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Solar Drying of Red Peppers: Effects of Air Velocity and Product Size

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Abstract: The purpose of present study was to determine the effects of drying air velocity and pepper size on drying time, the dried product's ascorbic acid level (Vitamin C) and color using response surface methodology. A solar dryer consisting of a solar collector and a drying chamber was used to conduct the experiments between September 4 and October 10, 2003 in Sanliurfa, Turkey. The overall drying conditions providing the minimum drying time, maximum ascorbic acid level and highest extractable product color were determined to be 1.3 m sec^{-1} and 6 slices per pepper.

Key words: Solar dryer, red pepper, response surface methodology, ascorbic acid

INTRODUCTION

Red pepper is a commercially important agricultural product of Turkey. Annual red pepper (*Capsicum annuum*) production in Turkey is about 25000 tons (Oztekin *et al*., 1999). Most of the produced red pepper is processed to make powdered red pepper. The powdered red pepper production process involves washing; sorting; removal of the stems and seeds; slicing; drying; grinding and packaging (Hayoglu, 1999). Drying is an important time and energy consuming process of powdered red pepper production. Traditional small scale drying operations are practiced by spreading the product in thin layers on a mat or paved grounds and exposing them to the sun and wind in an open environment (Oztekin *et al*., 1999; Hayoglu, 1999; Doymaz and Pala, 2002). Various large scale industrial drying of red pepper involves sun drying for about 24 h before the peppers are dried in a tunnel dryer to the required moisture levels. In some sun drying operations, peppers are spread on a plastic sheet with one or two levels or spread on elevated nets to increase the drying efficiency. The spread peppers are mixed frequently for uniform drying. During open sun drying, the products' exposure to environmental conditions such as dust, insect infestations, wind and rain deteriorates the quality of the dried product.

In the Southern and Southeastern part of Turkey, red pepper is dried during the months of August through the end of October. Open sun drying of peppers would take up to 6-10 days. Quality and yield losses occur if the moisture content of the product is not removed within a certain time (Garg *et al*., 1998; Mumba, 1995; Ong, 1999; Esper and Muhlbauer, 1998; Doymaz and Pala, 2002). Solar drying in a closed environment such as in a drying chamber would reduce the risk of environmental damage and provide a better control over the drying parameters.

Drying operations involve both heat and mass transfers. Product size, density, moisture content, drying air temperature, relative humidity and air velocity (Leon *et al*., 2002) are some of the major parameters affecting the drying time and dried product quality. Ascorbic acid (Vitamin C) content of the product is one indicator of the potential preservation of nutrients (Madhlopa, Jones and Saka, 2002) and would change with preprocessing, conditions of the drying air, light, heat and drying time.

During a solar drying operation, labor and energy are used for sorting, washing and slicing the peppers, loading and unloading the trays and mixing the product occasionally. The number of slices affects not only the drying time and quality, but also the labor hours. Generally, the higher the number of slices, the shorter the drying time, but the increased number of slices extends the time spent slicing the peppers. The number of slices is a direct indicator of the product size. Therefore, it is important to determine the optimum number of slices (size) for each pepper to minimize the slicing time providing the maximum ascorbic acid level and the minimum drying time.

Response Surface Methodology (RSM) is a statistical technique that is used to optimize unit operations in food processing. RSM design is commonly used for chemical engineering, food engineering, agricultural engineering and mechanical engineering processes and applications to optimize the processes. One of the advantages of RSM design is that it produces a reduced number of experiments which are still acceptable and would provide

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significant statistical information. Compared to the full factorial design and classical one-at-a time experimentation, it is less expensive, saves time and material for the optimization process. RSM can also be used for the optimization of drying processes (Madamba, 2002).

Drying air temperature, velocity and humidity, as well as product thickness and size are some of the important drying parameters that affect drying time and quality of the dried product. In this study, air velocity at the drying chamber inlet and the number of pepper slices were used as the drying control parameters. Although temperature of the drying air is an important parameter, it was not included in the experimental design because the solar dryer required a supplemental heating and control unit to ensure a constant air temperature in to the drying chamber. The objective of the investigation was to determine the optimal air velocity and number of slices resulting in minimum drying time, maximum ascorbic acid level and maximum color level using a solar dryer.

