Biosystems Engineering and Renewable Energies

Journal homepage: https://bere.gau.ac.ir

GUASNR

ISAMEM

Original Research Paper

The effects of various pretreatments on the thermal properties of rosemary leaves

Mohammad Vahedi Torshizi[1*], Arash Rokhbin[2], Mohammad Javad Mahmmodi[2]

[1] Department of Biosystems Engineering, Tarbiat Modares University, Tehran, Iran
[2] Department of Biosystems Engineering, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran

Biosystems Engineering and Renewable Energies 2025, 1 (1): 29-36

KEYWORDS

Thermal conductivity
specific heat
thermal diffusion
Microwave pretreatment
Rosemary

*** Corresponding author**
m_vahedi@modares.ac.ir

Article history
Received: 2024-11-06
Revised: 2024-11-15
Accepted: 2024-11-20

ABSTRACT

This study examines the rosemary thermal properties, including thermal conductivity, specific heat capacity, and thermal diffusion coefficient in the microwave, blanching, and oven pretreatments. To test the microwave pretreatment for three-time levels of 60, 90, and 120 s, the changes in the samples' weights in the microwave were recorded. The blanching pretreatment was done on the samples at three-time levels of 180, 360, and 540 s. Finally, in the oven treatment, the rosemary leaf samples were placed at three temperature levels of 30, 45, and 60 °C for 15 min. Then, in three voltages of 4, 7, and 10 V, the thermal properties were obtained separately for each of the pretreatments, and for all cases, a control treatment was considered. The data were analyzed as a factorial experiment based on a completely randomized design. Based on the results for microwave and blanching treatments, increasing the treatment time and reducing the oven temperature led to a decrease in thermal conductivity, specific heat capacity, and thermal diffusivity. An increase in voltage affected the thermal properties of rosemary leaves across all three pretreatments, showing effectiveness in each method. The pretreatment levels were significantly higher than the process voltage for the thermal conductivity and diffusion coefficient, which indicates that pretreatment has a more significant impact on the thermal properties of the process. The maximum value of the electrical conductivity coefficient is 0.4256, 0.5851, and 0.510 W m^{-1} °C^{-1}, and for the specific heat capacity of 2.58, 2.68, and 2.65 kJ kg^{-1} °C^{-1}, and also for the thermal diffusion coefficient of 2.48 × 10^{-6}, 2.81 × 10^{-6} and 2.50 × 10^{-6} m^2 s^{-1} for microwave, blanching, and oven pretreatments, respectively. Among the three pretreatments, microwave pretreatment significantly reduced the thermal conductivity, specific heat capacity, and thermal diffusion coefficient of rosemary leaves.

1. Introduction

Rosemary (*Rosmarinus officinalis*) is an aromatic plant from the Lamiaceae family and native to the Mediterranean region. The Murcia province in southeastern Spain is one of the major importers of rosemary. In the United States and Europe, rosemary is a unique spice and is commercially available as an antioxidant (Ntoanidou et al., 2024). Rosemary extract, due to its high potential for liver protection, potential for treating Alzheimer's disease, and antiseptic effects, has been used in the treatment of diseases (Nazir et al., 2024). Additionally, rosemary is used in preserving food by preventing oxidation and microbial contamination. Therefore, rosemary extract can serve as a useful alternative to synthetic antioxidants in foods. Furthermore, rosemary provides multiple preservation benefits to consumers. On the other hand, thermal parameters are critical features in the agricultural industry, as they are utilized in the design of necessary equipment for this sector (Rafya et al., 2024). Also, in computer designs and simulations, equipment optimization, and temperature control during storage and transportation, knowing a product's thermal properties is essential and sensitive (Raji et al., 2024). Today, most developed countries have conducted extensive studies to recognize the medicinal plants used in their country.

In Iran, due to the diversity of climate, different medicinal plants are cultivated naturally or mechanized, one of the most important of which is rosemary (Nargesi and Kheiralipour, 2024) (Motevali et al., 2017). Rosemary is a shrub, a perennial plant with ascending, fragrant branches. It belongs to the mint family and reaches a height of 2 m. Rosemary plants have slender and tipless leaves, and flowers are dark green and rarely pink or white. The leaves and flowers of this plant contain active ingredients, so the vegetative body of rosemary has a pleasant smell. The active ingredients of this plant are essential essences, tannins, and bitter substances. The fundamental essence content of dried leaves is between 0.5 and 1.5, and the most important compounds are rosemary, camphor, borneyl acetate, and rosemary acid essential essences. These unique compounds give rosemary its antioxidant, antibacterial, and antifungal properties (Shoja et al., 2015; Zarghi et al., 2015). On the other hand, in the agricultural industry, thermal properties are an essential parameter for measuring the design of equipment required in the agricultural sector. Also, in computer design and simulations, equipment optimization, and temperature control during warehousing and transportation, knowing the thermal properties of a product is very important and sensitive (Vahedi Torshizi et al., 2020; Azadbakht et al., 2013b).

