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SIMULATION MODELS OF THE THIN LAYER SOLAR DRYING OF BANANA SLICES

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ABSTRACT: ***Different slice thickness of banana (4 mm, 8 mm and 12 mm discs) pretreated with different solutions (1) 1% ascorbic acid (2) 1% sodium metabisulphite and (3) 1% citric acid at 70c^0 for 4 min were dried using a forced air solar drier. Significant decrease was observed in fat contents while the other chemical constituents did not affect significantly. Dry banana slices pretreated with sodium metabisulphite (1%) had a significantly higher rehydration ratio and rehydration coefficients 2.67 and 0.43, respectively while those pretreated with citric acid had the highest ($P \leq 0.05$) titretable acidity, texture and stress. Except moisture content slices 4mm had the highest rehydration ratio, rehydration coefficient, texture and firmness.***

In this study, suitability of several drying models available in literature in defining thin layer drying behavior of banana slices has been examined by using statistical analysis. For this purpose, drying models have been fitted to experimental data by means of the coefficients in the models. The results show that the regression analysis was performed using the experimental drying data to develop a thin layer drying model. Seven drying models were examined. The best fit of the thin layer drying of banana slices is obtained by tow-term (TT) and modified Henderson and Pabis (MHP) equations which are chosen for the mathematical modeling. The drying parameters of the Pabis equation were related to the various conditions (temperature, slice thickness, air velocity and humidity). The best fitted models were checked against the experimental data based on the value R^2. The developed models fitted well the experimental data and can further applied to predict the thin layer drying behavior of banana when industrially processed.

Keywords: ***Banana, mathematical modelling, solar drying, drying constant.***

INTRODUCTION

Banana (*Musa spp.*) is one of the most commonly consumed fruits in the world, being produced in almost all tropical countries. It has a high nutrition value and is a good source of energy due to its high level of starch and sugar, as well as been a source of vitamins A and C, potassium, calcium, sodium and magnesium. From a biological point of view, bananas are one of the fruits that present the highest losses by decomposition after cropping due to be extremely perishable and not allowing the use of freezing for its

conservation. As such, bananas can be dried in order to save the part of the production that will not be readily consumed, since drying is a classical food preservation method, which provides an extension of shelf-life, lighter weight for transportation and less space for storage (Sousa and Marsaioli., 2004). The drying technique as been observed to have an impact on the drying kinetics and the quality of the dried products (Chua *et al.,* 2001).

Many mathematical models have been proposed to describe the drying processes (Harmathy, 1969; Mikhailov, 1975; Szentgyorgyi & Molnar, 1978; Turner & Mujumdar, 1997). Reviews of the different mathematical models have been presented by Fortes and Okos (1980), Luikov (1975) and Rossen and Hayakawa (1977). Dehydration of fruits and vegetables, including banana, produces large changes in their volume and their heat and mass exchange area because of spatial and time variable structure. This shrinkage phenomenon affects in particular the diffusion coefficient of the material, which is one of the main parameters governing the drying process; it also has an influence on the drying rate (Lima *et al*., 2002; Queiroz & Nebra, 1996). Several theoretical and experimental studies were carried out to analyse and foresee the mass transfer in foodstuffs, including banana (Drouzas & Schubert, 1996; Kiranouidis *et al*., 1997; Mauro & Menegalli, 1995; Prasertsan & Saen-sabv, 1998; Rastogi, *et al*., 1997; Schirmer *et al*., 1996).

Drying is the basic step giving the characteristics properties to the banana chip. Understanding drying behavior of ripe banana slice is very important for the control of the drying process itself, any subsequent processes, and quality of the final product. Some attempts have been made to investigate air-drying behavior of ripe banana in different physical forms, e.g. whole (Dandamrongrak *et al*., 2002; Nogueira & Park, 1992; Queiroz & Nebra, 2001), chunks (Garcia *et al*., 1988; Mowlah *et al*., 1983), and sliced (Sankat & Castaigne, 1992; Sankat *et al*., 1996).

The purpose of the present work was to determine the empirical models discussed only the average moisture content as a function of the drying time. The average moisture contents within the dried materials may change when the drying conditions change. This paper aims to develop a mathematical model for different pretreatment and slicing assisted thin layer drying of banana slices. In this study, the relationship of the constants and coefficients of the best suitable model with drying variables like pretreatment and slicing of banana was also determined.