MATERIALS AND METHODS

Solar dryer: A forced convection solar dryer at the Faculty of Agriculture at Harran University in Sanliurfa, Turkey, was used to conduct the experiments. The dryer consisted of two sections: a solar air heater and a drying chamber. A flexible connector, 20 cm in diameter, provided a medium to transfer the heated air from the solar air heater to the drying chamber. Both the air heater section and the drying chamber were placed on two separate steel frames with wheels, as shown in Fig. 1.

The size of the air heater section was 192×98×12 cm. The bottom of the air heater was made of a 0.5 mm thick galvanized iron sheet. Glass wool 5 cm in thickness was placed on the bottom sheet and covered with a second galvanized iron sheet so that no glass wool would contaminate the drying air. The two sides of the air heater were made of 0.5 mm thick stainless steel metal sheets. A copper plate painted in black was placed 4 cm above the bottom of the air heater and a sheet of glass, placed 3 cm above the absorber plate, was used to cover the air heater. The inlet and outlet of the air heater was reduced to a duct with 20 cm in diameter made from a galvanized iron sheet. The air heater was placed on a 200×100 cm size iron frame. The upper end of the air heater was attached to the frame with hinges. The lower end of the frame was connected to two vertical bars having holes 5 cm apart on each side. This allowed height adjustment for the lower end of the collector from the ground. The frame had four wheels, each 10 cm in diameter, allowing for mobility of the air collector.

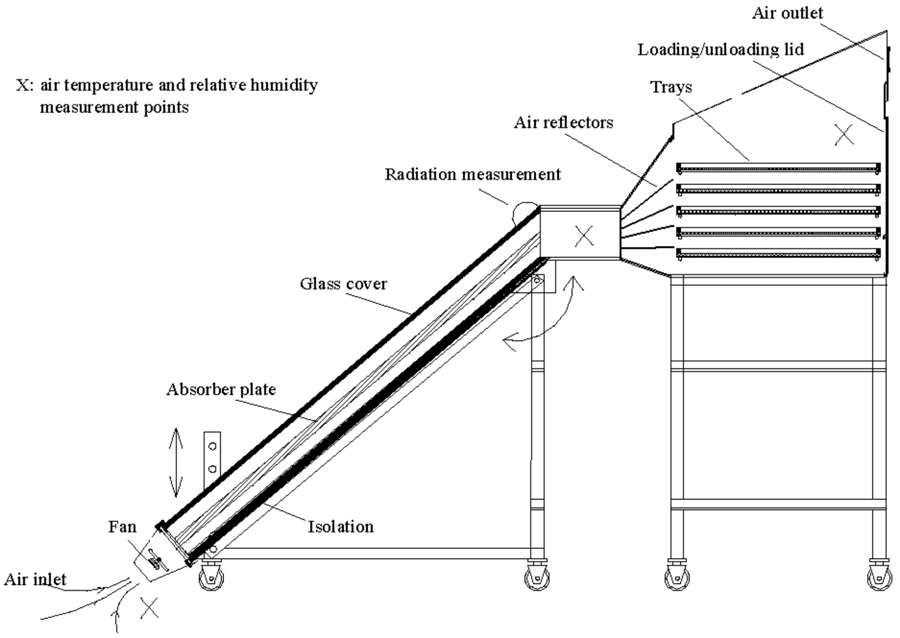


Fig. 1: Schematic view of the solar dryer used for drying red peppers. The dryer has five trays and the drying air is directed towards the trays with the help of air reflectors

The drying chamber was made of a steel frame covered by 0.5 mm stainless steel sheets. Styrofoam insulation, 3 cm thick, was used between the inner and outer surfaces of the drying chamber. A duct connected the south facing side of the drying chamber to an opening in the air heater. Four reflector plates welded inside the duct of the drying chamber directed the drying air toward the trays. The bottom of the drying chamber was 100×80 cm and the south facing side was 80 cm in height and the north end was 100 cm in height. A door was placed on the north side of the chamber for loading and unloading trays of dried material. Above the door, a 40×10 cm opening provided an adjustable air outlet. Five rails were placed 12 cm apart in the chamber to support the trays. The trays were made of Cr-Ni frames on all four sides with 0.65 cm stainless steel wire mesh on the bottom. The size of the trays was 90×70 cm. The five trays provided 3 m^2 drying surface area. The height of the drying chamber from the ground was 1.4 m. The air heater and drying chamber were connected with a 20 cm diameter flexible connector. A 600 W (220 VAC) centrifugal air blower was attached to the inlet of the air heater. A manually adjustable flap was fabricated and attached behind the air blower outlet to adjust the air velocity at the drying chamber inlet.