The thermal process is of great importance in drying and storing food products, and knowing factors such as specific heat capacity, thermal conductivity, and thermal diffusion coefficient are three engineering features for products that are of great importance in heat transfer. Thermal conductivity and thermal diffusion coefficient are used to measure the rate of heat transfer as well as the efficiency of the process of the devices (Azadbakht et al., 2022; Oloyede Christopher et al., 2018). Various researchers

© Published by Gorgan University of Agricultural Sciences and Natural Resources. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-ncnd/4.0/).

have done research on thermal properties. Fasina and Sokhansanj (1995) performed an experiment on the thermal properties of alfalfa pellets, which showed that the increase in the moisture content of alfalfa pellets was due to the increase in specific heat and thermal diffusion coefficient of the tested samples. Loha et al. (2012) conducted a study on the drying properties and thermal conductivity of ginger and concluded that increasing the moisture content in ginger increased the thermal conductivity, and a nonlinear relationship was also obtained to increase the moisture content and thermal conductivity. Barnwal et al. (2014) also examined the thermal properties of cinnamon, which showed that increasing moisture content and temperature increased the amount of electrical conductivity and specific heat of cinnamon and an increasing trend for thermal diffusion coefficient with increasing temperature. Akbarnejad et al. (2015) measured the thermal properties of banana skin and reported that the moisture content and temperature had a significant effect on the thermal properties of banana skin and that the thermal conductivity increased at all moisture content. Ghajarjazi et al., (2016) stated that the relationship between the thermal properties of canola pods with moisture content, porosity, and chemical content of different rapeseed cultivars had a significant difference in thermal properties with each other.

Hosainpour et al. (2022) found that the quality grading of dried white mulberries showed significant differences based on various color and texture features extracted through machine vision and that these characteristics played a key role in accurately classifying the fruit into high- and low-quality. Salari Kia et al. (2014) conducted a study on the effect of different levels of moisture content and temperature on the specific heat capacity of the grain and kernel of two Iranian pistachio cultivars. In this study, the percentage of moisture increased logarithmically, and the temperature increased linearly. Samimi Akhijahani and Khodaei (2013) investigated the specific heat and thermal conductivity of grapes with different moisture content, and they found that the specific heat and thermal conductivity of grapes increased linearly with increasing moisture content and that the effect of moisture content on the increase in specific heat and thermal conductivity of grapes was greater than the effect of temperature and proposed regression equations for specific heat and thermal conductivity of grapes.

It is useful to know information about thermal properties because researchers, engineers, processes, and other research departments that conduct research in food thermal processes must have sufficient information about thermal properties. This study examines the thermal properties of rosemary, and the purpose of this study is to investigate and compare the three pretreatments of the microwave, blanching, and oven on the thermal properties of rosemary because the operations before the thermal properties of the products are very important and will have a great impact on the changes in the thermal properties of the products.

2. Materials and Methods

2.1. Sample preparation

Rosemary specimens were obtained from the Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran. The leaves were removed from the trunk of rosemary branches. Attempts were made to separate the leaves in a healthy manner so as not to damage the leaves. The separated leaves were cleaned with a damp cloth and placed in the laboratory for a while to remove the moisture associated with their cleaning; then 100 g of each sample was removed and placed in the desired plates for the pre-treatment steps.

2.2. Pretreatment methods

Samples of the leaves underwent three types of pre-treatments: microwave, blanching, and oven. For microwave pretreatment, the samples were pre-treated at 360, 90, and 120 s at 360 W. For blanching, the samples were placed in hot water vapor for 180, 360, and 540 s and pre-treated, and for the pre-treatment of the oven, the samples were placed at 30, 45, and 60 ºC for 15 min.

2.3. Thermal properties

After pre-treatment, the thermal conductivity and thermal diffusion coefficients were set for three voltages of 4, 7, and 10 V. In this experiment, a transient heat transfer test device (Figure 1) with a linear heat source in the cylinder was used. Measuring the specific heat capacity was done using the mixture method. Because of simplicity and high accuracy, the method is commonly applied for measuring the specific heat capacity of agricultural and food products. Several assumptions were considered for using this method: (a) there was no heat loss when transferring samples to the calorimeter; (b) no evaporation occurred during the balance period; and (c) the heat capacity of the calorimeter remains in the studied range temperature. In order to determine the specific heat capacity of the product, we first need to determine the specific heat capacity of the calorimeter.

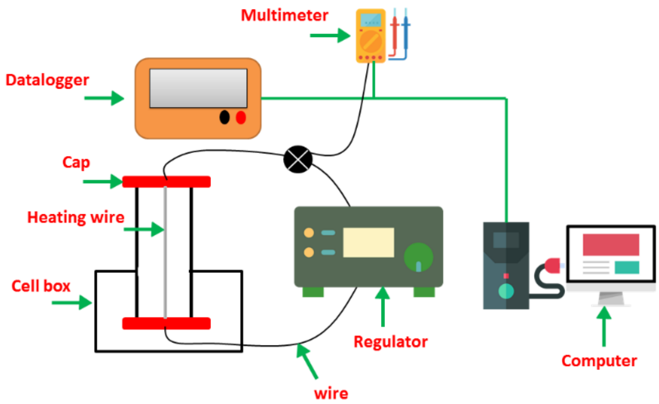

Figure 1. Schematics of linear heat source.

Since the type of calorimeter is a mixture of glass, metal, and insulation, determining its heat capacity in the experiment is simpler and correct than determining it by mass measuring each part of it particularly. In order to determine the heating capacity of the calorimeter value (H_{cal}), some distilled water was poured into the calorimeter, and after reaching the calorimeter and the water reaching the equilibrium, the equilibrium temperature (T_c) was recorded. Then, some warmer distilled water was added with T_h temperature and m_h mass. After the system reached equilibrium temperature (T_e), the calorimeter value (H_{cal}) was calculated using Eq. (1)

$$H_{cal} = \frac{m_h C_w (T_h - T_e) - m_c C_w (T_e - T_c)}{T_e - T_c} \quad (1)$$

$$m_{cal} C_{cal} = H_{cal} \quad (2)$$

where Cw is the average specific heat of water at the ideal temperature range and is equal to 4.18 kJ kg^{-1} ºC^{-1} (Salari Kia, 2012). By this method, the heat capacity of the used calorimeter was measured by three replications. In Eq. (2), C_{cal} and m_{Cal} were specific heat and mass for the calorimeter. It was assumed that the system was adiabatic and heat loss was very low during the balance period. For measuring the specific heat of rosemary in constant pressure, first, we chilled the calorimeter in the refrigerator; in this way, a few lost heats are ignored. 200 g of distilled water was boiled at 100 °C and poured into the calorimeter. Then, its heat was measured. We placed 10 g of samples, which were at ambient temperature in the mixture and then were allowed to reach heat balance. The specific heat of rosemary was measured by the balanced relationship between the gained and lost heat of water, and the calorimeter examined the gained and lost heat of samples.

