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Effect of Different Drying Systems on Drying Performance of Maraş Green Pepper (*C.annum*)

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ABSTRACT

Drying is the simultaneous transfer of heat and mass, which is defined as the reduction of moisture in food. The aim of the study the drying performances of refractance window drying (95°C), fluidized bed drying (95°C, $2m^3/m$ air velocity), and convective drying (95°C) were examined in the drying of Maraş green pepper (*C.annuum*). Drying performance was evaluated for effective diffusion coefficient (D_{eff}), activation energy (Ea), Chroma (C) and total color change (ΔE). Drying curves were obtained by recording sample weights in 10-min periods. For the refractance window drying, fluidized bed drying and convective drying the time for the samples to reach 6-7% humidity level according to the wet base was found to be 70, 80 and 110min, and the effective diffusion coefficient was $6.49x10^{-10}$, $5.68x10^{-10}$ and $4.87x10^{-10}$ m^2/s the activation energy was 53.54, 54.65 and 55.93kJ/mol, respectively. When the color properties are examined the Chroma value was determined as 18.23, 8.85 and 4.80 and the total color as 15.42, 26.29 and 30.33, respectively. It was seen that the closest value to the fresh product was in the samples dried with a refractance window drying. In the study, it was concluded that the use of a refractance window drying shortened the drying time by 14-36%, increased the effective diffusion coefficient, provided drying with lower activation energy, and better preserved the color quality in the production of dried Maraş green pepper.

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Introduction

Our country, Türkiye, is one of the rare countries where fruits and vegetables can be grown in good conditions and with high quality due to agricultural areas suitable for production, geographical location and ecological suitability. Maraş green pepper *(C.annum),* which has rich vitamin and mineral content, has a wide cultivation area in Gaziantep, Kahramanmaraş and Kilis regions. In addition to consuming fresh, it is consumed in the form of pickles, roasted products, frozen products, and powdered/chili powder as processed and dried. However, high moisture shortens the shelf life of the product after harvest and causes a decrease in product quality during storage. This situation limits the fresh consumption of Maraş green pepper. Various preservation methods are available to increase the durability of foods. Methods such as canning, vacuuming, brining, and freezing are frequently used, and drying is the most preferred. It is preferred in the food industry because it reduces packaging and transportation costs by providing long storage time, decrease in storage and reduction in volume (Zhang et al., 2017). The appropriate drying method, especially for sensitive biological products such as green pepper, is important for both the quality of the dried product and the expenses of the process (Mahanti et al., 2021). Vacuum-assisted microwave drying (Kumar et al., 2019; Kumar and Shrivastava, 2017), heat pump-assisted fluidized bed drying (Jafari et al., 2016), IR-assisted spouted bed dryer (Moradi et al., 2020) and osmotic drying (Odewole et al., 2016) are recent studies on green pepper. No study was found on Maraş green pepper in the literature review.

In this study, Maraş green pepper was evaluated in terms of the drying performances of refractance window drying, fluidized bed drying and convective drying, comparatively. Drying performance success was evaluated by effective diffusion coefficient, activation energy, Chroma and total color value.

Materials and Methods

Maraş green pepper samples were obtained from the local market in Kahramanmaraş. The samples were washed, separated from their stems and seeds, cut into 1x1cm in equal weights and kept at +4°C until analysis time.

Method

Pioneer brand Ohaus model analytical balance was used for weighing. Sample weights were recorded at 10-minute intervals and drying curves were obtained.

Drying Experiments

Refractance Window Drying

A pilot scale refractance window drying (RWD) was used in this study. The dryer was manufactured by Inova Kontrol Sistem Makine San. Tic. Ltd. Sti. in Türkiye. The dryer has an effective drying area of 0.6m^2, a cooling area of 0.24m^2 and a total length of 1.6m in the direction of belt movement. It also includes 3 outlet fans, a heater and 50µm thick Mylar film. The hot water bath was controlled with a thermocouple temperature sensor with a measuring range of -30°C to 105°C. Drying trials were carried out by spreading the samples evenly on the conveyor belt moving on the hot water surface at 95ºC.

Fluidized Bed Drying

Lab scale Sherwood brand M501 model was used for fluidized bed drying (FBD). 250 ml tubes were used for each sample. Drying experiments were carried out at 95°C and an air velocity of 2m^3/m. The weighed samples were placed in the dryer chamber and dried.

Convective Drying

Lab scale Heraeus brand T6 model tray convection was used for convection drying (CD) experiments. Drying was carried out at 95ºC. Drying continued until the difference between measurements was less than 1%.

