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Red Chili Pepper Drying by Farm Scale Hothouse

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Abstract: In this study a farm scale plastic high tunnel hothouse dryer was investigated to dry red chili pepper grown in southeastern Anatolian region. Hothouse dryer was installed in Kahramanmaraş where this crop is intensively cultivated. For drying purpose the green stem was removed manually and then material was split into two pieces. The core of seed was also removed. The fleshes of red chili peppers were placed on the shelf as a thin layer by a density of 2 kg/m^2. In this study the lost of moisture from crop and color change were measured. For first and second harvested red chili peppers drying duration varied between 26 and 27 hours. As the control sun-dried chili peppers was placed by 50 cm height from the ground in outside. The moisture loss from solar dried chili peppers was 2 to 4% higher than that of sun-dried variant. Although the drying time of solar and sun dried crops was similar, it is expected that the solar dried crops would resulted in higher food quality and safety. Thus the color of solar dried chili was much shining red in compare to sun-dried variant. Hothouse dryers have been already tested for different crops in laboratory scale. However, the implementation of farm scale hothouse dryer by using national and international funds would be a proper strategy to provide more information regarding to marketing advantages and management experiences on this issue.
Key words: Red chili pepper, drying, hothouse

INTRODUCTION

Red chili pepper (*Capsicum Annuum* L.) is an important spice crop in Turkey and produced in Southeast Anatolia region. Its consumption is mainly oriented to domestic market. Red chili spice export is almost negligible because of the food safety and quality compliance with relevant standards. As the moisture content of hand picked crop is about 80% (wet basis) during harvest, the drying is the first post harvest process. Formerly whole fruits with stem were sun dried on the ground near to cultivation area. Red chili spice produced from this raw crop does not comply with food safety and quality standards due to soil-based diseases such as mold and other harmful insects which exist during storage. Moreover the production cost of chili spice in Turkey is nearly four times higher than its competitors in the world market. Then its production is not competitive both in terms of cost and quality. If the poor quality red chili spices are used as ingredients in sauces, hot dog, sausages, and soups, the decrease in quality of final product is unavoidable. Then, the traceability of low quality spice in such products is also impossible. Over ten years comprehensive R&D and extension activities have been carried out in Southeast Anatolia region to sort out post harvest problems of chili pepper (Işıkber ve ark., 2003; Soysal ve ark., 2005a; Soysal ve ark., 2005b; Öztekin ve ark., 2005; Öztekin ve ark., 2006a, Öztekin ve ark., 2006b; Duman ve ark., 2007a; Duman ve ark., 2007b, Işıkber ve ark., 2007; Işıkber ve ark. 2008). Today, it is observed that the growers and processors begin to change their improper crop drying methods. Thanks to efforts of research institutes and extension services they are using now wooden shelves covered with plastic nets to dry the crop in the sun. These shelves are placed 40 to 50 cm higher from the ground, which is certainly a positive development. But, although the crop is placed higher from ground, there is still infestation risks coming from outside. Moreover, if the weather conditions are not suitable for sun drying, it could take more then one day. As there is no sterilization or disinfestation before or after drying, microbial contamination and insect pests could easily survive during storage period. Therefore, the main objective of this study is to use the solar energy for drying red chili pepper in closed atmosphere to eliminate microbial and insect infestation risks and to reduce operational costs.

For industrial drying of red chili pepper hot air is implicated in belt dryers. However, the investment and operational costs are relatively high in this process. The location of Southeast Anatolia region in the Sunbelt and its advantages in terms of solar radiation and coinciding of drying season with the period of higher solar radiation encourages the solar drying.