Statistical experimental design and drying experiments: Response Surface Methodology (RSM) was used to evaluate the effects of drying air velocity and number of slices on drying time and properties of red pepper. In the design it was assumed that a second order polynomial equation would represent the drying operation.

$$y = b_0 + b_1x_1 + b_2x_2 + b_{11}x_1^2 + b_{22}x_2^2 + b_{12}x_1x_2$$

Where, y is the predicted response and b_0, b_1, b_2, b_{11}, b_{22}, b_{12} are the coefficients and x_1, x_2 are the air velocity and number of slices factors, respectively.

Optimization was performed for minimizing the drying time, maximizing the ascorbic acid (Vitamin C) content and the extractable color. Five levels of air velocity (0.5, 1, 1.25, 1.5 and 2 m sec^{-1}) and five levels of the number of slices (2, 4, 5, 6 and 8 pieces) were used as the independent variables for the optimization. The experimental design was created with ECHIP experimental design software (ECHIP Inc., Hockessin, Del., USA). The design resulted in a total of 16 experimental runs; 11 of these were unique combinations of the independent variables and 5 were replicates (Table 1).

The experiments were conducted between September 4 and October 10, 2003, in Sanliurfa, Turkey. The solar collector and the drying chamber were moved to the top of a concrete roof about 7 m above ground level. There was no shading due to trees, buildings or other structures around the collector throughout the experiment process. The collector was oriented to the south with an angle of 10° and the angle between the collector and the ground was 34.

Sample preparation: The fresh peppers were purchased from a local produce market, sorted and washed with tap water. Before the peppers were sliced, five peppers were randomly picked and their lengths, widths and thicknesses were measured using a caliper. The average length, width and thickness of the peppers were 9.14 cm,

Table 1: Experimental design to determine the optimal air velocity and number of slices on solar drying time and the quality parameters of the dried pepper

		Max. drying air	Min. drying air	Control			Response		
Trial[a]	Run[b]	T. (°C)	T. (°C)	Air velocity (m sec^{-1})	No. of slices (piece)	Diurnal drying time (h)[c]	Total drying time (h)[d]	L-ascorbic acid (mg/100 g)	Extractable color (ASTA)[e]
1	2	62.1	36.3	0.50	5	14.0	29.0	20.62	234.52
1	3	58.0	29.7	1.25	8	15.3	30.3	21.65	425.22
2	8	63.5	33.5	1.00	2	21.5	51.4	27.18	184.50
2	10	55.1	38.0	2.00	6	13.4	44.0	30.06	243.54
3	2	61.5	35.3	0.50	5	16.6	47.0	23.13	202.54
3	7	53.8	32.0	1.50	2	18.0	50.0	15.48	368.18
4	6	63.8	29.1	0.50	2	12.6	28.1	27.77	224.68
4	11	60.1	29.3	1.00	6	18.0	33.0	30.88	172.20
5	3	56.7	29.0	1.25	8	13.3	44.3	33.93	170.92
5	4	52.5	32.3	2.00	8	21.4	50.4	23.13	191.27
6	9	54.0	32.0	2.00	4	13.5	27.5	29.44	405.04
7	1	64.3	38.0	0.50	8	13.2	44.4	24.20	196.18
8	4	52.1	33.2	2.00	8	14.4	45.4	22.92	191.32
9	5	51.9	26.0	2.00	2	13.8	28.2	21.10	219.60
10	5	62.7	26.0	2.00	2	21.6	68.0	21.80	227.60
11	1	62.5	33.5	0.50	8	25.6	72.0	23.23	181.94