2.4. Thermal conductivity coefficient

The transient heat transfer testing machine was made by a linear heat source in the PVC cylinder (300 mm height and 110 mm inner diameter). The top and bottom of the cylinder were sealed with a 10 mm thick fiberglass plate (Figure 2). The Nichrome with 0.127 mm diameter was inserted into the main axis of the cylinder, and the Nichrome wire was plugged into a DC adjustable power source (Bitra et al., 2010). To measure the centerline, a 4-channel data-connected K-type thermocouple was used, which was placed on a base 12 mm from the heat line source. During the test, it should be assumed that the sample holding temperature should be constant. Thus, there was a K-type thermocouple on the outer side of the chamber to show the temperature information. Due to the data output of the data logger, heat was recorded in each second. During the whole 450-s test, the diagram of amounts of heat and the normal logarithm of time was drawn. The slope of the diagram and determination coefficient were measured for each sample, and after obtaining the angle coefficient of the diagram, the thermal coefficient was determined (Fontana et al., 1998).

2.5. Thermal diffusivity coefficient

The thermal diffusivity coefficient of rosemary is calculated by Eq. (3) (Aviara and Haque, 2001; Azadbakht et al., 2013; Singh and Goswami, 2000; Yang et al., 2002)

$$\alpha = \frac{K}{\rho C_p} \tag{3}$$

where α is thermal diffusivity coefficient ($m^2\ s^{-1}$), K is thermal conductivity coefficient W m^{-1} $°C^{-1}$, and Cp is specific heat J kg^{-1} $°C^{-1}$.

2.6. Statistical design

In this study, three voltage-independent factors were considered for thermal properties, and three levels for microwave, blanching, and oven pre-treatments. Factors such as thermal conductivity, specific heat capacity, and thermal diffusion coefficient of rosemary leaves were also dependent factors. Three repetitions were considered for each experiment. Statistical analysis was performed for each of the microwave, blanching, and oven pre-treatments separately using a factorial experiment based on the completely randomized design using SAS software and an LSD test.

3. Results and Discussion

The results of the variance analysis for the electrical conductivity, specific heat capacity, and thermal diffusion coefficient of rosemary leaves are shown in Table 1. According to the results of the table, it is observed that for the electrical conductivity coefficient, two independent voltage and pre-treatment factors in microwave, blanching, and oven pre-treatments at the level of 1 % were significant. Also, for special heat, all three pre-treatments were statistically significant at 1 %, and for the thermal diffusion coefficient, the independent voltage factor was not significant in any of the applied pre-treatments. The process time factor in microwave and blanching precursors was statistically significant at 1 and 5 %, respectively, and for the temperature of the process in the pre-treatment of the oven, it was statistically significant at 5 %. Also, according to the results and the significance of the obtained factors, it can be seen that the effect of the microwave, blanching, and oven dryer pre-treatments have been much higher than the voltage on the thermal properties. From this, it can be seen that the use of pre-treatments has had a great impact on the thermal properties of rosemary.

3.1. Thermal conductivity

The thermal conductivity of rosemary leaves is shown for pre-treatment of microwave dryers in Figure 3-A. According to the figure, it can be stated that by increasing the pre-treatment time from 0 to 120 s, the amount of thermal conductivity has decreased. There has been a significant difference between all pre-treatment times, and the thermal conductivity has been reduced by increasing the voltage across the cell to measure thermal properties. The highest thermal conductivity was observed at 0 s before the pre-treatment and 4 V for the process voltage, which were 0.608 and 0.491 W m^{-1} $°C^{-1}$, respectively, and the lowest values were obtained at the pre-treatment time of 120 s and the process voltage of 10 V which were equal to 0.343 and 0.394 W m^{-1} $°C^{-1}$.

Figure 3-B shows the amount of thermal conductivity in the blanching pre-treatment. It can be stated that increasing the voltage, like the microwave dryer pre-treatment, reduces the thermal conductivity, and for this process, increasing the blanching time reduces the amount of thermal conductivity. At all times of 180, 360, and 540 s, there is a significant difference between all voltages. At 0 s, there was no significant difference between 7 and 10 V, but the two were significantly different from 4 V. Also, in voltage 4, there was a significant difference between all the pre-treatment times, but for voltage 7, there was no difference between 180 and 360 s, but they were different from 0 and 540 s. At 10 V, there was no significant difference between 360 s with 180 and 540, but this time was different from 0 s and was in another statistical group.

