STUDYING THE AFFECTING FACTORS ON DRYING RATES OF PLUM FRUITS UNDER VARYING DRYING AIR CONDITIONS

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Abstract: Thin-layer drying rates of plum fruits were determined experimentally under different controlled conditions of the drying air for estimation mathematically the affecting parameters on the drying time.
The results showed that cutting the plum fruits into two halves had the greatest effect on the drying rate, followed by the plums initial moisture content. The air temperature, the relative humidity of the drying air and the plums sugar content had a remarkable effect. The drying air velocity, the density of the plum fruits and the dipping time of the plum fruits in water at 100°C had the least effect.

Key words: Parameters estimation, controlled conditions & mathematical model.

1. INTRODUCTION

Food drying is an ancient process which humans copied from nature. The yearly amounts of the dried agricultural products in Egypt from 1985 to 1995 ranged between 4500 and 7000 tons, and between 16 million and 50 million L.E. respectively, CAPMS (1995). Also, the yearly amounts of imported dried plums in Egypt from 2000 to 2002 ranged between 461 tons and 547 tons, and between 4 million and 5 million L.E. respectively, FAO (2004).

Egypt is one of the countries which has favorable solar energy conditions well suited for solar drying.
It has a clear sky all year around except very few days during winter and spring equinox.

Determination of the time needed for accomplishing the drying process is difficult to achieve, especially in solar drying, due to the continuous variation in solar drying air temperature & humidity, the continuous changes in the moisture content of the drying fruit & vegetable and its tissue properties in conveying moisture.

However, this can be simplified if the drying rate is expressed as a function of these continuously changing affecting factors.

So, the problem of the present research work is the continuous changing conditions along the period of. the drying process. These conditions are also under continuous change through the different locations along the dryers. Besides, the drying rate does not have a constant value, rather it starts with a rising value, then it stays constant for a period of time, then it has a falling value. All these factors make it difficult to determine the volume of air needed for any drying process, the energy requirement for the process, the time duration of the process, and the most suitable values for the affecting factors to accomplish a successful drying process.

It was found that it is better to utilize a locally designed and fabricated special apparatus in the Post harvest Department, Institute of the Agricultural Engineering, (ATB), Potsdam, Germany, which can be used as an experimental apparatus to determine the impact of the affecting factors on the drying process of fruits and vegetables. Using this experimental apparatus, the affecting factors may be controlled to give all the expected variations during the solar drying process, which followed thin-layer drying.

this research plan carried out an attempt to study the factors affecting drying rate of plum fruits under controlling conditions for the drying air and to derive the mathematical equations which could directly determine the time needed for the drying process as a function of the affecting factors on drying rate. This was completely based on empirical data, and was done by applying the multiple linear regression analysis on all the data collected from the whole experimental work of this research, in order to express the required information as functions of all the affecting factors on the drying process of fruits. The derived mathematical equations covered all the stages of the drying process, which was only the stage of the falling drying rate.

According to Bolin et al. (1975), Eissen et al. (1985a), Eissen et al. (1985b), Bains et al. (1989), Fohr & Arnaud (1992); Ibrahim (1994); Amer (1999) and Amer et al. (2003) there are many factors affecting the drying rate of the agricultural products. The most affecting factors related to the drying air are the drying air temperature, the drying air relative humidity and the drying air velocity as well as the product initial moisture content.

The majority of investigators recommended that the best range to be used for the drying air temperature for fruits is between 55 to 75°C, according to Hassan, (1995), and the best drying air velocity for fruits is ranged between 6 to 72 (m/min), according to Eissen et al. (1985a). It is preferred to have the drying air relative humidity at its lowest values from 10 to 20%, according to Bains et al. (1989). On the other hand, the initial moisture content of the tested plum fruit variety Italian was found to be between 80 to 91% (wet basis).

The literature review revealed that there are many investigators studied the moisture ratio of grains "MR" as a function of the affecting factors, but there are just very few investigators studied the moisture ratio or the drying rate of fruits and vegetables as a function of the affecting factors.

2. MATERIALS AND METHODS

The selected fruit for the experimental work was plum, variety "Italian" for its great economical importance in Egypt, according to CAPMS (1995).

An experimental apparatus was designed and was locally built in ATB for the determination of the effect of the different factors on the drying process. This apparatus was designed as a thin-layer dryer for fruits and vegetables, Fig. 1.