The basic idea of this research is the fast and clean drying of red chili pepper in hothouse. Hothouse is actually a kind of greenhouse to be used for drying purpose. In previous researches hothouse dryers are usually built in laboratory scale due to easy application. To scale up these results to farm scale different mathematical models have been developed. But, the needs in practice could differ from theoretical approaches where the expectation of growers could not be fulfilled. Moreover it is probably not possible to convince the growers for investment of hothouse by scale up method, because they accept any system which works efficiently and economically. Therefore experimental hothouses in farm scale could have more potential to contribute red chili drying. In this context hot air has been used not only for drying but also for disinfestation of storage insects of dates such as *Carpophilus hemipterus* (Finkelman et al., 2006). They reported that the drying temperature of 55 ºC was sufficient to kill all the larvae, pupae and adults of *Carpophilus hemipterus* and the larvae inside of the fruit were forced to leave the date and died in the outside of fruit. This is very important for consumers, because dates are offered to the market without any insect fragment, which means hot-air application improves crop quality and quantity. Then similar effect of hot air on storage pests could be also expected for red chili. Although red chili pepper was usually known because of the *Aflatoxin* problem in Turkey, there are also some harmful pests such as ***Plodia interpunctella*** and ***Lasioderma serricorne*** which cause the serious reduction on crop quality and quantity during drying and storage period (Işıkber ve ark., 2008). The different pests could easily survive during the prolonged traditional sun drying of red chili pepper. If the red chili pepper could be properly dried immediately after harvest, the development of storage pests could be prevented.

The expected benefits of this study are given below:

- Hothouse dryer will be scientifically tested first time to dry red chili pepper in Turkey.
- In compare to sun drying the crop will be properly and cleanly dried, the risk of pest and fungal infestation will be minimized by grower; the added value of spice pepper will increase.
- The tunnel hothouse and solar collector combination is in the farm scale and modular. It could be easily manufactured and expanded according to local needs.
- Hothouse could be used for other farming facilities including the cultivation.
- There are different national-international sources for funding that encourage to apply renewable energy for solar drying.

MATERIAL and METHOD

Material

The used red chili variety in this study was *Sena* (*Capsicum Annuum* L.) which was selected and cultivated by Kahramanmaraş Agricultural Research Institute. The drying facility consisted of a polyethylene clad hothouse 8 m long x 6 m wide x 2.86 m high, specially prepared for farm scale drying of fruits and vegetables. It is designed and manufactured by TARTES (www.tartes.com.tr). The solar collector has a dimension of 6 m long x 6 m wide and was placed in the north side of greenhouse (Fig. 1). The hot air from collector is directed to hothouse from the bottom part of its north wall. An axial fan was placed above the entrance of hothouse on south wall. It creates an air flow in hothouse. The fan casing measures is 0.975 x 0.95 m, the fan diameter is 0.95 m, and fan power is 0.3675 W. The fan provides an air flow of 8500 m^3/h. The whole system takes advantage of ambient solar heat during the harvest season.

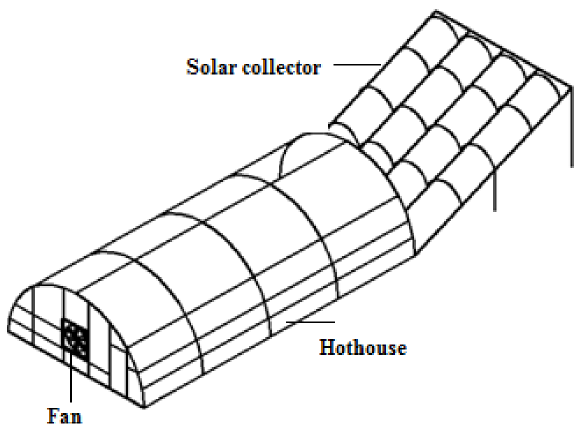

Figure 1. Greenhouse dryer

Drying facilities in hothouse consists of five rows of shelves spaced 30 cm in vertical direction. It is positioned in the middle of hothouse. Each shelf has a dimension of 2.5 m long x 1 m wide. The frame of shelves is covered with plastic mosquito net where the dried crop is placed on as a thin layer. Same drying shelf was also used at the outside that represent the sun drying. It was 50 cm higher from the ground. Including the crop density the material for sun drying was prepared in the same way as solar dried material.

Method

During the drying test air temperature and relative humidity values was measured by portable data loggers (Box Car, precision for temperature: 0.6 ºC, for relative humidity % 0.5). Initial moisture content was measured with standard oven method (105°C & 24 h) and given as a mean value of three samples each 20 g. For weighing precision balance was used (precision: 0.01 g, Sartorious BL 15005).

Moisture loss of crop samples was calculated by following formula,

$$m = \frac{m_b - m_a}{m_b} \times 100 \qquad (1)$$

Where;

M = Moisture loss of drying sample (%)

M_b= Mass of sample before drying (g)

M_a= Mass of sample after drying (g).