Figure 3-C also shows the effect of the pre-treatment of the oven dryer and process voltage on the heat conductivity of rosemary. As the pre-treatment temperature increases and the process voltage increases, the thermal conductivity of the samples decreases. For a temperature of 0 °C, which is a control example, there was no significant difference between voltages 7 and 10, but the two voltages were significantly different from voltages 4. For temperatures of 25, 35, and 45 °C, significant differences were observed at all voltages. Also, in all three voltages, 4, 7, and 10, there was a significant difference between all pre-treatment temperatures, which showed the positive effect of temperatures on the rate of thermal conductivity of the sample. The highest value of thermal conductivity was observed at a pre-treatment temperature of 0 °C and voltage 4 with 0.6307 (W m^{-1} $°C^{-1}$), and the lowest value was observed at a pre-treatment temperature of 45°C and voltage 10 with 0.312 (W m^{-1} $°C^{-1}$).

Based on the results, it can be stated that microwave and oven pre-treatment, compared to blanching pre-treatment, has reduced the moisture content of the samples, and decreasing the moisture in the samples has also decreased the amount of thermal conductivity. The reason for this is that with increasing moisture content, the thermal conductivity increases, and due to the fact that the thermal conductivity of water is higher compared to dry materials, the rate of thermal conductivity in blanched leaves has been higher than in microwaves and ovens, as the moisture output in this pre-treatment was less than the other two pre-treatments. Chandrakanthi et al. (2005) emphasized that high moisture content increases thermal conductivity. Their results are similar to the results of this study. Bitra et al. (2010) noted that the samples with higher moisture contents had lower thermal conductivities.

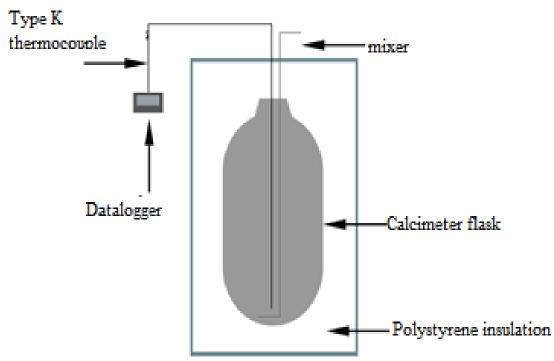

Figure 2. Schematics of special heat measurement system.

Table 1. The analysis of variance of thermal conductivity, specific heat capacity, and thermal diffusion coefficient of rosemary leaves in three pre-treatments: microwave dryer, blanching, and oven dryer.

		TC		SH		TDC	
	DF	**MS**	**F Value**	**MS**	**F Value**	**MS**	**F Value**
Microwave dryer treatment							
Volt	2	0.0279	37.10**	-	-	2.843E-13	2.88ns
Pretreatment time	3	0.1232	163.45**	0.4294	193.44**	8.947E-12	90.78**
Volt* Pretreatment time	6	0.00136	1.81ns	-	-	1.667E-13	1.69ns
Error	24	0.00075		0.00222		9.85E-14	
Blanching treatment							
Volt	2	0.0479	152**	-	-	4.024E-13	0.35ns
Pretreatment time	3	0.0604	191.61**	0.2836	237.32**	4.533E-12	3.97*
Volt* Pretreatment time	6	0.00263	8.36**	-	-	1.597E-12	1.40ns
Error	24	0.000315		0.00119		1.41E-12	
Oven dryer treatment							
Volt	2	0.02214	53.41**	-	-	6.49E-13	0.54ns
Pretreatment temperature	3	0.1139	274.94**	0.383	144.45**	5.64E-12	4.72*
Volt* Pretreatment temperature	6	0.0017	4.23*	-	-	1.44E-12	1.21ns
Error	24	0.00041		0.0026		1.19E-12	

TC= Thermal conductivity, SH= Specific Heat, TDC=Thermal diffusion coefficient, MS=Mean square

