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Rehydration Kinetics of Green Pea Grains Dried at Different Microwave Powers

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In this study, both untreated and pre-treated green pea grain samples dried at different microwave output powers (90, 180, and 360 W) were rehydrated at three different temperatures (30ºC, 50ºC, and 70ºC). The rehydration kinetics of dried peas were analyzed using both the Peleg and the first-order kinetic models. Observations revealed that the Peleg model exhibited better agreement with the experimental data. As both microwave power and rehydration temperature increased, the rehydration capacity also increased in both pre-treated and untreated peas. The highest moisture content was observed after rehydration in pre-treated peas dried at 360 W microwave power (2.80 g water/g dry matter and 213.40% mass gain), while the lowest moisture content was recorded in pre-treated samples dried at 90 W microwave power (1.66 g water/g dry matter and 119.30% mass gain). However, the samples were unable to reach the moisture level (3.10 g water/g dry matter) before drying at all rehydration temperatures. The activation energy of rehydration varied between 10.75 and 37.39 kJ/mol. The color properties of rehydrated green pea grains were significantly influenced by both microwave power and rehydration temperature. As these two parameters increased, the color differences of rehydrated peas compared to fresh peas also increased. The maximum total color difference (E = 17.66) in rehydrated peas compared to fresh peas was observed at 360 W microwave power and 70ºC rehydration temperature with untreated green peas, while the least total color difference (E = 8.69) occurred at 90 W microwave power and 30ºC rehydration temperature with pre-treated green peas.

Keywords: activation energy, color difference, green peas, Peleg model, rehydration

INTRODUCTION

The quality of products plays an increasingly important role in food dehydration processes. During dehydration, various significant changes take place, including structural and physicochemical alterations that affect the final product's quality. As a result, it is essential that dehydration processes maintain specific quality attributes such as color, nutritional composition, shape, and texture. Additionally, during the rehydration process, other factors such as rehydration capacity and velocity must also be considered. The success of the rehydration process is assessed by the ability to maintain the product texture as closely as possible to that before drying. Structural and chemical changes, along with food preparation and composition, play a crucial role in the rehydration process. Rehydration should not be regarded as merely the reverse of dehydration—it is influenced by the drying method, and the effect of the drying process on the material being rehydrated cannot be ignored (Sanjuán et al. 1999). Rehydration serves as an indicator of the structural and cellular disruption caused by the drying process of the product (Krokida et al. 1999; Sacilik and Elicin 2006).

Several factors, such as the boiling and drying methods, the physical structure of the product, its chemical composition, volume and density, and the salt content in the water influence the rehydration process. Analyzing the kinetics of rehydration, which involves three concurrent processes—water absorption by the dried product, swelling, and the filtration of soluble substances—can help optimize these processes for better efficiency and product quality (Dadali et al. 2008).

Rehydration temperature plays a significant role in determining the water absorption capacity of the product. Abu-Ghannam and McKenna (1997) observed that during the rehydration of red kidney beans at different temperatures, the final moisture content was significantly influenced by the rehydration temperature. Soaking at elevated temperatures led to a reduced time required to reach the equilibrium moisture content. The rehydration rate of the dried product is crucial for describing the structural changes that occur during the drying process (McMinn and Magee 1997).

During the rehydration process, the dried product is submerged in water at a designated temperature, allowing it to swell progressively over time. The rate of rehydration is determined by periodically weighing the product, following a similar method to that used during the drying process. The primary objective is to achieve the quickest rehydration while minimizing the loss of solid components, thus ensuring the quality of the rehydrated product (Doymaz and Aktaş 2018).

A variety of studies have examined the rehydration characteristics of different herbal products such as vegetables and fruits (Marques et al. 2009; Harnkarnsujarit et al. 2016). In this context, several mathematical models have been applied to describe the rehydration process (Celen et al. 2008). A developed model was used to estimate the rehydration rate constants and rehydration rates for mushroom slices dried using microwave vacuum and convective hot air methods. It has been reported that microwave vacuum drying leads to less shrinkage and a more porous structure compared to hot air drying which, in turn, improves the rehydration properties (Giri and Prasad 2007). The Peleg and Weibull kinetic models were used to evaluate the effect of drying conditions and temperatures on the rehydration kinetic parameters of spinach which was dried in the microwave at different output powers. It was found that, among these models, the Peleg model consistently yielded better results across all conditions. In this model, the activation energy was determined to be 23.84 kJ/mol (Dadali et al. 2008). The rehydration kinetic parameters were evaluated using the Peleg model. Potato slices, dried in a convective oven at 60ºC and subjected to microwave drying at 250, 440, and 600 W, were rehydrated in a water bath with temperatures ranging from 20ºC – 80ºC. The findings indicated that the rehydration rate increased with the solid-liquid ratio up to 1:50, while agitation was found to have a minimal impact on the rehydration parameters (Cunningham et al. 2008). The freeze-dried tomatoes were rehydrated in distilled water at 20ºC, 40ºC, and 50ºC. As the rehydration ambient temperature increased, a higher equilibrium moisture content was attained (57% at 50ºC, 37% at 20ºC). However, it is noteworthy that the moisture level before drying of the tomatoes could not be achieved at any of the rehydration temperatures (Lopez-Quiroga et al. 2019). To determine the activation energy, the rehydration process of the dried products is usually carried out in the temperature range of 20ºC – 80ºC (Cunningham et al. 2008; Lopez-Quiroga et al. 2019).

The rehydration kinetics of osmo-convective and convective-dried carrot cubes were investigated in distilled water at 30ºC for 12 h. Prior to convective dehydration, the carrot cubes underwent osmotic pre-treatment with solutions (10% NaCl, 55° Brix sucrose syrup, and 50° Brix + 10% NaCl) for 90, 180, and 360 min at 35ºC, 45ºC, and 45°C, respectively. In both conditions, the Peleg model proved to be the most suitable for describing rehydration. While osmo-convective dried samples exhibited negligible shrinkage, convective-dried (un-osmosed) samples showed a very high level of shrinkage (Singh et al. 2007).

