Egypt. J. Chem. **Vol. 65,** No. 3 pp. 455 - 464 (2022)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Performance of two terms exponential model on the drying kinetics of solar dried tomatoes (*Lycopersicum esculentum* L.) treated with and without chemical preservative

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Abstract

Open sun drying of horticultural produce results in contamination due to microbial and fungal attacks and could also be damaged by insects, pests, and rodents. Solar drying through solar collectors is, therefore, an important technique used for the preservation of foods and to extend the shelf life of produce, thereby reducing microbial attack and contamination. Therefore, an experiment was carried out to study the response of the drying kinetics of solar-dried tomatoes to the thin layer of preservatives on the drying and quality attributes. The tomato fruits were treated with natural preservatives (honey and aloe vera) and chemical preservatives (citric acid, sodium benzoate, and potassium meta-bisulfate). The tomato fruits were then kept at three (40, 45, and 50ºC) different temperatures using a parabolic trough solar air heater for drying purposes. Both the drying temperature and preservative levels significantly (P< 0.001) affected the drying and quality traits of tomato slices. At a temperature of 50 ºC and with citric acid as a preservative, the tomato attained the best average results for moisture lost hr-1, drying time, drying rate, total soluble solids (TSS) °Brix, fruit juice pH, titratable acidity (%) and vitamin C. Based on the average maximum results, 50°C temperature and citric acid as a coating material could be considered for attaining better quality attributes of dried tomatoes. A two-term exponential model on the moisture ratio of tomatoes was found to fit for correlation and regression.

Keywords: Drying Kinetics; Preservatives; Solar drying; Thin Layer Drying Models; Tomato.

1. Introduction

Over 25-30% of the crops are lost due to open sun drying. Losses could be reduced by using parabolic trough solar collectors, which provide us with suitable drying conditions and reduce the attack of microorganisms like bacteria. Drying of agricultural products has always been of great importance for the preservation of food by human beings [1]. Open sun drying is a well-known food preservation technique that reduces the moisture content of agricultural products, thereby preventing deterioration within a period regarded as the safe storage period. However, the quality of food can be seriously degraded, if unprotected from wind, storm, windborne dirt, dust, and infestation by rodents or other animals, so sometimes useful for production becomes inedible [2].

Solar drying is an ancient process of drying and preserving different fruits and vegetables. This is a valuable technique used for increasing shelf life and food security. In the process of solar drying, the products are dried to a moisture content of less than 10%, which reduces the attack of microbes and reduces chemical changes and rancidity. The products dried by the solar collectors are of high quality because they are dried in a controlled environment safe from the attack of pests and the decomposition of dust from the air. The dehydration is uniform, causing minimum losses to the useful ingredients inside the products, having good texture and export quality [3].

The tomato (*Lycopersicum esculentum* L.) belongs to the family Solanaceae (nightshade). It is a major vegetable crop that has achieved great popularity over

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EJCHEM use only: Receive Date: 31 August 2021, Revise Date: 01 September 2021, Accept Date: 20 September 2021
DOI: 10.21608/ejchem.2021.93566.4414

the last century. It is one of the most popular, versatile, and widely grown vegetables, ranking second in importance to potatoes in many countries [4]. It is cultivated over a vast area of land in the world. In the Indo-Pak sub-continent, its utility is growing year by year, resulting in more demand/cultivation. It is native to tropical America, where its indigenous name was tomatin [5]. Tomatoes are the major dietary source of the antioxidant lycopene, which has been linked to many health benefits, including a reduced risk of heart disease and cancer. They are also a great source of vitamin C, potassium, folate, and vitamin K [5]. With these components, tomatoes can help combat the formation of free radicals. Free radicals are known to cause cancer [6-10].

Tomatoes have a very short shelf life, so they are preserved for future use. One of the most ancient and most valuable techniques is the dehydration or drying of tomatoes. Tomatoes are usually dried by the open sun drying method, which is not hygienic, and the drying time is extended to a week in uncontrolled humidity. The modern and most sophisticated techniques are oven drying and solar drying by solar air heaters [11]. Solar dried tomatoes have an extended shelf life, are hygienic due to reduced microbial attack, and economical due to export quality and nutritional attributes remain constant. The dried tomato has good and stable quality because it is dried in the sun without any contamination by dust and microbes. Through drying, large portions of water content from fruit and vegetables are removed to keep their quality and extend their normal storage life. Successfully dehydrating depends upon a slow, steady heat supply to assure that the food is uniformly dried. Dried fruits have sweets because of increased sugars and better flavor and aroma due to good texture [12]. To improve the quality, the traditional sun drying technique could be replaced with industrial drying methods such as hot-air and solar drying [13-14]. Many chemicals, including sodium chloride, calcium chloride, potassium meta-bisulphite and sucrose, have been used by many authors [15- 20] as pre-treatment for tomato drying. Convective hot air is the most widely used technology for drying vegetables, with an air temperature of around 55ºC and a final moisture content of about 4-8% on a wet weight basis [21].

Hence, the present experiment was planned to study the effect of different drying temperatures and preservatives on the drying kinetics and quality parameters of tomatoes. To determine the efficiency of the parabolic trough solar concentrator collector for high performance and to find a fitted model for the moisture ratio of drying kinetics of tomatoes.

