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Mathematical modelling of greenhouse drying of red chilli pepper

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The purpose of this study was to examine twelve different mathematical models for red pepper plant (*Capsicum annum* L.) and to investigate the appropriate models of mass fraction (Mt / Mo) in relation to drying time.This study attempted to assess the efficiency and profitability of the drying of red pepper under the plastic tunnel greenhouse and a total of twelve models, including Newton, Page, Improved Page, Henderson and Pabis, Logarithmic, Wang and Singh, Diffusion, Two-Term Exponentia, Two-Term, and Simplified Fick Diffusion, were evaluated. The drying process was carried out in three different periods. During each application period, separate drying experiments were carried out for the product densities of 2, 3, 4, and 5 kg/m^2. The data obtained in the experiments were compared with the values found in the twelve different separable moisture content models in the literature and the most suitable model was determined by evaluating the expression coefficient (R^2), the sum of the squares of the residuals (RSS) and the estimated standard error (SEE). The best values were obtained in the first period when drying tests were carried out at a product density of 5 kg/m^2. According to statistical analysis results obtained using mathematical models, it was determined that the most appropriate mathematical model with the highest expression coefficient (R^2) was the Two-Term model given an equality of (Mt / Mo) = a exp ($-k_1$t) + bexp ($-k_2$t). When the coefficients of model, model coefficients and calculated values were compared with experimental data, the highest expression coefficient was obtained with Two-Term model and was at 0.9886-0.9977 level. This suggested that the model experiment could be used in practice for estimating conditions.

Key words: Red pepper, drying, greenhouse type dryer, mathematical model.

INTRODUCTION

In large scale, dried agricultural products in our country are known to be found in medical and aromatic products besides apricot, grape, fig and tea which have an export potential (Öztekin and Soysal, 2000). An essential product in massive drying in aromatic products is spice red pepper (*Capsicum annum* L.).

The production of red pepper spice is mainly concentrated in the Southeastern Anatolia Region, and

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the consumption is mostly the inner market-oriented. The spicy red pepper is not nearly as cheap to sell as the outside because the product does not comply with relevant norms in terms of food safety and quality. The first applied processing material is dried entirely in the sun without pulling the handle due to the high humidity of pepper cultivated by hand in the production of spice red pepper (>80%). Dried red pepper with stalked does not comply with food safety and quality norms due to the known negativities of diseases and other product pests such as such as moldly mildew that has been dried asphalt or soil on the ground. Moreover, the cost of red berry produced in our country as a spice is about 4 times more than that of competing countries in the world market. In that case, red flake or powdered pepper is costly in our country, and it has various doubts in its quality. More importantly, the traceability of the red pepper spice, which is at risk for health, becomes completely impossible if used in food products such as sausages, prepared soups, sauces, etc. In the last decade, especially in the Southeastern Anatolia region, serious efforts have been made to replace the wrong habits of producers and industrialists with research and development studies for the solution of these problems (Işıkber et al., 2003; Soysal et al., 2005a, b; Öztekin et al., 2005, 2006a, b; Duman et al., 2007a, b; Işıkber et al., 2007). Today, it is observed that the producers are gradually abandoning their drying habits of fresh harvested red pepper directly on the soil or asphalt pavement. Whether it is research studies or the efforts of publishers, red pepper is laid on net or plastic mesh 40-50 cm high from the ground. This is undoubtedly a positive development. However, even if the product is higher than the ground, it is still threatened by illness and harmful elements in the external environment. These factors are also effective in the storage process since no sterilization is performed in the product processing stage. The main aim should then be to dry the product in an environment isolated from external factors while keeping operating costs at a minimum. Drying in the industrial production of spice red pepper is usually provided by hot air in belt dryers. However, it is known that both the investment and operating costs of this process are high. It is expected that the use of solar energy in drying will be positively affected because the Southeastern Anatolian region will be beneficial in sunbelt and is advantage of sunbathing, also the drying season of agricultural products is encountered during periods when solar energy is intense (Ergüneş and Gerçekçioglu, 1999). On the other hand, when the pepper harvest season is sufficiently available in the summer months, the potential of solar energy makes it possible to do drying process. The basic design of this work is to make the drying of the sunshine, which the manufacturer has already done in the outdoor environment, take a closed and controlled environment to make drying faster and cleaner. Here, besides the selection of the energy source as the sun, another important point is the drying area. One of the drying systems that can be built with the local facilities used to produce cleaner products at the manufacturer level is the greenhouse. It is known in the literature that the researches have concentrated upon with lab-scale greenhouse type dryers because of their ease of application. However, adapting the results obtained on a small scale to the enterprise scale may not always give the expected results. A greenhouse drying system designed at the plant scale was also tested by Finkelman et al. (2006) in the process of drying date palm fruit. One of the original aspects of this study is that they do not approach the researchers as mere drying, but have examined the effects of temperature elevation in the drying environment on the different developmental stages of *Carpophilus hemipterus*, an important storage pest in the world. With the application of drying and disinfection, it was proved that this harmful completely destroyed larvae, pupae and adults at temperature of 55°C. At this temperature level, the harmful fruit is forced out of the fruit and dies in the outside environment. This is a very positive effect in terms of storage of the date palm without insect remains. In that case, red pepper can still be removed from storage pests while still on the manufacturer's hand. Although spicy red pepper is only due to aflatoxin problem in our country, it is known to be under serious threat of *Plodia interpunctella* and *Lasioderma serricorne* pests in Southeastern Anatolia region (Işıkber et al., 2008). In this study, a dryer with a polyethylene high tunnel greenhouse type shelf was used in order to dry spicy red pepper which is produced intensively in the province of Kahramanmaraş.