Determination of Moisture Content and Drying Rate

Moisture content of the samples during drying was calculated with Equation 1 according to the wet basis (Rurush et al., 2021):

$$MR = \frac{(M-Me)}{(M0-Me)} \qquad (1)$$

where MR: Moisture ratio, M: Moisture content (kg water/kg dry matter), M$_e$: Equilibrium moisture content of the air in drying conditions (kg water/kg dry matter), M$_0$: Initial moisture content of the product (kg water/kg dry matter).

Drying rate is defined as the change in moisture content in the dried product per unit time. It is calculated using Equation 2 (Wang et al., 2020):

$$DR = \frac{Mt_1-Mt_2}{t_2-t_1} \qquad (2)$$

where DR: Drying rate, M$_{t1}$ and M$_{t2}$: Moisture content at t$_1$ and t$_2$, respectively, t$_1$ and t$_2$: Drying time (m).

Determination of Effective Diffusion Coefficient and Activation Energy

The effective diffusion coefficient D$_{eff}$ (m^2/s), is related to the convection of moisture lost by the dried food (Kılıç and Calam, 2020). Liquid and/or gas diffusion is considered to be the main mechanism in the decreasing rate period in the drying of food. It is represented by Fick's 2nd law and calculated according to Equation 3 (Pekdoğan-Göztok and İçier, 2017):

$$MR = \frac{M_t-M_e}{M_0-M_e} = \frac{8}{\pi^2}\sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} exp\ (\frac{-(2n+1)^2\pi^2 D_{eff}t}{4L^2}) (3)$$

where D$_{eff}$: Effective diffusion coefficient (m^2/s), L: Half thickness (m) of the product. For long periods, taking the first term is considered sufficient. It is shown in Equation 4:

$$MR = \frac{8}{\pi^2} exp\ (-\frac{\pi^2 D_{eff}t}{4L^2}) \qquad (4)$$

D$_{eff}$ value, the variation of the ln(MR) values over time was plotted graphically, and the slopes (k) of the obtained lines and the D$_{eff}$ values were calculated according to Equation 5 (Ergüneş and Taşova, 2018):

$$k = \frac{\pi^2 D_{eff}t}{4L^2} \qquad (5)$$

The change in the effective diffusion of the product depending on the temperature is explained by Equation 6 using the Arrhenius equation (Rurush et al., 2022):

$$D_{eff} = D_0\ exp\ (-\frac{Ea}{RT}) \qquad (6)$$

where D$_0$: Diffusion coefficient (m^2/s), R: Gas constant (8.3143 kJ/molK), Ea: Activation energy (kJ/mol) and T: Drying temperature (K°).

The activation energy (Ea) and the effective diffusion (D$_{eff}$) were valued mathematically, a line graph was created against the 1/T values. The activation energy value was calculated from the slope value of the obtained line (Rurush et al., 2021).

Determination of Total Color and Chroma value

Color measurements of the dried samples were taken at certain periods in the study, Hunter Lab brand Color the Flex model was determined using a colorimeter. The measurement point of the samples was randomly selected and repeated in three parallel ways. L* value was defined as lightness/darkness, a* value as redness/greenness, and b* value as yellowness/blueness. Chroma (C) value, which defines the total color difference (ΔE) and color saturation between fresh and dried samples, was calculated according to Equation 7-8 (Yu et al, 2022):

$$\Delta E = \sqrt{(a_1^*\_a^*)^2 + (b_1^* - b^*)^2 + (L_1^* - L^*)^2} \qquad (7)$$

$$C = \sqrt{a^{*2} + b^{*2}} \qquad (8)$$

where a_1^*, b_1^*, L_1^*: The redness/greenness, yellowness/blueness and lightness/darkness values of fresh sample, respectively, a^*, b^*, L^*: The redness/greenness, yellowness/blueness and lightness/darkness values of dried sample, respectively.

Statistical Analysis

The effect of drying systems on drying time, drying rate and color properties of the samples was evaluated by applying a two-way analysis of variance at a 95% confidence interval with the SPSS Production Facility package program.

Results and Discussion

Drying is a thermodynamic process that provides mass and heat transfer simultaneously. Today consumers are turning to minimally processed foods and the demand for dried foods is increasing with the changing dietary habits (Kheto et al., 2021). Therefore, it is important to determine the optimum drying conditions for the food industries. In drying experiments fresh Maraş green pepper was dried until the final moisture content was 7.40 ±0.1% (Devi et al., 2021; Kheto et al., 2021; Kumar and Shrivastava, 2017). Drying performances of Maraş green pepper were investigated at 95°C with RWD, FBD (2m^3/m) and CD. The drying times of dried peppers in different drying systems are shown in Table 1. Drying times for RWD, FBD and CD were recorded as 70, 80 and 110min, respectively. It was determined that RWD had 14 and 36% less drying time than FBD and CD, respectively. However, drying rates and drying times were not found statistically significant in the two-way analysis of variance ($p>0.05$).