2. Experimental

Site selection and Experimental Set-up

An experiment on the influence of natural and chemical preservatives under the performance of a two-term exponential model was carried out to study the quality of solar dried tomatoes. The experiment was conducted in the agro-climatic conditions of Peshawar, located at 34.017° N latitude and 71.583° E longitude with a sub-tropical climate at 350m above sea level [22], Pakistan. Solar flats used for drying tomatoes were relocated with hands each hour to maintain accurate focus on the tomatoes [23]. The experimental set-up was installed on the roof top of the Department of Agriculture Mechanization, The University of Agriculture Peshawar, as given in Fig. 1. Different measuring instruments were installed inside the dryer, such as a pyranometer used for the measurement of solar radiation incidence and a thermos-hygrometer used for measuring the temperature of air and relative humidity. The solar collector made of steel was 1.83 m long, 0.91 m wide and had a 0.18 m thickness and a volume of 0.30 m3. Polyurethane foam with a thickness of 40 mm was used as a packaging material. The box of the solar collector, painted black, was fully airtight, which probably reduced the heat loss. Whereas a simple regulator was fitted to set the flow mass of air at 1.5kg/min. The collector was faced towards south to get full sun light access and the drier with a door of 1.12m length and 0.65 width using the procedure of Hanif et al. [24].

Fig. 1. Overview of the installed flat plate solar collector.

Experimental procedure and studied attributes

Tomatoes were brought from the fields of Horticultural Research Farm, Department of Horticulture, The University of Agriculture, Peshawar, Pakistan and washed with tap water. The tomatoes were then kept in hot water (70ºC) and placed on net trays in the dryer for drying (Figure 2). Tomato fruits were solar dried at three different temperatures (40, 45 and 50ºC) and treated with five different preservatives.

Fig. 2. Tomato slices placed on net inside the collector

The basic approach to using these preservatives was to prevent the growth of micro-organisms. As per categorical classification, the preservatives were used according to the class distribution of Dalton and Louisa [25]. The drying and organoleptic attributes of tomatoes were studied for the application of various temperatures and preservatives. After that, pre-treatment of 1% sodium benzoate solution was given for two minutes. The initial moisture content was determined by the oven drying method; tomatoes were put on trays of a drying unit having 80% perforation and dried until the consecutive weights of samples remained constant, i.e. the moisture content of 10% wet basis was achieved [26]. The moisture content was calculated using the following equation:

$$Mc = \frac{Wi - Wf}{Wi} \times 100$$

Where: Mc moisture content of the product in (%), Wi, initial mass and Wf final mass of the product in (g).

Drying time was taken as the whole time noted during complete drying process of tomato fruits drying. The drying rate Dr (g $dm^{-1}cm^{-2}$ h^{-1}) was calculated using the following equation:

$$Dr = \frac{WI - Wf}{Dm \times Ap \times Dt} \times 100$$

where Dr, drying rate of the product in (g $dm^{-1}cm^{-2}h^{-1}$), Wi, initial mass, Wf, final mass of the product of drying in (g), Dm, dry matter in product in (g), Ap, cross sectional area of the product in ($Cm^{2)}$ and Dt, time of drying {h).

Vitamin C was determined by the titration method as described by Rangana [27]. For this, 10 ml of sample was taken in a volumetric flask and made up to a volume of 100 ml with 3% Meta phosphoric acid and filtered. Then 10 ml of filtrate was taken into a conical flask and titrated against a standard dye solution to a pink endpoint. The following formula was used to calculate the observed readings of Vitamin C.

Ascorbic acid (mg 100 g^{-1}) = $\frac{F \times T \times 100}{D \times S} \times 100$

T = Solution (Dye) taken for the burette (mm)
F = Dye-factor
S = Fruit juice (g) used in dilution
D = Diluted sample used for titration (mm)

A standard method AOAC [28] was used to calculate the total soluble solid (TSS)°Brix using a refractometer. Fruit drops were used to keep on the prism and record the data. Similarly, the standard procedure of AOAC [28] was also used to calculate the titratable acidity in percent. Recorded titratable acidity was calculated by using the following formula:

Titratable acidity % = $\frac{N \times T \times F \times 10}{D \times F} \times 100$

Whereas:

N= NaOH Normality
T = 0.1 N NaOH taken in milliliter (ml)
F = Acid factor (Constant 0.0067 Citric acid)
D = Weight of sample (ml) use in dilution
S = Diluted sample (ml) used in titration

The pH of tomato fruit juice was determined by using an electronic pH meter, following the procedure described by Basit et al. [29]. The ash was determined by the method as reported in the handbook of AOAC [30]. Samples were weighed (5g) accurately in a previously cleaned and dried- weighed crucible. At first, the crucible containing the sample was placed in an oven (100-105 ºC) for 4 h to remove moisture. The moisture free sample was completely charred (free from carbon residues, appearing in grayish white) in a heating mantel followed by heating (ashing) in a muffle furnace at 6000ºC for 3 hours. Then it was removed from the furnace and cooled in desiccators and weighed.

Mathematical models

Weight loss at each hour was recorded using a digital portable balance (LC SK1 Round Pan) with a precision of 0.001. Moisture loss and drying rate at each hour was calculated from the data using the given formula.

$$Dr = \frac{WI - Wl}{Dm \times Ap \times Dt} \times 100$$

Different applied mathematical models given in Table1, were applied to the moisture ratio of tomatoes. R^2 (coefficient of regression) and RMSE (Root Mean Square Error) were calculated for each model using the equations described by Hanif et al. [31]. The highest R^2 and the lowest RMSE values described a model as a good model.