MATERIALS

This study aimed to dry *Sena* type of red pepper (*C. annuum* L.) with a solar greenhouse type dryer in Kahramanmaraş province conditions. The greenhouse used in drying process was a high plastic tunnel type drier module, which was designed and manufactured by TARTES (www.tartes.com.tr). This structure was 8 × 6 × 2.86 m in size and was connected to a solar collecting chamber measuring 6 × 6 m on the northern edge. In order to achieve this forced convection, a compartmentalized Alfan fan (2007) with a maximum airflow of 8500 m^3/h was installed on the high-plastic tunnel entrance door in 0.3675 kW of power and 0.98 × 0.95 m of dimensions (Figure 1).

The product was dried on top of shelves in a drying tunnel located in the middle of the high plastic tunnel. For the drying process, five shelves 2.5 × 1 m in size were placed on a shelf with a vertical spacing of 0.30 m (Figure 2). Fresh material was dried on a plastic fly screen stretched to the rack frame. In the open-air control drying experiments, thin-wire sieve-covered drying stands, which were manufactured from wood material, with a height of 0.50 m and dimensions of 2.50 × 1 m were used. In the experiments carried out in 2008, the first crushed red pepper was harvested in August and the second crushed in September.

METHODS

During the drying process, the temperature and relative humidity

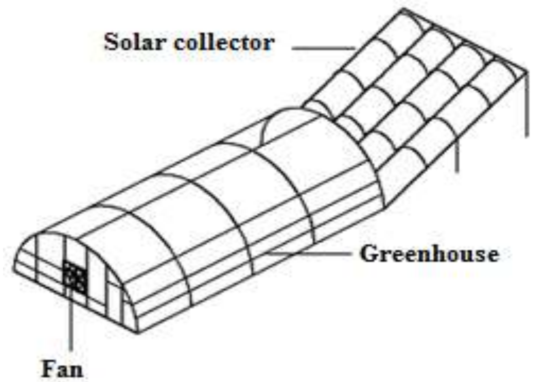

Figure 1. Solar greenhouse type dryer.

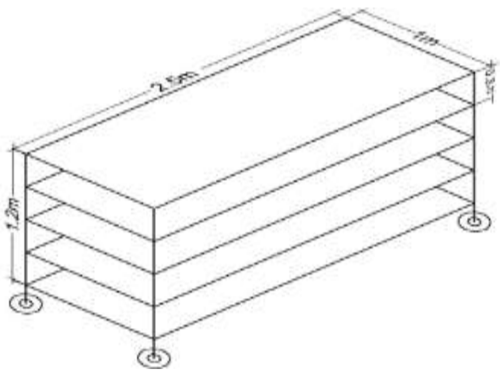

Figure 2. Product drying shelves.

values in the outdoor and in the solar greenhouse dryer were recorded with portable data measuring and recording systems (Sensitivity: 0.6°C temperature and 0.5% relative humidity, Software: Box Car Pro 3.7). The initial moisture contents of three 20 g products were determined by the oven method (24 h at 105°C) to determine the initial temperature prior to drying process. Sartorious BL 15005 digital scale, which can measure at a sensitivity of ± 0.01 g, was used in the weighing process. The following equation was used to determine the percent mass changes of dried red pepper samples.

$$m_y = \frac{m_o - m_t}{m_o} * 100 \quad (1)$$

where m_y = Percent mass changes of dried red pepper samples (%), m_0 = Mass of the samples before drying (g), and m_t = Mass of samples during weighing during drying (g).

