Investigation of Solar Drying Characteristics of Fresh Carrot Slices

[1]Dr Khan Chand, [2]Dr Vikono Ksh and [3]Dr Anupama Bora

[1]Department of Agricultural Engineering, School of Agricultural Sciences, Nagaland University, Medziphema campus-797106, District: Chumukedima

[2&3]Department of Vocational Studies and Skill Development, School of Agricultural Sciences, Nagaland University, Medziphema campus-797106, District: Chumukedima

Abstract:
The carrot root is considered as one of the most delicious and luscious roots and is highly nutritive. Solar drying is also preferred over mechanical and microwave drying because in these methods the nutritive value of the dried product is inferior to the solar dried product, also the texture in solar dried product is maintained whereas it gets destroyed in microwave drying. Carrots are one of the most commonly used vegetables for human nutrition due to high vitamin and fibre content. Dried carrots are used in dehydrated soups and in the form of powder in pastries and sauces. All the investigations were carried out in controlled solar dryer. The mean value of initial moisture content of fresh carrot slices was found to be 600.73 % (db). Moisture content of dried carrot slices varied from 8 to 10 % (db). It indicates that drying reduced the weight of carrot slices to nearly one sixth of its original value. The moisture content of 0.176g/cm^2, 0.256g/cm^2 and 0.353g/cm^2 loading densities decreased from 700% to 1%; 662.7% to 0.77% and 552.17% to 1.08%, to the equilibrium moisture content. The change in colour (ΔE) was minimum for 0.176g/cm^2 loading density at 50°C hence showing maximum color retention of the final product. The drying rate was faster at higher temperature and decreased with drying time. The decrease in drying rate with period of drying time was non-linear.

Keywords: Carrot roots, solar drying, moisture content, loading density, colour and drying rate.

INTRODUCTION

Carrot (*Daucus carrota* L.) belongs to the family Apiaceae. Carrot is a popular cool season root vegetable cultivated in temperate countries mainly during spring and summer season while in tropical region during winter season (Thamburaj and Singh, 2005). The most commonly eaten part of a carrot is the taproot, although the greens are edible as well. India's production statistics show an annual production of 3.5 lakh tons ranking 14th position in terms of production (FAO, 2008). The area under carrot cultivation in India is 22,538 ha (Thamburaj and Singh, 2005), Uttar Pradesh, Assam, Karnataka, Punjab, Haryana and Madhya Pradesh being the major carrot producing states. The drying of carrot is an important aspect for its value addition. The preservation methods, such as dehydration, canning and pickling can be successfully adopted to preserve carrot for the off-season and processing them into dehydrated products is the best option. Dehydrated carrot in the form of gratings can be used in the preparation of slice/chips, gajar halwa with skim milk, sugar and other ingredients. Carrot requires a long growing season and its harvesting period is limited. Hence, there is a need to preserve carrots for use in off-season. There are many preservation/processing methods i.e. drying, dehydration, storage, freeze drying etc out of these methods, drying is most appropriate as it makes the product suitable for storage and protects them against micro-organisms. The main principle of preservation by dehydration process is to remove the moisture content to a level where micro-organism activities are checked and hence degradation in quality is controlled. Drying and dehydration of carrots can be suitably carried out by sun drying, solar drying, mechanical drying, microwave drying etc.

In sun drying, somebody has to stay throughout the drying period to chase off domestic animals, to remove the produce when the weather becomes too windy and dusty, or when it rains, the dried product is often of poor quality as a result of grit and dirt and the product is often unhygienic as a result of microorganisms and insects such as flies. Therefore, solar drying is better method for drying. Solar drying is also preferred over mechanical and microwave drying because in these methods the nutritive value of the dried product is inferior to the solar dried product, also the texture in solar dried product is maintained whereas it gets destroyed in microwave drying (Mohanraj and Chandrasekar, 2007). Advantages of solar drying include faster drying because inside the dryer it is warmer than outside, less risk of spoilage because of the speed of drying. If the drying process is slow the fruit start to ferment and the product gets spoiled, the product is protected against flies, pests, rain and dust, it is labour saving. The product can be left in the dryer overnight or during rain, the quality of the product is better in terms of nutrients, hygiene and colour. It is important to determine the drying kinetics because the drying kinetics is often used to describe the combined macroscopic and microscopic mechanisms of heat and mass transfer during drying, and it is affected by drying conditions, types of dryer and characteristics of materials to be dried. Hence, they are essential for equipment design, process optimization and product quality improvement.

