



Assessment of Experimental Energy Consumption and Drying Kinetics Analyses of Processing Waste Pea (*Pisum sativum*) by Convective Drying

Muhammed Taşova^{1,a,*}, Samet Kaya Dursun^{1,b}

¹Tokat Gaziosmanpaşa University, Faculty of Agriculture, Department of Biosystems Engineering, 60250, Tokat/Turkey

*Corresponding author

ARTICLE INFO

ABSTRACT

Research Article

Received : 30.04.2025
Accepted : 01.06.2025

Keywords:

Energy Analysis
Physicochemical Properties
Drying Process
Microwave
Osmotic Pretreatment

Shelled pea is an important product due to the nutritional values it contains, and it is not possible to consume for a long time due to its high moisture content. For this reason, it can be consumed out of season after drying. In this study, the effect of potassium carbonate and microwave pretreatment was investigated by drying in a cyclone type convective dryer at air flow rates of 287.50, 575.00 and 862.50 m³/h to produce dry peas. The moisture content, drying rate, effective moisture diffusion, specific moisture absorption rate (SMER), specific energy consumption (SEC) and color properties of the drying processes were investigated. Air flows and pretreatments affected the drying kinetics, color and energy analysis of the drying processes. Drying rate values for drying processes varied between 0.01190-0.0237 g moisture/g dry matter per minute. It was determined that the effective moisture diffusion values varied between 7.60×10⁻⁸-1.24×10⁻⁷ m²/s. Drying processes did not preserve the color values compared to fresh (p<0.05). It has been determined that the SMER values of the drying processes vary between 4.10-8.10×10⁻⁴ kg/kWh and the SEC values vary between 1230.59-2451.15 kWh/kg. According to the findings obtained within the scope of the study, it is recommended to dry the shelled peas at 862.50 m³/h air flow rate and after dipping into potassium carbonate solution.

^a muhammed.tasova@gop.edu.tr

^b <https://orcid.org/0000-0001-5025-0807>

^b kayadrsn44@gmail.com

^b <https://orcid.org/0000-0002-8230-3560>



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Introduction

Pea (*Pisum sativum*) is one of the most important legumes grown by 33 countries in the world. The countries that produce the most peas are China, India, America, France and Egypt (FAO, 2012; Barzegar et al., 2015). According to FAO, the world pea production amount for 2020 is 25.50 million tons. Türkiye's pea production for 2022 is 120 455 tons (Stat Agri, 2023). In terms of its nutritional and health properties, peas contain vitamins, proteins, minerals and high amounts of fiber. It is widely used in diets because it has no cholesterol properties. Fresh peas have a short shelf life due to their high moisture content. For this reason, shelf life is extended after harvest by canning, freezing, cold storage and drying (Chauhan and Srivastava, 2009; Barzegar et al., 2015).

One of the most general preservation methods used from ancient times to the present is drying. The drying process is basically the removal of moisture from products. The most traditional drying method is open (shade-sun) drying. This method has some disadvantages because it does not offer the opportunity to dry anytime and anywhere, the drying time is long, the product cannot be reduced to the desired moisture level, and it is a method that is open to negative environmental effects (dust, wind,

rain, insects, pesticides, etc.) (Purohit et al., 2006; Sharma et al., 2009; Taşkın et al., 2021). Another method widely used in the drying industry is conventional artificial drying. This method has some disadvantages because the installation cost and energy consumption values are higher than the traditional drying method. However, the convective artificial drying method accelerates drying by providing a more homogeneous heat distribution within the product compared to open drying, saving time and producing higher quality dry products (Morais et al., 2018; Yan et al., 2019; Boateng and Yang, 2020). It is reported that the amount of energy spent between the production-consumption chain of agricultural products corresponds to approximately 30% of the total amount of energy produced (FAO, 2011; Jha and Tripathy, 2017; Jha and Tripathy, 2021). It is reported that an average of 10-20% of this amount of energy consumed is spent only in drying processes (Raghavan et al., 2005; Ali et al., 2020), and in industrially developed countries, this rate varies between 7-15% on average (Akpınar et al., 2005). Due to the high amount of energy consumed in drying processes, some pretreatments are applied both to reduce the amount of energy consumed and to preserve the quality characteristics of the