Determination of fruit moisture loss and hence the determination of both fruit moisture content and fruit drying rate could be done by weighing the drying tray of the designed apparatus with its load of fruits at successive periods of time, which are expected to be short periods at the beginning of the test and longer periods as the fruits lose more of its moisture.

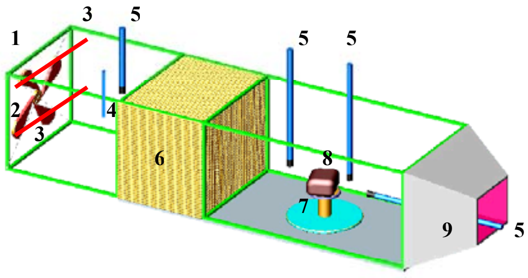

Fig. 1. Laboratory Set-up for Drying Experiments.

1. Flow-Channel Inlet.	2. Fan.
3. Heating Elements.	4. Thermostat.
5. Measuring sensors.	6. Air flow rectifier.
7. Balance.	8. Fruit.
9. Flow-channel outlet.	

2.1 The controlled affecting factors.

The temperature of the drying air. Many levels of drying air temperature: between 20 and 70 °C were tested, according to Hassan (1995). The air temperature was measured by a thermocouple transducer probe connected with a temperature recorder with accuracy ± 0.1°C. The thermocouple was firstly used to measure the dry temperature of the ambient air.

After heating the ambient air, the thermocouple was also used for measuring the drying air temperature just before entering the drying tray in which the fruits were placed for drying. Another digital instrument used also for measuring air temperature which was a "digital thermo-hygrometer" after connecting it with the temperature probe.

The relative humidity of the drying air. Many levels of the drying air relative humidity between 3% to 40% were tested, according to Bains et al. (1989). The typical method for the determination of air humidity was applied by the "digital thermo-hygrometer" with accuracy ± 1.5%.

The air velocity of the drying air stream. Many different levels of drying air velocity between 0.15 and 0,35 m/s were tested; according to Eissen et al. (1985a). The velocity of the drying air stream was measured by using a digital instrument "Anemometer" after connecting it with the velocity probe with accuracy ± 0.1 m/s.

The velocity of the drying air was measured just before entering the drying tray.

2.2 Determination for the moisture content of the plum fruits.

The moisture content, wet basis, of the fresh plum fruit used in the experimental work was ranging between 81% and 91%.

The original "initial" moisture content, dry basis, "Mw_o" of the fresh fruits was determined by the vacuum oven drying method.

Samples of the fresh fruit of weight "W_o" were dried in a vacuum oven at 70°C until the weight "W_d" of the dried sample became stable, according to A.O.A.C. (1984). The moisture content, dry basis, "Mw_o" of the fresh fruit was expressed as:

$$Mw_o = \frac{W_o - Wd}{Wd} \times 100 \quad (\%) \qquad (1).$$

For the determination of the moisture content, dry basis, "Mw_i" of the fruit at any time "t_i" during the drying process, the following equation could be used:

$$Mw_i = \frac{W_i - Wd}{Wd} \times 100 \quad (\%) \qquad (2).$$

Where:

W_i is the weight of the fruit at time t_i

The determination of the fruit weight was done by weighing the drying tray with its load of fruits at any time during the drying process.

2.3 Experimental work tested treatments.

The experimental work included many drying experiments. For all treatments, the whole weight of the drying tray was recorded periodically at time intervals of 5 minutes at the first part of the drying process, where the drying rate is expected to be constant. At the next part of the drying process when the differences of the successive readings of drying tray weight showed decreasing values.

During all the periods of the drying process, the values of the drying air affecting factors were periodically checked to be very close to the same values chosen for the executed experiment. Whenever any slight deviation occurred in any value, the suitable adjustments were immediately done to maintain their values exactly as the assigned ones.

3. RESULTS AND DISCUSSION

3.1 The characteristics of plum fruits.

For the determination of the characteristics of the selected plum fruits, many fruits of the selected size were taken. Table 1 shows the results of this determination as averages of the selected fruits.

These characteristics of plum fruits will surely affect the rate of moisture loss during the drying process. Since the selected fruits for conducting the experiments had almost the same size, weight and some other characteristics, the characteristics shown in Table 1 were manifested just for record.

