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Effect of Indirect Solar Drying by Airflow Orientation on Some Physicochemical Parameters of Mango (*Mangifera Indica*)

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Abstract: The present research aims to study the effect of indirect solar drying by airflow orientation on some physicochemical parameters of mango. The mangoes harvested at physical maturity were exposed in the drying chamber. The temperature and humidity sensors were placed inside and outside the dryer. For different airflow modes (surface airflow mode, direct airflow mode and crossed airflow mode). Temperature, humidity, irradiance and mass loss readings were taken on two mangoes samples. Acidity, pH, moisture and vitamin C contents were determined on dried mango slices in different modes. The kinetics of drying shows that the moisture loss of mangoes is faster for thin slats. Times for drying are 17, 22 and 30 h, respectively for the licking mode, mixed and through. The conservation of physicochemical properties varies, respectively for 47.5, 43.8 and 33.02% for licking, mixed and through mode. The flux variation influences the physicochemical parameters of the dried mango.

Key words: Indirect solar dryer, mango, physicochemical parameters, temperature, moisture, pH

INTRODUCTION

Solar thermal energy has many applications, heating, cooking, cooling and drying (Tchaya *et al*., 2014). Thus, it is used in the agri-food sector for the preservation of foods whose unavailability is not appreciable. Solar thermal energy in the case of drying food is exploited by solar dryers, sometimes made locally. The purpose of these dryers is to dehydrate foods in order to favour their storage and availability over long periods (Rivier *et al*., 2009).

In Sub-Saharan Africa, 30% of the population is chronically malnourished (Heilporn *et al*., 2012). Many African countries do not live up to food self-sufficiency and rely on imports to ensure people's food security despite the fact that 70-80% of the population are farmers. Almost 50% of vegetables and fruits are lost for the fault of lack or poor conservation after harvest (Heilporn *et al*., 2012). In Cameroon, the mango is harvested during the months of May to June with 60% of losses after harvest.

Drying involves removing excess moisture from a product by evaporating the water it contains. It is one of the oldest food preservation processes with the primary goal of converting perishable foods into stabilized products. This phenomenon causes a lowering of the water activity of the product that is to say, the remaining water is less available for micro-organisms and for chemical reactions. In dehydrated foods, due to low water activity, micro-organisms cannot proliferate and most chemical and enzymatic deterioration reactions are slowed down (Rivier *et al*., 2009).

The drying of mangoes can contribute to the reduction of losses, the conservation and the availability of the product. It also reduces the volume of the product and therefore, facilitates storage and reduces transport costs. The shelf life can be extended when the products are suitably conditioned (waterproof, air and flavour packaging).

Drying can alter the product in texture, shape, taste or nutritional qualities. These modifications can be sought or they can be of disadvantage (Yaldyz and Ertekyn, 2001; Rivier *et al*., 2009).

But one of the major problems related to the drying of food stuffs is the consumption of energy. Moreover, the agri-food industries generally devote nearly 60% of its energy consumption to drying (Rivier *et al*., 2009). The solar dryer can be a cost-effective solution to this problem as the energy source is available, free and clean.

Mango, originally from India was introduced in Africa and Brazil in the 16th century. This fruit is of variable size and shape, more or less flattened laterally and very different in weight depending on the variety. Generally, produced in the rainy season, mango is a fruit whose chemical composition (carbohydrates, fibers, mineral matter, vitamin C, etc) is varied and rich. However, drying process can degrade most of

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these nutritional values. Thus, this research aims to study the effect of airflow orientation on some physicochemical parameters of mango during indirect solar drying.

MATERIALS AND METHODS

Plant material; Ripe mango: Ripe mango studies were conducted on Haden variety mangoes (Fig. 1). They were picked at physical maturity in the MAKA orchard in the far-North Region of Cameroon, Diamare division in the city of Maroua.

Haden variety mangoes have a beautiful presentation; they have a reputation for being fragile and require rapid marketing. In addition, it is one of the first seven varieties of mangoes consumed on the fifteen varieties identified in the city of Maroua.

They were picked 3 or 5 months after flowering. Still in the mature green state, the control of its evolution is assured. After 10-11 days of storage, they were dried. To obtain the pulp, trimming operations (washing, peeling and coring) were carried out. Drying is performed on samples cut into strips (Fig. 2).