MATERIALS AND METHODS

2.1. Solar dryer.

An experimental forced convection solar dryer as schematically depicted in Fig (1) was used in all experiments. The dryer consisted of a solar collector and a drying chamber and made from readily available local materials. The dryer was constructed at the Agricultural Engineering Dept., Minoufiya

University, Egypt and installed on the roof of the Agric. Eng. Building and was oriented so that collector faces south. The solar collector was tilted at an angle of 20 degree from the horizontal plane, which was determined to be an optimum tilt angle for the specific location and time of the year. A corrugated galvanized iron sheet 0.5 mm thickness painted black was used inside the heater as an absorber plate for absorbing the incident solar radiation. The solar collector was covered with one layer of an ordinary glass; 3mm thickness was used as a transparent cover for the air heater to prevent the top heat losses. The frame was made of wood 2.5 cm thick Styrofoam insulation was used on the sides and bottom of the heater to prevent heat losses. The drying chamber was constructed with insulated wooden walls. The drying trays were made of an iron frame on all four sides with wire mesh (2x2 mm) on the bottom to hold the sample. A lid was connected on the north side of the drying chamber for loading and unloading the drying material. An electrically driven radial fan was fixed in the chimney and used to force the drying air. Ambient air was drawn in by a fan and heated up in the solar air heater. The heated air was allowed to enter in the drying cabinet from the bottom of the tray and flow up wand through the sample and finally through the chimney.

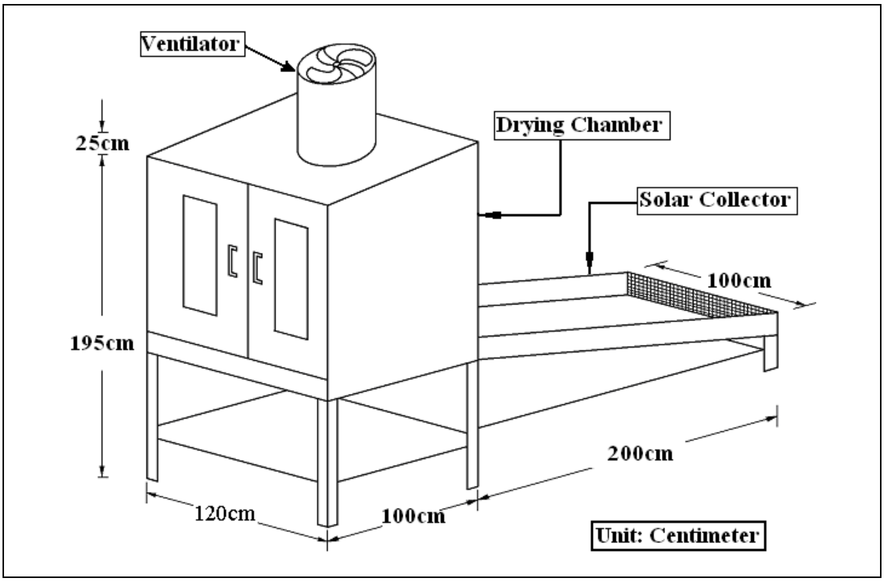

Figure (1): Schematic diagram of solar drying systems (Dim. In cm)

2.2. Measurements.

2.2.1. Solar radiation.

Apply Radio meter (Model 8-8 Serial No 14046) was used to measure the solar radiation (W/m^2) on the horizontal plane. A factor of $10.8 * 10^{-6}$ $v/w.m^2$ was used to convert the reading of the instrument to watts.

2.2.2. Temperature.

The temperature (^oC) was measured using the thermocouple wires placed in the required measuring points. Temperature reading at a certain time intervals (60 min) was recorded using a data logging system and basic computer program.

2.2.3. Relative humidity.

Thermos hygrometer (model 37200, OAKTON, USA) was employed to measure the air relative humidity (RH, %) outside and inside the drying chamber, and at the outlet point of the drying chamber.

2.2.4. Air velocity.

The air velocity of ambient air, inside the dryer and inside the collector was measured by means of a DWYER THERMAL ANEMOMETER 470 to the nearest ft/min. The readings were then converted into m/min.

2.2.5. Weight.

Initial and final weights and weight changes during drying experiments of each sample were measured by a laboratory electric balance having accuracy of 0.001 gm.

2.2.6. Moisture content.

The moisture content of initial and final products was determined according to AOAC (2003). All moisture contents determination was carried out on three replicates for each sample.

2.2.7. Chemical Analysis

Moisture was determined on three replicates by desiccation at 105 °C for 24 h.. Ash was determined in triplicate by heating the residue of moisture determination at 550°C for 6 h. Nitrogen content was obtained by applying the Kjeldahl method, and the protein content was calculated using a nitrogen factor of 6.25 according to the method described in AOAC, 2003.

Reduced sugar was determined in 70% ethanol extracts by the phenol sulphoric method of (Dubois *et al*., 1956). Ascorbic acid was extracted in 2% oxalic acid and determined using 2, 6 dichlorophenol indophenols according to Anonymous, (1966).

Rehydration ratio was measured as the total mass of rehydrated Banana per unit weight of dry mater. Coefficient of rehydration was determined according to (Ranganna, 1979) using the following equation:

$$CR = \frac{D_{WH} \times [100 - M_{CD}]}{[W_{DR} - M_{DR}] \times 100}$$

Where: *CR* = Coefficient of rehydration

D_{WH} = Drained weight of dehydrated sample
M_{CD} = Moisture content of sample before drying
W_{DR} = Weight of dried sample taken for rehydration
M_{DR} = Amount of moisture present in the dried sample taken for rehydration

2.2.8. Texture.

The texture of samples was measured according to Amer Essa, 1998. with some modification. The peak deformation force required to compress the sample to a depth of 2 mm on a non-lubricated flat platform using a cylindrical probe (2 mm diameter) was recorded by the texture analyzer and used as a measure of product firmness. The samples were placed with the cut surface facing the cylindrical probe. The cross-head speed was 1 mm s^{-1}.

