PJN
ISSN 1680-5194

# PAKISTAN JOURNAL OF NUTRITION

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Pakistan Journal of Nutrition 12 (11): 1003-1007, 2013
ISSN 1680-5194


# Convective Drying and Mathematical Modeling of Onions Dried Using a Flat Plate Solar Air Heater

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**Abstract:** Solar drying of fruits, vegetables and grains is the oldest processing technique used for food preservation. In this research a flat plate solar air heater having an efficiency of 20% was used for drying onion flakes. The solar air heater assembly provides a temperature in the range of 40-50°C and humidity 10-30% in each day of drying period to the drying section. The drying section provides a total of 6 hours period per day as a suitable range for onions drying. Onions were dried and drying curves were developed for the drying kinetics of onions. The initial moisture in onions was 93% which was reduced to 5%. The moisture loss curve shows that onions lost 11% in each hour at an average. The drying curves of drying rate shows that the average drying rate of onions was 0.30 $gH_2O$. $g_{DM}$/h. Five published models (Newton, Page, Modified Page, Two-term expo and Wang) were tested to find relationship of drying curves with drying time. Among the five models Two-term expo model was the best describing drying kinetics on onions with $R^2$ value 0.974 and Root Mean Square Error 0.447 for moisture lost and 0.953 and 0.451 for drying rate. It was concluded that flat plate solar air heater dries onions in short period of time. The quality of onions dried by a flat plate solar air heater may be better than open sun drying system. Among the five models Two-term expo model was the best describing drying kinetics on onions.

**Key words:** Flat plate, solar air heater, drying, onions, mathematical modeling

## INTRODUCTION

India (21%) and China (19.3%) is the leading producer of onions (*Allium cepa*. L). Besides India and China onions are mostly grown in Pakistan, Iran, Turkey and Brazil (Kalse *et al*., 2012). Onions are the vegetable used in almost all the common dishes of Pakistan. They are generally red, yellow and white in color. As food stuff they are usually used as a vegetable or part of a prepared savory dish and can also be eaten raw or used to make pickles or chutneys. Bulb onions are considered to be one of the most important vegetable in Pakistan which is presently attracting attention of vegetable markets due to rise in prices. Pakistani farmers grow onions as a crop which fetches very good market prices during the last season (Storm, 2011). The vegetable is usually eaten fresh but can also be dried for storage and later consumption. Due to increase in market value, onions are dried on season and may be used in off season when the market price is high. The top ten countries which are producer of dried onions are (FAOSTAT, 2012)

Solar dried onions are famous in all over America and Asia. They add a rich flavor to any dish in which they are a part of recipe that is why there is high demand and good market of solar dried onion all over the world. They fetch good price if processed, dried and packed well. In open sun drying, the abandoned drying environment is the main cause of pathogen attack, dust infectivity, destruction of nutrients and vitamins due to ultra violet rays and bad aroma due to uncontrolled humidity (Patil *et al*., 2012) but if dried well using hot convective air then onions have good color, texture, flavor and nutritive value (Ahmad *et al*., 2012).

There is a need of good quality driers which dries onions in a controlled and sanitized environment. This will not only reduce the attack of pathogens and dust but also the product dried will be of good quality, high in nutrients. Drying of onions using a flat plate solar air heater is a very good choice to get quality dried onions. Solar drying technology in the form of solar air heaters or solar collectors is cheap, easily constructible, have controlled drying environment and dries the products in less time as compared to open sun drying system (Hanif *et al*., 2012 a,b).

Convective drying of onions using solar collectors gives valuable dried onions as compared to open sun drying. The onions dried by solar collectors have good quality as compared to the open sun dried onions. Hence it is very much important to study the drying kinetics of onions dried by the help of solar collectors. Mathematical modeling in this regard help us to identify the most suited model to be selected that best

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describes the relation ship of drying environment with the drying mechanism of onions (Hagi, 2001).

**Objective of the study:** The present research aim to study the convective solar drying and mathematical modeling of onions dried by a flat plate solar air heater.