[a]Trials with different number indicates the unique set of experimental conditions, [b]Run shows the order in which the experiments were conducted, [c]Shows the total No. of hours that the air blower was on. excludes the night hours, [d]Indicates the total drying time including the night hours and [e]ASTA (American Spice Trade Association) unit

4.01 cm and 2.47 mm, respectively. The stems and seeds of the peppers were separated and discarded. Depending on the experiment number, the peppers were sliced into 2, 4, 5, 6 or 8 pieces. The peppers were sliced longitudinally for all of the experiments except the experiments with 8 pieces. To dissect a pepper into 8 pieces, it was first sliced longitudinally into 4 equal pieces, then each piece was halved. The experiments in the design were completely randomized and were conducted in the order shown in Table 1. The average maximum and minimum air temperatures at the drying chamber inlet for each trial are shown in Table 1. The average maximum and minimum drying air temperatures that were measured at the drying chamber inlet during the drying period (September 4 and October 10, 2003) were 58.4°C (±4.6°C) and 32.1°C (±3.7°C), respectively.

Measurements and analyses: There were 5 trays in the drying chamber, each having 0.6 m^2 of surface area. For each experiment, 5 kg of pepper was dried in the drying chamber. After slicing the peppers, 200 g of fresh sliced pepper was placed in an air tight plastic bag and placed in a freezer for the analyses of initial moisture content, ascorbic acid content and extractable color. The peppers were weighed and exactly 1 kg was spread on each tray with the inner surfaces of the peppers facing upward. The temperatures and relative humidity levels of the ambient air, the air at the drying chamber inlet and outlet were measured using a Hygro-Thermometer sensor (Extech Ins.-Model 444701). An anemometer (Extech Ins.) was used to measure the ambient wind velocity and the air velocity at the drying chamber inlet. Incident solar radiations on the ground and on the solar collector surface were measured using a pyranometer (Apogee Ins., Model PYR silicon pyranometer). The weight of each tray of peppers was measured once every two-three hours during the daytime. Drying continued until the weight of the peppers on the trays decreased to less than 200 g (20% below the initial weight). Once the weight of the peppers decreased to less than 200 g, the peppers on each tray were collected and put in separate air tight plastic bags. The experiment number and the tray numbers were marked on the bags and kept in a freezer for the analyses of ascorbic acid (Hisil, 1993) and extractable color (Anonymous, 1985).

RESULTS AND DISCUSSION

During the experiments, the temperature difference between the ambient air and the air at the solar collector exit was a minimum of 8.5°C and a maximum of 19.4°C. These differences are mostly due to the air velocity used for each experiment and the time of the day the measurements were taken. The temperature difference between the ambient air and the air at the collector exit was high for the experiments where the air velocity was set to the minimum (0.5 m sec^{-1}). This makes sense because the lower air velocity increased the residence time of the air in the solar collector and increased its exposure to the solar collector plate and sun light.

The dried red peppers were visually observed after each experiment. Samples from five experiments, where the number of pepper slices were 2, had moulds. This was an expected result because the less the number of slices, the larger the slice size and the longer the drying time. Red peppers with non-uniform shapes and large sizes extend the drying periods which allows the mould developments in the end product.

Data collected from the experiments were analyzed using ECHIP experimental design software. Analyses were conducted to fit the experimental data on the drying time, ascorbic acid content and extractable color level of the samples. The effects of air velocity and the number of slices on drying time, ascorbic acid and extractable color of the red peppers were determined using response surface experiments (Table 2). The number of pepper slices had a significant linear effect on both the diurnal drying time and the total drying time ($p<0.001$). It also had a significant quadratic effect on both the diurnal drying time ($p<0.01$) and the total drying time ($p<0.001$). Air velocity and the number of slices had a linear effect on the total drying time ($p<0.01$).