In a study by Doymaz and Aktaş (2018), the aim was to examine the effects of air temperature and pre-treatments on the drying characteristics, rehydration capacity, color, and appearance of eggplants during drying in a hot air dryer. The results showed that rehydration capacity improved with higher rehydration temperatures and the application of pre-treatments. Interestingly, it was found that the color of the dried eggplant samples treated with citric acid was lighter compared to those treated with other pre-treatments. Kumar et al. (2020) investigated the alterations in rehydration and color properties of sweet corn kernels at 15-d intervals over a 3-mo storage period. The researchers noted a significant decrease in both rehydration coefficient and rate during storage, along with notable effects on color parameters.

Green pea grains are widely consumed in Turkey and globally. It can be consumed fresh in season or dried throughout the year. In addition to drying, it is also consumed canned. Dried green pea grains are rehydrated using different methods before consumption. This study involved rehydrating untreated and pre-treated green pea grain samples at three different temperatures (30ºC, 50ºC, and 70ºC). These samples were previously dried at varying microwave output powers (90, 180, and 360 W). The rehydration parameters were assessed using both the Peleg and the first-order kinetic models.

The aim of this study was to investigate the rehydration kinetics of green pea grains dried at different microwave output powers and sample quantities. The study also explored the impact of rehydration temperatures on the rehydration kinetics of green pea grains after drying, using the Peleg and the first-order models to analyze the rehydration process. Furthermore, the effect of the rehydration process on the color parameters (L*, a*, b*) of the green pea grains was examined.

MATERIALS AND METHODS

Rehydration Process

To determine rehydration parameters, green pea grain samples, previously dried at microwave output powers of 90, 180 and 360 W, were used. Some of the green pea grain samples underwent pre-treatment by boiling for 1 min at 100ºC before drying (Kayisoglu 2020).

The rehydration of green pea samples was conducted at controlled temperatures of 30ºC, 50ºC, and 70ºC with a 25 g sample weight in distilled water. The moisture content of the peas was 0.214 g water/g dry matter at the beginning of the rehydration process. The rehydration process was repeated three times for each temperature. Pea samples were subjected to the rehydration process until they reached a constant weight. During this period, they were taken out of the water and weighed every 15 min. Samples were rinsed with paper towels before weighing (Dadali et al. 2008; Kumar et al. 2011).

Moisture Content Measurement

Moisture content analysis was performed using a moisture analyzer (Model MB 25, OHAUS, Switzerland). Green pea grain samples were placed in the analyzer and heated uniformly at 120ºC until the sample weight stabilized. The moisture content of the green pea samples, expressed as g water/g dry matter, was calculated based on the recorded weight change (Lopez-Quiroga et al. 2019).

Rehydration Kinetics Modelling

Several mathematical and empirical models are employed in the rehydration process. However, due to their mathematical simplicity and practicality, the Peleg and the first-order models were selected for this research. Other commonly utilized models, such as the Weibull model and the Page model, are also prevalent in rehydration studies.

The mass gain rates of the samples depending on the time during the rehydration process were calculated with the following equation (García-Segovia et al. 2011):

$$m_{gt} = \frac{m_t - m_i}{m_i} \, x \, 100 \quad (1)$$

where: m_{gt} (%) and m_t (g) are the mass gain rate and mass of sample at a specific time, respectively; m_i (g) is the mass of the sample at the beginning of the rehydration process.

The Peleg model, which describes water absorption kinetics during rehydration, is presented below (Peleg 1988; Díaz et al. 2003):

$$X_t = X_i + \frac{t}{k_1 + k_2\, t} \quad (2)$$

where: X_t (g water/g dry matter) is the moisture content at time t; X_i (g water/g dry matter) is the initial moisture content; t (min) represents the measurement time, recorded at 15-min intervals throughout the rehydration process; k_1 (min. g dry matter/g water) is the kinetic rate constant of the Peleg model; and k_2 (g dry matter/g water) is the characteristics constant of the Peleg model.

The equilibrium moisture content after the rehydration process was calculated using the following equation as *t* approaches infinity (Kumar et al. 2011):

$$X_{eq} = X_i + \frac{1}{k_2} \quad (3)$$

where: X_{eq} (g water/g dry matter) is the predicted equilibrium moisture content of the sample at the end of the rehydration process.

The Arrhenius equation is commonly used to describe the temperature dependence of reaction rates or kinetic processes such as drying or rehydration. It links the rate constant of a process with temperature and activation energy. In this study, the activation energy of the Peleg model was calculated using coefficients derived from the exponential relationship between k_1 and (1/*T*) in the Arrhenius equation (Dadali et al. 2008; García-Segovia et al. 2011; Cox et al. 2012):

$$k_1 = k_0 \, exp\left(\frac{-E_A}{RT}\right) \quad (4)$$

where: E_A (J/mol) is the activation energy; k_0 (min. g dry matter/g water) is the pre-exponential constant; R (8.31439 J/mol.K) is the universal gas constant; and *T* (K) is the rehydration temperature.

The first-order kinetic model given below is used to fit the results of moisture increase (García-Segovia et al. 2011):

$$X_t = X_{eq} + \left(X_i - X_{eq}\right) x \, exp(-k_r.t) \quad (5)$$

where: X_t (g water/g dry matter) is the moisture content at time t; X_{eq} (g water/g dry matter) is the predicted equilibrium moisture content of rehydrated green pea samples; X_i (g water/g dry matter) is the initial moisture content; k_r (min^{-1}) is the rehydration rate; and *t* (min) is the rehydration time.