The study was planned randomized block design with three replications. Moisture loss change was used as dependent variable to determine the influence of drying on crop drying. Analysis of variance was performed by using Sigma-Plot software (SPSS 13.0).

Sample colour was measured before and after drying by using a colour meter (Minolta Co.; Model: Chroma CR-100). The colour meter was calibrated against a standard calibration plate of a white surface and set to CIE Standard Illuminant C (Soysal, 2000). The display was set to CIE L*a*b* colour coordinates. Ten random readings per sample were recorded and the average values of colour parameters with standard deviation values were reported. The colour brightness coordinate L* measures the whiteness value of a colour and ranges from black at 0 to white at 100. The chromaticity coordinate a* measures red when positive and green when negative, while the coordinate b* measures yellow when positive and blue when negative. Also, hue angle α (Eqn. 2), chroma C (Eqn. 3), were calculated from the values for L*a*b* and used to describe the colour change during drying;

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

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

Prior to drying fresh red chili peppers were washed, stems were removed and fruits were split into two pieces. Then the cores and seeds were also removed. The fleshes of red chili peppers were spread on the tray by a density of 2 kg/m^2. Although the red chili is traditionally dried as whole, two pieces of fruit flesh would dry faster. As spices produced from thick flesh red chili more appealing to consumers taste, such varieties are preferred by food industry. If thick flesh red chili varieties dried properly by growers, its marketing chance with higher price will increase. This would be a considerable contribution to improve their income. There are two registered varieties in Southeast Anatolian region. The flesh thickness of first one, which is named as "*Sena*" is 1.4…1.8 mm. The second registered variety is called as "*Maraş 1*" and its flesh thickness is 1.2…1.4 mm (Arpacı, 2009). Although no data is available about the influence of flesh thickness on drying, it is expected that the thick flesh red chili pepper would dry slowly.

During the tests drying time and color measurement has been carried out. Air temperature, relative humidity and air velocity were measured and recorded. Solar radiation data's were provided from weather station of Kahramanmaraş Research Institute. Sample masses were measured two hourly. Drying was continued until the crop mass on trays decreases until one fifth.

RESULTS

The main factors affecting drying time are temperature and relative humidity of drying air. In case of the moisture content lower then 20% energy consumption and thus drying costs are increasing. The fastest drying was obtained between 10^{00} and 15^{00} hours where the air temperature in the hothouse rises till to 55-65°C. In the air temperature of over 65 °C red color of chili pepper was darkened.

When the inside air temperature is closer to 70 °C the fruit was almost burned. The reason for that is mixed influence of convection and intensively solar radiation. At the same time there was no burning on the samples dried outside, because the air temperature has never reached to this high level.

As the fruits are ripening in different times the red chili pepper is usually harvested two times. The first harvest is at the end of the August and the second is in the mid-September. The results of both harvests were given below.

Drying of first harvest red chili pepper

The drying curves of first harvest crop are given in Fig. 2 (S1: top shelf, S5: bottom shelf). Variance analyses of cumulative moisture loss (%) and the results of Duncan test was shown in Tab. 1. As expected the fastest drying was obtained in the top shelf in hothouse. For example, while fastest drying was obtained on the top shelf (S1) after two hours from starts, the slowest drying was occurred on bottom shelf (S5). According to multiply comparison test it was found that the moisture loss on third (S3) and fourth shelves (S4) was same with the bottom shelf (S5). While within first two hours the red chili in top shelf has lost 22% of initial mass, the material in the bottom shelf has lost 19% of its initial mass. That means the crop on the top shelf has lost 3% more moisture in compare to bottom shelf. The red chili dried in outside has lost 19.60 % of its initial mass which is statistically the same with the bottom shelf in hothouse. Thus, while the fruits on top shelf in hothouse losses its moisture by 2.4 % more, the material in bottom shelf lost its moisture by 1 % more in compare to sun dried red chili peppers. According to these results it could be concluded that except the top, crop dry on lower shelves in hothouse slower than the outside. Sun dried red chili peppers on the shelf placed 50 cm higher from ground dry faster than the crop on the lower shelves at hothouse. After six hours drying losses in mass was 55.16 % on top shelf and 47.28 % on bottom shelf at hothouse. At sixth hours crops on top shelf lost by 7.88 % more in compare bottom shelf. After six hours the loss of mass in sun dried crop was 44.88 %. It is 10.28 % smaller than that of top shelf at hothouse.