Table 1. Characteristics of whole fresh plum fruits "Italian"

Characteristics	Average Values
Fruit shape	prelate
Fruit weight	50 - 70 g
Big diameter	2.7 – 3.1 cm
Small diameter	2.2 - 3 cm
Fruit thickness	2.1 - 2.8 cm
Fruit size	30 - 58 cm^3
Fruit density	1100 - 1300 kg/m^3
Moisture content, wet basis,	81 - 91%(g_w/g_{fresh})
Dried material of the fruit,	15 – 9%(g_{dry}/g_{fresh})

However, some of these characteristics were used in some of the calculations. As an example, the diameter of the fruits was used in calculating the actual velocity of the drying air passing through the inter spaces between plum fruits from the average air velocity just beneath the drying tray.

Also, in each conducted drying experiment, the fruits were taken for the determination of the initial moisture contents of the fresh fruits. After the determination of the dried material of these fruits, the moisture content (wet basis) was determined and the results are shown too in Table 1.

3.2 Experimental work for drying plum fruits.

It was proposed that the readings for the decreasing weight of the drying fruit correspondent to the passing time through the drying process are the main important data in the many experiments which were carried. From these data, the results dealing with the loss of moisture, the new moisture content of the drying fruit, and the instantaneous drying rate could be all calculated and related to the time.

3.3 Determination of the effects of the affecting factors on the drying process of plum.

In general the results of the experimental work showed that the drying process is only one stage which was falling drying rate periods.

The drying process starts with a certain original or initial moisture content value "Mw_o" of the fresh fruit, and ends with an acceptable final moisture content value "Mw_F" of the dried fruit at the end of the drying process.

In general the results of the experimental work showed that the drying process is only one stage which was falling drying rate periods.

The effect of the drying air temperature and drying air velocity on the drying rate of plum fruits were showed in Figures 2 and 3. Also, The effect of cutting the plum fruits was showed in Fig. 4.

By applying the multiple linear regression analysis technique to the whole data of the many experiments of the experimental work, the empirical mathematical equation was derived with "R^2" values ranged is 0.93. This equation gave the values of:

$$t = C + C1\ (T) + C2\ (RH) + C3\ (u) + C4\ (Mw_o) + C5\ (\rho) + C6\ (S) + C7\ (Dp) + C8\ (Ct) \qquad (3).$$

Where:

"t" is the total time of the drying process, (hr).

"C" is the overall constant for the equation and its value (-68.11).

"C1" is the constant for the drying air temperature (°C), and its value (-1.24)

"C2" is the constant for the drying air relative humidity (%), and its value (0.59)

"C3" is the constant of the drying air velocity (m/sec), and its value (-0.28)

"C4" is the constant for the initial moisture content, wet basis for plum fruit (%), and its value (4.06)

"C5" is the constant for the density for the plum fruit (kg/m^3), and its value (-0.039)

"C6" is the constant for the sugar content inside the plum fruit (g/kg), and its value (0.94)

"C7" is the constant for the dipping time of the plum fruits in boiling water at 100°C (sec), and its value (-0.072)

"C8" is the constant for the cutting the plum fruits for two halves, and its value (-138.51), since it multiplicities in one in case of drying half fruit and multiplicities in zero in case of whole fruit.

The reason of applying this multiple linear regression technique instead of using an exponential equations in the form like that of Page's equation, is that in the actual drying process, especially in solar drying processes, the fruits in each location in the dryer and at different times along the whole drying time will have unique drying conditions from the very beginning to the very end of the drying process.

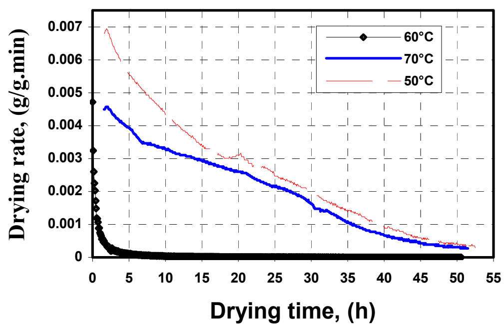

Fig. 2. Effect of the air temperature on the drying rate of plum fruit with a constant air velocity 15 cm/s with the same initial and final moisture content for plum fruits.