For Modeling of Moisture Ratio, the R^2 (coefficient of regression) and RMSE (Root Mean Square Error) values were calculated statistically using the equations given by Togrul [32].

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

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

Mrpred,I = ith predicted moisture rate
Mrexp, i = ith experimental moisture loss
N = number of observations

Table 1: Mathematical equations of the models used for thin layer kinetics of solar dried tomatoes.

Equations	Models
$MR = a^1 exp(-kt)^1 + a^2 exp(-kt)^2$	Two Term Exponential
$MR = exp(-kt)$	Newton
$MR = 1+at+(at)^2$	Wang
$MR = exp(-kt^n)$	Page
$MR = exp(-(kt))^n$	Modified page

Statistical analysis

The collected data was subjected to analysis of variance (ANOVA) for Randomized Complete Block Design (RCBD) with a two-factor factorial arrangement as described by Basit et al. [33]. The mean values were compared through the Least Significant Difference (LSD) test at a 1% level of significance.

3. Results and discussion

Almost all the attributes were found significant ($P \leq 0.01$) for drying temperatures (DT) and preservatives (P) except for the ash content. Whereas the interaction between DT×P were also found significant except TSS, Ash and Vitamin C contents of tomatoes (Table 2).

Moisture content lost (% h^{-1})

The statistical analysis of data showed that both drying temperature and preservatives and their interaction significantly affected the moisture content lost ($P < 0.001$) of tomatoes. The mean comparison for drying temperature (Figure 3a) showed that a maximum of 8.2 % moisture per hour was lost during drying at 50ºC followed by 6.8% at 45ºC and the minimum moisture lost (6.3%) was recorded for 40ºC. Data regarding preservatives (Figure 4a) showed that a maximum of 7.8 % moisture loss per hour was observed in tomato fruits treated with 2% citric acid solution, followed by moisture loss of 7.3% in sodium bi-carbonate solution. The minimum 6.6% moisture loss was recorded in the solution of 1% potassium meta-bisulfate. As concerned to interaction (Figure 5a), maximum of 9.3% moisture lost per hour was attained by 50ºC×2% citric acid solution, while a minimum of 5.9 % was observed in 40ºC×1% potassium meta-bi-sulfate solution. During the drying process, internal mass transfer occurs with liquid diffusion, vapor diffusion, and capillary forces in the interior region of the product, and water evaporates as it reaches the surface [34]. Moisture removal has capillarity movement when the water content of tomato slices is high. Then, water removal occurs through capillary forces on the surface of the fruit. Free moisture evaporates from the fruit surface as the drying process progresses, therefore shrinkage of fruits occurs. Moisture loss or uptake is one of the most important factors that control the shelf life of foods. As water activity in a foodstuff decreases, the number and growth rate of microbial species able to grow in that environment also decreases [35-36]. These results are in accordance with the findings of Ibrahim [11] who recorded a significant decrease in moisture lost per hour due to an increase in temperature. Hanif et al. [37] also recorded a significant effect of preservatives on the overall moisture lost by tomatoes.
They used 5% Aloe vera and 20% honey solution as preservatives. The moisture loss from apricots and the drying rate were more rapid at high temperatures and high air mass flow rates that dried the apricots quickly and were of good quality and taste [31].

Table 2 Analysis of variance for different attributes studied

*Significant at 0.05% confidence interval, ** Significant at 0.01% confidence interval, NS - nonsignificant effect.

Parameter	P of Drying Temperature (T)	Significance	P of Preservatives (P)	Significance	P of Interaction (T x P)	Significance
Moisture lost (% h^{-1})	0.0031	**	0.0216	*	0.0360	*
Drying time (hrs)	0.0051	**	0.0011	**	0.0096	**
Drying rate (g_{H2O}. $g_{D.M.}$ hr^{-1})	0.0000	**	0.0000	**	0.0016	**
TSS (ºBrix)	0.0212	*	0.0000	**	0.0763	NS
pH	0.0000	**	0.0000	**	0.04205	*
Acidity (%)	0.0312	*	0.0011	**	0.0451	*
Ash (g)	0.6502	NS	0.6051	NS	0.3861	NS
Vitamin C (mg)	0.0112	*	0.0099	**	0.0993	NS

Drying time (h)

The statistical analysis of data showed that both drying temperature and preservatives as well as their interaction have a significant ($P<0.001$) effect on the drying time (hrs) of tomato slices. The mean comparison for drying temperature (Figure 3a) data showed that maximum drying time (17.3 hours) was taken during drying at 40 ºC followed by 16.2 hours at 45 ºC and a minimum was recorded for 50 ºC which was 13.8 hours. Data regarding preservatives (Figure 4a) showed that maximum drying time (16.5 hours) was attained by fruits treated with 25% aqueous honey solution, followed by 16.2 in 25% aqueous aloe vera solution and a minimum of 14.9 hours was recorded in 2% citric acid solution. The interaction of temperature and preservatives indicated (Figure 5d) that the highest drying time (18.1 hours) was recorded at 40 ºC × 25% aqueous honey solution, while the lowest drying time (13.1hours) was observed at 50ºC × 2% citric acid solution. It was observed in our experiment that a decrease in drying rate caused a reduction in relative humidity inside the concentrator. Where a maximum increase in drying rate was noted during decreased temperature. Sunny conditions and higher ambient solar radiation lead to increased concentrator effectiveness and a reduction in drying time. Reducing relative humidity within the dryer plays a larger part in reducing drying time than increasing temperature [38].