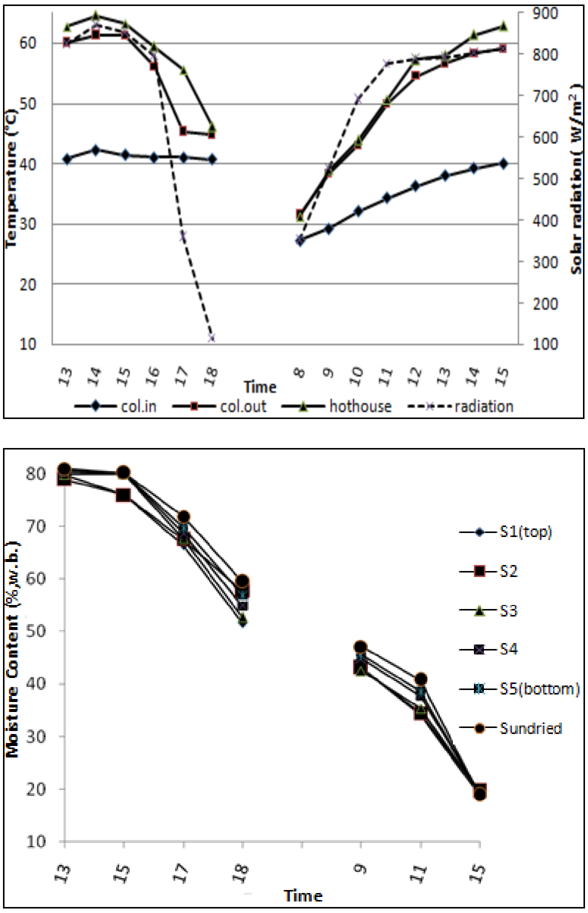

Figure 2. Moisture contents of first harvest red chili pepper, inlet and outlet temperatures of solar collector, inside temperature in hothouse and solar radiation

Table 1. Cumulative moisture losses of first harvest red chili pepper

h	Shelves					sun dried
	S1 top	S2	S3	S4	S5 bottom	
2	21.76[a]	20.62[ab]	19.48[bc]	19.02[bcd]	18.9[cde]	19.6[bc]
4	40.77[a]	38.76[b]	37.66[bc]	36.3[cd]	35.22[de]	36.72[bc]
6	55.16[a]	52.52[bc]	50.88[c]	48.26[cde]	47.28[def]	44.88[ef]
9	64.22[a]	61.94[bc]	60.21[cd]	57.8[de]	56.9 [ef]	53.02[ef]
24	69.88	67.72	66.64	62.68	62.76	57.52
26	81.54	80.09	80.04	79.97	79.91	77.53

Additionally, the difference between top and lower shelves at hothouse was still persisting. In the twenty sixth hours of drying the crop on the top and bottom shelves at hothouse lost 81.54 % and 79.91 % of its moistures, respectively. However this difference is statistically insignificance. According to these results while the crop moisture content on first four shelves at hothouse was dropped below 20 % after twenty six hours, sun dried crop was required much more time to reach the same moisture level. This shows that the drying at hothouse is advantageous in compare to sun drying. Especially higher inside temperature during the daylight hours causes rapid loss of moisture in hothouse. Additionally, solar dried material was protected from any adverse affects coming from outside such as dust, infestation, etc.

Color values of dried samples and results of statistical analyses were given in Tab. 2. While the brightness value (L*) on the top shelf was greatest, lowest brightness was found on the bottom dried crop at hothouse. According to multiple comparison tests there was no difference among the brightness value of third, fourth and bottom shelves. The brightness of sun dried sample was lower than top shelf, but greater than the bottom shelf. The chromaticity coordinate a* (redness) was the highest at the top shelf in hothouse. According to multiple comparison tests there was no difference among the redness value of crops dried on top (S1), second (S2) and third (S3) shelves. The redness value of outside sample was close to solar dried crop on top shelf in hothouse. This result is confirmed by multiple comparison tests. The highest value of b* coordinate (yellowness) was obtained in the second shelf. According to multiply comparison test b* value of first and third shelves was same. The b* value of outside dried product was higher then that of top shelf in hothouse. L^*, a^* and b^* values of fresh crops were 39.01, 27.14 and 25.85, respectively. L*, a* and b* value of fast drying crops on the top shelf in hothouse comparing to fresh crop was reduced 28.45 %, 33.80 % and 23.71 %, respectively. In prolonged drying period color change was increased considerably. Except the top shelf the red chili peppers on the lower shelves was oxidized which is the main reason of color change. Although the measured L*, a* and b* values are basic color parameters, they do not represent the consumers perception of color. To give better idea on color a/b ratio, Hue angle (α) and chroma (C*) values were calculated.