2.3. Solar drying experiments.

The solar drying experiments were carried out during May, 2006 at shibin El-kom city, Egypt (Latitude 30^0 N). The Bananas (*Musa spp.*) used in these experiments were purchased from private farm. The samples were washed, manually peeled and quickly sliced to a thickness of (4, 8 and 12 mm thick-slices). Each thickness were divided three parts soaked for 4 minutes at (70 ± 2 ^{0}C) in different three solutions (citric acid 1%, sodium metabisulphite 1% and ascorbic acid 1%). Three samples were picked randomly from the pretreated fruits slices, drained and the initial moisture content (78%, wet basis) was determined.

The pretreated fruits were spread evenly (single layer) with a near uniform distribution density on the drying trays. The loaded trays were then placed very quickly in the drying chamber. Drying started at 8.00 a.m and continued till 6.00 p.m.

Drying data were monitored using labeled samples, which were individually weighed and positioned on the trays. The weights of the labeled samples were recorded every 2 hours throughout the drying test.

The drying test was terminated when the decrease in the weight of the samples had almost ceased. According to (AOAC, 2003) the final moisture content of the dried samples was determined. Moisture contents were reported as a percent wet basis and then converted to kg water/kg dry matter

for the modeling. Measurements of solar radiation, drying air temperature, air velocity and relative humidity were recorded during the drying tests.

2.4. Statistical analysis.

The data analysis of this experiment was carried out by using the Statistical Analysis System (Statistical Analysis System, 1996). Measured data were analyses by ANOVA. Least Significance Difference test was used to determine differences between means. Significance was assumed at (P ≤ 0.05).

2.5. MATHEMATICAL MODELLING OF SOLAR DRYING CURVES.

Solution of Fick's second law, with the assumptions of moisture migration being by diffusion, negligible shrinkage constant temperature and diffusion coefficients, and for a sphere is given below, (Mahmutog la *et al*., 1996; Di Matteo *et al*., 2000).

$$\frac{M - M_e}{M_0 - M_e} = \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\, e^{\left(\frac{-n^2\pi^2 D_{eff}\, t}{R^2}\right)} \qquad \text{---------------- (1)}$$

where (Me) is equilibrium moisture content, (M) is moisture content at interval time, (Mo) is initial moisture content, (D_{eff}) is the moisture diffusion (m^2/sec), R is the radius of the sphere (m) and the (t) is the time (s). For long drying times, equation (1) can be further simplified to a straight line equation as:

$$\ln\left(\frac{M - M_e}{M_0 - M_e}\right) = \ln\frac{6}{\pi^2} - \frac{\pi^2 D_{eff}\,.t}{R^2} \qquad \text{--------------- (2)}$$

Equation (2) is usually refereed to as the exponential equation when written in a more general form:

$$\frac{M - M_e}{M_0 - M_e} = e^{-kt} = ke^{-ct} \qquad \text{------------------- (3)}$$

Where (k and c) are constants. An alternative approach to the analysis of thin layer drying has been to use empirical relationships. One equation that has been widely used in thin layer drying studies is Page's equation (Diamante and Murno, 1993; Madamba *et al.,* 1996).

$$\frac{M - M_e}{M_0 - M_e} = e^{-xt^y}$$

Where (x and y) are constants.The solar drying curves obtained were fitted with seven different moisture ratio equations (Table 1). The correlation coefficient (r) was one of the primary criteria to select the best equation to

account for variation in the solar drying curves of the dried samples (Sarsavadia *et al*., 1999; Ozdemir and Devres, 1999). In addition to reduced Chi -square as the mean square of the deviations between the experimental and calculated values for the models was used to determine the goodness of the fit. The lower the values of the reduced χ-square, the better the goodness of the fit. This can be calculated as:

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{pre,i}\right)}{N-n}$$

The coefficient of determination (R^2), the reduced mean square of the deviation – Chi-square (χ^2) – and the root mean square error (*RMSE*) were used to evaluate the goodness of fit (Ertekin & Yaldiz, 2004; Ozdemir & Devres, 1999):

$$RMSE = \left[\frac{\sum_{i=1}^{N}(MR_{pre,i} - MR_{\exp,i})^2}{N}\right]^{1/2}$$

where $MR_{\mathrm{exp},i}$ is the ith experimental moisture ratio, $MR_{\mathrm{pre},i}$ the ith predicted moisture ratio, *N* the number of observations and *n* the number of constants in the drying modal (Yaldiz *et al*., 2001). The effects of initial and final moisture content, drying air temperature, relative humidity and air velocity on drying constants have been investigated by many researchers (Pangavhane *et al*., 1999; Prabhanjan *et al*., 1995 and Tulasidus *et al*., 1993). After regression analysis using each of seven equation in Table (1) for each of the runs, the relationship of the constants and coefficients of the best suitable model with the drying variable, like mean drying air temperature (mean temperature of the half hourly readings between 11:00 A.M and 2:P.M). The regression analysis was performed using the statistical computer program (Expert 3.1).