Drying rate ($g_{H2O}.g_{D.M}.hr^{-1}$)

The drying rate (($g_{H2O}.g_{D.M}.hr^{-1}$) of tomatoes in the drying period is given in Figure 3b. Statistical analysis showed that drying temperature, preservatives, and their interaction had a significant (P<0.001) effect on drying rate ($g_{H2O}.g_{D.M}.hr^{-1}$). The mean comparison for drying temperature (Figure 3a) showed that a maximum drying rate of 0.31 $g_{H2O}.g_{D.M}.hr^{-1}$ was recorded at 50 ºC followed by 0.025 $g_{H2O}.g_{D.M}.hr^{-1}$ at 45 ºC and minimum was recorded at 40 ºC (0.023 $g_{H2O}.g_{D.M}.hr^{-1}$). The data of preservatives (Figure 4a) showed that the highest value of 0.030 $g_{H2O}.g_{D.M}.hr^{-1}$ was observed in 2% citric acid solution, followed by a drying rate of 0.027 $g_{H2O}.g_{D.M}.hr^{-1}$ in 1% potassium meta-bi-sulfate solution, and a minimum of 0.024 $gH_2O.gD.M.hr^{-1}$ drying rate was recorded in sodium benzoate solution. Regarding interaction (Figure 5b), maximum drying rate of 0.036 $g_{H2O}.g_{D.M}.hr^{-1}$ was recorded at 50 ºC × 2% citric acid solution, while a minimum of 0.021 $g_{H2O}.g_{D.M}.hr^{-1}$ was recorded at 40 ºC × 25% aqueous honey solution. For the highest quality, many studies, including Andritsos et al. [39] recommend drying tomatoes at mild temperatures between 45 and 55 ºC. Temperatures lower than this lead to longer drying times, increasing the risk of microbial activity. Higher temperatures can result in shell hardening and can cause color and aroma quality losses [39]. Citric acid acts as a chelating agent and acidulant, which functionally inhibits poly phenol oxidase (PPO) activity [40]. Sulphate, which acts as a PPO inhibitor, reacts with intermediates to prevent pigmentation [41-42]. Similar results were observed by Hanif et al. [31] who reported that drying time increased by increasing the temperature and rate of mass flow.

Total soluble solids (ºBrix)

The statistical analysis of data showed that both drying temperature and preservatives have significant while their interaction has a non-significant (P<0.001) effect on TSS (ºBrix). The mean comparison for drying temperature (Figure 3b) data showed that the highest content of total soluble solid (1.25 ºBrix) was recorded during drying at 50 ºC followed by 1.06 ºBrix at 45 ºC and a minimum 0f 1.04 ºBrix was recoded at 40 ºC. Similarly, (Figure 4b) indicated that maximum total soluble solid (1.23 ºBrix) was noticed in 2% citric acid solution followed by 1.11 ºBrix in 1% potassium meta-bi-sulfate solution. Whereas the minimum total soluble solid (1.08 ºBrix) was recorded in 25% aqueous honey solution and 25% aloe vera. Regarding interaction, maximum total soluble solid (1.30 ºBrix) was observed at 50 ºC × 2% citric acid solution, while minimum total soluble solid (1.00 ºBrix) was noted in 45 ºC × 25% aqueous aloe vera. The increment in total soluble solids of fruits might be due to the high rate of respiration and metabolic activity which enhances the breakdown of protopectin to pectic substance, disaccharides to monosaccharides and sucrose to fructose and glucose [43]. The present finding is in accordance with the findings of Ali et al. [44] who reported that the higher respiration rate increases the synthesis and use of metabolites, resulting in higher TSS due to the more conversion of carbohydrates to sugars. The degradation of pectin, hemicelluloses, and cellulose in the cell wall within the segment releases some soluble constituents which have a direct effect on total soluble solids [45]. Decreased respiration rates slow down the synthesis and use of metabolites, resulting in a slower rate of decrease in TSS [46]. It has been documented that reducing sugars (fructose and glucose) generally correlates with the total soluble solids [47]. Total dissolved solids and moisture content of the fruit can aggregate and make TSS percentage [48].

Titratable acidity (%)

The titratable acidity of tomato fruits plays a key role in their taste. The drying temperature and preservatives as well as their interaction have a significant (P<0.001) effect on the titratable acidity of tomatoes. The mean comparison for drying temperature (Figure 3b) showed that the highest 1.11% titratable acidity was recorded during drying at 40 0C followed by titratable acidity (0.93%) at 50ºC, which was on par with 45 ºC. The data of preservative (Figure 4b) showed that a maximum of 1.35% acidity was recorded in 2% citric acid solution followed by 1.05% in 25% aqueous honey solution and a minimum of 0.70 % titratable acidity was observed in 2% sodium benzoate solution. Regarding interaction (Figure 5c) maximum titratable acidity (1.91%) was recorded for 40 ºC × 2% citric acid solution, while minimum titratable acidity (0.35%) was recorded for 40 ºC × 2% sodium benzoate solution. These results show that a significant change may occur in the acidity of tomatoes by an increase in temperature under different chemical preservatives. The higher acidity in coated fruits observed in this study might result in a reduction in respiration rate due to limited availability of oxygen [49]. Sugar and acids are related to fruit taste. Fruit flavor should be maintained by having the proper amount of titratable acidity. The retention of titratable acid content by the coated tomato fruits might be due to the protective effect of the leaf powders /films, which act as a barrier to oxygen from the surrounding atmosphere [50] and a reduction in respiration [51].