The experiments were carried out using triplicate and randomized plot design. Percent mass change data was used as a dependent variable in the analysis of variance to determine the effects of drying conditions on drying of products. Analysis of variance was made with the help of SPSS 13.0 statistical program. Minolta Spectrometer (Minolta CR-100) was used to measure the color of fresh and dried products. In order to determine the color changes in fresh and drier dried products, color measurements were made in 20 fresh products and 3 repeated ones in dried products used in each experiment. The measurements were made in the L* a* b* mode at C position of the device. During color measurements, product color change was also observed and recorded. The Lab scale has a vertical L* axis brightness value that varies from black to white, and can range from 0 to 100 depending on the measured color (Soysal, 2000). When the a* axis value on the color space has a positive value, the measured color is red. On the other hand, it is green when it has a negative value. Likewise, when the b×axis has positive value, the measured color is yellow and when it is negative value it is blue. The metric color tone (α; hue) was calculated from the following equation based on a* and b* values:

$$\alpha = \arctan \frac{b*}{a*} \quad (2)$$

C* is a dimensionless value that specifies the metric chroma and can range from 0 to 60. The metric color chroma was also calculated from the following equation based on the a* and b* values:

$$C* = \sqrt{a*^2 + b*^2} \quad (3)$$

Dried red peppers were washed, then stalked and separated into two, rather than whole, as opposed to the drying method common in practice, and dried after the seed house was removed. In the Southeastern Anatolia Region, red pepper varieties which are rich in spicy red pepper production are preferred by spice industrialists because they appeal more to consumer taste. Thick fleshy red pepper varieties can be marketed more easily and at a higher price if the manufacturer does not entirely remove the stalk and after the seed nest is removed and dried neatly. The thickness of the flesh of the two varieties of *Sena* type red pepper registered in the Southeastern Anatolia Region varies between 1.4 and 1.8 mm and 1.2 and 1.4 mm in Kahramanmaraş (Arpacı et al., 2008). No research has been done on the effect of fruit flesh thickness on drying in spicy red pepper. However, thick fleshy red pepper is expected to dry out later. In order to compare red peppers dried in a greenhouse type dryer, the same amount of product was laid outdoors on a drying rack under direct sun and at a height of 50 cm from the ground. In the experiments, drying time and color measurements were made and temperature, relative humidity, wind speed, and radiation values were also recorded. During the drying process, reductions in product mass were measured 2 to 3 h due to the long drying process. The drying process operation was continued until the mass of the product in each shelf was reduced by about 1/5.

RESULTS AND DISCUSSION

Red pepper drying applications in high plastic tunnel type dryer were made in three periods. The first semester was held on 21-29.08.2008, the second semester was held on 09-16.09.2008 and the third semester was held on 01-07.09.2009. During each implementation period, separate drying experiments were carried out for the product densities of 2, 3, 4, and 5 kg/m^2. Only natural radiation was used in the frist two periods and an additional electric heater in the third period was used in the high plastic tunnel. The best values were obtained in the first period in which drying tests were carried out at a product density of 5 kg/m^2.