Measuring equipment: Data acquisition is done by an acquisition station (ALMEMO). It allows storing the drying parameters with the appropriate sensors every 5 min. From the sensors of temperature, humidity and irradiance, the measurements of the parameters were made for drying days.

Protocol for drying mango: Figure 3 (Goyal *et al.*, 2006) describes the process we used to dry the mango samples.

Mass measurement in discontinuous: The measurement of the mass in discontinuous is carried out to evaluate the quantity of water evaporated. It is done at regulars intervals of time. The product is spread in the tray and the measurements are taken every 5 min. As soon as the mass variation between two successive taps is small, the time interval between mass taps increases. So, on until a significant change in mass is no longer observed.

The solar dryer was exposed to the sun at 8 am. The products in slices to be dried were placed on the trays in an indirect solar dryer which allows the variation of the air flow in the drying chamber (Tchaya *et al.*, 2014). A set of six tests were performed for three airflow modes in the drying chamber (through, licking and mixed) and two thicknesses of the product (2.64 and 1.38 mm). The average density of loading is 0.11 gcm^{-2}.

(a) (b)

Fig. 1: (a) Mango with physical maturity (left) and (b) mango with commercial maturity (right)

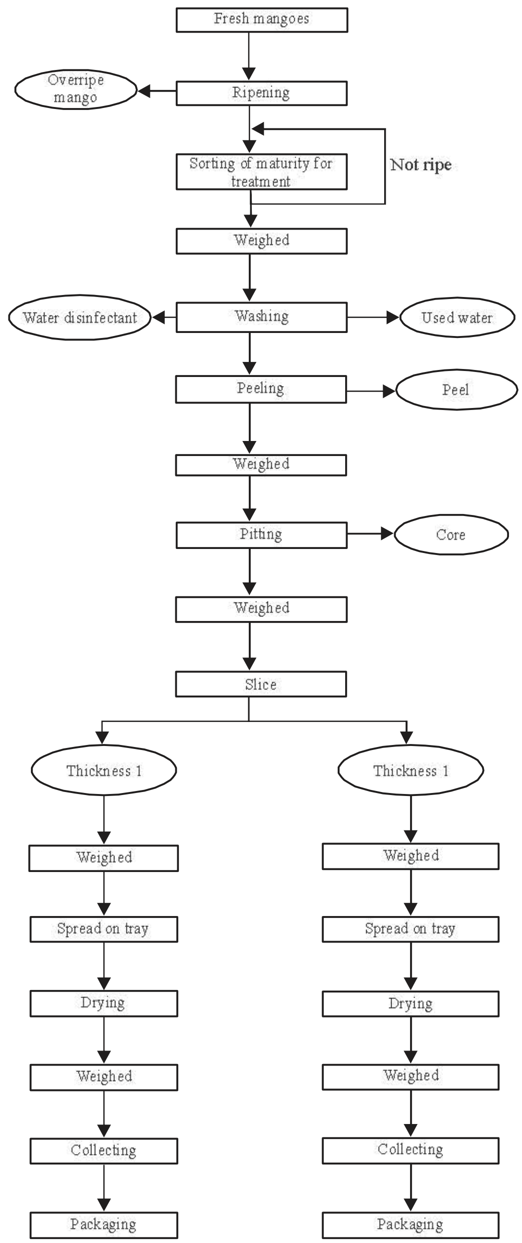

Fig. 2: Protocol for drying mango

Determination of the physicochemical parameters of dried mango

Moisture content: The moisture content was determined by the method of Association of Official Analytical Chemists (AOAC). A quantity of weight sample P1 is placed in the "Memmert" oven at a temperature of 105°C. Weighed regularly using a precision balance until a constant weight is obtained. While bringing out the oven, the dry product is placed in a desiccator containing the silica for 30 min. Its weight P2 is determined:

$$\text{The water content} = \frac{P1\text{-}P2}{P1} \times 100 \qquad (1)$$

Trials were performed in triplicate.

Vitamin C content: The method used is that using 2-6 dichlorophenol indophenol.

Operating mode: Weigh 3 g of sample and mix with 5 mL of 90% acetic acid in a mortar. Transfer the extracts to a 50 mL volumetric flask and add with distilled water. Filter with Whattman No. 1 paper and record the volume of the V_T filtrate.