MATERIALS AND METHODS

One of the most fundamental unit operations carried out in the food industry is drying, it is done for reducing the moisture content of perishable produces to extend their shelf-life. The experiment was planned to study the drying characteristics of carrot and also to see the effect of temperature and loading density on colour of dried carrot slices in a solar dryer. Drying of carrot was carried out in a solar dryer.

Experimental Plan

On the basis of literature review solar dryer was selected for drying of carrots to maintain the quality. Samples were subjected to different drying temperature ranging from 55-75°C. Full factorial design (Eqn 1) was used to evaluate total number of experiments given in Table 1.

Full Factorial Design (N) = V^k ..1

Where "V" shows levels and "K" indicates number of independent variables and we had 'V'=3 and 'K'=2

Table 1 Levels of Independent variables

SI. No.	Variable Parameters	Levels	Range
1.	Loading density (g/cm^2)	3	0.176, 0.265, 0.353
2.	Temperature (°C)	3	50, 60 & 70

Measurement of Variables

Air temperature

The temperature of the air was measured using thermometer (Sonar laboratory, capacity: 0-110°C, least count: 1°C) as well as digital temperature recorder (capacity: 0-200°C, least count: 0.1°C). The air temperature was controlled within ±2°C during the experiments by adjusting input voltage to heater using autotransformer.

Loading density

Loading density is defined as the ratio of mass of the sample and area of the tray in which sample is dispersed and evaluated by using Eqn 2.

$$\text{Loading Density} = \frac{M}{A} \quad ..2$$

Where, M = mass of the sample (g) and A = Area of the tray (cm^2).

Moisture content

Moisture content of fresh carrot slices was determined by oven dry method. Three samples each weighing 30g, 45g and 60g were kept in the oven at 105°C for 24 hours and final weight of sample taken after oven drying (Eqn 3). The initial moisture content of the samples was determined using the Associaton of Official Analytical Chemists Method (AOAC 934.06, 1990).

$$M_{db} = \frac{W_w}{W_d} \times 100 \quad ..3$$

Where, M_{db}= Moisture content percent on dry basis; W_w= Weight of water in the sample, (g); W_d = Weight of dry matter of sample, (g).

Equilibrium moisture content

Since equilibrium moisture content (EMC) is an integral part of equation which used for calculation of moisture ratio (MR), therefore calculation of EMC was done as per the method, in which last three moisture contents readings of drying experiment work considered. The equation given below was used to determine the equilibrium moisture content (Eqn 4) (Mujumdar, 1995b).

$$M_e = \frac{M_1 \times M_3 - (M_2)^2}{M_1 + M_3 - 2M_2} \qquad ..4$$

Where, M_1= Moisture content (%db) at time t_1; M_2= Moisture content (%db) at time t_2 and, M_3= Moisture content (%db) at time t_3; Moisture content should be considered with the following condition. $(t_3 - t_2) = (t_2 - t_1)$

Moisture ratio and drying rate

The moisture content of carrot was expressed in dimensionless form as moisture ratio (MR) with the following equation (5). (Erenturk *et al.*, 2004; Midilli, 2001).

$$MR = \frac{M_t - M_e}{M_o - M_e} \qquad ..5$$

Where, MR = Moisture ratio; M_t = Moisture content at particular time; M_O = Initial moisture content and, Me = Equilibrium moisture content.

Drying rate is defined as,

$$\frac{dm}{dt} = \frac{M_2 - M_1}{\Delta t}$$

where, Δt is difference in time.

Colour

The L*a*b* values was calculated for determination of the colour of carrots. L* is the luminance or lightness components, which ranges from 0 to 100, and a* (from green to red) and b* (from blue to yellow) are the two chromatic components which range from -120 to +120. These L, a, b values were used to calculate the required L*, a*, b* values by using formulae given below (Gnanasekharan *et al.*, 1992),

$$L^* = \frac{Lightness}{250} \times 100 \ ; \ a^* = \left(\frac{240a}{255}\right) - 120; \ b^* = \left(\frac{240b}{255}\right) - 120$$

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

Where, ΔE= colour difference between the fresh and dried sample

RESULTS AND DISCUSSION

The full factorial designed experiments were conducted to characterize the drying behaviour of carrot for three levels of temperature (50°C, 60°C and 70°C) having three levels of loading density (0.176g/cm^2, 0.265 g/cm^2, 0.353g/cm^2) in solar dryer at constant air velocity. The samples were dried to a safe moisture content of 4-6 % (db). The loss in weight was converted to corresponding moisture loss for calculating moisture content (db).