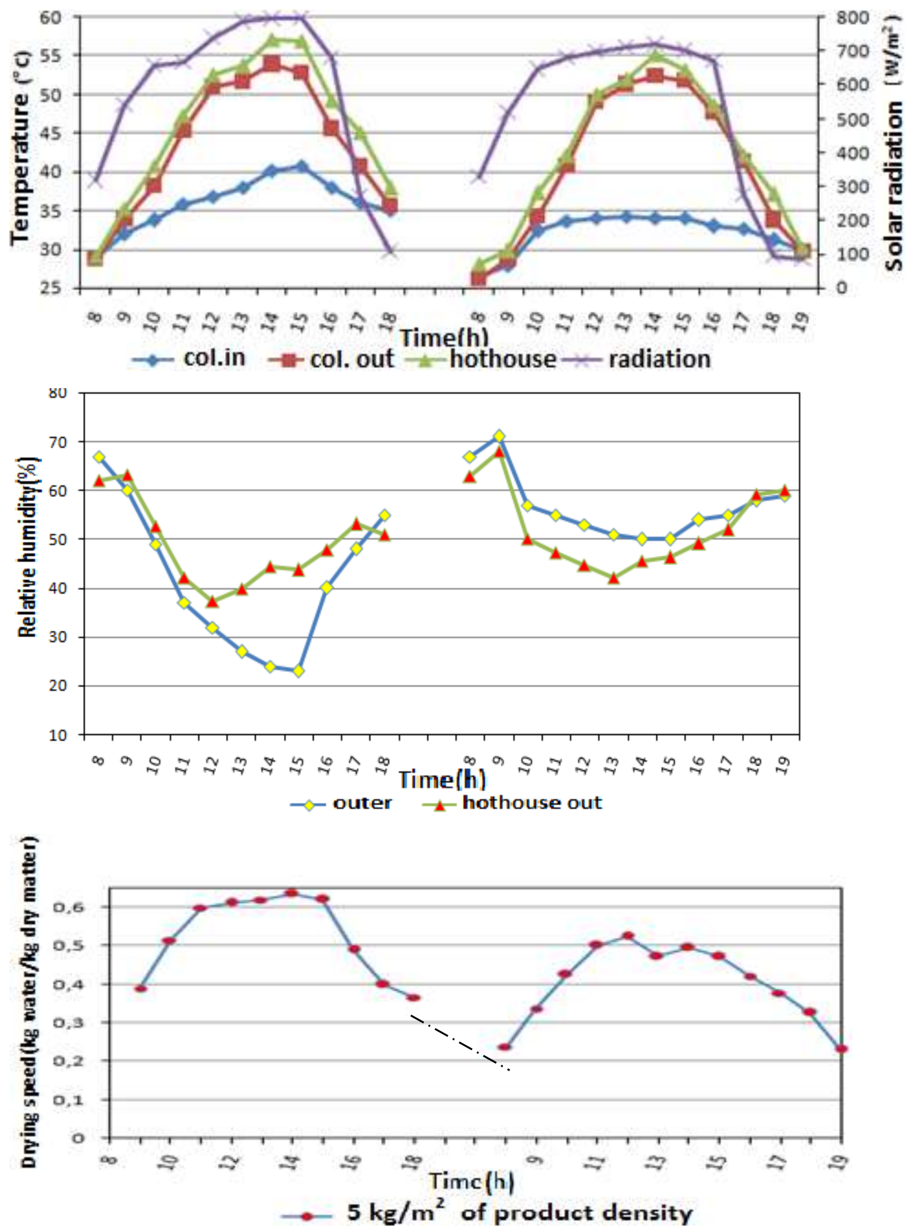

Figure 3. Experimental temperature, solar radiation, relative humidity, drying rate and product humidity values for the product density of 5 kg/m^2 in the first period.

Drying test in 5 kg/m^2 product density in the first period

In the first period, it was determined that the solar radiation values in the experiment of product density of 5 kg/m^2 were changed between 318.1 and 798.3 W/m^2. It was also determined that the temperature difference between the inlet and outlet temperatures of the heat collecting unit changed between10 and 20°C again (Figure 3). In this experiment, the temperature value at the exit of the heat collection unit (at the entrance of the plastic tunnel) varied between 26.2 and 53.9°C. The temperature in the plastic tunnel was measured as 28.1°C and the highest as 57.4°C. The relative humidity measured at the exit of the plastic tunnel was 60 to 65% on the first day and 65 to 70% on the second day in the morning hours and 35 to 40% on the first day and 40-45% on the second day at noon. Relative humidity increased again in the evening hours, reaching around 50% on the first day and about 55 to 60% on the second day (Figure 3). When we compared drying rate and relative humidity data, it was observed that the relative humidity was high in morning and evening hours and the drying rate was low. The increase in drying speed was

Table 1. Duncan test results between the columns of the cumulative mass loss (%) values obtained in the product density of 5 kg/m^2 (p<0.05).