products (Lewicki and Gupta, 1995; Soomro et al., 2020). Pre-treatments applied to agricultural products prevent or reduce the occurrence of local negativities such as shrinkage by ensuring that the heat is distributed more uniformly within the product and on its surface (Salim et al., 2016). However, it is reported that it reduces the average drying time of the products by 13-46%, depending on the difference and severity of the pre-treatments applied (Junqueira et al., 2017; Vallespir et al., 2018), which contributes to the reduction of energy consumption. In the literature; Kaveh et al. (2021), conducted a drying study of peas at temperatures of 40, 55 and 70°C with convective and convective assisted dryers. They investigated the drying kinetics and energy analysis of the drying process. In the study, they determined the lowest specific energy consumption (SEC) value at 40°C. Zielinska et al. (2013) dried peas in a heat pump convective dryer and a vacuum microwave dryer at 60°C and 60°C + 3 kPa vacuum pressure + 100 W microwave power conditions, respectively. Within the scope of the study, the drying kinetics of the drying processes, moisture diffusion, microstructure and some physical parameters of the product were investigated. They determined the average drying rate of the product as 0.590 and 0.201 g moisture/g dry matter.minute, respectively. They reported that the structural change in the product dried in the vacuum type microwave drying system occurred less than in the convective dryer. Iheonye et al. (2020) dried pea grains in a fluidized bed convective dryer at temperatures of 50, 55 and 60°C. They determined the real-time shrinkage properties of dried grains. In drying peas, Kaur et al. (2023), Gao et al. (2016) and Taşova (2019) conducted similar studies. Within the scope of the research, no study was found that investigated the effects of different air flow rates and pre-treatments on physico-chemical and energy analyses by drying shelled peas in a cyclone type convective dryer. In this respect, the study is thought to be original.

The aim of this study was to investigate the effects of air flow rates and pretreatment on the drying rate, moisture content, effective moisture diffusion, color properties, specific moisture absorption rate, and specific energy consumption values of shelled peas dried with a cyclone type convective drying system.

Material and Method

Drying Material

Freshly shelled peas were harvested in May 2023 from a producer garden in Tokat/Erbaa provincial (Turkey). The harvested products were immediately brought to the drying laboratory of Tokat Gaziosmanpaşa University and stored in the refrigerator at $+4\pm 0.5^\circ\text{C}$ until the end of the study. Before moisture determination and drying, the unconsumed end parts of the peas were cut off and sliced into thirds transversely.

Pretreatments

Pre-treatments were applied to preserve the quality characteristics of shelled pea samples, increase drying kinetics and reduce energy consumption values.

Dipping Pre-Treatment in Potassium Carbonate Solution

Pre-dipping in potassium carbonate solution was applied to break the resistance of the hazy structure on the shelled peas. For the prepared 2% potassium carbonate solution, 5 g of potassium carbonate (K_2CO_3) was added to 245 g of pure water and dissolved by stirring. Freshly shelled pea samples were dipped into the solution for 5 minutes. Çelik (2019) applied a pre-treatment of dipping the fresh grapes they used for drying in 5% potassium carbonate solution. An et al. (2019) dipped the blueberry fruit in 3% potassium carbonate solution for 5 minutes to break the hazy structure.

Microwave pre-treatment

Microwave pre-treatment was applied to reduce the drying time of the product by breaking the resistance of the peroxidase enzyme in shelled peas. Pea samples were kept under 720 W microwave power for 1.5 minutes. Lin et al. (2022) pretreated the Pacific white shrimp product at 500 W microwave power before drying.

Moisture Content

To determine the initial moisture content of shelled peas on a wet basis (w.b.), the temperature was set at 70°C (Kaveh et al., 2018), and dried in an oven (Şimşek labor teknik brand-ST-055 model) until the weight change was stabilized. The total moisture content of the samples was calculated according to Kaveh et al. (2018) was calculated according to their method. The initial moisture content was determined as $84.98\pm 0.29\%$ (w.b.).

Dryer

The cyclone types convective dryer, designed and manufactured within the scope of a project, was used to dry fresh shelled pea samples (Figure 1).

The basic working principle of the cyclone type convective dryer is that the ambient air is swept by a fan (1) and transmitted to the heater compartment (2) and then transferred to the drying compartment. Electric serpentine type resistances are used to heat the drying air. The heated hot air passing through the resistances is passed through a cyclone type cylindrical channel (3) and transferred to a cyclone type drying chamber (4).

The hot air is brought into contact with the drying materials from bottom to top to remove moisture. The section where the product is dried is cylindrical and divided into three compartments. The flow rate and temperature values of the drying air are adjusted from the control panel.