Titration: Put the standard vitamin C solution in a burette, 1 mL of the colored indicator and a drop of 90% acetic acid in an Erlenmeyer flask and record the volume V_1 of this standard vitamin C solution needed to decolorize 1 mL of 2, 6 dichlorophenol-indophenol. Repeat the titration using the solution extracted from the sample and record the Volume V_2 of this solution necessary to decolorize 1 mL of 2, 6-dichloropheno l indophenol. Assuming the concentration of standard vitamin C and 2, 6 dichlorophenol-indophenol of 1 mg/100 mL and 0.1 gL^{-1}, respectively, calculate the vitamin C content by applying the following equation:

$$T = \frac{V_1 \times V_T}{V_2 \times M} \qquad (2)$$

T : Vitamin C content (mg/100g)
V_1 : Standard vitamin C volume (mL)
V_T : Volume of filtrate (mL)
V_2 : Sample volume to discolour the colored indicator (mL)
M : Mass of the test sample (g)

The test is repeated three times for one sample.

Titratable acidity and pH test: The titratable acid content is the quantity of acid (low and high) present in a product.

Principle of determination: For titratable acidity, the product is first diluted if the concentration of organic acids is high. A portion of the diluted solution is then titrated with a standard NaOH 0.1 N solution in the presence of an indicator (Phenolphthalein). In general, the pH is determined by potentiometry method using a pH meter.

Operating mode: About 5 g of dried mango crushed material are introduced into 50 mL of hot distilled water (50-60°C) contained in a flask becher of 100 mL. After homogenization of the contents, the flask becher is refluxed in an oven for 15-30 min. After cooling the centrifuged contents to 3000 rpm for 15 min, the residue is rinsed with distilled water and the volume is made up to 100 mL with distilled water. The pH was determined at this level by a pH meter. A 25 mL sample is diluted with 25 mL of distilled water and titrated with NaOH 0.1 N. The total acidity level is calculated using the following relation:

$$\frac{\left(N \times V \times V_t \times M_{eq}\right) \times 100}{VP \times PE} \qquad (3)$$

Where:
% : Total acidity of the sample (%) citric acid
N : The 0.1 N (normality of NaOH)
V : Volume (mL) of NaOH poured into the sample
PE : Test sample (0.5 g)
M_{eq} : Milli equivalent of citric acid (0.070)
V_t : Total volume (mL) of the stock solution of the sample
VP : Volume (mL) taken for titration

The test is repeated three times for one sample.

Statistical analysis of the results: The results of analyzes were presented as mean±standard deviation. Data on the composition of samples were analyzed by one-way Analysis of Variance (ANOVA). The Statistical Package for Social Science (SPSS) Version 16.0 was used for data analysis. Differences between samples were tested according to Tukey test and considered to be significant when $p<0.05$.

RESULTS AND DISCUSSION

Results of measurements of the external and internal parameters of the dryer: The average ambient dryer parameters during the month in which the experiments were conducted are as follows: mean temperature is 29.8±1°C, mean relative humidity is 36.6±2.4 and mean irradiance is 633±12 Wm^{-2}. Table 1 presents the parameters in the dryer loaded by the mango slices. The drying air temperature is between 30.5 and 62.55°C. It is a range that is above average for the ambient temperature.

Presentation of dried mango: The solar drying of mango variety Haden, minced into slices, allowed us to obtain soft strips, yellow-orange and above all not crusted. They are flexible and do not stick to touch (Fig. 4 and 5).

The dimensions of the fresh and dried slices are presented in Table 2. The results of the study of the dimensions of the dried mango slices shows a reduction of the thickness at a rate of 67.83±6.57% and 38±0.79%, respectively for the thicknesses of 1.38 and 2.64 mm of fresh mango. This drop in thickness between the fresh lamellae and the dried lamellae is explained by the effect of dehydration. The loss of thickness is greater on the thickness of 2.64 mm because at this thickness, the coverslip contains more water compared to that of 1.38 mm, for identical surfaces of lamellae.

The masses of the fresh and dried lamellae as a function of the thicknesses and the air inlet modes and the corresponding mass losses are recorded in Table 3. The measurements made on 27 samples of each couplet (thickness, drying mode) show that: for the crossing mode, the loss of mass is greater for the thicknesses of 2.64 than, the 1.38 mm. For the mixed mode, the mass losses are almost identical, so, the thickness variation would have no influence on the mass losses for this drying mode.