Fruit juice pH

The statistical analysis of data showed that both drying temperature and preservatives as well as their interaction have a significant ($P<0.001$) effect on the fruit juice pH of tomatoes. The mean comparison for drying temperature (Figure 3c) showed that the highest fruit juice pH (6.32) was recorded during drying at 45 ºC followed by 6.14 at 40 ºC and a minimum of 6.13 pH was recoded at 50 ºC. The data of preservatives (Figure 4c) showed that a maximum of 6.71 pH was recorded in 25% aqueous honey solution, followed by 6.60 in 2% sodium benzoate solution and a minimum of 5.30 was recorded in 2% citric acid solution. Regarding interaction (Figure 5e), highest value of (6.84) fruit juice pH was recorded for 50 ºC × 25% aqueous honey solution, while the lowest fruit juice pH (5.05) was noted in 50 ºC × 2% citric acid solution. The determination of fruit juice pH is done by evaluating the hydrogen ion concentration in the fruits. Percent acidity and pH are inversely related to each other, lower the percent titratable acidity, the higher the pH and vice versa. Many changes occur in the normal cellular operation and process of fruit quality that are affected by calcium. As a result, it alters other processes, such as lowering the acidity of the cells [52]. This variation was observed to be due to variations in temperature, preservatives, period of drying and thickness of slices. The change in temperature results in a variation in the reaction kinematics which causes a change in the pH of fruit juice. Similar findings were also observed by Joseph [53] who recorded the highest pH of 5.90 in solar dried tomatoes.

Ascorbic acid (mg 100g^{-1})

The statistical analysis of data showed that both drying temperature and preservatives have a significant ($P<0.001$) effect on ascorbic acid, while their interaction was found to be non-significant. The mean comparison for drying temperature data (Figure 3c) showed that maximum ascorbic acid (5.6 mg100g^{-1}) was recorded during drying at 40 and 45 ºC followed by (5.5mg 100g^{-1}) at 50 ºC which was the lowest. The data for slices with different preservatives (Figure 4c) showed that maximum ascorbic acid (6.3 mg 100g-1) was observed in 2% citric acid solution, followed by (5.73 mg 100g^{-1}) in 2% sodium benzoate solution, and minimum ascorbic acid (5.2 mg100g^{-1}) was observed in 25% aqueous honey solution, which was statistically like 1% potassium meta-bi-sulfate solution. The Vitamin C content of tomatoes is important because of its anti-oxidative characteristics. Ascorbic acid is one of the most thermo labile components of food products, a fact also confirmed by tomato drying [37]. Ascorbic acid gradually declines with increasing storage duration because it is a relatively less stable compound [54-55]. The ascorbic acid content in fruit shows its nutritional value. The decline in ascorbic acid might be due to high pH and temperature [56]. During storage, a decline in Vitamin C occurs above 0 ºC temperature [57]. As the drying time and the temperature increased, which was expected because of the sensitivity of ascorbic acid to heat, similar results were also reported by Hussein et al. [58]. The variation in the vitamin C content is in conformity with the studies that show the dehydration process can affect the physiochemical properties of tomato powder [59-66]. The results of this study are partially in conformity with the findings of Hanif et al. [67] who used 5% aloe vera and 20% honey solution and recorded a significant decrease in ascorbic acid (mg100 g^{-1}) of tomatoes due to an increase in temperature under different natural and chemical preservatives.

Ash content (g) and modelling results for applied models

Data in Table (3) shows that no significant variation was observed in the ash content for temperatures and preservatives as well as their interaction. The moisture ratio data was subjected to already used models of drying kinetics. The results in Table 4 showed that the two-term exponential model (bold) was the best model for describing the drying kinetics of tomatoes. The model had an R2 of 0.99, which was the highest, and a RMSE of 0.0001, which was the loss of all models. So, it is recommended to apply a two-term exponential model to the moisture ratio of tomatoes to get good results in correlation and regression and best fit. The results are in accordance with the findings of Hanif et al. [68] and Ibrahim [11] who reported their results in terms of correlation and regression of moisture ratio.

Table 3. Mean for analysis of ash contents.

Treatments	P_1	P_2	P_3	P_4	P_5	Mean
T1	5.38	4.12	3.69	3.91	4.28	**4.28**
T2	4.98	3.72	5.83	4.15	4.67	**4.67**
T3	5.71	6.16	5.69	5.68	5.81	**5.81**
Mean	**5.36**	**4.67**	**5.07**	**4.58**	**4.92**	

P1: 25% Aqueous honey solution, P2: 25% Aloe vera, P3: 2% Sodium benzoate solution, P4: 1%Potassium meta-bi-sulfate, P5: 2% Citric acid solution.

Table 4

Results of R2 and RMSE mathematical tested models for drying of tomatoes for thin layer drying kinetics.