	Racks					Sun dried	p
Time(h)	Top R. 1	2	3	4	Bottom R. 5		
2	7.23^{a}	7.19^{ab}	7.17^{ab}	7.15^{bcd}	7.13^{bcd}	6.85^{cde}	0
4	16.92^{a}	16.86^{ab}	16.82^{ab}	16.78^{bcd}	16.74^{bcd}	16.10^{cde}	0
6	26.96^{a}	26.88^{ab}	26.82^{ab}	26.76^{bcd}	26.71^{cde}	25.69^{cde}	0
8	35.84^{a}	35.73^{ab}	35.66^{bc}	35.59^{bcd}	35.52^{cde}	34.05^{def}	0
10	41.97^{a}	41.83^{bc}	41.72^{bcd}	41.63^{cde}	41.55^{cde}	39.60^{def}	0
24	43.87^{a}	43.72^{bc}	43.60^{bcd}	43.51^{cde}	43.41^{cde}	41.19^{def}	0
26	49.97^{a}	49.79^{bc}	49.66^{bcd}	49.55^{de}	49.44^{def}	46.74^{def}	0
28	58.18^{a}	57.97^{bc}	57.82^{cd}	57.70^{def}	57.57^{def}	54.37^{def}	0
30	65.94^{a}	65.69^{bc}	65.51^{cd}	65.37^{def}	65.24^{def}	61.09^{ef}	0
32	73.09^{a}	72.82^{bc}	72.62^{cd}	72.46^{def}	72.33^{def}	67.46^{ef}	0
34	78.72^{a}	78.44^{bc}	78.22^{cd}	78.05^{def}	77.89^{def}	73.36^{ef}	0
35	80.57	80.27	80.04	79.86	79.71	75.00	1

related to the drop in relative humidity in the afternoon. The air will approach saturation value at high relative humidity values. This makes it difficult to transmit the moisture from the air to the air.

The reason why the drying rates are low in the morning and evening hours can be explained in this way. According to the shelf order (1: top shelf), the product moisture values obtained at a product density of 5 kg/m^2 are as shown in Figure 3. The Duncan test results for bulk product mass loss between the columns are shown in Table 1 depending on the loss of moisture after the beginning of the drying. It was seen that there was a statistically significant difference between the mass change values of the products dried in the different racks and the external environment until a certain time between the trial materials ($p < 0.05$). This statistical difference continued until weighing at the 33rd hour. Later, this difference between them got out of the way. As expected, the fastest drying occurred again in the first rack, which was the top shelf. For example, the fastest drying at the end of the 6th hour of drying due to mass loss was at the 1st rack, the slowest drying at the 5th rack. According to the multiple comparison test conducted, it was determined that the percent mass loss of the products on the 2nd and 3rd racks was the same as the percentage mass loss change of the products on the 4 and 5th racks. During the first 6 h of drying process, the product at 1st rack lost about 30% of its initial mass while the material at 5th rack lost 28% of its initial mass. The first rack product lost about 2% more moisture. In the samples dried under the external conditions, there was a mass loss of 27.13% at the end of the drying period of 6 h. The product on the top of the plastic tunnel lost 2.8% more mass than the outer layer, while the material on the 5th floor lost about 1% more mass than the outer control group. At the 33rd hour of the experiment, the product in the first rack lost 80.53% of the moisture while the product in the fifth rack suffered a loss of 79.41% moisture. Humidity loss was 72.93% in the dried product in outdoor conditions. When these results were taken into consideration, red pepper samples on the 1st, 2nd, 3rd, and 4th racks dropped below 20% humidity after 33 h. On the other hand, it was observed that the samples in the outdoor environment needed more drying time than 33 h. Taking these results into consideration, it can be said that the heat-collecting high-quality plastic tunnel-type desiccant drier system is partially superior to the desiccant made at a specific height from the outside (in terms of total drying time).

Findings related to mass fraction change

For the first period, time dependent graphs of the mass fraction (Mt/Mo) change measured in the dryer and in the external environment are as shown in Figure 4.

Looking at the mass fraction time graphs, it was seen that the products dried in the racks of the plastic tunnel dryer in the first days were drying out faster than those dried in the outdoor environment. On the second days, the mass losses of the products in the dryer were parallel to those dried out on the outside. This was related to the fact that the mass fraction ratios of the products in the outdoor environment and the plastic tunnel are close to each other at the end of drying. When the mass fraction and the drying rate diagrams are compared, the parallelism of these parameters depending on the amount of moisture removed from the product is also important for the applicability of the tunnel type dryer.