($M - M_e$)/($M_0 - M_e$) was simplified to (M/M_o)=MR since relative humidity of the drying air continuously fluctuated for solar drying experiments, so a correct M_e could not be estimated. Also M_e is small compared to M or M_o, hence the error involved in the simplification is negligible (Diament and Munro, 1993; Doymaz pala, 2002). Models are a tool for engineers to predict the drying behavior of a material. The best model should provide predicted values close to the actual values. By definition, the drying constant value represents the drying rate constant, a measure of rate of moisture transfer from the material.

Table (1). Mathematical models given by various authors for drying curves.

Model No.	Model name and Symbol	Model equation	References
1	Newton (*N*)	$MR = exp (-k. t)$	O'Callaghan *et al*. (1971)
2	Page (*P*)	$MR = exp (-k. t^n)$	Page (1949)
3	Henderson and Pabis (*HP*)	$MR = a. exp (-k. t)$	Henderson and Pabis (1969)
4	Logarithmic (*L*)	$MR = a. exp (-k. t)+c$	Yagciolu *et al.* (1999)
5	Two term (*TT*)	$MR = a. exp (-k_0.t) + b\ exp (-k_1\ t)$	Sharaf-Eldeen *et al*. (1980)
6	Wang and Singh (*WS*)	$MR = 1+ a.t+bt^2$	Wang and Singh (1978)
7	Modified Henderson and Pabis (*MHP*)	$MR = a. exp(-k. t) + b. exp (-g. t) + c. exp(-h.t)$	Karathanos (1999)

3. RESULTS AND DISCUSSION

3.1. Drying air characteristics.

During the experiments, ambient air temperature ranged from 24.8 to 34.5°C, ambient air relative humidity from 46.8 to 74.6 %, drying air from 26.2 to 48.8 °C, drying air relative humidity from 25.5 to 65.5 % and average solar radiation was about 580 w/m^2. The difference of the maximum air temperature between ambient and drying air temperature was 11.3 °C. This gave an indication about the efficiency of the dryer. The average air flow rate through the drying chamber was about 2 m^3/min.

3.2. Drying rate.

Figure (2) presents the mean moisture content versus drying time (drying rate for sliced banana (4, 8, 12 mm thickness) dried by solar dryer. The total drying times required to reach final moisture content (14.25, 15.5, and 17.25%) were (20, 24 and 28h) for 4, 8, 12 mm thickness, respectively. Examination of Fig (2) reveals that in the first 12 hours the extent of moisture content reduction was significantly dependent on the slices thickness. The order of rate of moisture loss was 4mm > 8mm > 12mm. After 12 hours of drying, further loss in moisture was minimal in 4mm thick slices. Slight moisture reduction continued for 8 & 12 mm thick slices.

The mean moisture content versus drying time for four different pretreated banana slices as shown in Fig (3). The final moisture content of pretreated banana slices were 16.33, 14.25, 15.5 % for 1 % citric acid, 1 % sodium metabisulphite and 1 % ascorbic acid, respectively. The data indicated that, the differences in drying rate between all treatments were small. Fig (5) shows the relation between moisture content and drying rate of 4, 8, and 12 mm thickness slices for the different pretreatments. The drying data

indicated that, the drying rates were quite low during the first hours while solar radiation on the collection was low in the morning and as the drying chamber warmed up. The maximum drying rate occurred between 2 to 8 hours, and corresponded to the drying chamber reaching its maximum temperature during the hottest pant of the day (Fig.2, 3).

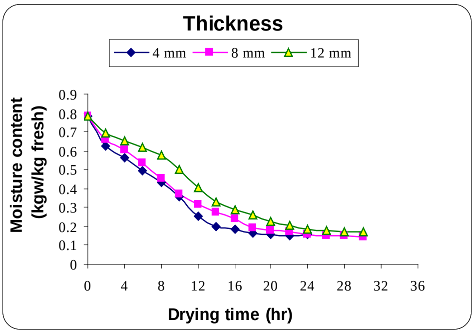

Fig (2): Drying rate versus moisture content for banana slices.

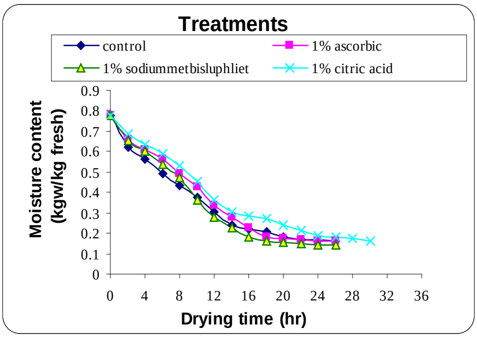

Fig (3): Thin layer solar drying curves of banana as affected by different pretreatment.