For licking mode, the mass losses are greater for the thickness of 1.38 mm. This could be justified by the fact that the slice of this thickness could have a greater hot air contact area than those of 2.64 mm. For the thickness of 1.38 mm, the mass losses are almost identical for the three drying modes. For the thickness of 2.64 mm, the loss of mass is greater in licking mode than in mixed mode. The drying mode, therefore has an influence on the loss of mass.

The losses of masses are explained by the fact of the dehydration, the lost mass is that of the evaporated water. On each trays taking an average of 300 g of fresh slices, after drying, a mass of 56.7 g is counted: a mean mass loss of about 81.1%. This mass reduction offered by solar drying could be a considerable asset for the technical and economical means of transporting mangoes.

Kinetics of drying of different tests: Figure 6 shows the moisture loss curves as a function of time for different flux mode and thickness of the mango slice. The curve characterizing the crossing mode, thickness 2 (in red) resembles that obtained during the electric drying of mango variety Kent. In addition, it respects the four phases of mango drying: the first phase corresponds to the temperature rise phase and lasts 3 h and the water content increases from 86-82% whereas previous works shows that for this phase, we observe a drop in water content of 80-75% in 4 h. The second phase corresponds to the

Table 1: Parameters in the dryer

Variables	Inlet temperature of the drying chamber (°C)	Relative humidity at the outlet of the drying chamber (%)	Outlet temperature of the drying chamber (°C)	Surface temperature of the absorber (°C)
Minimum value	31.8±1.2	20.8±1.3	28.5±0.6	33.3±0.6
Maximum value	69.3±2.6	63.5±2	52.8±2.1	72.3±0.9
Average	42.8±1.5	37.5±1	40.4±0.45	56.7±1.2

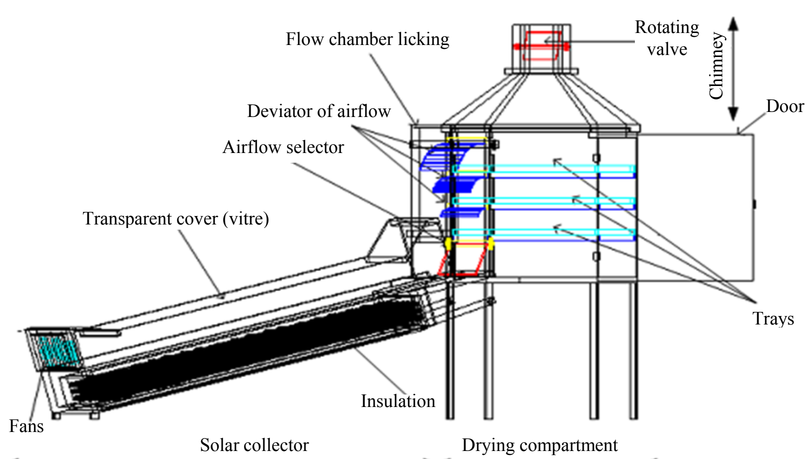

Fig. 3: Indirect solar dryer

evaporation of the free water; it is found that the water content rises from 82-55% in 5 h of time whereas the previous results shows a variation of 75-45% in 8 h of drying. The third phase describes a slowdown in the drying rate with a variation of the water content of 55-15% in 19 h against a variation of water content of 45-15% in 12 h according to the research of Djantou. The fourth phase corresponds to the evaporation of bound water. It is characterized by a drop in water content of 15-11% in 3 h against a variation of 15-12% in 4 h. These differences could be justified by the difference in lamella thicknesses, varieties used and the differences of the dryer used.