Findings related to mathematical modeling of drying curves

As a result of the experiments, changes in the moisture

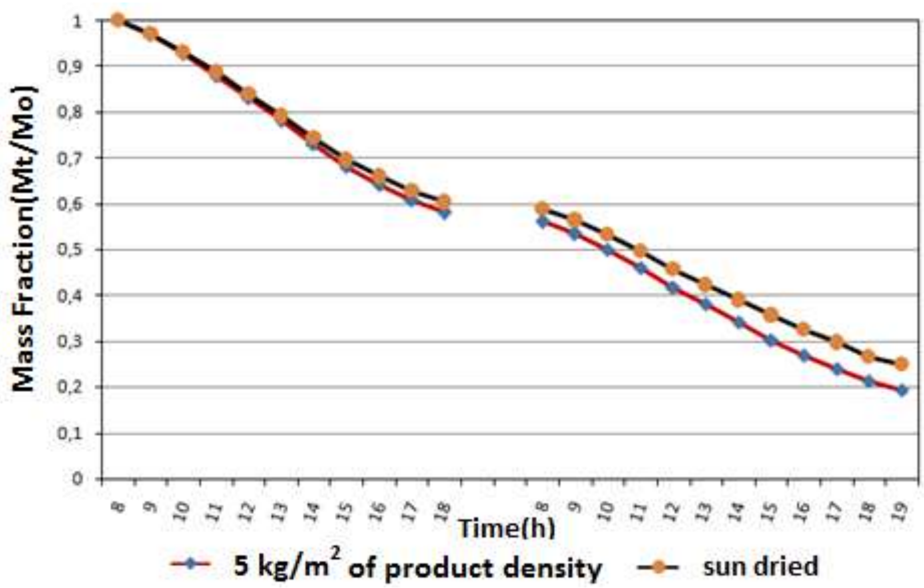

Figure 4. The mass fraction rate of red pepper recorded in the experiment for the first period product density of 5 kg/m^2.

content of the product depending on the time were investigated. Twelve equations were worked out to find the most suitable model that related the drying time of the mass fraction (M_{MF}) , which was defined as the ratio of the moisture content (M) of the product to the initial moisture content (M_0) of the product at a given time. In the experiments performed, the results for R_2, RSS and SEE for all model equations are shown in Table 2.

According to statistical analysis results obtained using mathematical models, it was determined that the most suitable mathematical model with the highest expression coefficient (R_2) was the two-term model given by equality.

$$(M_t / M_o) = a\ exp(-k_1 t) + b exp(-k_2 t) \quad (4)$$

When the models, model coefficients and calculated values were compared with experimental data, the highest expression coefficient was obtained with Two-Term model and it was at a level of 0.9886-0.9977 (Table 3). This has shown that this model can be used in practice for estimating the conditions under which the experiment is performed.

The fresh and after drying brightness (L*), redness (a*) and yellowness (b*) values of first period red pepper dried at a product density of 5 kg/m^2 are as shown in Figure 5. In addition, the color parameters are shown in Table 4.

CONCLUSION AND RECOMMENDATIONS

This research is the first study on the drying of spicy red pepper in a module high plastic tunnel on the operating scale in Turkey. According to the results obtained in this research, the product dried in the high plastic tunnel was dried in a shorter period of time than the product dried in the outdoor environment. This process was very rapid in the first stage of drying when water was physically removed from the product. Mass loss was reduced after the first 5 to 6 h of drying and thus drying seemed to slow down in the study. The study shows that rapid drying was not to be expected as in artificial dryers in high tunnel drying. The products in high tunnel and outdoor environment are practically dried in close proximity. However, the most important advantage emerging in favor of a high tunnel dryer is that the product is dried in a clean environment without being exposed to any contaminants. It is undoubtedly an unwanted condition that the disease and pests originating from the soil in the outdoor environment drift with the wind and dust. Today, increasingly competitive conditions make it possible to ensure that the final product produced is not only price-neutral, but also superior in terms of food safety and quality. For example, it has been found that the samples dried in a high plastic tunnel in terms of color, one of the quality parameters, have a brighter red color than the samples dried in the outside. It is then essential to dry the product in a clean environment with reasonable investment and operating costs and with minimal loss of quality and quantity. It is not surprising to predict that the profit margin of the manufacturer, which does not dry the product cleanly in the future, will decrease. On the other hand, it is possible that temperatures above 60°C in a high plastic tunnel could provide a significant advantage in the disinfection of storage pests in the product. In this study, it was determined that the optimum loading

Table 2. Analysis results of the model equations used for drying of red pepper harvested in the first period.