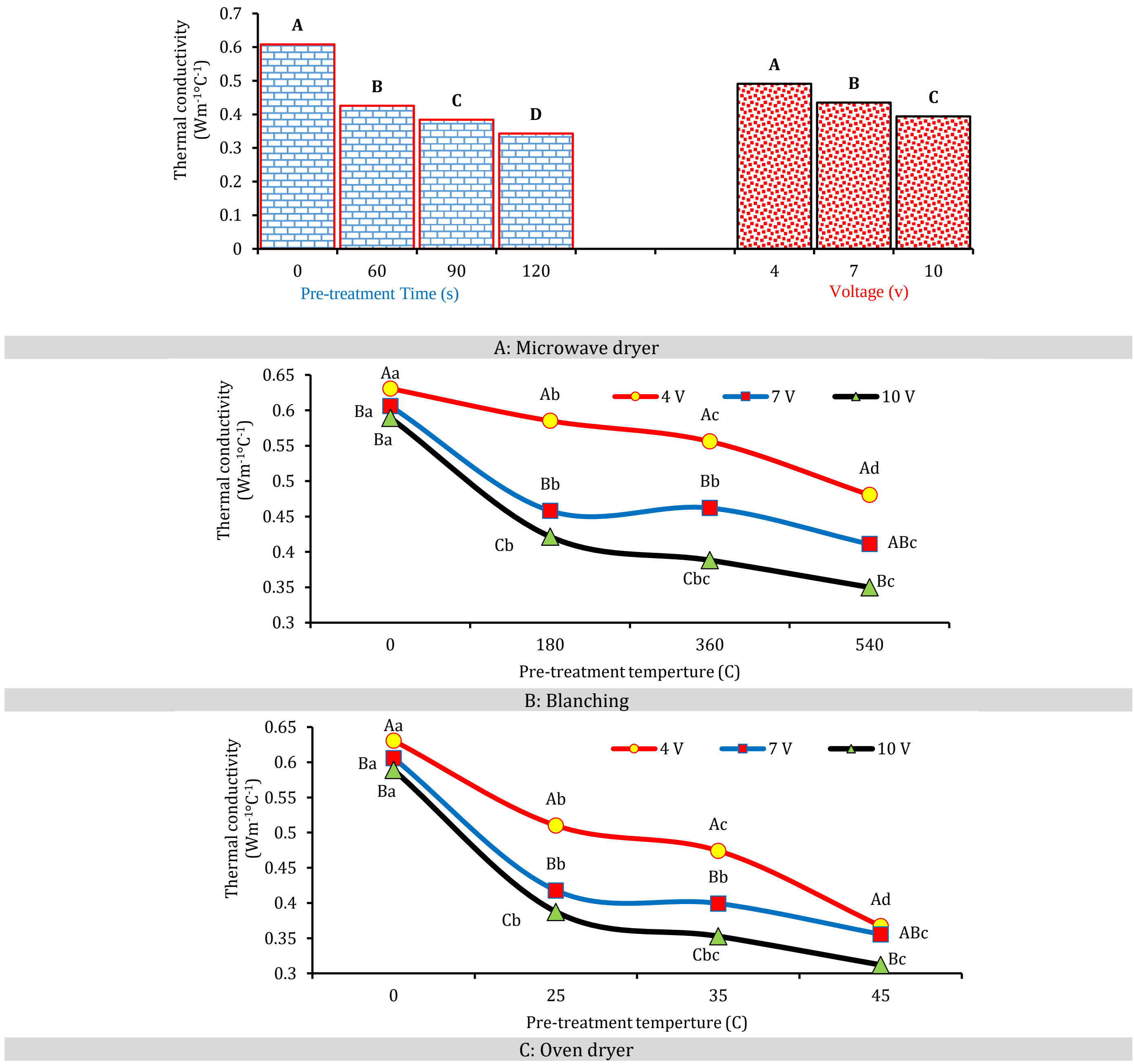

Figure 3. The effect of process voltage and pre-treatment changes on the rate of rosemary thermal conductivity. Values with similar small letters do not have significant differences in a constant voltage, while values with similar capital letters do not have significant differences at a fixed time.

3.2. Specific Heat

Rosemary's special heat is shown in Figure 4-A for microwave pre-treatment. According to the figure, there is a significant difference between all pre-treatment times. The highest specific heat was observed at 0 s with a value of 2,844 kJ kg^{-1} °C^{-1}, which is also a control sample, and this is the highest value in all cases and the lowest value for microwave pre-treatment in 120 s with a value of 2.31 kJ kg^{-1} °C^{-1} is obtained. The reason is that due to the definition of specific heat capacity increase in power levels, and microwave pre-treatment time, the amount of moisture content of rosemary leaves decreases. Therefore, the lower the moisture content of the product, the lower the amount of heat required to increase the temperature of the product. The results of this study are similar to the results of Samimi Akhijahani and Khodaei (2013) on the thermal properties of grapes.

In Blanching pre-treatment, the specific heat capacity of rosemary decreased, and there was a significant difference between all pre-treatment times. The lowest value was obtained at 540 s with 2,425 kJ kg^{-1} °C^{-1}, the results of which are shown in Figure 4-B. For the pre-treatment of the oven dryer, the same results were obtained as in the previous two pre-treatments and are shown in Figure 4-C. This is because the reduction in moisture content occurs at higher values of temperature and pre-treatment time of the oven, as well as the direct relationship between the moisture content and the thermal emission coefficient. The results of this study were similar to the results of Barnwal et al. (2014) on the thermal properties of fenugreek. According to the results, the lowest amount of heat capacity was when the microwave pre-treatment was used, and the highest amount was obtained using the blanching pre-treatment. This indicates a greater effect of microwave pre-treatment on heat capacity. The results were similar to the results of a study by Samimi Akhijahani and Khodaei (2013) on the thermal properties of grapes.