The goodness-of-fit for the models was evaluated using the coefficient of determination (R^2) and the root mean square error (RMSE) as performance metrics (Marques et al. 2009; Kumar et al. 2020):

$$RMSE = \sqrt{\frac{\sum_i^N \left(X_{exp,i} - X_{pred,i}\right)^2}{N}} \quad (6)$$

where: $X_{exp,i}$ is the ith experimental moisture content; $X_{pred,i}$ is the *i*th predicted moisture content; and *N* is the number of observations.

Color Measurement

The color parameters of the green pea grain samples were measured with a colorimeter (Chroma Meter - CR-400, Konica Minolta) in the CIE Lab color space, providing Cartesian coordinates L*, a*, and b*. The instrument was calibrated with a white standard. The total color difference was calculated using Eq. 7, with green pea grains before rehydration as the reference. A larger ΔE indicates a greater color change from the reference material (Zielinska and Markowski 2016; Chahbani et al. 2018; Kumar et al. 2020):

$$E = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2} \quad (7)$$

Here, L^* represents the degree of lightness (ranging from light to dark), with L_0^* indicating its initial value. Similarly, a^* denotes the degree of redness (positive) to greenness (negative), with a_0^* as its initial value. Lastly, b^* signifies the degree of yellowness (positive) to blueness (negative), with b_0^* as its initial value.

For each application, color parameters were measured on the surfaces of 10 randomly selected green pea samples to compare their values before and after rehydration. All color measurements were performed in triplicate to ensure accuracy and reliability (Jiao et al. 2013).

Statistical Analysis

All experimental data were analyzed using a two-way analysis of variance (two-way ANOVA) at a significance level of $P < 0.05$ with the SPSS Version 18 statistical software. The Tukey test was employed to compare means, and variance homogeneity was assessed using the Levene statistic. The coefficients for the Peleg and the first-order models were calculated through non-linear regression analysis, also performed in the SPSS program.

RESULTS AND DISCUSSION

Rehydration Capacity

The mass gain of untreated and pre-treated dried green pea samples during the rehydration process is given in Fig. 1. While there was a rapid mass increase in the initial stages of the rehydration process, the rate of mass increase slowed down as time passed. The rapid water uptake of the capillary tubes and cavities close to the surface of the green pea grains caused the mass increase to be high at the beginning of rehydration (Markowski et al. 2009; Doymaz and Kocayigit 2011). In all rehydration experiments, it was observed that the green pea grain samples did not reach the moisture level before drying (3.10 g water/g dry matter). In previous studies, it was observed that the most important factor influencing the decrease in rehydration capacity was the structural damage and cell shrinkage of green pea grains during microwave drying (Krokida and Philippopoulos 2005; Dadali et al. 2008). The highest moisture content was observed after rehydration in pre-treated peas dried at 360 W microwave power (2.80 g water/g dry matter and 213.4% mass gain), while the lowest moisture content was recorded in pre-treated samples dried at 90 W microwave power (1.66 g water/g dry matter and 119.3% mass gain). As microwave power increased during drying in both untreated and pre-treated pea samples, rehydration capacities increased at all rehydration temperatures (Fig. 1). Drying time is shorter in microwave drying, so cell shrinkage is less compared with cell shrinkage from other drying methods. As microwave power increases during drying, drying times also decrease (average 315 min at 90 W, 270 min at 180 W, and 195 min at 360 W). During the microwave drying process, the high vapor pressure in the spaces between the cells of the green pea grains increases the rehydration capacity by creating a porous structure (Torringa et al. 2001; Cunningham et al. 2008). Dadali et al. (2008) reported that in the rehydration process of microwave-dried spinach at various temperatures, the rehydration capacity showed an increase with higher microwave power level.

While the rehydration curves of untreated samples were closer to each other across different microwave powers and temperatures, the intervals between the curves were slightly larger in pre-treated peas. Moreover, as the rehydration temperature increased at all microwave powers, the rehydration capability also increased. In their study examining the rehydration behavior of peas dried by different methods, More and Tayade (2019) found that the rehydration capacity increases as the rehydration temperature increases in all drying methods—an observation similar to the findings in this study. In their research to determine the rehydration capacities of different products, Cunningham et al. (2008), Dadali et al. (2008), and Doymaz and Kocayigit (2011) also stated that as the rehydration temperature increases, the rehydration capacity also increases.

There was no significant difference between the rehydration capacities of pre-treated and untreated green pea grains. İsmail et al. (2014) also obtained similar results in their research on the rehydration of air-dried peas.

Rehydration Kinetics

To analyze the rehydration kinetics of microwave-dried green pea grains, two empirical models were employed: the Peleg model and the first-order model. The parameters derived from these models are presented in Tables 1 and 2, respectively. Among the two, the Peleg model demonstrated superior performance as evidenced by its higher determination coefficients (R^2) and lower root mean square error (RMSE) values (Table 1), making it more suitable for all experimental conditions. Additionally, the kinetic rate constant (k_1) of the Peleg model was higher in pre-treated peas compared to