Table 2. Color parameters of first harvest red chili pepper

Variant		Color parameters					
		L*	a*	b*	a*/b*	C*	α
fresh		39.01	27.14	25.85	1.04	37.50	43.58
sun dried		26.52	18.66	20.89	0.89	28.01	48.22
hothouse	1	27.91	18.10	19.72	0.91	26.76	47.45
	2	26.43	17.35	19.75	0.87	26.28	48.70
	3	25.85	16.55	19.09	0.86	25.26	49.07
	4	25.56	16.16	18.36	0.88	24.45	48.64
	5	25.33	15.47	17.13	0.90	23.08	47.91

a*/b*, hue angle and chroma values of fresh crops were 1.04, 43.58º and 37.50, respectively. The lowest a*/b* value was obtained in the third shelf. The lowest hue angle was calculated in top shelf. The lowest chroma value was found in bottom shelf. a*/b* and hue angle of top shelf was close to fresh crop. Drying has an impact on chroma values and therefore it reduces by 29 %. The highest chroma value was found in top shelf. The red chili peppers in hothouse loss their brightness with prolonged drying period. The general rule for drying is also guilty for hothouse drying which shorter drying is almost better.

Drying of second harvest red chili pepper

Drying curves for second harvest was given in Fig. 3. Variance analyses of cumulative moisture loss (%) and the results of Duncan test was shown in Tab. 3. The difference among the moisture losses of different shelves was statistically significant ($p<0.05$). This difference was disappeared from twenty seventh hours after drying start. The fastest moisture loss was measured in top shelf and the slowest was in the bottom at hothouse. According to multiply comparison test loss of mass (%) in third and fourth shelves was the same with the crop on bottom shelf. While during the first two hours of drying the crop on top shelf was lost approx. 21 % of its mass, the crop on bottom shelf was lost 18 % of its mass. The sun dried crop lost 18.53 % of its mass. This value was statistically same with third shelf. The crop on first shelf lost its moisture 2.47 % more than that hat of sun dried chili. The lost in moisture content on bottom shelf was only 0.53 % than that of sun dried crop. Except the statistical evaluation this small difference between hothouse and outside plays actually not important role in practice. From practical point of view the drying rate in hot house and sun dried crops was almost close to each other. At the end of first six hours moisture losses of top and bottom shelves were 53.08 % and 45.39%, respectively. The crop in the top shelf lost by 7.69 % more moisture then that of bottom shelf. At the same time the crop in the sun lost 42.83 % of its moisture. This value is 10.25 % lower than the moisture loss on top shelf (S1) at hothouse. After two hours of drying there was still difference between moisture content of top and bottom shelves in hothouse. In twenty seventh hours of drying the crops in top and bottom shelves lost 80.98 % and 79.82 % of their moistures, respectively. On the other hand sun dried crop lost 78.91 % of its moisture. But this difference is statistically insignificance. According to these results the drying was completed within twenty seven hours. The crop in the sun was dried approximately two hours longer than that of hothouse.