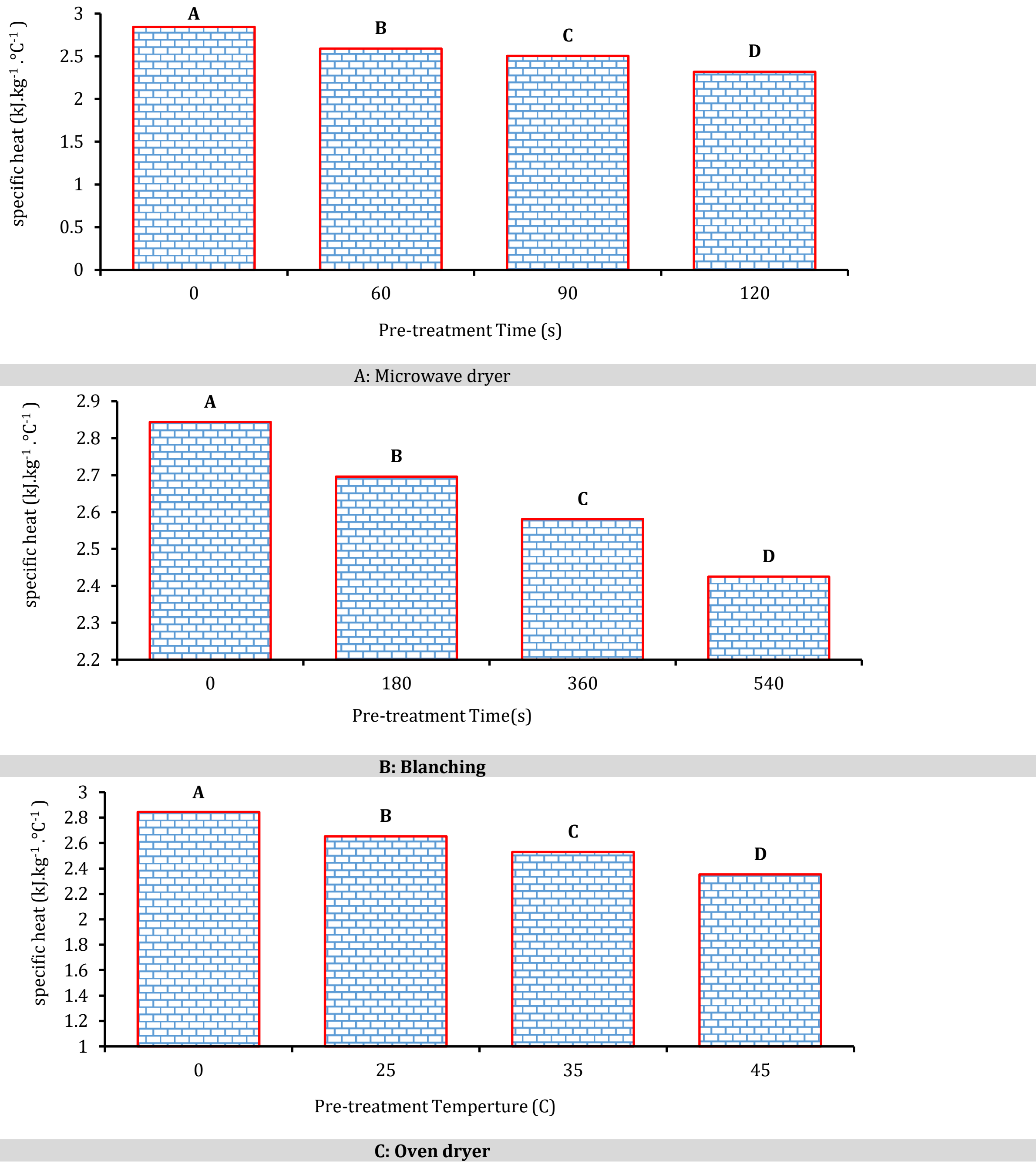

Figure 4. Pre-treatment effects on the specific heat of rosemary leaves

3.3. Thermal diffusion coefficient

According to Figures 5-A and 5-B, it can be stated that increasing the pre-treatment time of the microwave and blanching process has reduced the amount of thermal diffusion coefficient. There is a significant difference between all the times in both pre-treatments, and there is a significant difference from the control sample, which is 0 s. Also, according to Figure 5-C, a decreasing trend was observed for the Rosemary thermal diffusion coefficient, and a significant difference was observed between the mentioned temperatures. For the effect of voltage changes, it was observed that only this factor is significant for microwave pre-treatment, and according to the significance in Figure 5-A, a decreasing trend can be observed with increasing voltage, and a significant difference between different voltages can be observed. Among the three pre-treatments, it can be stated that blanching with 2.81 × 10^{-6} m^2 s^{-1} has the highest value and 2.48 × 10^{-6} m^2 s^{-1} has the lowest value when the effects of pre-treatments on time and temperature factors were considered. The pre-treatment of the oven dryer with a value of 2.50 × 10^{-6} m^2 s^{-1} was somewhat close to the pre-treatment of the microwave. Due to the fact that the thermal diffusion coefficient is directly related to the amount of thermal conductivity, therefore, this value also increases with increasing thermal conductivity. In a study, Azadbakht et al. (2013) pointed to the positive effect of moisture on the amount of thermal conductivity.