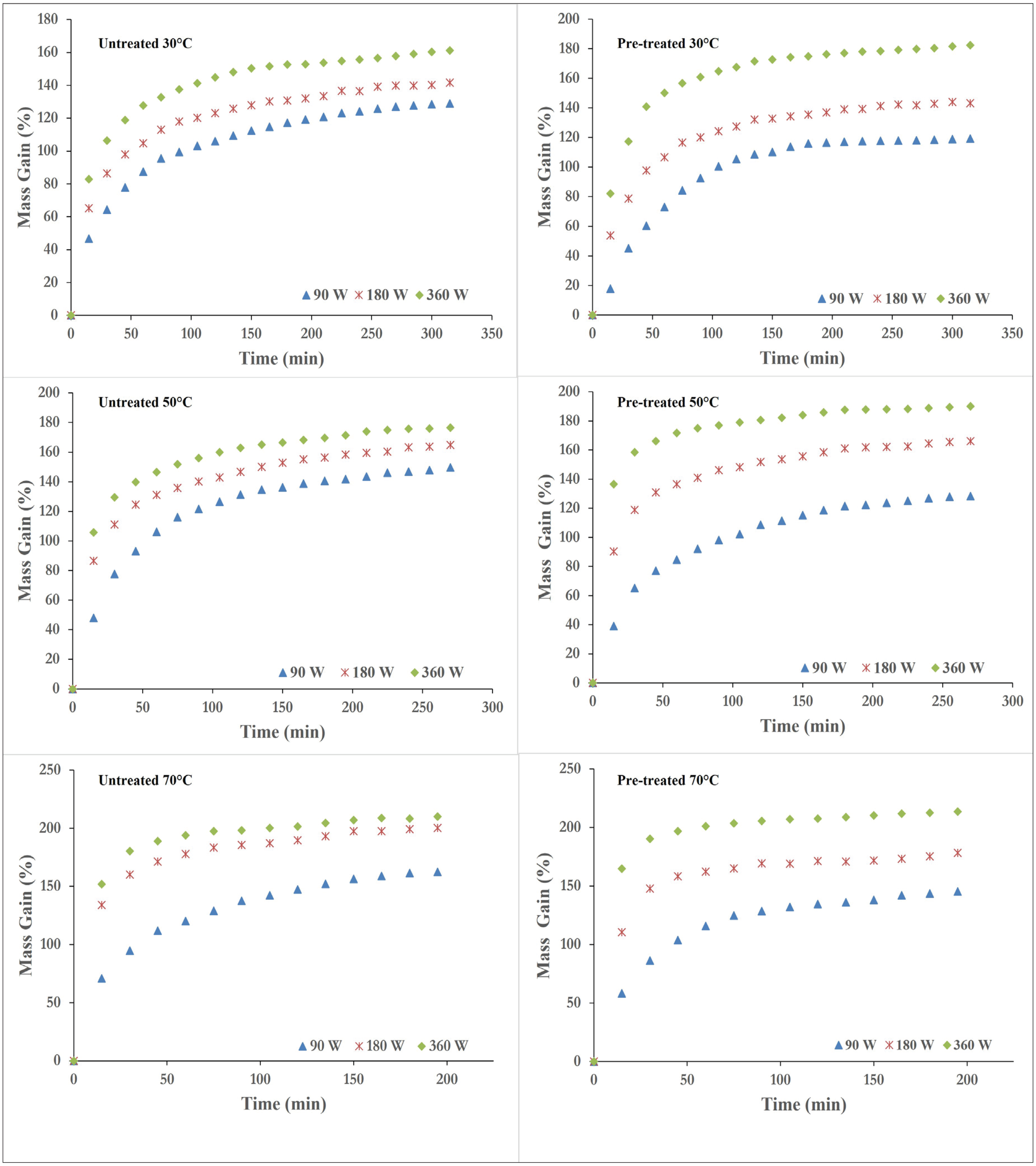

Fig. 1. Mass gain rates of dried green pea samples at different microwave powers at 30ºC, 50ºC, and 70ºC rehydration temperatures.

untreated peas, except for those dried at 360 W. In the Peleg model, the constants k_1 and k_2 decreased as the microwave output power in drying increased. Rehydration temperature also had the same effect on these constants. Additionally, during drying, microwave output power positively affected the equivalent moisture content (X_{eq}) in both kinetic models (Table 1). Dadali et al. (2008) also obtained similar results in the rehydration of microwave-dried spinach—in their study on the rehydration of microwave-dried spinach, they stated that better results were obtained with the Peleg model than other kinetic models. Solomon (2007) also stated that in the Peleg model, the lower the k_2 value, the higher the rehydration capacity, resulting in an increase in the equivalent moisture content of food. In their research, İsmail et al. (2014) and Kumar et al. (2020) also obtained similar results in the rehydration of different products in their own studies.

Table 1. Estimated parameters of the Peleg model at various rehydration temperatures.

Temperature	Process	Parameters	90 W	180 W	360 W
30°C	Untreated	k_1	21.504 ± 1.112	12.531 ± 0.915	8.542 ± 0.721
		k_2	0.578 ± 0.054	0.553 ± 0.014	0.493 ± 0.025
		X_{eq}	1.944 ± 0.125	2.022 ± 0.182	2.242 ± 0.236
		R^2	0.997	0.996	0.997
		RMSE	0.022	0.026	0.023
	Pre-treated	k_1	32.662 ± 2.024	14.816 ± 1.127	7.92 ± 0.988
		k_2	0.556 ± 0.088	0.523 ± 0.095	0.426 ± 0.071
		X_{eq}	2.013 ± 0.202	2.126 ± 0.150	2.561 ± 0.207
		R^2	0.982	0.999	0.998
		RMSE	0.055	0.012	0.02
50°C	Untreated	k_1	17.443 ± 1.752	8.064 ± 0.705	5.61 ± 0.501
		k_2	0.487 ± 0.096	0.482 ± 0.078	0.454 ± 0.042
		X_{eq}	2.267 ± 0.221	2.289 ± 0.250	2.417 ± 0.307
		R^2	1.000	0.994	0.995
		RMSE	0.010	0.034	0.033
	Pre-treated	k_1	24.027 ± 1.963	6.894 ± 0.606	2.828 ± 0.158
		k_2	0.554 ± 0.061	0.478 ± 0.055	0.428 ± 0.032
		X_{eq}	2.019 ± 0.125	2.306 ± 0.164	2.55 ± 0.188
		R^2	0.998	0.997	0.998
		RMSE	0.020	0.025	0.021
70°C	Untreated	k_1	12.747 ± 1.065	3.411 ± 0.652	2.351 ± 0.401
		k_2	0.448 ± 0.026	0.401 ± 0.018	0.385 ± 0.015
		X_{eq}	2.446 ± 0.228	2.708 ± 0.369	2.811 ± 0.482
		R^2	0.995	0.998	0.999
		RMSE	0.037	0.027	0.02
	Pre-treated	k_1	13.238 ± 1.128	3.927 ± 0.505	1.761 ± 0.289
		k_2	0.500 ± 0.051	0.447 ± 0.035	0.380 ± 0.022
		X_{eq}	2.214 ± 0.264	2.451 ± 0.259	0.372
		R^2	0.999	0.996	1.000
		RMSE	0.016	0.033	0.013