## MATERIALS AND METHODS

**Site selection:** The experiment was conducted on a flat plate solar air heater installed on the roof of the Department of Agricultural Mechanization, Khyber Pakhtunkhwa Agricultural University Peshawar, Pakistan.

**Description of the flat plate solar air heater:** The solar air heater having efficiency of almost 20% was used in the experiment and was composed of two units. The first unit was a flat plate solar collector which heats up the air. The collector was composed of an insulated box (0.92×1.82×0.32 m) made of wood. There is a black painted V-corrugated steel sheet used as an absorber (0.9×1.82 m×3 mm) fixed in the middle of the insulted box. The absorber was shielded from air using cover material or glazing which was (0.9×1.82 m×5 mm) thick glass sheet placed at the top of the insulated box. The inlet and outlet were 0.145m in diameter made up of P.V.C pipe. There was a 0.17m exhaust fan fixed in the outlet of the air heater for pushing the hot air in to the drying air section. This fan provides hot air with velocity high enough (2 to 3.5 m/sec) for drying. The air heater was supported and tilted with the help of frame made of angle iron. The frame was built with four legs in such a way that the front two legs have a height of 0.36 m and the rear two are 1.12 m high making the air heater tilted at 38° with the horizontal facing south. The second unit was a drying section which was actually a (1.07×0.72×0.66 m) wooden box. It was connected to the outlet duct to receive hot convective air for drying of onions. The drying section was divided in to two shelves that were provided with trays for drying the onions. Total space available for drying in the drying section was 0.98 $m^2$. The drying section can dry 6 kg onions at a time.

**Experimental procedure:** Onions were cut into flakes and blanched. After blanching they were put on the trays of the drying section. After each hour of drying the data of temperature, humidity, moisture loss and drying rate was taken. Onions were dried tell the moisture content become less then 8%.

**Drying environment provided by the solar air heater to onions:** The temperature of the drying section was determined by the help of thermometers placed inside the drying section connected to the flat plate solar collector while humidity was calculated using Ashare Psychometric calculator (Wang *et al*., 2007).

**Moisture loss by onions:** The moisture content of the samples was determined after each hour of drying. The initial moisture content was determined by the oven method while the moisture after each hour in drying was determined by taking the initial weight and weight lost after each hour with the help of an electric balance. Moisture loss after each hour of drying was determined using the equation (Hanif *et al*., 2012a):

$$M.c = \frac{W_i - Wf}{W_i} \times 100$$

**Drying rate of onions:** The drying rate of the samples was determined to study who much moisture was lost in each hour of drying from a unit mass of a dry matter in the product. The drying rate was determined using the equation (Hanif *et al*., 2012b):

$$Dr = \frac{W_i - Wf}{Dm \times Ap \times td}$$

**Mathematical models:** Already published and studied mathematical models (Table 2) given by various authors for drying curves of onions are tested for $R^2$ and RMSE. The highest $R^2$ and lowest RMSE determine the best model that fits and describes the drying kinetics of onions (Ibrahim, 2012).
$R^2$ and RMSE are calculated using equation 2 (Demir *et al*., 2007) and Eq. 3 (Hagi, 2001):

$$R^2 = 1 - \sum_{i=1}^{N} \frac{(Mr_{pred,i} - Mr_{exp,i})^2}{\sum_{i=1}^{N}(Mr_{pred,i} - Mr_{exp,i})2^2} \quad (2)$$

$$RMSE = \frac{1}{N}\left[\sum_{i=1}^{N}(Mr_{pred,i} - Mr_{exp,i})^2\right]_{1/2} \quad (3)$$

where, MR exp, I is the ith experimental moisture ratio, MR pred,i is the ith predicted moisture ratio, N is the number observations and n the number of drying constants. The best fit that could describe the thin-layer drying characteristics of persimmons fruit was selected as the highest value of correlation coefficient ($R^2$) and the lowest value of RMSE.