In the literature Rajoriya et al. (2019) stated that in dried apple slices, RWD had a higher drying rate and 25–37.5% less drying time than CD. Das et al. (2020) stated that the drying time of FBD is 2 times faster than CD in drying paddy. Rurush et al (2021) and Franco et al. (2019) concluded that RWD is a more economical and faster method for drying fruit and vegetables. The results are in agreement with the literature.

Moisture rates and drying rates of pepper samples were calculated using Equation 1 and Equation 2. The variation of the moisture content of the dried samples depending on the drying time is given in Figure 1, and the variation of the drying rate with the moisture content is given in Figure 2.

Due to the high moisture content of the samples, the drying rate increased initially, but the increased slope decreased as the moisture content decreased. There was no constant rate period during drying and drying took place in a decreasing rate period (Kumar and Shrivastava, 2017; Uddin et al., 2016).

Considering the results, the moisture content decreased as the drying time increased. RWD had a higher drying rate and reached final moisture content faster than FBD and CD. Calderon-Chiu et al. (2020) stated that drying with radiant heat transfer is faster at the beginning, but as the moisture content decreases, the angle of reflection decreases and the transition becomes more difficult in RWD. And it has been reported that residual moisture evaporated by conductive heat transfer, thus leading to a lower moisture content in a shorter time. Purple yam (Santos et al., 2022) in RWD, tomato (Castoldi et al., 2015), corn (Alonso and Picado, 2021) and pumpkin (Mujaffar and Ramsumair, 2019) in FBD, persimmon (Jia et al., 2019) and sweet potato (Onwude et al., 2019) in CD was founded in literature. The results are in agreement with the literature.

The effective diffusion coefficient is a kinetic parameter that describes the movement of moisture velocity in the drying of foods. It refers to the effect of heat and mass transfer on food during the drying process (Khan et al., 2017). In the study, the effective diffusion coefficient of dried Maraş green pepper in different drying systems was calculated by using Equation 6 and shown in Table 2. The effective diffusion coefficients for RWD, FBD and CD were determined as 6.49×10^{-10}, 5.68×10^{-10} and 4.87×10^{-10} m^2/s, respectively. It has been determined that the effective diffusion coefficients are in the range of 10^{-12} to 10^{-8} m^2/s determined for food products in the literature (Doymaz and Aktaş, 2018).

When the results were examined, it was seen that the effective diffusion coefficient of the dried samples in RWD was greater than FBD and CD. It was concluded that drying in RWD evaporated the moisture in the pepper more easily and quickly, and the increase in moisture diffusion rate was due to the increase in drying rate. In the literature, Rajoriya et al. (2019) stated that the effective diffusion coefficient value of RWD is higher than CD. In addition, it was reported that conductive and radiant heat transfer increased the water vapor pressure in the pores of the food and caused a change in the cellular structure. Thus it was concluded that more homogeneous diffusion is achieved in the tissue and water molecules move faster by shortening drying. Comparing to RWD and CD, Franco et al. (2019) and Rajoriya et al. (2019) measured the D_{eff} values for dried apple slices as $2.88\text{-}15.30\times10^{-10}$ - $0.14\text{-}3.01\times10^{-10}$ and $2.50\text{-}7.14\times10^{-10}$ - $1.20\text{-}2.17\times10^{-10}$, respectively.

Table 1. Drying times of dried Maraş green pepper samples in different drying systems

Drying System	T (°C)	Drying time (m)
RWD	95°C	70
FBD	95°C, 2m^3/m	80
CD	95°C	110

Table 2. Effective diffusion coefficient and activation energy values of dried Maraş green pepper in different drying systems

Drying System	T (°C)	Def (m^2/s)	Ea (kJ/mol)
RWD	95°C	$6.49\text{x}10^{-10}$	53.54
FBD	95°C, 2m^3/m	$5.68\text{x}10^{-10}$	54.65
CD	95°C	$4.87\text{x}10^{-10}$	55.93

Table 3. L*, a*, b*, ΔE and C values of dried Maraş green pepper in different drying systems

Drying System	L*	a*	b*	ΔE	C
Fresh	28.07	- 7.34	28.24	-	29.18
RWD	22.76	1.9	18.01	15.42	18.11
FBD	13.6	2.36	8.53	26.29	8.85
CD	9.57	1.52	4.56	30.33	4.80