The relationship between the moisture content predicted by the Peleg model and the experimentally measured moisture content at different rehydration temperatures for untreated and pre-treated dried green pea grains is illustrated in Fig. 2. The results demonstrate that the model's predictions align well with the experimental data. This alignment becomes increasingly pronounced with higher microwave power levels. Similar findings were reported by Dadali et al. (2008) in their study on the rehydration of dried spinach.

Activation Energies

The activation energies in the rehydration of green pea grains, calculated using the kinetic parameters (k_1) of the Peleg model, are given in Table 3. The highest activation energy was observed in peas that were pre-treated and dried at 360 W microwave power (37.39 kJ/mol), while the lowest activation energy was recorded in peas that were untreated and dried at 90 W microwave power (10.75 kJ/mol). As the microwave power increased in the drying process, the activation energies of rehydration also increased. The difference between the activation energies of pre-treated and untreated green pea grains was found to be statistically significant ($P < 0.05$). The

Table 2. Estimated parameters of the first-order model at various rehydration temperatures.

Temperature	Process	Parameters	90 W	180 W	360 W
30°C	Untreated	k_r	0.027 ± 0.006	0.030 ± 0.006	0.037 ± 0.004
		X_{eq}	1.708 ± 0.152	1.837 ± 0.178	2.067 ± 0.205
		R^2	0.972	0.961	0.964
		RMSE	0.063	0.076	0.081
	Pre-treated	k_r	0.016 ± 0.004	0.026 ± 0.004	0.035 ± 0.008
		X_{eq}	1.685 ± 0.200	1.902 ± 0.214	2.350 ± 0.401
		R^2	0.996	0.988	0.989
		RMSE	0.025	0.046	0.055
50°C	Untreated	k_r	0.023 ± 0.002	0.040 ± 0.006	0.050 ± 0.008
		X_{eq}	1.965 ± 0.172	2.094 ± 0.185	2.247 ± 0.309
		R^2	0.992	0.959	0.960
		RMSE	0.042	0.093	0.096
	Pre-treated	k_r	0.020 ± 0.003	0.044 ± 0.010	0.079 ± 0.010
		X_{eq}	1.728 ± 0.161	2.127 ± 0.199	2.437 ± 0.258
		R^2	0.983	0.968	0.978
		RMSE	0.052	0.083	0.075
70°C	Untreated	k_r	0.028 ± 0.010	0.069 ± 0.013	0.085 ± 0.018
		X_{eq}	2.107 ± 0.225	2.529 ± 0.358	2.668 ± 0.407
		R^2	0.976	0.980	0.989
		RMSE	0.082	0.087	0.066
	Pre-treated	k_r	0.031 ± 0.096	0.067 ± 0.010	0.099 ± 0.020
		X_{eq}	1.917 ± 0.201	2.289 ± 0.269	2.729 ± 0.321
		R^2	0.994	0.994	0.993
		RMSE	0.037	0.041	0.054