Figure 1. Cyclone type convective dryer

Drying processes

Freshly shelled pea samples, sliced transversely, were placed in drying chambers. Drying processes were carried out at a constant temperature of 60°C and air flow rates of 287.50, 575 and 862.50 m³/h. An average of 50±1.50 g of fresh sample was used for each drying process. The final moisture content of the samples was dried to an average of 9.15±1.43% (b.b.). In pea drying studies, the final moisture value of the product was determined by Kaveh et al. (2021) to 12% (w.b.) and Pardeshi et al. (2009) reduced it to 6-7% (b.b.) humidity levels. AND brand GF-300 model precision balance (0.01 g) was used to follow the weight change of the dried samples.

Drying Rate (DR)

Equation 1 was used to calculate the drying rates of the samples (Doymaz et al., 2006).

$$DR = \frac{M_t - M_{(t+dt)}}{dt} \quad (1)$$

Here: M_t; Moisture content at time *t* (g water/g dry matter), d_t; minute, DR; Drying rate (g water/g dry matter min).

Moisture Rate (MR)

Equation 2 was used to determine the moisture content of the samples during drying (Maskan, 2000).

$$MR = \frac{M - M_e}{M_0 - M_e} \quad (2)$$

Here: MR; Moisture rate, M; Instant moisture content of the product (g water/g dry matter), M_e; Equilibrium moisture content of the product (g water/g dry matter), M₀; It represents the initial moisture content of the product (g water/g dry matter).

Effective Moisture Diffusion

Equation 3 was used to calculate the effective mass diffusion values of moisture moving away from freshly shelled pea samples (Corzo et al., 2008).

$$\ln MR = \ln \frac{8}{\pi^2} - \frac{\pi^2 \cdot D_{eff} \cdot t}{4L^2} \quad (3)$$

Here: D_{eff}; effective diffusion value (m²/s), L; It represents half of the thickness value (m) of the product.

Specific moisture extract rate (SMER)

Equation 4 was used to calculate the specific moisture absorption rates (SMER) of drying processes (Surendhar et al., 2019).

$$SMER = \frac{\text{Evaporated moisture (kg)}}{\text{Consumpted energy (kWh)}} \quad (4)$$

Here: SMER; Specific moisture removal rate (kg/kWh).

Specific energy consumption (SEC)

Equation 5 was used to calculate the specific energy consumption (SMER) values of drying processes (Motevali et al., 2012).

$$SEC = \frac{E_t}{m_w} \quad (5)$$

Here: SEC; specific energy consumption (kWh/kg water), E_t; total consumed energy (kWh), m_w; amount of water removed (kg).

Color values

The total color change value shows the total change of heat-degraded (non-enzymatic) color pigments in the drying processes. Equations (6-7) were used to calculate these values.

Statistical Analyses

To evaluate the color values of the samples statistically, Duncan's multiple comparison test (P<0.05) was performed in the SPSS 17 program. SigmaPlot 10.0 program was used to create curves for drying rate, moisture rate and energy analysis of the products.

Results And Discussion**Drying values**

The drying curves of the products are given in Figure 2.

Drying air flow rate and pre-treatments affected the drying values of shelled peas. According to Figure 2, it was seen that there was an inverse relationship between drying air flow rate and drying time. Iheonye et al. (2020) reported in their study that dried pea grains at temperatures of 50, 55 and 60°C, that the drying time decreased as the temperature increased. When the air flow rate increased from 287.50 m³/h to 862.50 m³/h in the shelled pea drying process, the drying time decreased by 25.00, 30.00 and 33.33% for the control, potassium carbonate and MW pre-treated samples, respectively. The reason for this is thought to be that the increase in air flow rate causes more moisture to be swept away from the product, reducing the drying time. Royen et al. (2020) dried apple slices in a batch-type convective dryer at temperatures of 40, 45 and 50°C and air speeds of 0.60, 0.85 and 1.1 m/s.

They reported that increasing the drying air speed reduced the drying time of the product. They found that if the drying temperature was constant at 50°C and the air speed increased from 0.60 m/s to 1.1 m/s, the drying time decreased by 22.73%. It was observed that the findings obtained within the scope of the study were compatible with the findings in the literature. It has been observed that microwave pre-treatment applied before drying is more effective on the drying time of the product than pre-treatment by dipping it in potassium carbonate solution. Doymaz and Küçük (2017) applied the pre-treatment of pea grains by turning them into puree and dipping them in potassium carbonate + ethyl oleate solutions before drying them at 55, 65, and 75°C temperatures.