Model's Equation	R^2	RMSE
MR = exp (-kt)	0.98	0.0003
MR = exp (-kt^n)	0.79	0.0019
MR = exp (-(kt))^n	0.89	0.0008
MR = a^{1}exp (-kt) ^{1} + a^{2}exp (-kt) ^{2}	**0.99**	**0.0001**
MR = 1 + at+ (at)^2	0.98	0.0003

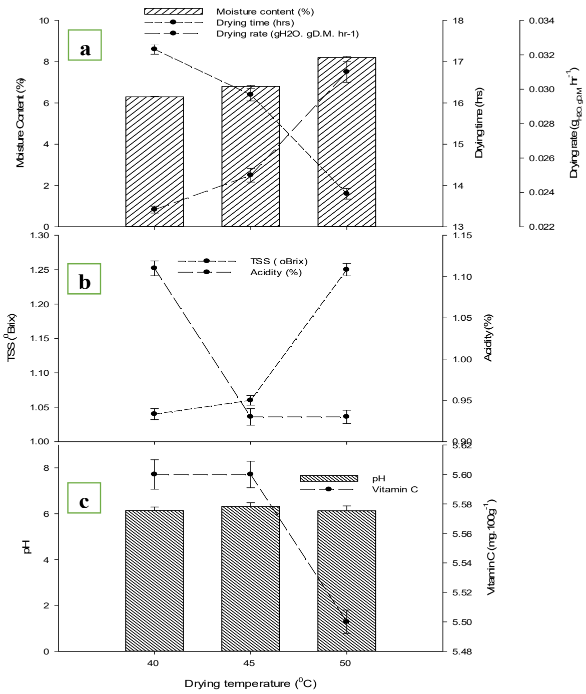

Fig. 3. (a) Moisture content, drying time and drying rate (b) Total Soluble Solids (TSS) and acidity (c) pH and Vitamin C of tomatoes affected by drying temperature.

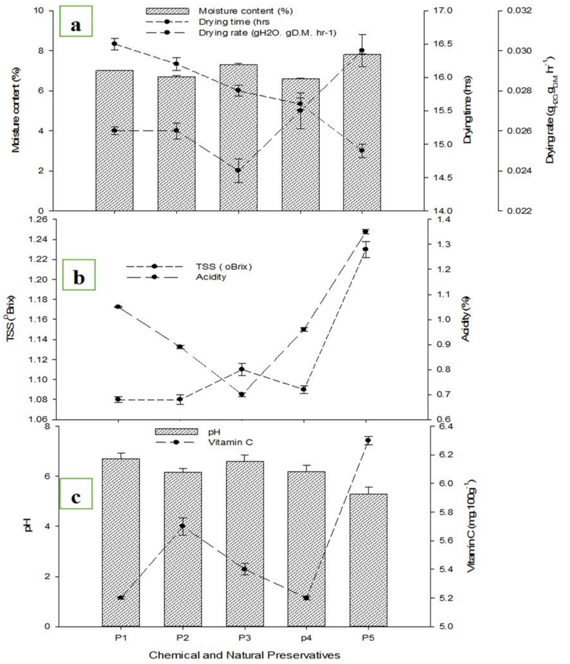

Fig. 4. (a) Moisture content, drying time and rate (b) Total Soluble Solids (TSS) and Acidity (c) pH and Vitamin C of tomatoes affected by chemical and natural preservatives.

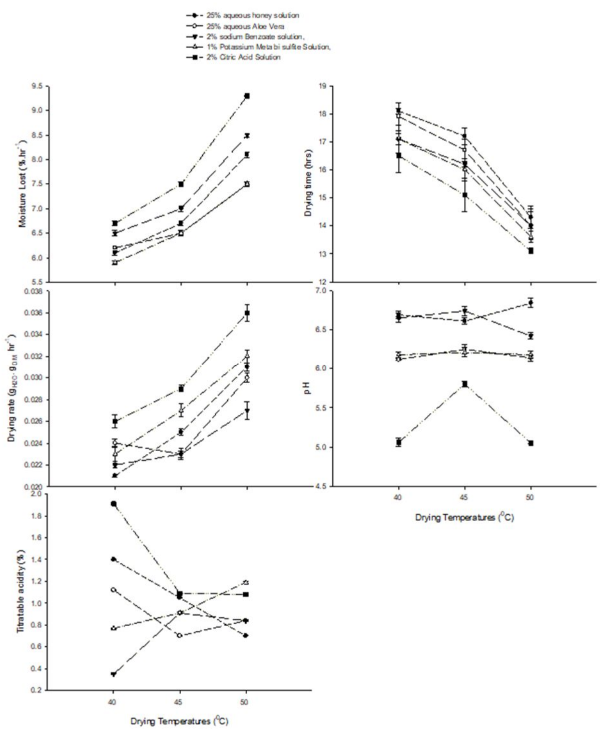

Fig. 5. (a) Moisture content (b) Drying rate (TSS), (c) Titratable acidity, (d) Drying time and (e) pH of tomatoes as influenced by interactive effect of drying temperature and preservatives

4. Conclusion

Based on the research results, it was concluded that among three different drying temperatures, 50 ºC was proven the best in all drying and quality parameters, but it may cause a reduction in the vitamin C content of tomatoes. Similarly, Citric Acid was the best preservative for preserving the quality attributes of dried tomatoes at maximum. Also, the two-term exponential model gave the highest values of correlation and regression on the moisture ratio of tomato.