3.3. Mathematical modeling of drying rates.

For the semi-theoretical models given in Table (1), standard error of estimate (*SEE)* and determination of coefficient (R^2) were calculated by the computer program (Expert 3.1) and are given in Table (2). As shown in Table (2), the best R^2 value for banana slices is proved by Two Term model (TT), Modified Henderson & Papis (MHP) and page models. The moisture content data of the different pretreated samples and different thickness converted to a moisture ratio then fitted against the drying time. The 12 drying curves fitted with 7 equations (Table 1). The Two Term, Modified Henderson & Papis, and page models gave a higher R^2 and lower χ^2 as shown in Table (2), so they were selected to represent the solar drying behavior for thin layer drying of banana slices. The values of constants *k* (min^{-1}) and n (dimensionless) were regressed against those of drying air temperature and air velocity using multiple regression analysis (Expert 3.1, SPSS was used for this purpose) to account for the effect of drying variables on the Two Term and Modified Henderson & Papis models constants. All possible combinations of drying variables were included and tested in the regression

Table 2

analysis. The multiple combinations of different parameters which gave the highest R^2 were finally included in the model. The accepted model constant, based on the multiple regression analysis were as follows:

MR (MHP) = $a.\ exp\ (-k.\ t) + b.\ exp\ (-g\ .t) + c.\ exp\ (-h.\ t)$ **R^2=0.997**

MR (TT)= $a.\ exp\ (-k_0.t) + b\ exp\ (-k_1\ t)$ **R^2=0.989**

So that the moisture content of the banana (4mm, thickness) slices at any time during the drying process could be estimated within the experimental boundary conditions. Validation of the Two Term and Modified Henderson & Papis models were confirmed by comparing the estimated and predicted moisture ratio at any particular drying condition. The validation of the Two Term and Modified Henderson & Papis models for different slice thickness are shown in Fig. (4). The predicted data generally banded around the straight line which showed the suitability of the Two Term and Modified Henderson & Papis models in describing the drying behavior of the banana slices (4, 8, 12mm thickness).

The effect of slice thickness and pretreated on the models constants were regressed using multiple regression analysis and included in Table (2). All possible combinations of the different parameters that gave the higher R^2 were finally included in the best models. Based on the regression analysis, the accepted models constants and coefficients as shown in Table (2). So the moisture content of banana at any time during the drying process could be estimated.

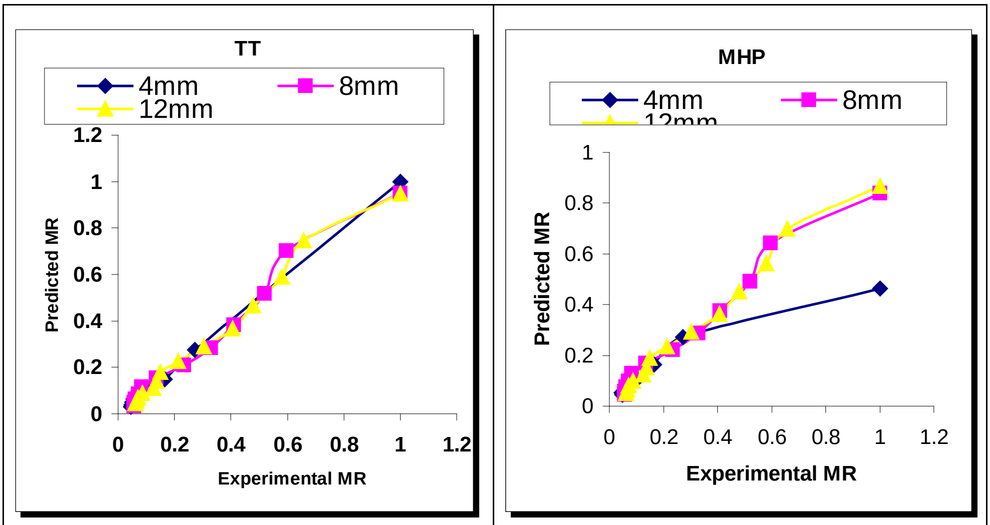

Fig (4): Comparison of experimental moisture ratio with predicted moisture ratio from Two Term (TT) and Modified Henderson and Papis (MHP) models for banana slices.