## RESULTS AND DISCUSSION

**Drying environment provided by the solar air heater to onions:** Drying Environment provided by the flat plate solar air heater to the onions is given in Fig. 2 and 3. Figure 2 shows the temperature data of the solar air heater assembly. The temperature of the absorber fitted in solar air heater start rising from 40°C at 9:00 am and reached to almost 100°C at Noon. It begins to decrease from Noon to 4:00 pm and reaches to 45°C. Due to the temperature of the absorber the temperature of the drier changes as absorber helps to make the air hotter which

Fig. 1: Solar air heater assembly

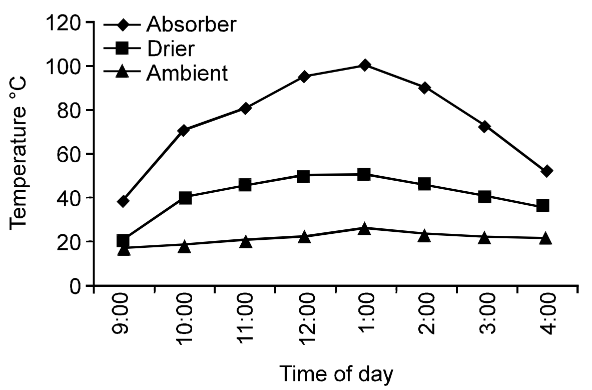


Fig. 2: Temperature data of the solar air heater assembly

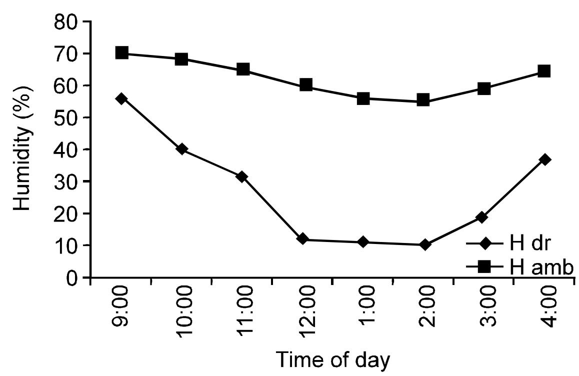


Fig. 3: Humidity of the drier and ambient air

is then given to the drier. In the drier the temperature reaches to 20°C at 9:00 am which begun to rise and reaches to almost 50°C at Noon. It again starts decreasing and reaches to 25°C at the end of the drying period of the day. The drier provide a temperature in the range of 40-50°C from 10:00 am to 3:00 pm. Figure 3 shows the humidity inside the drier and of outside environment. The humidity of the drier start decreasing at 9:00 am from 65% and reached to almost 10% at Noon. It begins to increase from Noon to 4:00 pm and reaches to 55%. This change is due to the change in the driers temperature. The drier provide humidity in the range of 10-30% from 10:00 am to 3:00 pm. The results of temperature and humidity show that there were 6 h of drying available in the day for suitable drying of onions. These results are in accordance with the findings of Hanif *et al.* (2012b) who dried grapes using a dish type solar air heater and with the findings of Altfeld *et al.* (1988).

**Drying curves of onions:** Moisture loss in each hour of drying by onions is shown in Fig. 4. The initial moisture of onions flakes was 93% which reduced to 5% in 16 hours of drying which was equal to two days of drying period in the drying section. At first day the onion flakes lost 30% moisture and on the second almost 55% of moisture was lost by onions. The two term exponential model shows that there is a good relationship between moisture loss and time of day with $R^2$ value of 0.974. These results are in accordance with the finding of