Acknowledgements

Our team is grateful to Almighty Allah for giving us the opportunity and capability to work for the service of humanity. Higher Education Commission (HEC) Pakistan is greatly acknowledged for financial support of the study through a research project entitled "To study the efficiency of both solar collectors for water distillation, water heating and for drying of different fruits and vegetables" under National Research Grants Program for Universities (NRPU). The University of Agriculture, Peshawar and Department of Agricultural Mechanization is also acknowledged for providing logistic support to undertake the task for successful execution of this project.

Competing interests

The authors declare no competing interests.

Authors' contributions

Conceptualization, IU and MH; methodology, IU, FA and AB; software, IU and STS; formal analysis, IU, MKK and STS; investigation, IU, IA and AB; resources, AU, AJ and FA; writing-original draft preparation, AB and HIM; writing-review and editing, AB and HIM; supervision, MH.
All authors have read and agreed to the final version of the manuscript.

References

1.Yaciuk G., Food Drying. Int. Dev. Res. Cent. Press. Ottawa, Canada (1981).
2. Sacilik K., Elicin A.K., Unal G., Drying kinetics of Üryani plum in a convective hot-air dryer. J. Food Engg., **76**(2006), 362–368 (2005).
3. Mansoor K. K, Hanif M., Maazullah K, Muhammad R., Abdurab, Comparison of drying process and preservatives on drying kinetics, texture and antioxidants retention in mulberry fruits. The Journal of Animal and Plant Sci., **29**(6), 231-238 (2019).
4. Gebhardt C., The historical role of species from the Solanaceae plant family in genetic research. Theor Appl Genet., **129**, 2281–2294 (2016).
5. Sainju U.M. and Dris R., Sustainable production of tomato. p.190-216. In: R. Dris (ed.), Crops: Quality, growth, and biotechnology. WFL Publisher, Helsinki, Finland (2006).
6. El-Beltagi H.S., Mohamed H.I., Safwat G., Megahed B.M.H., Gamal M., Evaluation of some chemical constituents, antioxidant, antibacterial and anticancer activities of *Beta vulgaris* L. root. Fresenius Environ. Bullet. **27**(9), 6369-6378(2018).
7. El-Beltagi H.S., Mohamed H.I., Abdelazeem A.S., Youssef R. and Safwat G., GC-MS analysis, antioxidant, antimicrobial and anticancer activities of extracts from *Ficus sycomorus* fruits and leaves. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca.* **47**(2),493-505 (2019a).
8. El-Beltagi H.S., Mohamed H.I., Elmelegy A.A., Eldesoky S.E., Safwat G., Phytochemical screening, antimicrobial, antioxidant, anticancer activities and nutritional values of cactus (*Opuntia Ficus* Indicia) pulp and peel. Fresenius Environ. Bullet. 28(2A),1534-1551(2019b).
9. El-Beltagi H.S., Mohamed H.I., Safwat G., Gamal M., Megahed B.M.H., Chemical composition and biological activity of *Physalis peruviana* L. Gesunde Pflanz. **71**,113–122(2019c).
10. Hamed M.M., Abd El-Mobdy M.A., Kamel M.T., Mohamed H. I. and Bayoumi A.E., Phytochemical and biological activities of two asteraceae plants *Senecio vulgaris* and *Pluchea dioscoridis* L. PharmacologyOnline. **2,**101-121(2019).
11. Ibrahim D., Evaluation of some thin-layer drying models of tomato slices (*Diospyros kaki* l.) Energy Conversion Manag., **56**(2), 199–205 (2012).
12. Parka Y., Jungb S., Kangc S., Delgado-Licond E., Leticia A., Ayalae M., Maria A., Tapiaf S., MartıˊN-Bellosog O., Trakhtenbergh S., Gorinstein S., Drying of tomatoes (*Diospyros kaki* L.) and the changes in the studied bioactive compounds and the TRSAs. J. LWT. **39,** 748–755(2006).
13. Kaymak-Ertekin F., Gedik A., Sorption Isotherms and Isosteric Heat of Sorp-tion for Grapes, Apricots, Apples and Potatoes, Lebensmittel-Wissenschaft Und Technol., **37**, 429-438(2004).
14. Diamante L. M., Munro P.A., Mathematical modelling of the thin layer solar drying of sweet potato slices. Solar Energy. **51**, 271–276(1993).
15. EL-Safy F.S., Hassan S.R., Shahat Y. O., Amin T. S., Methods of drying of tomato slices and the effect of the using of its powder on the production and characteristics of extruded snacks. Misr J. Ag. Eng., **33**(4), 1537 – 1558(2016).
16. Sofy A.R., Dawoud R.A., Sofy M. R., Mohamed H. I., Hmed A. A., El-Dougdoug N. K., Improving regulation of enzymatic and nonenzymatic antioxidants and stress-related gene stimulation in Cucumber mosaic cucumovirus infected cucumber plants treated with glycine betaine, chitosan and combination. Molecules **25**, 2341; doi:10.3390/molecules25102341(2020).
17. El-Beltagi H.S., Sofy M.R., Aldaej M. I., Mohamed H. I., Silicon alleviates copper toxicity in flax plants by up-regulating antioxidant defense and secondary metabolites and decreasing oxidative damage. Sustainability **12**, 4732; doi:10.3390/su12114732(2020)
18. Mohamed H. I., El-Beltagi H. S., Aly A. A., Latif H. H., The role of systemic and non systemic fungicides on the physiological and biochemical parameters in *Gossypium hirsutum* plant, implications for defense responses. Fresenius Environ. Bullet. **27** (12), 8585-8593(2018).