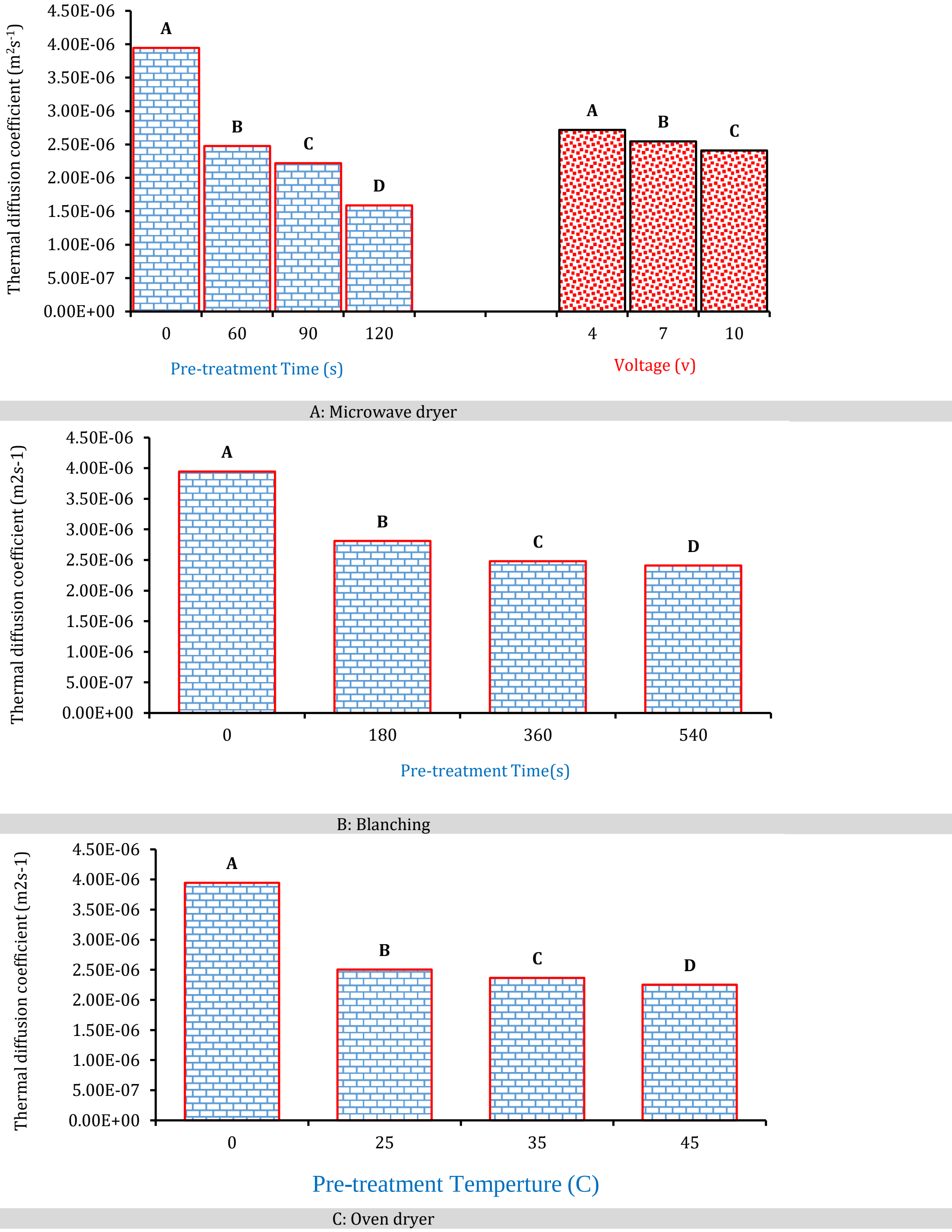

Figure 5. Pre-treatment effects on the thermal diffusion coefficient of rosemary leaves

4. Conclusion

Based on the results, it can be said that microwave pre-treatment had a greater effect than reducing the values of thermal conductivity, specific heat capacity, and thermal diffusion coefficient compared to the other two pre-treatments and since then, oven pre-treatment has had a greater impact than Blanching's pre-treatment. For the thermal conductivity coefficient, when the microwave pretreatment was used, a 43.58 % decrease was observed compared to the control sample, and for the oven and Blanching pre-treatment, 43.29 and 30.67 % decrease compared to the control thermal coefficient were observed, respectively. For special heat, microwave, oven, and blanching precursors were reduced by 18.5, 17.26, and 14.73 %, respectively, compared to the controlled heat capacity sample. Finally, for the thermal diffusion coefficient in microwave pre-treatment, a decrease of 59.74 % was observed in the amount of thermal diffusion coefficient, which was the highest decrease compared to the other two pre-treatments, and for the other two pre-treatments, there was a decrease of 42.89 and 38.41 %, respectively, compared to the control sample, which was in the pre-treatment of oven and Blanching. In general, all pre-treatments decreased the thermal properties of rosemary leaves and the effect of the microwave was much higher.

References

Akbarnejad, A., Azadbakht, M., & Asghari, A. (2015). Determination of thermal properties of the Cavendish banana peel as a function of temperature and moisture. *Agricultural Engineering International: CIGR Journal*, *17*(4), 387–396.

Aviara, N. A., & Haque, M. A. (2001). Moisture dependence of thermal properties of sheanut kernel. *Journal of Food Engineering*, *47*(2), 109–113. https://doi.org/10.1016/S0260-8774(00)00105-9

Azadbakht, M., Khoshtaghaza, M. H., Ghobadian, B., & Minaei, S. (2013). Thermal properties of soybean pod as a function of moisture content and temperature. *American Journal of Food Science and Technology*, *1*(2), 9–13. https://doi.org/10.12691/ajfst-1-2-1

Azadbakht, M., Mahmoodi, M. J., Ghazagh Jahed, R., & Vahedi Torshizi, M. (2022). Mathematical modeling of the biochemical properties of carrots by microwave drying with different pretreatments using response surface methodology. *Food Engineering Research*, *21*(1), 35–56. https://doi.org/10.22092/fooder.2020.343389.1273

Barnwal, P., Singh, K. K., Mohite, A., Sharma, A., & Zachariah, T. J. (2014). Determination of thermal properties of cryo- ground cinnamon powder. *Journal of Spices and Aromatic Crops*, *23*(2), 262–267.

Bitra, V. S. P., Banu, S., Ramakrishna, P., Narender, G., & Womac, A. R. (2010). Moisture dependent thermal properties of peanut pods, kernels, and shells. *Biosystems Engineering*, *106*(4), 503–512. https://doi.org/10.1016/j.biosystemseng.2010.05.016

Chandrakanthi, M., Mehrotra, A. K., & Hettiaratchi, J. P. A. (2005). Thermal conductivity of leaf compost used in biofilters: An experimental and theoretical investigation. *Environmental Pollution*, *136*(1), 167–174. https://doi.org/10.1016/j.envpol.2004.09.027

Fasina, O. O., & Sokhansanj, S. (1995). Bulk thermal properties of alfalfa pellets. *Canadian Agricultural Engineering*, *37*(2), 91–95.

Fontana, A. J., Wacker, B., Campbell, C. S., & Campbell, G. S. (1998). Simultaneous thermal conductivity, thermal resistivity, and thermal diffusivity measurement of selected foods and soil. *2001 ASAE Annual Meeting*, 1. https://doi.org/10.13031/2013.5543

Ghajarjazi, E., Azadbakht, M., & Ghaderi-Far, F. (2016). Relationship between thermal properties of canola pods (without seed) with moisture content, porosity and chemical composition of pods. *Agricultural Engineering International: CIGR Journal*, *18*(1), 384–398.