No		1	2	3	4	5	6	7	8	9	10	11-12
Model		Newton Model (Ayensu, 1997)	Page Model (Zhang and Litchfield, 1991)	Henderson and Pabis M (Chhninman, 1984)	Logarithmic Model (Yaldız et al., 2001)	Wang and Singh Model (Wang and Singh, 1978)	Diffusion Model (Toğrul and Pehlivan , 2002)	Verma Model (Verma et al., 1985)	Two-Term Exponential (Sharaf-Elden et al., 1980)	Two-Term Model (Henderson, 1974)	Simplified Fick Model (Toğrul and Pehlivan, 2003)	Midilli and Küçük (Sacılık 2006); Improved Page Model (White et al., 1981)
2 kg/m^2	RSS	0.0254	0.0212	0.0252	0.0087	0.0130	0.0254	0.0194	0.0254	0.0052	0.0252	0.0055-0.0212
	SEE(±)	0.0442	0.0421	0.0458	0.0282	0.0329	0.0480	0.0420	0.0460	0.0228	0.0478	0.0236-0.0421
	R^2	0.9671	0.9725	0.9674	0.9887	0.9831	0.9671	0.9748	0.9671	0.9933	0.9674	0.9928-0.9725
3 kg/m^2	RSS	0.0390	0.0161	0.0296	0.0082	0.0084	0.0082	0.0159	0.0391	0.0052	0.0296	0.0076-0.0161
	SEE(±)	0.0442	0.0291	0.0395	0.0214	0.0210	0.0214	0.0298	0.0453	0.0174	0.0406	0.0211-0.0291
	R^2	0.9682	0.9869	0.9758	0.9933	0.9932	0.9933	0.9870	0.9682	0.9958	0.9758	0.9938-0.9869
4 kg/m^2	RSS	0.0401	0.0134	0.0294	0.0055	0.0056	0.0056	0.0133	0.0401	0.0034	0.0294	0.0051-0.0138
	SEE(±)	0.0448	0.0265	0.0393	0.0176	0.0172	0.0176	0.0272	0.0459	0.0142	0.0404	0.0173-0.0270
	R^2	0.9672	0.9891	0.9760	0.9955	0.9954	0.9954	0.9891	0.9672	0.9972	0.9760	0.9958-0.9887
5 kg/m^2	RSS	0.0371	0.0093	0.0254	0.0036	0.0038	0.0038	0.0092	0.0372	0.0032	0.0254	0.0035-0.0093
	SEE(±)	0.0411	0.0211	0.0348	0.0135	0.0135	0.0137	0.0215	0.0421	0.0131	0.0356	0.0136-0.0211
	R^2	0.9734	0.9933	0.9818	0.9974	0.9973	0.9973	0.9934	0.9734	**0.9977**	0.9818	0.9975-0.9933

SEE is the standard error of the estimate, R^2 is the coefficient of specification, RSS is the sum of the squares of the residuals.

Table 3. Model coefficients of Two-Term model in working conditions of solar energy greenhouse type shelf dryer of red pepper samples.

Controlled variable parameter		R^2	SEE (±)	RSS
I. Period (kg/m^2)	2	0.9933	0.0228	0.0052
	3	0.9958	0.0174	0.0052
	4	0.9972	0.0142	0.0034
	5	**0.9977**	0.0131	0.0032
II. Period (kg/m^2)	2	0.9924	0.0246	0.0073
	3	0.9964	0.0166	0.0050
	4	0.9966	0.0157	0.0044
	5	0.9975	0.0138	0.0036
III. Period (kg/m^2)	2	**0.9886**	0.0326	0.0105
	3	0.9946	0.0216	0.0061

(a=-0.01009 k_1=-0.07854 k_2= 0.04674 ve b=1.08), the sum of the squares of the remaining (RSS), standard error of estimation (SEE), and specification coefficient (R^2) values.