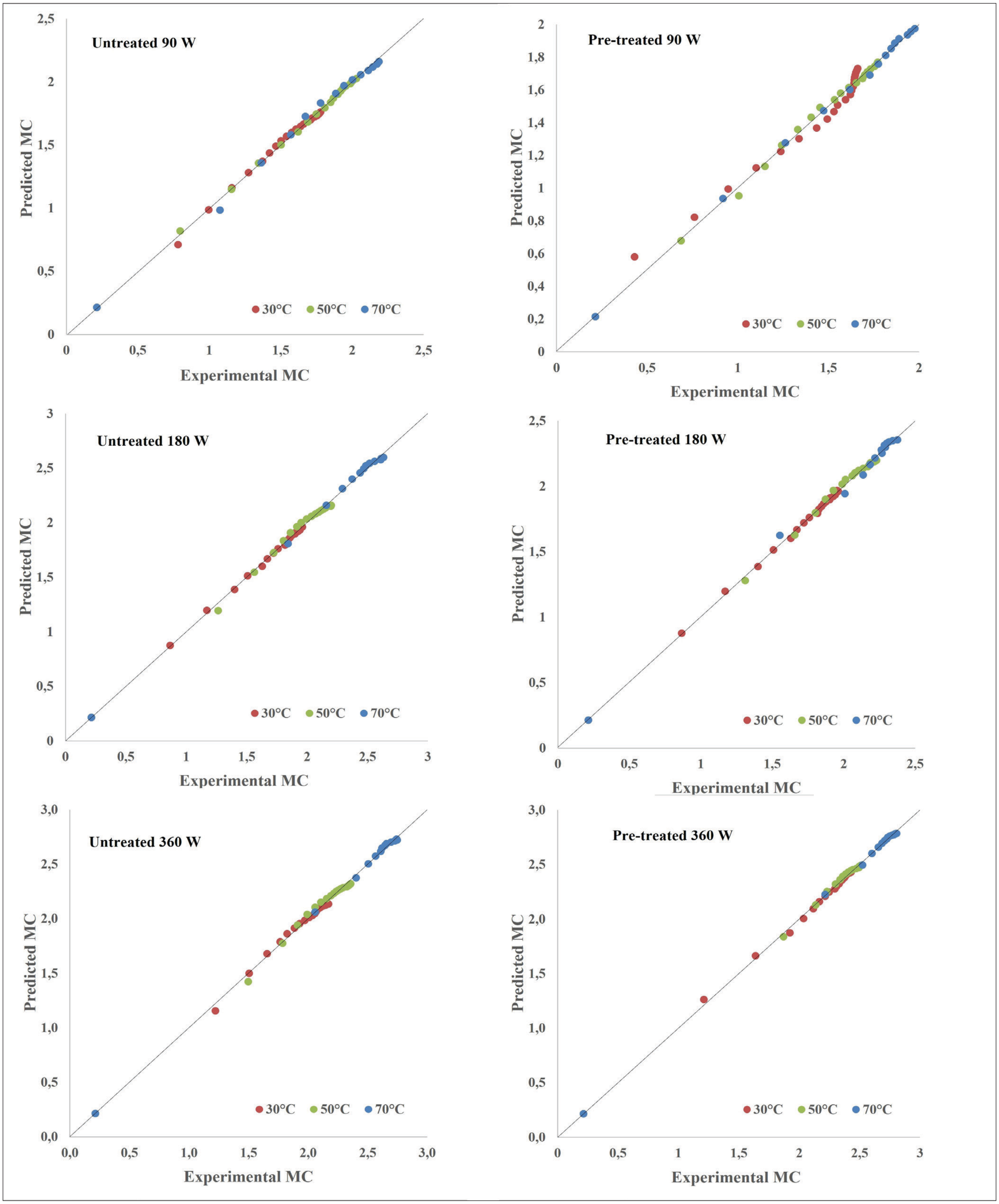

Fig. 2. Correlation between moisture contents predicted in the Peleg model and experimental moisture contents of dried green pea grains at three rehydration temperatures.

Table 3. Activation energies calculated in the rehydration of green pea grains.

Treatment	Power (W)	E_A (kJ/mol)	RMSE	R^2
Untreated	90	10.75±0.29 [a]	0.280	0.978
	180	23.78±0.96 [c]	0.551	0.960
	360	23.34±0.74 [c]	0.296	0.954
Pre-treated	90	17.31±0.25 [b]	0.816	0.955
	180	29.80±0.40 [d]	0.029	0.999
	360	37.39±0.73 [e]	0.078	0.989

activation energies of pre-treated green peas were higher than those of untreated green peas. Higher activation energy implies that rehydration is more sensitive to temperature changes. In other words, the rate of reaction increases with rising temperatures (Dadali et al. 2008). Hence, it can be concluded that rehydration is more sensitive to temperature changes in pre-treated samples. In the interaction where all rehydration processes were collectively evaluated, the differences between the averages of activation energies were found to be statistically significant ($P < 0.05$). While the activation energies of untreated peas dried at 180 and 360 W microwave powers fell into the same group, each of the other averages formed separate groups. Dadali et al. (2008) calculated the activation energy in the rehydration of spinach dried at 360 W microwave power as 23.84 kJ/mol. Doymaz and Kocayigit (2011) found that the activation energy of the peas dried by applying different pre-treatments was between 22.01 and 30.99 kJ/mol. In previous studies where peas were dried and rehydrated under different conditions, the activation energies were found to be 28.40 kJ/mol (Sanjuán et al. 1999), 22.48 kJ/mol (Kostaropoulos and Saravacos 1995), and 43.0 kJ/mol (Resende et al. 2007). The activation energies obtained in this study were close to the values obtained in previous studies.

Color Analysis

Color parameters of untreated dried, pre-treated dried, and fresh green pea grains are given Table 4. After the drying process, L^* and b^* values decreased, while a^* value increased in both pre-treated and untreated pea samples. However, with increasing microwave power, L^* and a^* values increased, while b^* value decreased (Kayisoglu 2020). The changes in color parameters of fresh and dried peas were statistically significant ($P < 0.05$). The dried products exhibited lower L^* values compared to the fresh peas, indicating a darker appearance. However, with increasing microwave power, the drying times decreased, and the L^* values were higher than lower microwave powers. An increase in the a^* value indicated a reduction in the green color, while a decrease in the b^* value with higher microwave power reflected a decline in the yellowish hue. Similar trends were observed by Chahbani et al. (2018) in their study on the drying kinetics of green peas using microwave technology. The relatively high levels of sugars, proteins, and chlorophyll were key contributors to the observed color changes in the dried green peas. The reductions in a^* and b^* values can likely be attributed to the breakdown of chlorophyll and other pigments, such as carotenoids, alongside non-enzymatic reactions (Zielinska et al. 2013).

Table 5 presents the color parameters of fresh and microwave-dried green pea grains following the rehydration process conducted at various temperatures. To analyze the differences in the color parameters of rehydrated peas compared to dried and fresh peas more effectively, total color differences (E) were calculated using Eq. 8 and two-way ANOVA.

Table 4. Color parameters of fresh and microwave dried green pea grains.