Color values of dried samples and results of statistical analyses were given in Tab. 4. Similar to the test with first harvested red chili the highest brightness value (L*) was obtained in the first shelf and lowest value was in the bottom shelf. According to multiple comparison test brightness values of bottom, third and fourth shelves were almost the same. The brightness value of sun dried crop was lower than that of top shelf, but higher than that of the other shelves in hothouse. The highest redness value (a*) was obtained in the top shelf. There was also no significant difference among the redness values of top, second and third shelves in hothouse. The redness value of sun dried crop was also close to above mentioned crops. The multiple comparison tests confirmed this statement. The highest yellowness value (b*) was measured in second shelf. According to multiple comparison test there is no difference among the (b*) values of top, second and third shelves. The highest value was obtained in second shelf. The (b*) value of sun dried crop was higher than that of top shelf at hothouse. The L*, a* and b* values of fresh crops were 38.89, 27.03 and 25.88, respectively. In compare to fresh crop the L*, a* and b* values of fastest dried top shelf were decreased by % 28.43, % 33.22 ve % 23.68, respectively. The change in color was increased with prolonged drying period. Similar to the first test color change in lower shelves were found much higher than the top shelf due to oxidation. a*/b*, hue angle and chroma values of fresh crops were 1.04, 43.75º and 37.42, respectively. The lowest a*/*b value was obtained in third and fourth shelves. The lowest hue angle was calculated in top shelf. The lowest chroma value was found on bottom dried sample (S5).

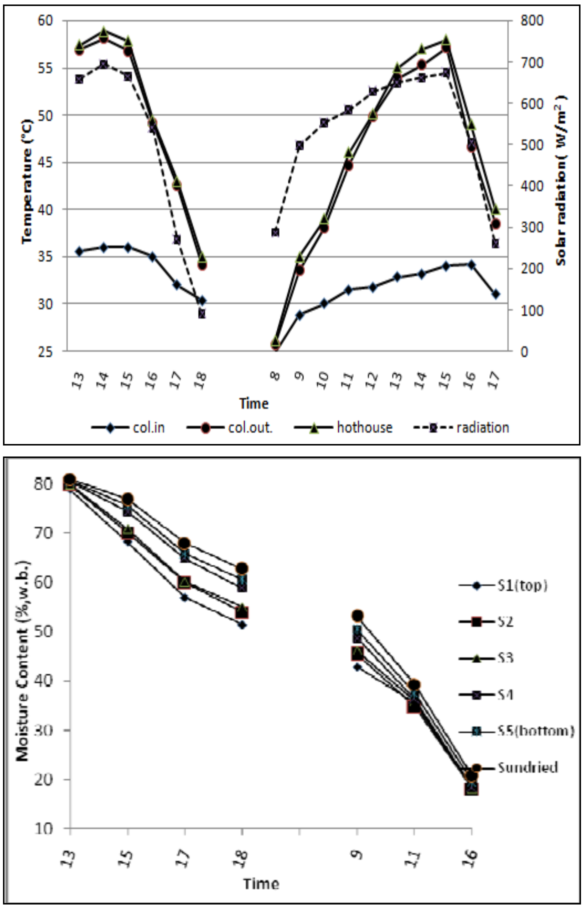

Figure 3. Moisture contents of second harvest red chili pepper, inlet and outlet temperatures of solar collector, inside temperature in hothouse and solar radiation

Table 3. Cumulative moisture losses of second harvest red chili pepper

h	Shelves					sun dried
	S1 top	S2	S3	S4	S5 bottom	
2	20.66^{a}	19.54^{ab}	18.42^{bc}	18.17^{bcd}	18.08^{cde}	18.53^{bc}
4	39.27^{a}	37.48^{b}	36.39^{bc}	35.91^{cd}	34.83^{de}	35.58^{cde}
6	53.08^{a}	50.41^{bc}	48.72^{c}	46.18^{de}	45.39^{def}	42.83^{ef}
9	62.72^{a}	60.59^{bc}	58.82^{cd}	54.93^{def}	53.88^{ef}	51.37^{ef}
24	67.96^{a}	65.85^{bcd}	64.82^{cd}	60.13^{d}	59.97^{de}	56.89^{ef}
26	76.83	75.62	74.35	70.91	70.13	68.23
27	80.98	80.63	80.53	79.91	79.82	78.91

Table 4. Color parameters of second harvest red chili pepper

Variant	Color parameters					
	L*	a*	b*	a*/b*	C*	α
fresh	38.89	27.03	25.88	1.04	37.42	43.75
sun dried	26.41	18.54	20.91	0.88	27.94	48.43
1	27.83	18.05	19.75	0.91	26.75	47.57
2	26.35	17.31	19.78	0.88	26.28	48.80
3	25.86	16.57	19.03	0.87	25.23	48.95
4	25.49	16.10	18.41	0.87	24.45	48.82
5	25.27	15.45	17.19	0.89	23.11	48.05

a*/b* value and hue angle of top shelf was close to fresh crop. Drying has an impact on chroma values and due to drying it reduces by 28.51 %. The highest chroma value was calculated on top dried chili (S1). The red chili peppers loss their brightness with prolonged drying period.