Drying Characteristics

The drying behavior of carrot was analyzed using the experimental data on moisture of product at various time intervals for different drying conditions. The samples were dried up to safe moisture content level from 4 to 6 % dry basis as reported (Suhaimi, 2013). for high moisture foods. The moisture content ranged between 759.95- 486.5 % (db) to 10.00-8.00 % (db) for fresh and dried carrot respectively. The final moisture content attained was considered to be safe as recorded (Baysal *et al.*, 2003). The samples were dried in the solar dryer at different set temperature to reach a safe level of moisture content. The moisture content, moisture ratio and drying rate for different time were compared for the different loading density and for different temperatures.

Moisture content

The initial moisture content was observed 600.73 % (db). The treated samples were subjected to drying at different temperatures in solar dryer. The variation in moisture content with drying time for treated samples in shown in Fig. 1 to 3, exhibiting a non-linear decrease of moisture content with drying time. Initially, moisture decreased rapidly and then the decrease in moisture slows down considerably. The minimum time was found to be 210 min for 0.176g/cm^2 loading density at 70°C and the maximum time was observed to be 390 min for 0.353g/cm^2 loading density at 50°C. From the graph it can be observed that for all the three temperatures the moisture content is falling rapidly in the beginning and as the moisture content decreases the rate of fall of moisture content also decreased and the curve becomes less steep.

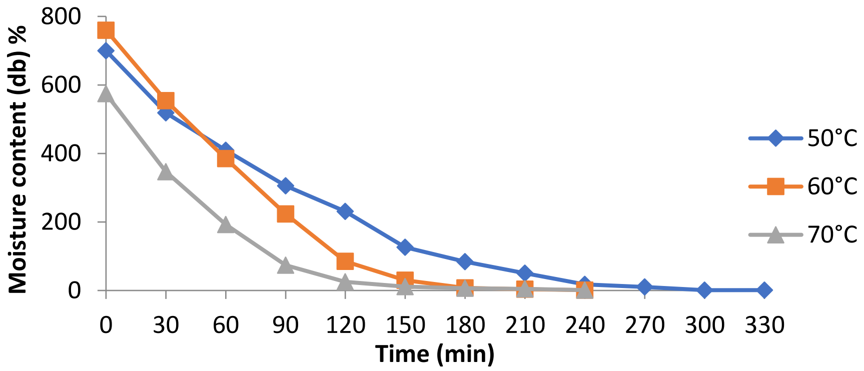

Fig. 1 Change in moisture content (% db) with time (min) for 0.176g/cm^2 loading density

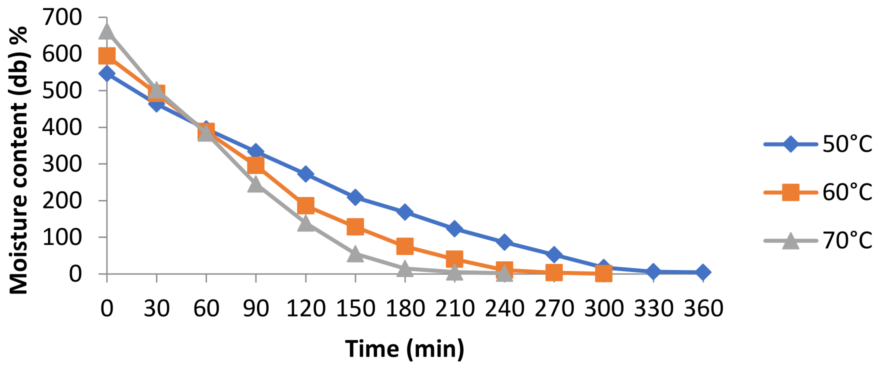

Fig. 2 Change in moisture content (% db) with time (min) for 0.265 g/cm^2 loading density

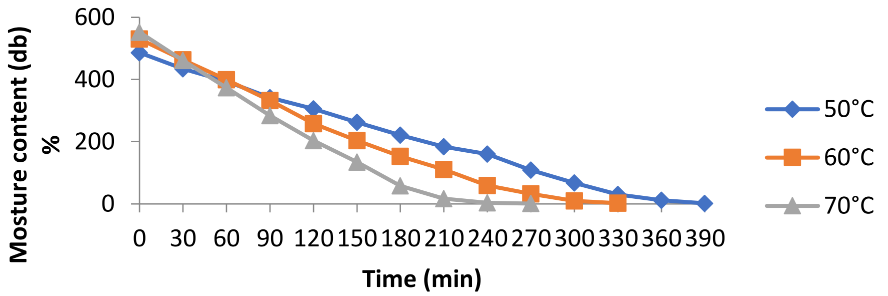

Fig. 3 Change in moisture content (% db) with time (min) for 0.353g/cm^2 loading density.