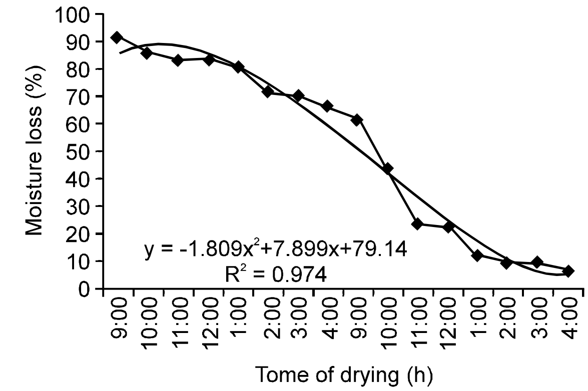


Fig. 4: Moisture loss in each hour by onions

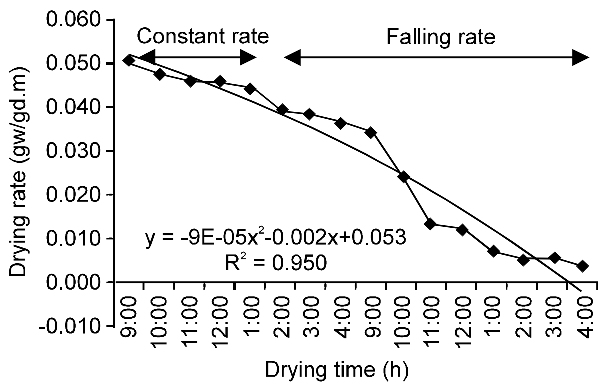


Fig. 5: Drying rate of onions

Kumar *et al.* (2005) and Kadam *et al.* (2008) who recorded moisture loss at the same drying conditions using a flat plate solar air heaters and a solar tunnel dryer. Drying rate of onion flakes at each hour of drying is shown in Fig. 5. The initial drying rate of onion flakes was 0.05 $gH_2O$ $g._{DM}$/h which reduced to 0.01 after 16 h. of drying. The first 4 h of drying shows the constant rate drying while the rest of 11 h was falling rate drying. The first day the drying rate starts at 0.05 and reaches to 0.035 at end of the day which was again initiated at second day and reached to 0.01 at the end of the drying periods. The two term exponential model shows that there is a good relationship between drying rate and time of day with $R^2$ value of 0.950. These results are in accordance with the finding of Strom (2011) and Hanif *et al.* (2012 a,b) who recorded moisture loss at the same drying conditions using a flat plate solar air heaters.

**Mathematical modeling of the drying curves of onions:** The mathematical modeling of onion curves is shown in Table 2. Among the five published Models, two terms exponential model (bolded) was best describing the drying kinetics of onion flakes. This model showed higher values of $R^2$ and lowest of RMSE for both moisture loss and drying rate. The $R^2$ value is 0.974 and

Table 1: Top ten dried onion producing countries of the world

| Country | Production in metric tones |
|---|---|
| China | 20,507,759 |
| India | 13,372,100 |
| United state | 3,320,870 |
| Egypt | 2,208,080 |
| Iran | 1,922,970 |
| Turkey | 1,900,000 |
| Pakistan | 1,701,100 |
| Brazil | 1,556,000 |
| Russia | 1,536,300 |
| Republic of Korea | 1,411,650 |

Table 2: Mathematical models for testing of drying kinetics of onions

| Eq. Model | Model's Name | Reference |
|---|---|---|
| MR = exp (-kt) | Newton | Ibrahim (2012) |
| MR = exp (-ktn) | Page | Demir *et al.* (2007) |
| MR = exp $(-(kt)^n)$ | Modified page | Hagi (2001) |
| MR = $a^1$ exp $(-k^1t)$ +$a^2$ exp $(-k^2t)$ | Two-term expo | Hii *et al.* (2008) |
| MR = $1+a^1t+a^2t^2$ | Wang | Wang *et al.* (2007) |

Table 3: Mathematical modeling of drying curves of onions

| | Moisture loss | | Drying rate | |
|---|---|---|---|---|
| Eq. Model | $R^2$ | RMSE | $R^2$ | RMSE |
| Newton | 0.911 | 0.461 | 0.891 | 0.453 |
| Page | 0.867 | 0.501 | 0.854 | 0.489 |
| Modified page | 0.801 | 0.521 | 0.895 | 0.492 |
| Two-term expo | 0.974 | 0.447 | 0.950 | 0.442 |
| Wang | 0.953 | 0.451 | 0.931 | 0.467 |

RMSE 0.447 for two term exponential model followed by Wang model with $R^2$ value of 0.953 and RMSE value of 0.451.

These results are in accordance with the modeling done by Hii *et al.* (2008). Similar results were also described by Wang *et al.* (2007) and Hagi (2001).

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