CONCLUSION

In terms of drying time solar dried red chili pepper was dried few hours shorter than that in sun dried crop. Drying rate in the first period of drying was very fast where the physical bound moisture was removed. This period corresponds to the first five to six hours of drying. Afterwards the moisture loss decreases by progressive drying. This result indicates that high speed drying presented by hot air belt driers should not be expected from hothouse drying. Practically the drying time of hothouse and sun dried red chili pepper were similar to each other. For this reason, it may be not easy to propose a farm scale hothouse and to convince the farmer for investment such a facility. The growers mainly concern on the drying time. Therefore they would have no motivation to improve their traditional process since the drying time of hothouse does not differ from sun drying. Moreover they could use in outside same shelf system as in hothouse to increase their drying capacity per unit area. But, main advantage of hothouse is the drying of red chili in clean, closed environment where the risk of infestation is completely eliminated. The sun dried crop could be easily contaminated by the microorganisms and insect pests which are unfavorable conditions. Today reducing production costs and offering cheaper product is not sufficient for competition in market. The product must also comply with existing food law and regulations in terms of quality and safety. In this study the results indicated that the red chili dried in hothouse had brighter red color than sun dried product. Then a drying in a clean environment with reasonable investment and operating costs and minimum loss of quality and quantity are essential rules. Although this statement may seem as a common expression the profits of growers will decrease if they do not dry the red chili pepper properly. As the consequent there will be thread of being lost of its domestic market and it could be replaced by export crop, since the export spice is cheaper and cleaner. This case is well known from other agricultural crops in Turkey.

Another important advantage of hothouse is the temperature increase till to 60 ºC. Although it is a topic of another study, such a temperature rise will certainly contribute to disinfection of storage pests of red chili pepper. Since the influence of radiation is more in hothouse than the outside, the moisture in the crop is removed by temperature increase. On the other hand, in outside the moisture removal is occurring predominantly by wind convection. The temperature increase in hothouse would be a great advantage for pest disinfestation, since the outside air temperature normally never increases as that in hothouse.

To improve the efficiency of solar collector and to distribute the air homogeneously in hothouse will certainly contribute the drying process and capacity. During the tests the higher air temperature of 55-60 ºC was continued three to four hours. If the module number of hothouse is increased, more energy would be collected and efficiently used which means the hot air stay much longer time in hothouse. The precautions such a recirculation of drying air and better insulation of hothouse will contribute to increase drying efficiency. The feasibility of fuel oil burner would be also an option which allows uninterrupted heating during night periods. However, an investment for a burner will certainly affects operating costs which means increase in production costs as well.

Since the growers are avoiding the drying and storing processes due to its troubles, they prefer usually contract farming with spice industry where they collect fresh red chili pepper as soon as it is harvested. In the market the red chili variety *Sena* having thick flesh would be primarily preferred due to its properties as spice. But, the industry purchase the variety *Maraş 1* having thin flesh due to its cheaper drying costs. If the variety *Sena* is split into two parts and dried seedless, it would have better change in the market, because the most severe and costly part of processing work would be taken over by grower. Of course the industry pays much more money for dried chili than fresh product. But the varieties such *Sena* could not be dried properly in the sun even on shelves placed higher than ground. So, the idea "hothouse" is not an alternative to industrial belt driers. It is just proposed to increase added value of new varieties of red chili pepper and the income of local growers. On the other hand the hothouse could be also used for other drying facilities such as tomato drying or even for cultivation, because it has finally same structure as greenhouse.

The experiences gained from this research should be supported by management skills in practice. The using solar energy to heat the hothouse would be an attractive reason to apply to national and international funds for supporting such a project in regional scale. In that sense the Ministries of Agriculture and Industry, the regional development agencies, the governorships in Turkey and EU and other funds support the systems using the renewable energy sources. Since a planning and operating of central drying hothouses would be managed by technical staffs, it could provide the employment for the agricultural engineers. Thoroughly both of growers and engineers could have a benefit by implementing such projects.

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