Color values	Equations	References	No
Chroma	$C = (a^2 + b^2)^{1/2}$	Ramallo and Mascheroni (2012)	(6)
Color difference	$\Delta E = \sqrt{(L - L^*)^2 + (a - a^*)^2 + (b - b^*)^2}$	Tan et al. (2001)	(7)

L^* , a^* , and b^* values indicate the brightness, redness and yellowness color values of dried shelled pea samples. L , a , and b values indicate the brightness, redness and yellowness color values of fresh shelled pea samples.

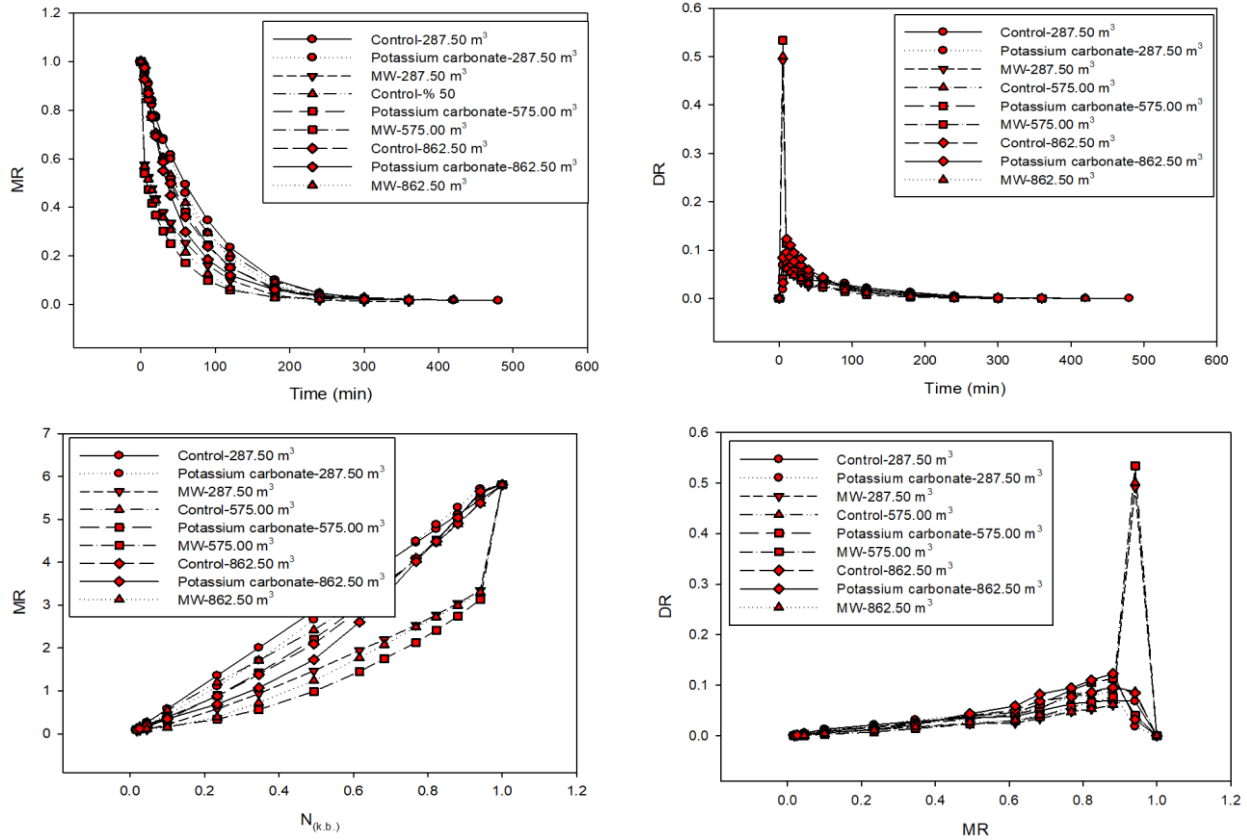


Table 1. Effective moisture diffusion values

Flow rate (m ³ /h)	Pretreatment	Effective moisture diffusion (m ² /s)	R ²
287.50	Control	7.60×10 ⁻⁸	0.963
	Potassium carbonate	8.52×10 ⁻⁸	0.967
	MW	9.75×10 ⁻⁸	0.959
575.00	Control	7.91×10 ⁻⁸	0.974
	Potassium carbonate	9.52×10 ⁻⁸	0.970
	MW	9.75×10 ⁻⁸	0.906
862.50	Control	9.21×10 ⁻⁸	0.978
	Potassium carbonate	1.04×10 ⁻⁷	0.974
	MW	1.24×10 ⁻⁷	0.965