Levels of the control variables providing the optimums for the dependent variables are summarized in Table 3. The contour and 3D plots of diurnal drying time as a function of air velocity and the number of slices is shown in Fig. 2. The maximum diurnal drying times from the experiments were between 13.2 and 25.6 h. The air velocity and the number of slices providing the minimum diurnal drying time found to be 1 m sec^{-1} and 6 slices. The processing conditions in trial 8 (1 m sec^{-1}, 6 pieces) were

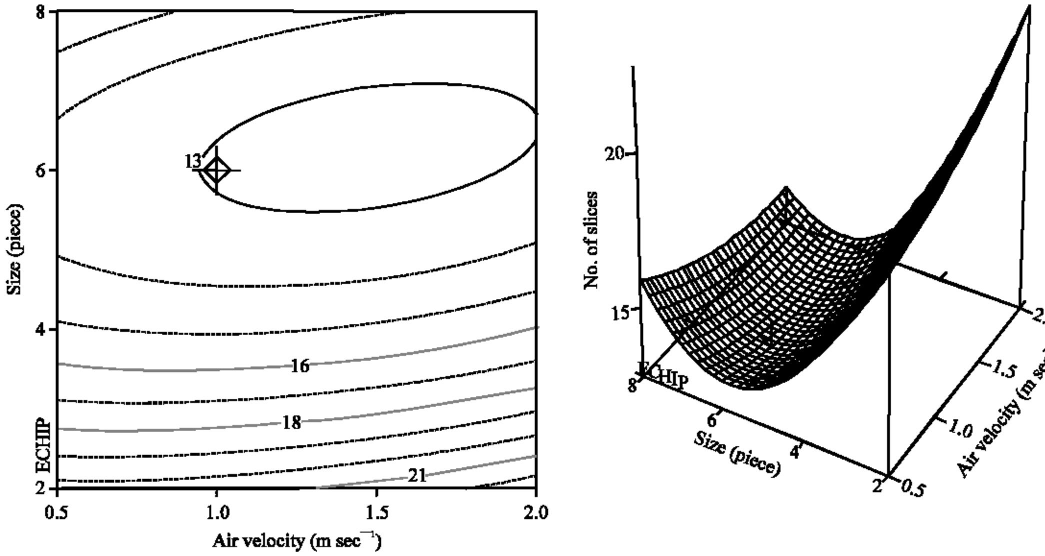
Table 2: p-values for the test statistics from analyses of variance

	p-values			
Parameter	Diurnal drying time (h)	Total drying time (h)	Ascorbic acid (mg/100 g)	Extractable color
Air velocity (m sec^{-1})	0.8758^{NS}	0.1121^{NS}	0.7627^{NS}	0.4265^{NS}
Number of slices	0.0005***	0.0001***	0.4945^{NS}	0.7524^{NS}
Air velocity×No. of slices	0.2106	0.0056**	0.5471^{NS}	0.6583^{NS}

, * Correspond to 0.01 and 0.001 significant levels, respectively. NS: Not significant

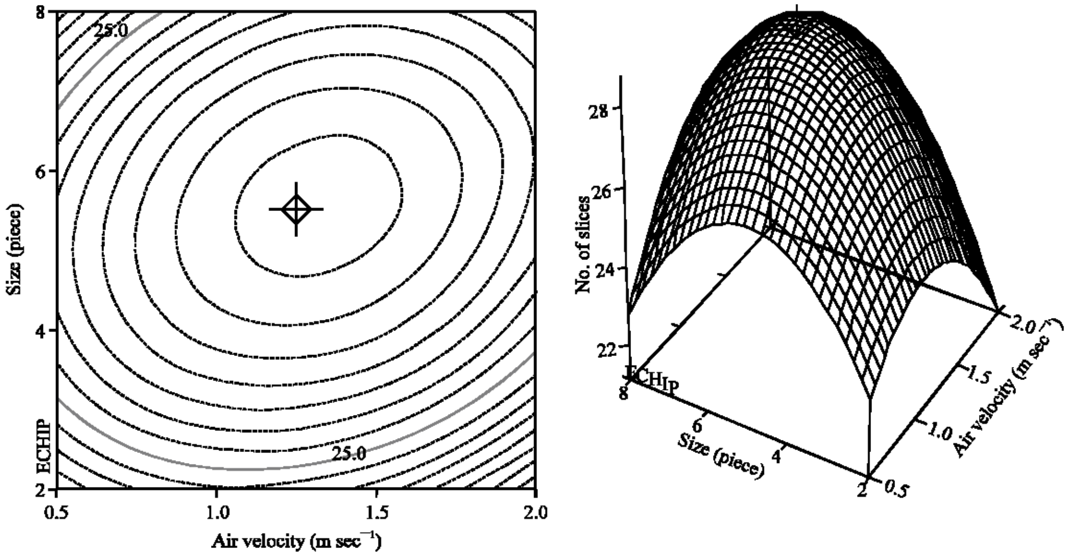
Table 3: Optimal conditions for providing the minimum diurnal and total drying times and maximum ascorbic acid content and extractable color level