Average drying rate

The average drying rate represents the rate of change of moisture content (db) over a particular time of interval and is attributed to the middle of time interval. The average rate of drying is expected to decrease continuously with the increase in time, being faster at higher temperature except for constant rate drying conditions (Wang and Xi, 2005). The rate of drying was affected by temperature and loading density. The drying rate was faster at higher temperature and decreased with drying time. The decrease in drying rate with period of drying time was non-linear. It was observed that the drying rate was higher at higher temperature. The graph between drying rate and time has given below from Fig. 4 to 6.

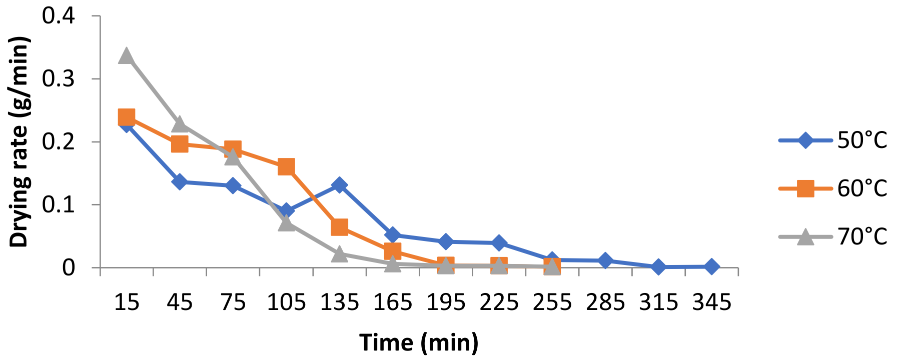

Fig.4 Change in drying rate with time for 0.176g/cm^2 loading density

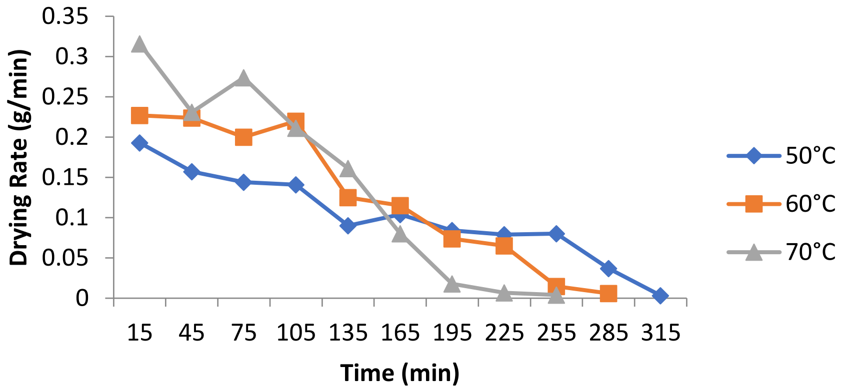

Fig.5 Change in drying rate with time for 0.265g/cm^2 loading density

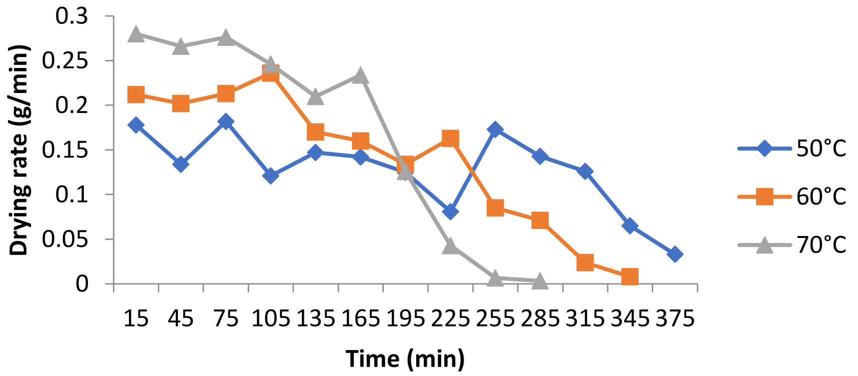

Fig .6 Change in drying rate with time for 0.353 g/cm^2 loading density

Drying Kinetics

Effect of drying condition on moisture ratio