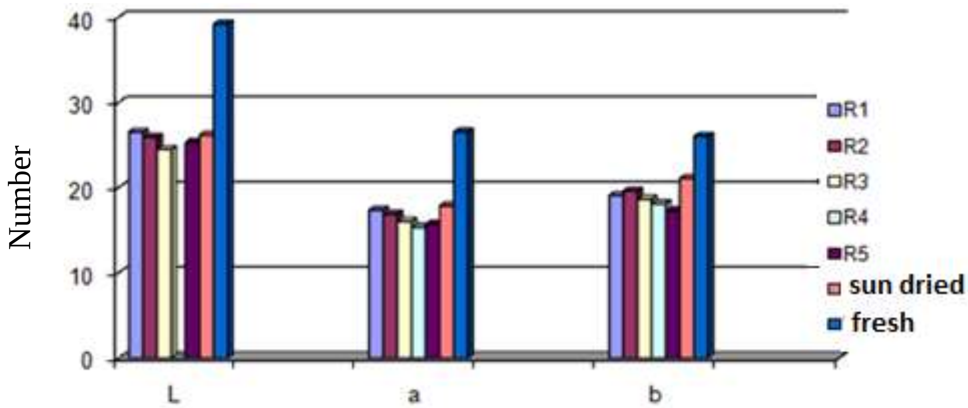

Figure 5. The fresh and after drying brightness (l*), redness (a*), and yellowness (b*). Values of first period red pepper dried at a product density of 5 kg/m^2.

Table 4. First period color parameters of dried red pepper at a product density of 5 kg/m^2.

Variant	Color Parameters					
	L	a	b	a/b	X	α
Fresh	38.79	28.46	26.38	1.07	38.80	42.82
Sun dried	26.11	18.02	20.31	0.88	27.15	48.42
1	26.63	17.52	19.85	0.88	26.47	48.56
2	25.91	16.84	19.79	0.85	25.98	49.60
3	25.06	16.04	19.67	0.81	25.38	50.80
4	25.30	16.46	18.92	0.87	25.07	48.97
5	24.41	15.68	18.53	0.84	24.27	49.76

capacity could be increased up to 187.5 kg due to the technical and economic performance criteria taken into account in the red pepper drying study carried out in 3 different periods. Taking into consideration the maximum loading capacity, it is calculated that a mass of about 187.5/48=3.9 kg/m^2 can be dried in this trial scale installation if this plastic tunnel is deemed to have a floor area of 48 m^2. If the base area and elevation of the prototype plastic tunnel used in the trial are effectively assessed, there should be no doubt that this figure will increase in a commercial plastic tunnel. On the other hand, according to the results obtained in the optimum loading capacity calculated in the first period, it has been determined that the plastic tunnel dryer is a profitable investment that can meet initial investment, operation and fixed expenses within one season. Only this result is convincing reason why plastic tunnel dryers can be offered to producers. Moreover, the product transport and transportation costs as well as the reduction of quality and quantity losses should not be forgotten in case of the positive contribution of drying in a closed environment in terms of food safety and quality, the system being suitable for other undergrowth and drying activities outside the drying season, and the establishment at the place of production in the plastic tunnel. In this way, the economic profitability of the system can be increased by making maximum use of the plastic tunnel. Another measure to take in the high plastic tunnel dryers is to take technical measures to increase the collecting efficiency and raise the ambient temperature within the high plastic tunnel. It was determined that the temperatures in the high plastic tunnel were around 60°C for 3 to 4 h during the experiments. As the length of the high tunnel module increases, it will be more beneficial for the beam that is accumulated either in the high plastic tunnel or the collectors. So, hot air will go a long way in high plastic tunnel. Undoubtedly, the provision of good insulation in order to prevent heat losses in the high plastic tunnel and the recirculation of the high plastic tunnel air by re-circulating it are other measures that can make it possible to take longer advantage of the heat obtained from the collecting. In addition, the use of heat perception in the system contributes significantly to the prevention of heat losses. On the other hand, if there is a condition in which the manufacturer can sell a different product in the greenhouse, the option of heating with a burner may be necessary in order to continue drying in the nighttime. Because heating in the night time will increase unit drying costs in terms of both burner investment and operating costs.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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