	Optimal response				
Control variables	Min. diurnal drying time	Min. total drying time	Max. ascorbic acid level	Max. extractable color	Combined optimum
Air velocity (m sec^{-1})	1	1.19	1.3	1.5	1.31
No. of slices (piece)	6	5.72 (~6)	5.53 (~6)	4.53 (~5)	5.46 (~5)



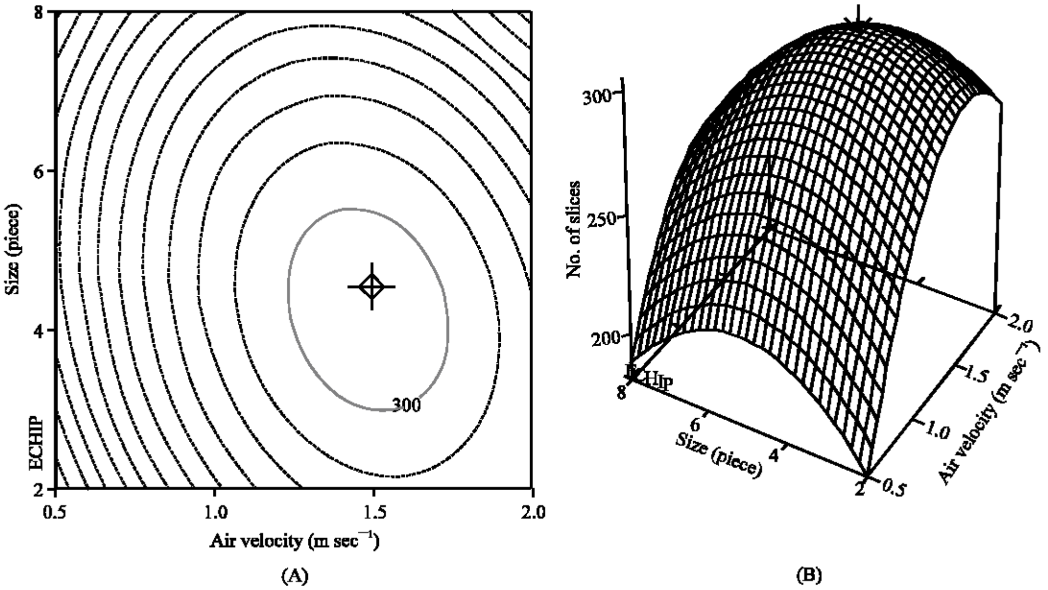
(A) (B)

Fig. 2: Contour plot (A) and 3D view (B) of diurnal drying time as a function of air velocity (m sec^{-1}) and the number of slices. The minimum diurnal drying time was found to be at air velocity of 1 m sec^{-1} and 6 pieces