Color Parameters	Untreated Dried			
	Fresh	90 W	180 W	360 W
L^*	48.53 ± 3.01 ***a***	22.74 ± 2.55 ***b***	27.42 ± 1.58 ***c***	31.23 ± 1.78 ***d***
a^*	-14.95 ± 0.92 ***a***	-5.90 ± 0.69 ***b***	-3.59 ± 0.69 ***c***	-2.35 ± 0.35 ***d***
b^*	25.31 ± 1.73 ***a***	13.31 ± 1.76 ***b***	8.05 ± 1.05 ***c***	5.79 ± 0.75 ***d***
Color Parameters	**Pre-treated Dried**			
	Fresh	**90 W**	**180 W**	**360 W**
L^*	44.19 ± 1.95 ***a***	20.59 ± 2.48 ***b***	24.4 ± 32.78 ***c***	27.93 ± 3.12 ***d***
a^*	-12.00 ± 0.61 ***a***	-5.04 ± 0.32 ***b***	-3.37 ± 0.63 ***c***	-1.14 ± 0.84 ***d***
b^*	26.19 ± 1.53 ***a***	10.84 ± 1.70 ***b***	6.06 ± 0.87 ***c***	3.05 ± 0.63 ***d***

Total color differences (E) between rehydrated and microwave-dried green pea samples are shown in Fig. 3. No statistically significant difference was observed in the total color difference between untreated and pre-treated peas ($P > 0.05$). However, microwave power and rehydration temperature had a significant impact on the total color difference ($P < 0.05$). As microwave power and rehydration temperature increased, the total color difference decreased. The highest color difference was recorded at 30 W microwave power and a rehydration temperature of 30ºC.

Total color differences (E) between fresh and microwave-dried green pea samples are shown in Fig. 4. There was no statistically significant difference between untreated and pre-treated dried peas in terms of total color difference ($P > 0.05$). Microwave power and rehydration temperature significantly affected the total color difference ($P < 0.05$). The total color difference increased with increasing microwave power and rehydration temperature. The maximum color difference was observed at 360 W microwave power and 70ºC rehydration temperature. In their study on the rehydration of dried mushrooms at different microwave powers, Inla et al. (2023) observed that as the microwave power increased, the total color change after rehydration also increased. This occurs because microwaves disrupt the cell structure and lead to the loss of chemicals and amino acids in the product during drying (Das and Arora 2018).

Table 5. Color parameters of rehydrated green pea grains at various temperatures.

Temp.	Color	Untreated			Pre-treated		
	Param.	90 W	180 W	360 W	90 W	180 W	360 W
30ºC	L^*	40.02 ± 4.50	41.87 ± 1.10	44.21 ± 1.10	37.92 ± 1.00	40.23 ± 1.00	40.81 ± 0.90
	a^*	-11.80 ± 1.40	-10.48 ± 0.40	-9.30 ± 0.30	-9.11 ± 0.30	-7.84 ± 0.30	-6.97 ± 0.40
	b^*	22.62 ± 3.00	18.92 ± 0.50	16.33 ± 0.50	21.33 ± 0.30	17.05 ± 0.50	15.10 ± 0.40
50ºC	L^*	37.06 ± 4.20	39.55 ± 1.10	41.15 ± 1.00	35.26 ± 0.90	36.29 ± 0.90	36.86 ± 0.90
	a^*	-9.68 ± 1.10	-7.57 ± 0.30	-8.20 ± 0.30	-8.46 ± 0.30	-7.11 ± 0.30	-6.63 ± 0.30
	b^*	19.30 ± 2.60	16.15 ± 0.50	14.12 ± 0.40	19.84 ± 0.30	15.23 ± 0.40	13.37 ± 0.40
70ºC	L^*	35.24 ± 4.00	38.26 ± 1.00	39.89 ± 1.00	32.99 ± 0.90	34.71 ± 0.90	35.98 ± 0.80
	a^*	-8.56 ± 1.00	-7.06 ± 0.30	-6.07 ± 0.20	-7.32 ± 0.30	-6.15 ± 0.20	-5.57 ± 0.20
	b^*	17.03 ± 2.30	15.11 ± 0.40	13.02 ± 0.40	17.06 ± 0.20	14.51 ± 0.40	12.50 ± 0.40

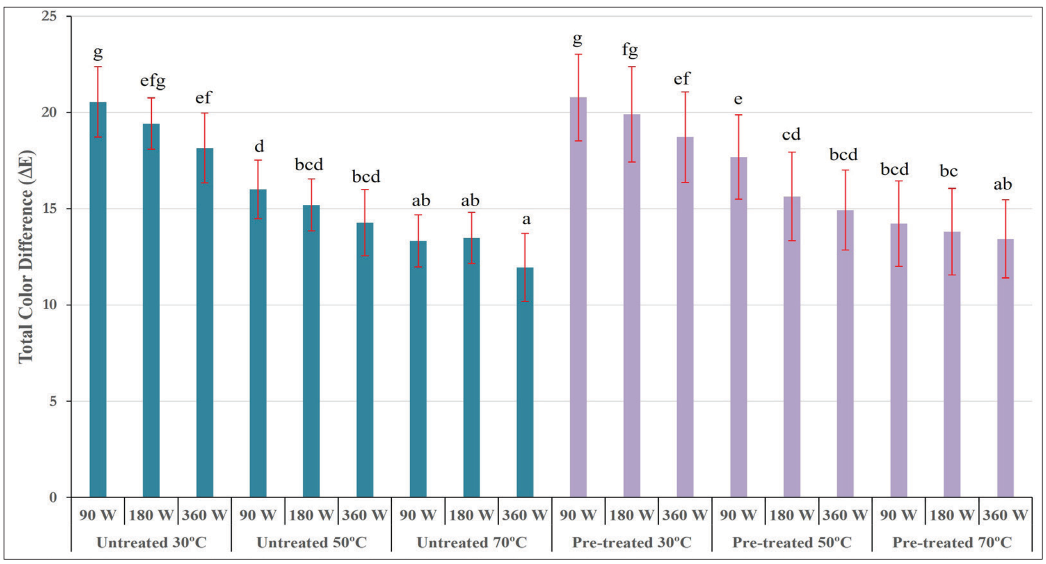

Fig. 3. Total color differences between rehydrated and dried green pea samples.