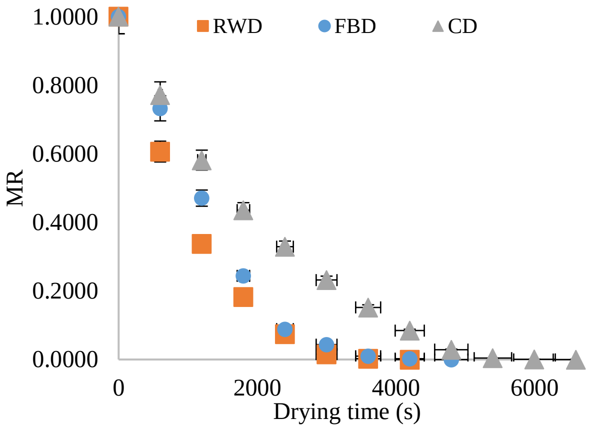

Figure 1. Variation of moisture ratio with a drying time of Maraş green pepper samples on different drying systems

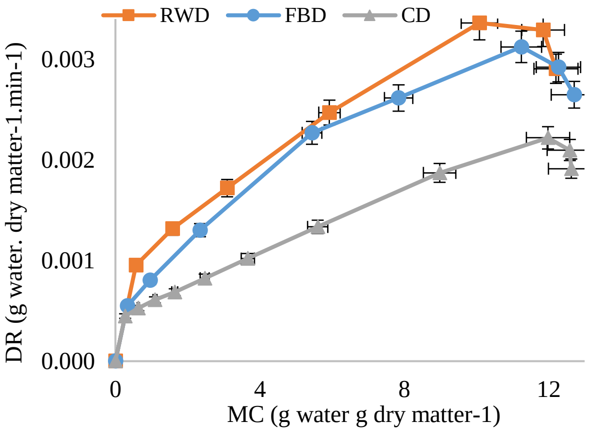

Figure 2. Variation of drying rate with the moisture content of Maraş green pepper samples on different drying systems

Compared to FBD and CD, Walde et al. (2006) found it to be 1.33×10^{-6} and 1.21×10^{-6} in mushrooms, respectively. It was also reported that the D_{eff} value is lower because the drying time is longer in CD. It was measured as $0.114–6.86\times10^{-10}$ for green chilies in CD (Kheto et al., 2021), $1.95\text{-}7.0\times10^{-11}$ for green pepper (Srinivasakannan and Balasubramanian, 2009), and $4.68\text{-}18.63\times10^{-10}$ for pumpkin (Mujaffar and Ramsumair, 2019) in FBD. It was concluded that the main factor controlling the drying process in RWD is water content rather than food structure (Franco et al., 2019). The observed findings are in agreement with the literature.

The minimum energy required to start the drying process is called the activation energy. It is used to describe the internal behavior of dried food (Çelen and Moralar, 2020). In the study, activation energy values of pepper samples dried in RWD, FBD and CD were measured. Activation energy values were calculated by using the linear equations of the graph drawn against 1/(T+273.15) after the ln value of the effective diffusion (D_{eff}) value given in Equation 6. The effect of temperature on activation energy values for samples dried in RWD, FBD and CD is shown in Equations 9, 10 and 11, respectively.

In samples dried in a refractance window drying;

$$Deff = exp\left(-\frac{6440}{(T+273{,}15)}\right) + 2{,}59x10^{-2} \qquad (9)$$

In the samples dried in a fluidized bed drying;

$$Deff = exp\left(-\frac{6574}{(T+273{,}15)}\right) + 3{,}26x10^{-2} \qquad (10)$$

In the samples dried in the convective drying;

$$Deff = exp\left(-\frac{6728}{(T+273{,}15)}\right) + 4{,}24x10^{-2} \qquad (11)$$

The activation energy was calculated by Equations 9, 10 and 11 for dried samples in RWD, FBD and CD as 53.54, 54.65 and 55.93kJ/mol, respectively. The activation energy values of the results obtained were found to be in the range of 12.7-110 kJ/mol, which was determined in the literature for foods (Macedo et al., 2020). In the study it was determined that the activation energy values of dried peppers in RWD were lower than the other methods, therefore less energy was required for drying (Doymaz and İsmail, 2010). In the literature, the Ea values were calculated as 49.43-52.57kJ/mol for turmeric (Talukdar et al., 2021) and 41.3-31.1 kJ/mol for goldenberry (Puente - Diaz et al, 2020) in RWD, 43.9kJ/mol for dried pumpkin in FBD (Mujaffar and Ramsumair, 2019) and 47.10 kJ/mol for green pepper (Faustino et al., 2007) in CD. The findings agree with the literature.