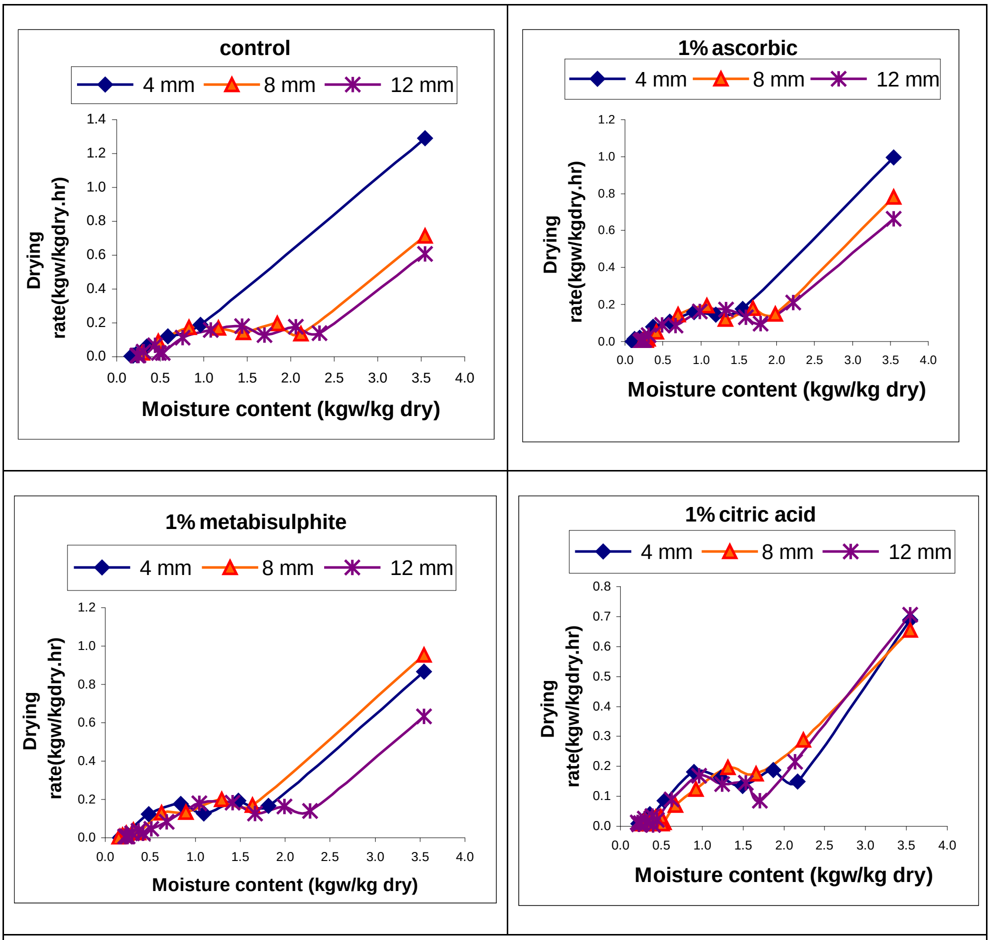

Fig (5): Drying rate versus moisture content d.b for banana slices.

Non-linear regression was used to fit drying curves to the data based on the seven drying models, namely, the simple (Newton), Page, Henderson & Pabis; Logarithmic, the Two-Term, Wang & Singh and Modified Henderson & Pabis models. The coefficients of correlation R^2, the *RMSE* and the χ^2 for the seven models are presented in Table (2).

Except Newton, logarithmic and Wang & Singh models, all fitted curves matched well with the experimental values (The R^2 values were higher than 0.97). However, the R^2, RMSE and χ^2 for these models were always significantly different to the corresponding values for the other models. This indicates that these models were not adequately describing the drying curves of bananas for all treatments. Based on these results, the Two-Term,

Modified Henderson & Pabis was chosen as the best modal to represent the drying of banana. Mathematical modeling of drying is crucial for the optimization of operating parameters and performance improvements of the drying systems. The modified Henderson & Pabis, Two-Term and Page models predicted moisture contents closely, matching the experimental values for all treatments. These results were similar to those of Hacihafizoglu *et al.,* (2008) in rough rice, and Ceylan *et al.,* (2007) for tropical fruits.

3.4. Chemical composition.

Chemical compositions (on dry weight basis) of fresh and dried banana are showed in Table (3). Fresh banana contained 5.49%, 6.02%, 4.87%, 72.93%, 5.04% and 12.73% of protein, fat, reducing sugars, total carbohydrates, ash and crude fiber, respectively. No significant ($P \leq 0.05$) differences were observed in protein, and crude fiber contents among all treatments. Reducing sugars were significantly ($P \leq 0.05$) decreased in the samples pretreated with sodium metabisulphite this decrease may be due to leaching out of the reducing sugars during the pretreatments. The highest reduction rate of total carbohydrates were noticed for the samples pretreated by 1% citric acid (1.9%) followed by that treated by ascorbic acid (1.28%). Except for banana pretreated by 1% citric acid no significant ($P \leq 0.05$) differences were noticed in ash content among the other pretreated samples this may be due to leaching out of more minerals contents in the pretreatment acidic solution.

Table (3): Effect of pretreatments on chemical composition of solar dried banana slices (gm/100gm dry weight).