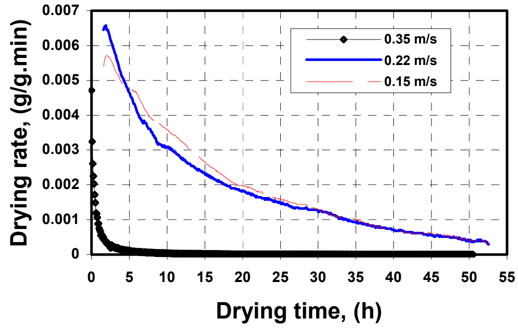

Fig. 3. Effect of the air velocity on the drying rate with a constant air temperature 60°C with the same initial and final moisture content for plum fruits.

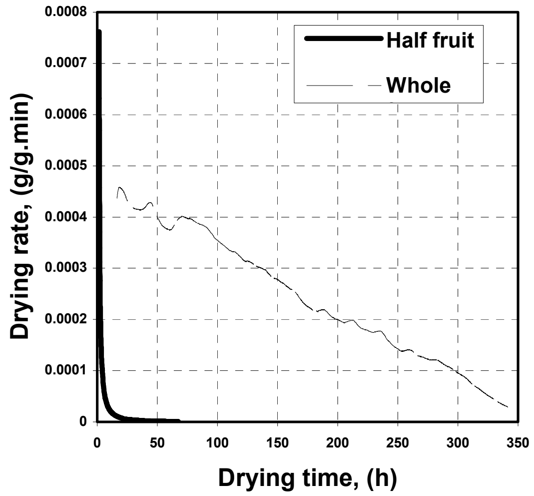

Fig. 4. Effect of the cutting the plum fruits on the drying rate with a constant air temperature 50°C and air velocity 0.22 m/s with the same initial and final moisture content for plum fruits.

Therefore, the drying constant "K" and the drying parameter "N" in any derived exponential equation have to have numerous values for the numerous locations of the dryer and not just one value for each.

So, in the actual drying processes, it is better to use a finite differences technique since the drying air at each location will have its specific temperature and relative humidity which are determined by the previous location. Also, at any location, the drying air temperature and relative humidity will change with the passing of time due to the continuous decrease in the drying rate of the fruits in the previous locations.

So, at each location in the dryer, and at each time of the drying process, the drying conditions have to be applied to determine the drop of fruit moisture content in this location. It is expected that the fruits in the first locations in the dryer will reach the desired moisture content "Mw_F" at shorter periods of time than those at the end of the dryer.

4. CONCLUSION

1. Plum fruits, variety "Italian" could be dried with an accepted quality under controlling conditions of air temperature ranges from 20 to 70°C, relative humidity ranges from 3 to 40% and air velocity ranges from 0.15 to 0,35 m/s.

2. The initial moisture content of the fresh plum fruits "Italian" (half and whole) is ranging from 81% to 91% (w.b.). The final accepted moisture content of the dried fruits is around 25% (w.b.).

3. The results assured that the drying rate of plum fruits is consisting of only one distinct period, which is: the falling drying rate-period. It was not noticed the constant drying rate during the drying process of the half plums fruit, but it was noticed during the drying process of the whole fruit.

4. The total drying time of plum fruits "Italian" treatments for the half fruits from 70 to 20°C respectively ranged from 50 to 150 h, and ranged from 200 to 500 h for the whole fruits at the same range of the drying air temperature.

5. The air temperature and air humidity were stable in the most of period for each experiment.

6. The results showed that the cutting the plum fruits for two halves had the greatest effect on the drying rate of plum fruits, followed by the initial moisture content of plum fruits. The drying air temperature, the relative humidity of the drying air and sugar content for plum fruits had a remarkable effect. The drying air velocity, the density of the plum fruits and. the dipping time of the plum fruits in boiling water at 100°C had the least effect.

7. The drying rate for the half fruit was more than for the whole fruit.

8. Drying plums at 70°C is not good because the sugar inside the fruits have been crystallizing and cause to decrease the drying rate.

9. It was found that the best condition for drying plum fruit is drying at air temperature of 60°C with low relative humidity of 4-7 %, air velocity between 0.35 m/s. Also, it was found that dipping the plum fruit in boiling water at 100°C for 180 seconds is very important to scratch its skin for increasing the drying rate.

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