Table 2. Color values

Flow rate	Pretreatment	L*	A*	B*	C*	ΔE
Fresh	-	51.01±1.92a	-2.26±0.88g	20.43±1.35a	23.83±1.21a	-
287.50	Kontrol	34.08±2.40h	0.53±1.72a	13.44±2.23e	13.46±2.63d	22.38±2.86a
	Potasyum karbonat	38.48±3.10d	-6.19±1.99d	15.83±2.61c	17.06±3.08c	14.82±2.39d
	MW	35.64±1.63f	-4.09±2.49c	12.93±1.07e	13.65±1.68d	19.12±2.65c
575.00	Kontrol	34.63±2.14gh	-0.06±1.66a	13.62±1.31e	13.66±1.27d	21.58±3.10ab
	Potasyum karbonat	40.30±2.99c	-8.34±1.83 ^{cf}	16.73±1.44b	18.73±1.61b	12.11±3.41e
	MW	37.56±2.77e	-7.60±2.29 ^{de}	15.27±2.13cd	17.09±2.08c	15.20±3.09d
862.50	Kontrol	35.37±2.14fg	-1.56±1.66b	13.29±1.31e	13.63±1.27d	20.44±3.10bc
	Potasyum karbonat	42.40±2.99b	-9.33±1.83f	17.32±1.44b	19.69±1.61b	9.67±3.41f
	MW	38.68±2.77d	-6.94±2.29 ^{de}	14.75±2.13d	16.34±2.08c	14.74±3.09d

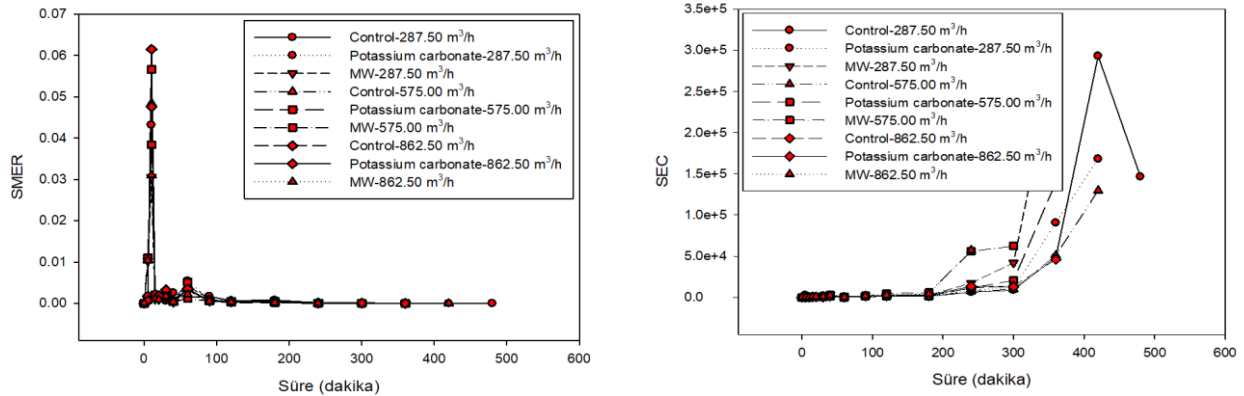


Figure 3. SMER and SEC energy consumption kinetics

They reported that when the samples with control, pureeing and dipping pre-treatments were dried at 75°C, the drying time was reduced by around 450, 330, and 300 minutes, respectively, compared to 55°C. When shelled peas were dried at air flow rates of 287.50, 575.00 and 862.50 m³/h, average drying rates were determined to vary between 0.01190-0.01593, 0.01357-0.01893 and 0.01585-0.02370 g moisture/g dry matter.minute, respectively. With the increase in drying air flow rates, the drying rate values of the material increased. The reason for this is thought to be related to the removal of more moisture from the drying material per unit time with high air flow rates.