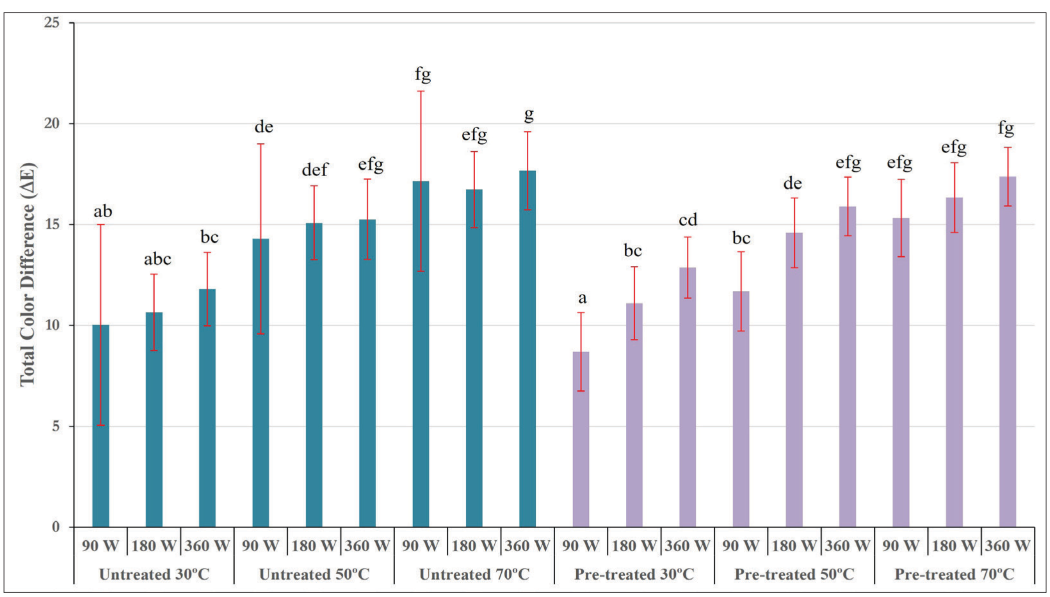

Fig. 4. Total color differences between rehydrated and fresh green pea samples.

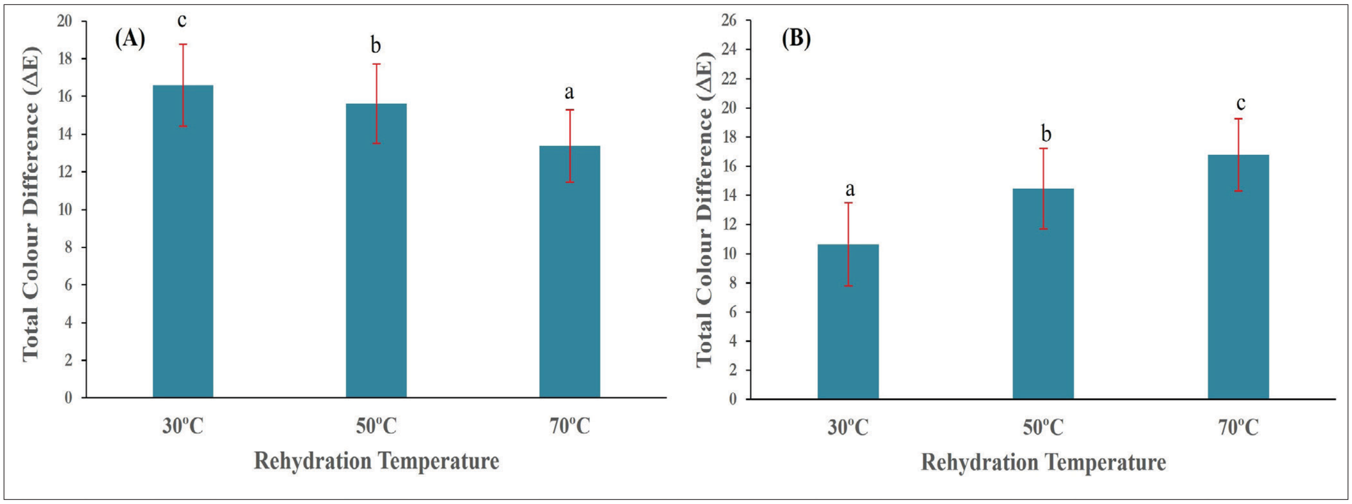

Figure 5. Total color differences (ΔE) according to rehydration temperatures; (A) rehydrated to dried; (B) rehydrated to fresh.

The total color differences of rehydrated green peas compared to dried and fresh green peas, depending on the rehydration temperature, are presented in Fig. 5. The total color differences of rehydrated green peas were statistically significant both with microwave-dried and fresh green peas ($P < 0.05$). As the rehydration temperature increased, the total color difference decreased compared to microwave-dried green peas and increased compared to fresh green peas. In their study on color change kinetics during rehydration, Moreira et al. (2008) found that as the rehydration temperature increased, the total color difference also increased compared to the fresh product.

CONCLUSION

This study investigated the rehydration kinetics and color properties of peas subjected to drying at three different microwave powers and rehydration at three distinct temperatures, with pre-treatment applied to some peas prior to drying. The Peleg model proved to be the most suitable for analyzing rehydration kinetics. Notably, rehydration capacity was significantly impacted by both rehydration temperature and microwave power during the drying process, with higher levels of both leading to increased rehydration capacity. The activation energy of rehydration increased as the microwave power increased. Furthermore, significant differences in color parameters were observed after rehydration, with rehydrated peas exhibiting color characteristics closer to those of fresh peas as microwave power and rehydration temperature decreased. For direct consumption as food, it is recommended to dry green pea grains at 90 W microwave power and rehydrate them at a temperature of 30°C.

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