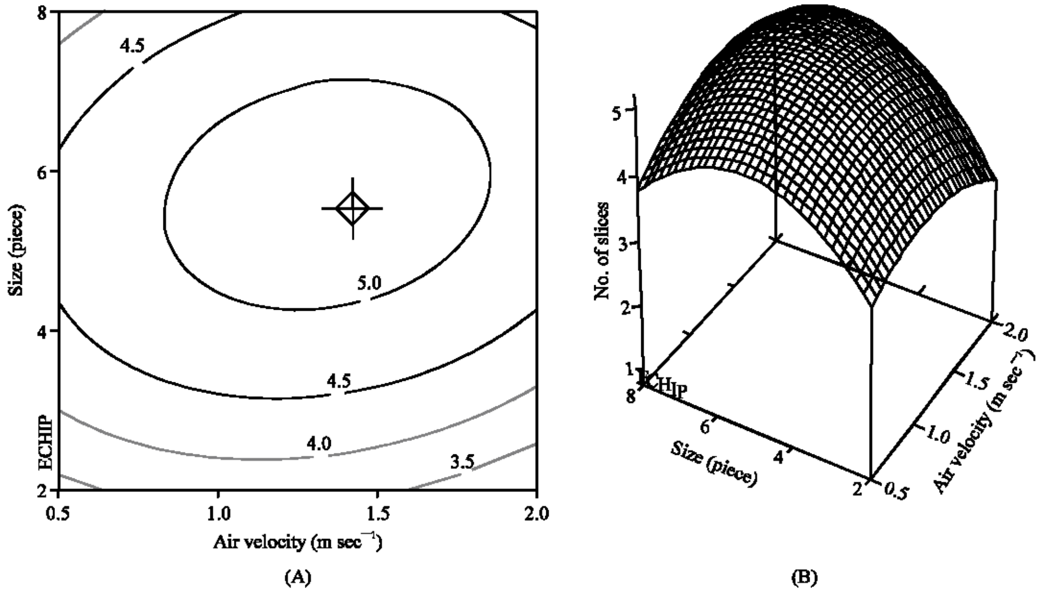
(A) (B)

Fig. 3: Contour plot (A) and 3D view (B) of ascorbic acid level as a function of air velocity (m sec^{-1}) and the number of slices. The maximum Vitamin C content was found to be at air velocity of 1.25 m sec^{-1} and 5.5 (~6) pieces



(A) (B)

Fig. 4: Contour plot (A) and 3D view (B) of extractable color values as a function of air velocity (m sec^{-1}) and the number of slices. The maximum extractable color value was found to be at air velocity of 1.5 m sec^{-1} and 4.53 (~5) pieces



(A) (B)

Fig. 5: Contour plot and 3D view of the common optimum as a function of air velocity (m sec^{-1}) and the number of slices. The (+) sign in contour plot and the down arrow sign in 3D plots show the optimums

similar to the optimal conditions determined from the quadratic model and provided the minimum diurnal drying time. The predicted minimum diurnal drying time at the optimal conditions was found to be 12.95 h (7.81-18.08 h in 95% confidence interval) using the developed model. Under the same conditions, the actual diurnal drying time was 18 h which is in the 95% confidence interval of the predicted optimum.

Figure 3 shows the contour and 3D plots of ascorbic acid (Vitamin C) contents based on the air velocity and the number of slices. The optimal air velocity and the number of slices providing the maximum ascorbic acid content were found to be 1.25 m sec^{-1} and 5.5 (~6) pieces. Figure 4 shows the contour and 3D plots for the extractable color values based on the air velocity and the number of pepper slices. The optimal air velocity and the optimal number of pepper slices providing the highest extractable color values were found to be 1.5 m sec^{-1} and 4.53 (~5) pieces.

The ECHIP software enables the user to define a combined response variable which can be created as a weighted sum of all the responses. In the combined response all or some of the individual responses can be included and their weight can be assigned between 0 and 1. With that, running the software for analyses provides the overall optimum conditions for the responses. The overall optimum for the combined response could also be determined by superimposing the individual contour plots and by finding the intersection of the plots. The conditions providing the optimum combined response were determined to be 1.31 m sec^{-1} and 5.65 (~6 pieces). Figure 5 shows the contour and the 3D plots for the combined response.

CONCLUSIONS

A forced convection solar dryer was used to analyze the effects of air velocity at the inlet of the drying chamber and the number of pepper slices on the drying time, ascorbic acid content and the extractable color level. The air velocity and the number of slices had significant effects on the drying time but did not show significant effects on neither the ascorbic acid content nor the extractable color value. Drying experiments with low number of pepper slices took longer time to dry compared to the experiments with high number of pepper slices. Mould development was also observed on the samples from the experiments where the number of pepper slices was low. Response surfaces methodology was successfully applied to determine the optimal air velocity and number of pepper slices resulting in minimum drying time, maximum ascorbic acid level and maximum extractable color using a solar dryer.

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