Effective moisture diffusion values

According to Table 1, it was seen that the drying air flow rate and pre-treatments had an effect on the effective moisture diffusion values of shelled peas. It has been determined that effective diffusion values increase with increasing drying air flow rate. It is thought that this situation causes the increase in drying air flow to remove more moisture from the product and to spread the removed moisture over a larger area. Abbaspour-Gilandeh et al. (2019) reported that the effective diffusion value increases with increasing temperature. Kaveh et al. (2020) reported in their pea drying study conducted with the convective method that effective diffusion values increased with increasing temperature and air flow rate. In the study, they found that the effective moisture diffusion varied between 3.34×10^{-12} - 1.58×10^{-11} m²/s in drying processes at 40, 55 and 70°C temperature values and 5, 10 and 15 rpm air flow rates. It is thought that the differences in the initial moisture content of the products, texture structure, crustiness of the product and thermodynamic properties of the drying systems are effective in the fact that the values in the literature are lower than the values obtained in this study. Kaveh et al. (2018) reported that the effective moisture diffusion values of food products generally vary between 10^{-12} - 10^{-8} m²/s. SMER, SEC Values

The specific moisture absorption rate and specific energy consumption values of the drying processes are given in Figure 3.

According to Figure 3, air flow rate and pre-treatments affected the energy analysis of shelled peas. Kaveh et al. (2020) reported that air flow rate and drying temperature parameters affected the exergy energy efficiency of the pea drying process. In this study, as the air flow rate increased, the total amount of consumed energy decreased and the

specific moisture absorption rate (SMER) increased. The reason for this is that more moisture is removed from the product in drying processes at high air flow rates, causing an increase in the amount of moisture falling into the kWh energy consumption value. Tohidi et al. (2017) reported that there was a linear relationship between air speed and energy consumption values in their rice drying study in a deep bed convective dryer. It was observed that there was a difference between the findings obtained in the study in the literature and the findings obtained within the scope of this study.

It is thought that the reason for this is that the increase in the amount of energy consumed by the fan as the air speed increases is more dominant than the increase in the amount of moisture removed as the air speed increases. It was found that the SMER values of the pre-treated samples during the drying process were higher than the control samples. Pretreatments increased the SMER values by reducing the drying time of the product and reducing the total amount of energy consumed. Llavata et al. (2020) reported in their study that drying pretreatments reduced energy consumption values. In this study, microwave pretreatment increased the SMER values of the drying processes more than the potassium carbonate solution dipping pretreatment. This is because the drying time of the microwave pretreated samples was shorter and the energy consumption values decreased.

Wu et al. (2019) stated that the ultrasound pre-treatment applied to the stems of the pakchoi plant at a power value of 300 W reduced the drying time of the product by 25% and therefore contributed to the reduction of the total amount of energy consumed. In the literature, Dehsheikh et al. (2019) and Abbaspour-Gilandeh et al. (2019) found a similar relationship in their study. In this study, specific energy consumption (SEC) values decreased with increasing air flow rate. The reason for this is that as the air flow increases, the drying time of the product decreases and the total amount of energy consumed also decreases. This situation caused the SEC values to decrease. Toriki-Harchegani et al. (2016) found in their study that there was an inverse relationship between drying temperature and SEC values. This situation is thought to be related to the decrease in drying time and therefore the decrease in the total amount of energy consumed as the drying temperature increases. It was observed that the findings obtained within the scope of the study and the relationships determined between the findings were compatible with the literature.

Conclusion

It was observed that drying air flow rate and pre-treatments affected the drying kinetics, color and energy analyses of shelled peas. Increasing the drying air flow rate decreased the drying time of the product and positively affected the drying kinetics of the product by increasing the drying rates and effective mass diffusion values. In the study, increasing the drying air flow rate decreased the SMER values and increased the SEC values. Increasing the drying air flow rate reduced the drying time of the product and therefore decreased the amount of energy consumed. Microwave pretreatment increased the drying kinetics of shelled peas more than potassium carbonate pretreatment. It was observed that the color properties of the samples pretreated with potassium carbonate were preserved better compared to microwave pretreatment. Within the scope of the study, it is recommended to dry shelled peas at high air flow rate and by applying microwave pre-treatment in terms of drying kinetics, while in terms of color quality, it is recommended to dry them by applying potassium carbonate pre-treatment at high air flow rate. For shelled peas, it is recommended that in future studies, studies should be carried out at intermediate drying temperature values, intermediate air flow rates and different pre-treatments, where it is thought that the color, bioactive and drying kinetics properties will be preserved together.

Acknowledgements

The use of data will be made available upon appropriate request.

Conflict of Interest

The author in the study has no conflict of interest with any other author.

Authors' Contribution

Muhammed Taşova: Planning, data processing, article writing.

Samet Kaya Dursun: Laboratory work, data processing.

Data Availability

All the data used in the manuscript are available in the tables and figures.

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