The variation in moisture ratio with time for experimental range of temperatures (50-70° C) is shown in figure 7 to 9. The relationship shows that there was rapid decrease in moisture ratio with faster rate at initial stage of 60 to 120 minutes of drying; however, in later stage of drying the decrease in moisture ratio was at slower rate as moisture content approached to equilibrium moisture content. Moisture ratio curve for all the three levels of temperatures showed that the drying of 70°C was faster than other drying temperatures (Chand, 2024). Constant drying rate period was not observed in the drying curves and the whole process take places in the falling rate period. This shows that diffusion is dominant physical mechanism governing moisture movement in samples. Similar results were obtained by other authors working with other foods (Madhiyanon et al., 2009; Zielinska and Markowski, 2010).

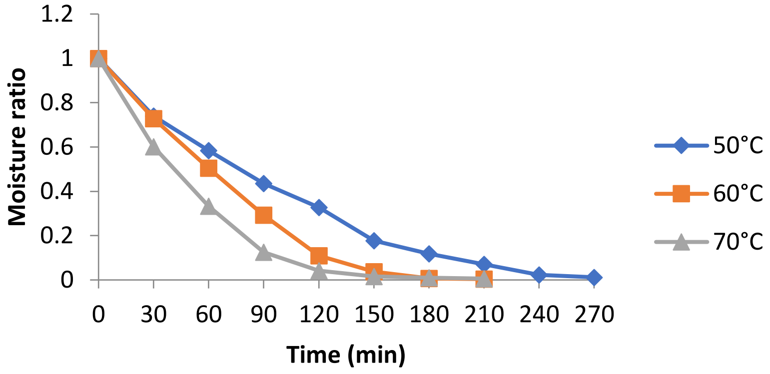

Fig 7. Change in moisture ratio with drying time in solar dryer for 0.176g/cm^2 loading density.

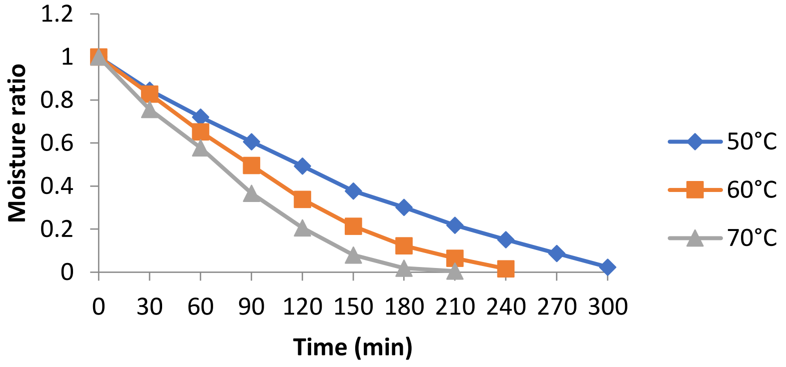

Fig.8 Change in moisture ratio with drying time in solar dryer for 0.265g/cm^2 loading density.

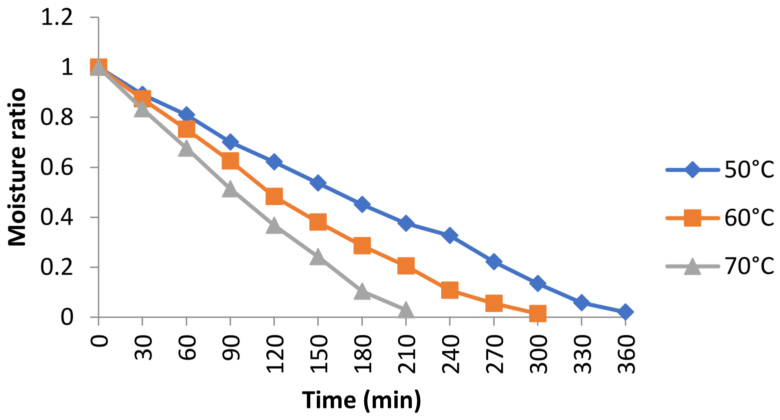

Fig .9 Change in moisture ratio with drying time in solar dryer for 0.353g/cm^2 loading density.