Color is an important parameter to increase the acceptability of processed products for consumers. It is accepted as an indicator of the nutritional content and storage time of food products. It varies depending on drying methods and drying conditions, especially in dried fruits and vegetables. (Zalpouri et al., 2022). In the study color values of dried pepper samples were measured in RWD, FBD and CD. The effect of different drying systems on color values was determined by L*, a* and b* values. The color values of L*, a*, b*, ΔE and C of dried pepper samples are shown in Figure 2. Compared to the fresh sample L* and b* values were lower and the* value was higher for dried samples in RWD, FBD and CD. The highest L* value was measured in RWD and the lowest L* value was measured in CD. The* value, known as greenness/redness, was found to be the lowest in CD and the highest in FBD. The b* value of dried samples, known as yellowness/blueness, in the drying systems was lower than a fresh sample. The highest b* value was in RWD while the lowest b* value was in CD. In the two-way analysis of variance L* and b* values were statistically significant ($p<0.05$), but it was not significant a* values ($p>0.05$). Hernández-Santos et al (2016) reported that color values were better preserved on carrot slices in RWD than CD. Tontul et al. (2018) observed better-colored dried cornelian cherry pulp in RWD, with 4-12% higher L* and C values than CD.

The total color value (ΔE) defines the difference between the color characteristics in fresh and dried food. The lower the ΔE value, the less the change in the color of the food, so the brightness of the dried food is at the preferred level. If the ΔE value is low it indicates that the change in the color of food is less, therefore the brightness of dried food is at the preferred level. The ΔE values of dried samples were calculated by Equation 7 and recorded as 15.42, 26.29 and 30.33 in RWD, FBE and CD, respectively (Table 3). Pigment degradation and browning reaction occurred and the ΔE value increased in dried samples. (Shende and Datta, 2019), It was observed that the highest value was in CD and the lowest value was in RWD. In addition, the color change of the dried samples in FBD and CD was 1.7 and 1.9 times more than in RWD, the closest value to the fresh sample was also seen in RWD. In the two-way analysis of variance ΔE values were found to be statistically significant ($p<0.05$). In the literature, the color change of goldenberry (Puente-Diaz et al., 2020), apple (Baeghbali and Niakousari, 2018) and kiwifruit (Jafari et al., 2016) were investigated. RWD is closer to the fresh sample and has less color variation than CD. Jafari et al. (2016) reported that the RWD drying time is shorter, thus lower ΔE values are obtained and undesirable pigment formation is reduced. Zalpouri et al. (2022) concluded that reduced unwanted color changes by using RWD.

The Chroma (C) value is defined as color saturation. It is a color parameter that determines the quality of light (Padhi et al., 2022). C values were calculated by Equation 8 and resulted in 29.18, 18.23, 8.85 and 4.80 for fresh, RWD, FBD and CD, respectively (Table 3). The highest value was observed in RWD, and the lowest value in CD. The values closest to the fresh sample were determined to be in RWD. In the two-way analysis of variance C values were found to be statistically significant ($p<0.05$). In the literature, Shrivastas et al., (2021) stated that the C value of the dried strawberry puree decreased from 33.81 to 19.79 in RWD, and the color intensity of the dried product was less than fresh. Hernández-Santos et al (2016) showed that the angle of refraction decreases as the moisture content of the food decreases, thus preventing undesirable color changes and color intensity in the RWD.

Conclusion

Fruit and vegetable products are very sensitive to the drying process due to their structure. Maraş green pepper (*C.annuum*) needs alternative preservation techniques due to its limited harvest time and prone to spoilage. Valuation of Maraş green pepper in the industry will enable it to be transformed into products with long shelf life and boost value. Drying is the most preferred preservation method in the industry. The appropriate drying process is important in terms of economic and product quality.

In this study drying performances of Maraş green pepper were investigated comparatively in RWD, FBD and CD. The time to reach 7.40±0.1% drying rate in the dried Maraş green pepper was determined as 70, 80 and 110 minutes for RWD, FBD and CD, respectively ($p<5.05$). The highest D_{eff} and lowest Ea values were found in RWD. The increase in ΔE value was measured to be higher in FBD and CD than in RWD ($p<5.05$). Compared to the fresh sample, the C value decreased by 37% in RWD, 69% in FBD and 83% in CD ($p<5.05$). The use of RWD is thought to be a good drying alternative for Maraş green pepper.

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