Treatments	**Total Protein**	**Fat**	**Reducing sugar**	**Total carbohydrate**	**Ash**	**Fiber**
Fresh	**5.49^{a}**	**6.02^{a}**	**4.87^{a}**	**72.93^{a}**	**5.04^{a}**	**12.73^{a}**
Dried						
Control	**5.17^{a}**	**4.08^{b}**	**4.05^{ab}**	**72.00^{ab}**	**4.86^{ab}**	**12.89^{a}**
Citric acid %	**5.35^{a}**	**4.19^{b}**	**4.52^{a}**	**71.03^{c}**	**4.63^{b}**	**13.27^{a}**
Sodium metabisulphite%	**5.02^{a}**	**3.96^{b}**	**3.81^{b}**	**72.10^{ab}**	**5.39^{a}**	**12.92^{a}**
Ascorbic acid %	**5.23^{a}**	**3.92^{b}**	**4.24^{a}**	**71.65^{b}**	**4.80^{ab}**	**12.82^{a}**

Means in the same column with different letters are significantly different ($p \leq 0.05$)

3.5. Quality attributes.

Effect of pretreatment (for 4 minutes at 70 ± 2 ^{0}C in 1%citric acid, 1%sodium metabisulphite and 1% ascorbic acid) on some quality attributes of solar dried banana slices are shown in Table (4). Dried banana slices presoaked in 1% sodium metabisulphite had significantly ($P \leq 0.05$) higher rehydration ratio (2.67) and rehydration coefficient (0.43) followed by that

pretreated in 1%citric acid (2.46 and 0.37, respectively). Banana slices pre-dipped in 1% citric acid had a significantly ($P \leq 0.05$) higher titretable acidity (2.22%), texture (55.68 N), moisture (16.66%) and stress (101.58 N), while it had the lowest ($P \leq 0.05$) pH (4.12). Dried slices pretreated in 1% ascorbic acid had significantly ($P \leq 0.05$) higher V.C. contents (20.44 mg/100g d.w.), while the control slices (without pretreatments) had the lowest content of V.C. This may be due to absorption of some ascorbic acid during the pretreatment.

Table (4): Effect of pretreatment on some quality attributes of solar dried Banana slices.

Treatments	Rehydration Ratio	Rehydration Coefficient	pH	Titretabel Acidity %	V.C mg/100g d.w	Texture (N)	Moisture %	Stress N/cm^{2}
Fresh	-	-	4.80	0.52	18.6	3.81	78.00	2.03
Dried Control%	2.19^{c}	0.31^{c}	4.71^{a}	1.53^{c}	14.45^{c}	53.17^{bc}	16.33^{a}	96.50b^{c}
Citric acid%	2.46 ^{b}	0.37^{b}	4.12^{d}	2.22^{a}	16.22^{b}	55.68^{a}	16.66^{a}	101.58^{a}
Sodium metabisulphite%	2.67 ^{a}	0.43 ^{a}	4.60^{b}	1.63^{c}	16.72^{b}	53.60^{b}	14.66^{c}	94.28^{c}
Ascorbic acid%	2.22c	0.32^{c}	4.26^{c}	1.85^{b}	20.44 ^{a}	52.51^{bc}	15.00^{bc}	95.38^{c}

Means in the same column with different letters are significantly different ($p \leq 0.05$)

Table (5) represents the effect of slicing (4mm, 8mm and 12mm) on the quality aspects of the pretreated, solar dried banana slices. Slices 4mm had significantly ($P \leq 0.05$) higher rehydration ratio (2.72), rehydration coefficient (0.41), texture (54.47N) and stress (99.21N), while it retained the lowest ($P \leq 0.05$) V.C. (16.13 mg/100g d.w.) and moisture content (14.25%). This may be due to 4mm slices had the highest surface area which, resulted in more quick water transfer (El-beltagy *et al*, 2007).The high lose of V.C. might be due to the high sensitivity of ascorbic acid to the light.

On the other side, 12mm pretreated dried slices retained the highest amount of moisture (17.25%) and V.C. (17.71 mg/100g d.w.) this may be due to the smaller surface area which reduces the moisture transfer and V.C. oxidation rates. No significant ($P \leq 0.05$) differences were observed among all slices in pH and titretable acidity.

Table (5): Effect of slicing on some quality attributes of solar dried Banana slices.

Treatments	Rehydration Ratio	Rehydration Coefficient	P^{H}	Titretable Acidity %	V.C mg/100g d.w	Texture (N)	Moisture %	Stress N/cm^{2}
4 mm	2.72^{a}	0.41$_{a}$	4.44^{a}	1.82 ^{a}	16.13^{b}	54.47^{a}	14.25^{c}	99.21^{a}
8 mm	2.28^{b}	0.35^{b}	4.41^{a}	1.79 ^{a}	17.38^{a}	52.94^{b}	15.50^{b}	93.81^{c}
12 mm	2.13^{c}	0.29^{c}	4.40^{a}	1.73 ^{a}`	17.71^{a}	46.30^{c}	17.25^{a}	97.78^{b}

Means in the same column with different letters are significantly different ($p \leq 0.05$)

CONCLUSIONS

The two-term and Modified Henderson and Pabis models was the best model to describe the drying characteristics of bananas due to the meaningful parameter values given by the model parameters in the model realistically represented the equilibrium moisture content, the moisture to be removed, and the drying rate of bananas. The correlation coefficient, RMSE and χ^2 were effective measures to evaluate the models. Moisture diffusivity was significantly improved with pre-treatments both citric acid % and sodium meta bisulphite 1%. For increasing the rehydration ratio, rehydration coefficient and drying rate, banana could be sliced to 4 mm and pretreated with 1% sodium meta bisulphate.