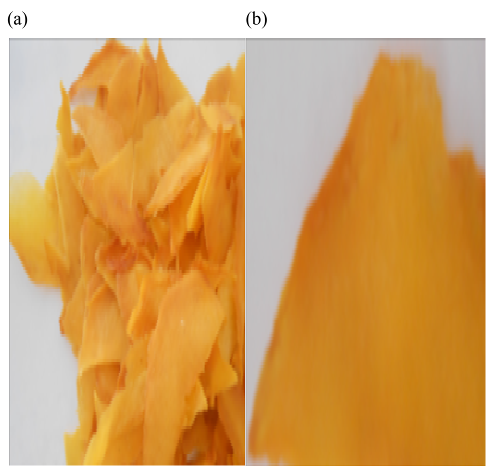

Fig. 4: Photo of dried mango (a) Pile of slices and (b) A slice

On the other hand, the characteristic curve of the licking mode, thickness 1 (in orange) and crossing mode thickness 1 (in blue) resembles that resulting from the research on dried mangoes in a wind tunnel.

Drying times ranging from 17-31 h are obtained depending on the thickness of the slat and the air inlet mode in the dryer. These results are superior to those of which have a drying time of 27 h of sunshine (3-4 days) for the drying of mango by direct drying. On the other hand, they are inferior to those by Heilporn *et al.* (2012) who have a drying time of 7-9 h using an indirect drier with gas booster.

Table 2: Dimensions of slices of fresh mangoes and dried slices

Fresh slices	Dried slices
Thickness of 1.38 mm	
Length	77.51±3.89
Width	26.12±2.91
Thickness	0.44±0.09
Thickness of 2.64 mm	
Length	77.05±3.63
Width	27.75±3.16
Thickness	0.47±0.02

Table 3: Mass of fresh and dried slats and mass loss for different drying modes and different thicknesses

Thickness (mm)	Crossing mode	Mixed mode	Licking mode
Fresh mangoes	**Mass (g)**		
E = 1.38	4.34±0.35	4.84±0.80	3.62±0.56
E = 2.64	3.71±0.49	6.38±0.80	5.76±0.86
Dried mangoes			
E = 0.44	0.83±0.12	0.99±0.16	0.66±0.13
E = 0.47	0.60±0.14	1.31±0.15	1.14±0.16
	Mass loss (%)		
E = 1.38	80.72±1.51	79.32±1.99	81.84±1.79
E = 2.64	84.10±2.36	79.52±1.25	80.11±1.16

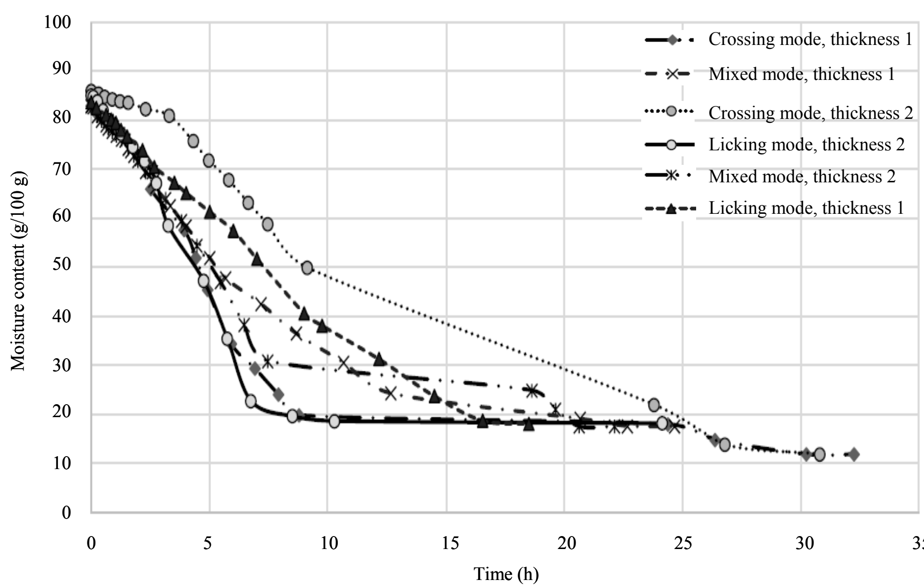

Fig. 5: Evolution of the moisture content as a function of time for various drying modes and various thicknesses

Table 4: Physicochemical composition of dried mangoes

Crossing mode	Mixed mode	Licking mode
Moisture content (g/100 g)		
11.84±0.01[a]	17.51±0.01[b]	18.07± 0.00[b]
Vitamin C (mg/100 g)		
12.02±1.07[a]	15.94±2.09[b]	17.28±0.23[b]
Total acidity (% citric acid)		
1.96±0.01[a]	3.30±0.04[b]	6.02±0.02[c]
pH		
3.1±00[a]	3.5±00[a]	4.0±00[a]

Mean values with different superscript letters in the same row are significantly different ($p<0.05$)

The results obtained from the different curves are such that the drying times are 17, 22 and 30 h, respectively for the licking mode, the mixed mode and the through mode. This is explained by the fact that in the through mode, the hot air at the entrance to the drying chamber is moistened by the dehydration of the bottom tray before reaching the middle and top trays.