Colour

The colour of the product during storage is an important attribute, by which dried carrot slices were accepted for the consumption by human being. The data mentioned in the Tables (2 to 4) depicts that the maximum colour change occurred in carrot slices with 0.353g/cm^2 loading density at 70°C and the minimum colour change occurred in carrot slices with 0.176g/cm^2 at 50°C. The a* value decreased as the temperature increased indicating decrease in redness. The b* value decreased as the temperature increased indicating decrease in yellowness. The L* value decreased as the temperature increased indicating decrease in lightness. For the fresh carrots the L*a*b* values were calculated by the using the following relationship:

L* = 57.2; b* = 61.64 and a* = 58.8

The tables (2, 3 & 4) shows the variation of colour after drying at different temperatures for getting the best results of dried carrot.

Table 2. Results of L*a*b* and ΔE values for loading density 0.176g/cm^2

Temperature	Loading density	L*	a*	b*	ΔE
50°C	0.176g/cm	65.66	44.71	64.03	16.61
60°C		39.9	40.1	49.2	22.97
70°C		42	39.05	36.23	35.5

Table 3. Results of L*a*b* and ΔE values for loading density 0.265g/cm^2

Temperature	Loading density	L*	a*	b*	ΔE

50°C 60°C 70°C	0.265g/cm^2	46 44.7 43.84	61.6 40.22 34.67	55.05 45.2 35.62	17.72 23.73 37.91

Table 4. Results of L*a*b* and ΔE values for loading density 0.353g/cm^2

Temperature	Loading density	L*	a*	b*	ΔE
50°C 60°C 70°C	0.353g/cm^2	68.8 68.2 48.24	42.5 40 32.65	69.07 50.35 33.7	21.06 24.5 39.3

CONCLUSIONS:

It was concluded that most of the food products are exported in the form of dried products. Further, in order to increase the shelf life of the product like carrot, removal of water is essential. Therefore, due to the ability of solar drier to dry carrots reasonably and rapidly to a safe moisture content without effecting the colour to a reasonable level and any negative effect on the environment it can be used in developing countries to ensure proper drying of carrots for storage purpose and reduce the losses that occurs due to lack of storage facilities. The total colour change ΔE was minimum for 0.176g/cm^2 loading density at 50°C which shows maximum colour retention of the dried carrot product in 240 minutes.

REFERENCES:

1. AOAC Standard. (1990). Determination of the moisture content for dried fruits, Economc and social council, United Nation. 2P.
2. Baysal, T., Icier, F., Ersus, S., and Yıldız, H. (2003). Effects of microwave and infrared drying on the quality of carrot and garlic. *European Food Research and Technology*, 218(1): 68-73.
3. Erenturk, S., Gulaboglu, M. S., and Gultekin, S. (2004). The thin-layer drying characteristics of rosehip. *Biosystems Engineering*, 89(2): 159-166.
4. FAO (2008) Production year book, vol 55. Food and Agriculture Organization of the United Nations, Rome.
5. Gnanasekharan, V., Shewfelt, R. L. and Chinnan, M.S. (1992). Detection of Colour Changes in Green Vegetables. *Journal of Food Science*, 57(1): 149-192.

6. Khan Chand, (2024). Drying kinetics of Concentrated Malta Juice for production of Malta Powder. Goya Journal, 17(10):424-440.
7. Madhiyanon, T., Phila, A., and Soponronnarit, S. (2009). Models of fluidized bed drying for thin-layer chopped coconut. *Applied Thermal Engineering*, 29(14): 2849-2854.
8. Midilli, A. (2001). Determination of pistachio drying behaviour and conditions in a solar drying system. *International Journal of Energy Research*, 25(8): 715-725
9. Mujumdar, A. S. (1995b) Advances in drying, Volume II. Washington, Allyn and Bacon, Bosten.
10. Suhaimi, M. (2013). Review on the application of a tray dryer system for agricultural products. *World Applied Sciences Journal*, 22(3): 424-433.
11. Thamburaj, S. and Singh, N. (2005). Textbook of vegetables, tuber crops and spices. *Indian Council of Agriculture Research*, New Delhi, 151.
12. Wang, J., and Xi, Y. S. (2005). Drying characteristics and drying quality of carrot using a two-stage microwave process. *Journal of food Engineering*, 68(4): 505-511.
13. Zielinska, M., and Markowski, M. (2010). Air drying characteristics and moisture diffusivity of carrots. *Chemical Engineering and Processing: Process Intensification*, 49(2): 212-218.