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نماذج محاكاة لدراسة سلوك التجفيف الشمسى لشرائح الموز

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الملخص العربي

يهدف هذا البحث إلي دراسة تأثير سمك الشرائح و كذلك معاملات ما قبل التجفيف علي معدل تجفيف الطبقة الرقيقة من شرائح الموز و كذلك دراسة مدي ملائمة أي من نماذج التجفيف لسلوك تجفيف الطبقة الرقيقة لشرائح الموز.

وقد شملت الدراسة:

- تصميم مجفف شمسي غير مباشر يعمل بالحمل الجبري باستخدام مروحة لسحب الهواء.
- تم دراسة العوامل الشمسية من شدة إشعاع الشمس ودرجات حرارة الهواء والرطوبة النسبية وتأثيرها علي خواص هواء التجفيف داخل حجرة التجفيف.
- تم استخدام سبعة نماذج لدراسه سلوك الطبقه الرقيقه لشرائح الموز المجففه وذلك بإستعمال التحليل الاحصائى وكانت افضل النماذج لتجفيف الطبقه الرقيقه لشرائح الموز هم:
  Two Term & Modified Henderson and Pabis and Page
  وهم الأدق فى التنبأ بتجفيف شرائح الموز٠
- تم تقييم الشرائح المجففة بعدة طرق لبيان مدي جودتها واستخداماتها في الصناعات الغذائية.

و أظهرت النتائج أن:

١– المجفف الشمسى الغير مباشر تحت ظروف التشغيل أعطى نتائج جيده فى تجفيف شرائح الموز من حيث مدة التجفيف وجودة المنتج ٠حيث كان الزمن الكلى والمطلوب للتجفيف ٢٠،٢٤،٢٨ ساعه لكل من سمك شرائح الموز ٤مم،٨مم،١٢مم على الترتيب ٠وكانت رطوبه نهائيه١٧.٢٥،١٥.٥،١٤.٢٥ على الترتيب ٠وكانت جوده شرائح الموز جيده .

٢- شرائح الموز التى تم معاملتها قبل التجفيف بإستخدام صوديوم ميتا باي سلفيت ١٪ كانت الأعلى فى نسبة الاسترجاع وكذلك معامل الاسترجاع بينما اظهرت تلك المعاملة بحامض الستريك ١٪ محتوى أعلى من الحموضة ودرجة صلابة أعلى.

٣- شرائح الموز بسمك ٤ مم كانت أعلى من الشرائح الأكثر سمكاً من حيث الاسترجاع والقوام بينما كانت أقل فى المحتوى الرطوبى بعد التجفيف.

٤- وجد أن معدلات التجفيف يمكن أن تتوافق مع أكثر من معادلة حسابية من معادلات التجفيف.

٥- ثابت التجفيف ومعدلات التجفيف تأثرت بدرجة كبيرة بدرجة حرارة هواء التجفيف ونسبة مساحة السطح المعرضة إلى الكتلة.

Table (2): Empirical models, coefficients, determination of coefficients (R^2), chi-square (χ^2) and root mean square error (RMSE) of banana drying.

Slicing	Pretreatment	Coefficients									Modal	R^2	χ^2	*RMSE*
		n	a	b	c	g	h	k	K_0	K_1				
4 (mm)	Control		0.006	0.222	0.236	0.275	0.274	-0.129			MHP	0.997	0.00007	*0.178*
	Citric acid		0.938					0.139			HP	0.979	0.0015	*0.038*
			0.469	0.469					0.139	0.139	TT	0.979	0.0018	*0.038*
	Sodium metabisulphite		0.366	0.366					0.156	0.155	TT	0.989	0.0009	*0.084*
	Ascorbic acid		0.278	0.278					0.127	0.127		0.986	0.0003	*0.103*
8 (mm)	Control	0.847						0.219			P	0.962	0.0016	*0.036*
			0.279	0.279	0.279	0.133	0.133	0.133			MHP	0.975	0.0017	*0.055*
	Citric acid		0.782	0.092					0.179	0.019	TT	0.994	0.0004	*0.035*
								0.162			N	0.997	0.0023	*0.045*
	Sodium metabisulphite		0.324	0.324					0.159	0.159	TT	0.989	0.0003	*0.102*
	Ascorbic acid		0.381	0.381					0.129	0.129	TT	0.977	0.0010	*0.071*
12 (mm)	Control		0.289	0.289	0.289	0.109	0.109	0.109			MHP	0.986	0.0011	*0.037*
	Citric acid	0.725						0.264			P	0.976	0.0008	*0.026*
			0.251	0.251	0.251	0.107	0.107	0.107			MHP	0.983	0.0008	*0.065*
	Sodium metabisulphite		0.282	0.282	0.282	0.111	0.111	0.111			MHP	0.983	0.0007	*0.047*
	Ascorbic acid		*0.271*	*0.271*	*0.271*	*0.114*	*0.114*	*0.115*			*MHP*	*0.981*	*0.00134*	0.056