Physico-chemical composition of dried mango: Table 4 shows the moisture content, the vitamin C content, the total acid content and the pH of the dried mango slices, respectively for the air intake modes in the dryer, namely the through, mixed and licking modes. The moisture content, vitamin C content, total acidity content and pH were determined from 14-29 days after drying.

The moisture content: The average moisture content of fresh mango is 81.3%. The results obtained after drying showed water contents of the dried mango of 11.84% for the through-drying mode, 17.51% for the mixed mode and 18.07% for the licking mode. The mode of drying has an influence on the water content of the final product.

These moisture contents are acceptable according to the national standard in Burkina Faso which fixes it between 12-18% and the research of Djantou had presented value is 17.75±1.20 for lamellae in an electric dryer.

Vitamin C: The fresh mango contains 36.4 mg of vitamin C/100 g. However, the results obtained with dried mangoes have vitamin C contents of 12.02, 15.94 and 17.28 mg/100 g, respectively for the through, mixed and licking drying modes. That is a conservation of vitamin C levels of 33.02, 43.8 and 47.5%. Indeed vitamin C is a the RMO sensitive substance and therefore, very unstable. The losses are due to drying temperatures and storage conditions.

To minimize losses of vitamin C during drying, the pretreatment time prior to raking must be reduced to limit slice contact with oxygen in the air. And storage must be done in sealed jars and protected from the air.

pH and total acidity: The acidity of the variety mango Haden is revealed by the results obtained. The analyzed samples have pH of 4, 3.5 and 3.1. For all three drying modes, the pH values are not significantly different. Kameni *et al.* noted a pH, ranging between 3.7 and 4.2 would increase with maturity and depend on varieties. These results show that the drying mode influences the pH of the product. The drying mode for having the highest pH is the licking mode with a value of 4.0.

Such pH values would be unfavourable to contaminations and the development of certain microorganisms but favourable to acidophiles. Studies made by Millogo show of 3.17 and 3.60. This difference could be due to differences in varieties used and drying equipment and even the degree of maturity of the samples.

The total acidity levels (% citric acid) are 1.96, 3.30 and 6.02, respectively for through, mixed and licking drying modes. These differences in results also show that the drying mode has an influence on the total acidity of the dried mango.

CONCLUSION

This study has shown that the mode of variation of the flux has an effect on the physicochemical parameters of the dried mango. Indeed drying times are 17, 22 and 30 h, respectively for the licking mode, mixed and through. Moreover, there is a conservation of physicochemical properties varying, respectively by 47.5, 43.8 and 33.02% for licking, mixed and through mode. It can also be noted that the thin slices dehydrate faster than those of great thickness. In perspective, we will study the values of the other constituents of dried mango (protein, lipid and β-carotene)

REFERENCES

Goyal, R.K., A.R.P. Kingsly, M.R. Manikantan and S.M. 2006. Thin-layer drying kinetics of raw mango slices. Biosyst. Eng., 95: 43-49.

Heilporn, C., B. Haut, A. Nonclerq and L. Spreutels, 2012. Design and operation of a mixed sun-gas solar dryer for mangoes in West Africa. Proceedings of the International Drying Symposium (IDS 2012), November 11-15, 2012, Xiamen, China, pp: 1-7.

Rivier, M., J.M. Meot, T. Ferre and M. Briard, 2009. [The Drying of Mangoes]. Quae, Versailles, France, ISBN:978-92-9081-421-4, Pages: 112.

Tchaya, G.B., M. Kamta and C. Kapseu, 2014. Improvement of an indirect solar dryer with forced convection by variation of air flow mode. Intl. J. Emerging Technol. Adv. Eng., 4: 518-522.

Yaldyz, O. and C. Ertekyn, 2001. Thin layer solar drying of some vegetables. Drying Technol., 19: 583-597.