Hosainpour, A., Kheiralipour, K., Nadimi, M., & Paliwal, J. (2022). Quality Assessment of Dried White Mulberry (*Morus alba* L.) Using Machine Vision. *Horticulturae*, *8*(11), 1011. https://doi.org/10.3390/horticulturae8111011

Loha, C., Das, R., & Choudhury, B. (2012). Evaluation of Air Drying Characteristics of Sliced Ginger (Zingiber officinale) in a Forced Convective Cabinet Dryer and Thermal Conductivity Measurement. *Journal of Food Processing & Technology*, *03*(06). https://doi.org/10.4172/2157-7110.1000160

Motevali, A., Hashemi, J., & Kiani, R. (2017). Investigation of Thermodynamic Parameters and Essentioan Oil Content in Drying of Rosemary by Applying a Microwave Pulsed Pretreatment. *Energy Engineering & Management*, *7*(2), 42–51.

Nargesi, M. H., & Kheiralipour, K. (2024). Visible feature engineering to detect fraud in black and red peppers. *Scientific Reports*, *14*(1), 25417. https://doi.org/10.1038/s41598-024-76617-1

Nazir, R., Qadir, R. U., Yousuf, M., Sultan, P., Nawchoo, I. A., & Hassan, Q. P. (2024). Exploring the efficacy of hormonal treatments and pre-sowing techniques on seed germination of Salvia rosmarinus Spenn. *Journal of Applied Research on Medicinal and Aromatic Plants*, *42*, 100564. https://doi.org/10.1016/j.jarmap.2024.100564

Ntoanidou, S., Kaplani, A., Paloukopoulou, C., Bazakos, C., Patelou, E., Doukidou, L., Kotoula, A.-A., Gklavakis, E., Hatzilazarou, S., Karioti, A., Nianiou-Obeidat, E., Kostas, S., & Kanellis, A. K. (2024). Identification of high carnosic acid rosemary (*Salvia rosmarinus* Spenn.) genotypes through genetic diversity exploitation, chemical profiling, and transcriptomic approaches. *Industrial Crops and Products*, *214*, 118562. https://doi.org/10.1016/j.indcrop.2024.118562

Oloyede Christopher, T., Akande Fatai, B., Oriola Kazeem, O., & Oniya Oluwole, O. (2018). Thermal properties of soursop seeds and kernels. *Research in Agricultural Engineering*, *63*(2), 79–85. https://doi.org/10.17221/22/2016-rae

Rafya, M., Zehhar, N., Hafidi, A., & Benkhalti, F. (2024). Review of Rosmarinus officinalis L. essential oil, hydrosol, and residues analysis: Composition, bioactivities, and valorization. *Industrial Crops and Products*, *221*, 119392. https://doi.org/10.1016/j.indcrop.2024.119392

Raji, F., Maghool, S., Shayesteh, H., & Rahbar-Kelishami, A. (2024). Effective adsorptive removal of Pb^{2+} ions from aqueous solution using functionalized agri-waste biosorbent: New green mediation via Seidlitzia rosmarinus extract. *Chemosphere*, *363*, 142759. https://doi.org/10.1016/j.chemosphere.2024.142759

Salari Kia, A. ., Aghkhani, M. ., & Abaspourfard, M. . (2014). The effect of moisture content and temperature on the specific heat capacity of nut and kernel of two iranian pistachio varieties. *Journal of Agricultural Machinery*, *4*(1), 30–36.

Salari Kia, A. (2012). *The effect of different levels of moisture and temperature on grain and kernel thermal properties of two Iranian pistachio cultivars*.

Samimi Akhijahani, H., & Khodaei, J. (2013). Investigation of specific heat and thermal conductivity of rasa grape (*Vitis vinifera* L.) as a function of moisture content. *World Applied Sciences Journal*, *22*(7), 939–947. https://doi.org/10.5829/idosi.wasj.2013.22.07.3447

Shoja, N., Dianat, M., Hoseyni, S. ., & Ramazani, G. (2015). The evaluation of the protective effects of the hydro-alcoholic extract of rosemary (*Rosmarinus officinalis* L.) on ventricular arrhythmias in rats. *Journal of Babol University of Medical Sciences*, *17*(5), 66–72.

Singh, K. K., & Goswami, T. K. (2000). Thermal properties of cumin seed. *Journal of Food Engineering*, *45*(4), 181–187. https://doi.org/10.1016/S0260-8774(00)00049-2

Vahedi Torshizi, M., Azadbakht, M., & Kashaninejad, M. (2020). A study on the energy and exergy of Ohmic heating (OH) process of sour orange juice using an artificial neural network (ANN) and response surface methodology (RSM). *Food Science & Nutrition*, *8*(8), 4432–4445. https://doi.org/10.1002/fsn3.1741

Yang, W., Sokhansanj, S., Tang, J., & Winter, P. (2002). Determination of thermal conductivity, specific heat and thermal diffusivity of borage seeds. *Biosystems Engineering*, *82*(2), 169–176. https://doi.org/10.1006/bioe.2002.0066

Zarghi, H., Golian, A., & Kemanshahi, H. (2015). The Effect of Different Levels of Dried Rosemary Leave (*Rosmarinus officinalis* L.) on Performance and Egg Quality in Laying Hens. *Iranian Journal of Animal Science Research*, *8*(4), 646–655. https://doi.org/10.22067/ijasr.v1i1.34021