. (2024a) confirmed that the rehydration ratio of dried faba beans was significantly

increased from 308.4% to 327.1% with the extension of ultrasonic pretreatment time from 0 to 15 min ($p<0.05$).

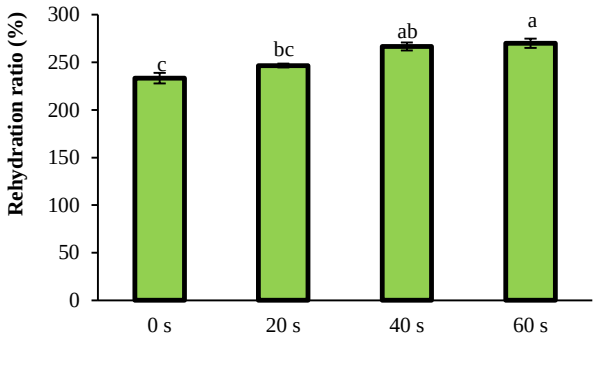

Fig. 6. Impact of microwave pretreatment on rehydration ratio of dried faba beans. Different lowercase letters represent significant differences ($p<0.05$) and the same letter represents no significant difference ($p>0.05$).

3.5. Texture hardness

Fig. 7 shows the influence of MPT on the crust or hull hardness of cooked faba beans. As the pretreatment time increased, the shell of cooked faba beans became harder and their hardness increased. The minimum and maximum crust hardness values were for the untreated and treated samples for 60 s, respectively. In this study, with increasing the extension of MPT time from 0 to 60 s, the crust hardness of cooked faba beans significantly increased from 3.7 N to 7.8 N ($p<0.05$).

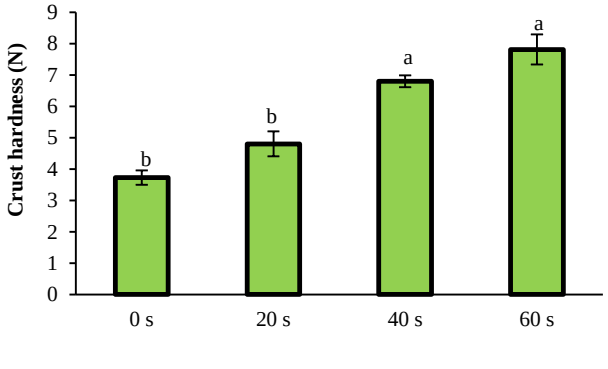

Fig. 7. Impact of microwave pretreatment on crust hardness (hull) of cooked faba beans. Different lowercase letters represent significant differences ($p<0.05$) and the same letter represents no significant difference ($p>0.05$).

Fig. 8 shows the influence of MPT on the texture firmness of cooked faba beans. According to ANOVA results, MPT has a significant influence on the texture firmness of cooked faba beans ($p<0.05$). In this study, the average texture firmness was 2.61 N for the untreated faba beans, while 3.90 N, 4.63 N, and 5.09 N were found for 20 s, 40 s, and 60 s treated samples, respectively.

3.6. Sensory evaluation

Faba beans require long cooking time to achieve a satisfactory softness and palatability and to improve protein digestibility (Dhull et al., 2022). The quality of cooked faba beans was reflected in the 5 major characteristics of crust color, odor, texture, flavor, and overall acceptability. The influence of MPT (for 0 s, 20 s, 40 s, and 60 s) on the sensory attributes of cooked faba beans is shown in Fig. 9. The MPT increased the sensory acceptance of the cooked faba beans and the highest appearance, odor, texture, flavor, and overall acceptance were for the 60 s pretreated faba beans. The average overall acceptance was 5.38 for the untreated faba beans, while 6.25, 6.44, and 7.31 were found for 20 s, 40 s, and 60 s microwave treated samples, respectively. In line with the findings of this research, Jafari et al. (2019) reported that the crust color and flavor of air-dried potato sticks were improved by using MPT.

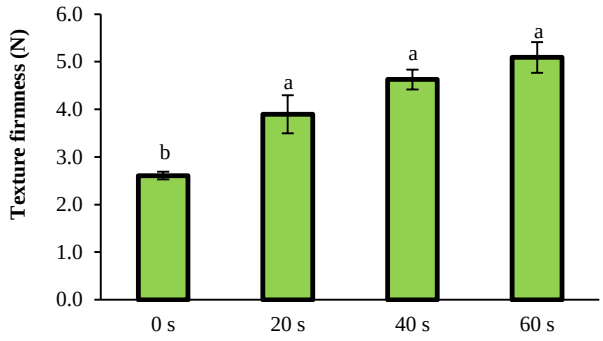

Fig. 8. Impact of microwave pretreatment on texture firmness of cooked faba beans. Different lowercase letters represent significant differences ($p<0.05$) and the same letter represents no significant difference ($p>0.05$).

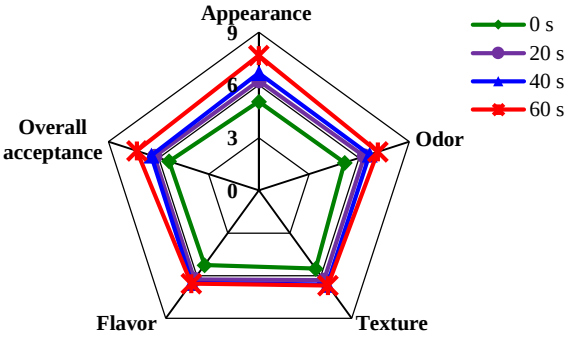

Fig. 9. Impact of microwave pretreatment time (0-60 s) on sensory properties of cooked faba beans.

4. Conclusion

The results of this work demonstrate that using MPT can improve the drying process for fresh faba beans. The finding showed that the drying time of fresh samples was meaningfully shortened by using the proposed technique. The mean D_{eff} of fresh faba beans throughout drying in the hot-air dryer exhibited an upward trend when the duration of MPT was extended from 0 to 60 s. Among different kinetic models, the Page model showed the best r value of >0.9945 to describe the drying rate of fresh faba beans. The result evidences the improvement of rehydration with MPT with a higher rehydration rate. The minimum and maximum crust hardness and

texture firmness values were for the untreated and microwave treated samples for 60 s, respectively. The MPT improves the appearance, odor, texture, flavor, and overall acceptability of the cooked faba beans.

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Conflict of interest

The authors declare that there is no conflict of interest.

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