19. Mohamed H. I., Elsherbiny E. A., Abdelhamid M. T., Physiological and biochemical responses of Vicia faba plants to foliar application with zinc and iron. Gesunde Pflanz. 68, 201-212(2016).
20. Moustafa-Farag M., Mohamed H. I., Mahmoud A., Elkelish A., Misra A. N., Guy K. M., Kamran M., Ai S., Zhang M., Salicylic acid stimulates antioxidant defense and osmolyte metabolism to alleviate oxidative stress in watermelons under excess boron. Plants **9**, 724; doi:10.3390/plants9060724(2020).
21. Grabowski S., Marcotte M., Drying of fruits and vegetables and spices. In Handbook of postharvest Technology: Cereals, Fruits, Vegetables, Tea and Spices, eds. Chakraverty. A., A.S. Mujumdar, G.S.V. Raghavan and H.S. Ramaswamy, 653 – 688. New York, NY: Marcel Dekker, Inc (2003).
22. Ahmad M., Khattak M.R., Jadoon S.A., Rab A., Basit A., Ullah I., Khalid M.A., Ullah I., Shair M., Influence of zinc sulphate on flowering and seed production of flax (*Linum usitatissimum* L.): A medicinal flowering plant. Int. J. Biosci., **14**(4), 464-476(2019).
23. Stiling J., Li S., Stroeve P., Thompson J., Mjawa B., Kornbluth K., et al., Performance Evaluation of an Enhanced Fruit Solar Drying Using Concentrating Panels. Energy Sustain Dev., **16** (2),224–30(2012).
24. Hanif M., Khattak M.K., Amin M., Ramzan M., Zakir S., Ullah S., Khan Z., Development of an Efficient Flat Plate Solar Air Heater for Drying and Water Heating Purposes. Sains Malaysiana. **45**(3), 489–497(2016).
25. Dalton, Louisa. Food Preservatives. Chemical Engg. News. **80**(45), 34–40(2002).
26. Santos B.M., Quiroz R., Borges T.P.F., A Solar Collector Design Procedure for Crop Drying. Brazilian J. Chem. Eng., **22**, 104-132(2005).
27. Rangana S., Manual of analysis of fruit and vegetable products. McGrawHill, New Delhi (1977).
28. AOAC (Association of official Analytical Chemists). Official methods of analysis, 15th edition (Ed. Helrich, K.) Arlington, Verginia, USA. 513(2000).
29. Basit A., Ayaz S., Rab A., Ullah I., Shah S.T., Ahmad I., Ullah I., Khalid M.A., Effect of stevia (*Stevia Rebaudiana* L.) leaf extract on the quality and shelf life of lemon (*Citrus limon* L.). Pure Appl. Bio. **8**(2), 1456-1468(2019).
30. AOAC (Association of Analytical Chemists). Moisture in dried fruits. In: Williams S, editor. Official methods of analysis of the Association of Official Analytical Chemists. Arlington, Va.: AOAC. 415pp (1984).
31. Hanif M., Rahman M., Khan M., Aamir M., Ramzan M., Amin M., Mari I.A., Impact of drying temperatures and air mass flow rates on the drying performance of a Parabolic Trough Solar Collector (PTSC) used for dehydration of apricots. Food Science and Nutrition. Emir. J. Food Agric. **25** (6), 418-425(2013).
32. Togrul I.T., Pehlivan., Mathematical modeling of solar drying of apricots in thin layers. J. Food Engg., **55**(3), 209–216(2002).
33. Basit A., Shah K., Rahman M.U., Xing L., Zuo X., Han M., Alam N., Khan F., Ahmed I., Khalid M.A., Salicylic acid an emerging growth and flower inducing hormone in marigold (*Tagetes*sp. L.). Pure Appl. Bio., **7**(4), 1301-1308(2018).
34. Aghbashloo M., Kianmehr M.H., Samimi-Akhijahani H., Evaluation of thin-layer drying models for describing kinetics of barberries (*Barberries vulgaris*). J. Food Process Engg., **32**, 278–293(2009).
35. Idah P.A., Aderibigbe L.A., Quality changes in dried tomatoes, stored in sealed polythene and open storage systems. Electronic J. Prac. Tech.,**10**, 123 – 136(2007).
36. Sofy A.R., Sofy M.R., Hmed A.A., Dawoud R.A., Alnaggar A.E., Soliman A.M., El-Dougdoug N.K., Ameliorating the adverse effects of tomato mosaic tobamovirus infecting tomato plants in Egypt by boosting immunity in tomato plants using zinc oxide nanoparticles. Molecules **26**(5),1337(2021a).
37. Hanif M., Khattak M.K., Rehman M.U., Ramzan M., Amin M., Aamir M., Sher S., Hafizullah, Khan S., Saeed M., Khan A., Saqlain M., Effect of drying temperature and natural preservatives on reducing aflatoxins in solar dried tomato (*Diospyros Kaki* L). Pak. Acad. Sci., **52**(4), 361–365(2015).
38. Ringeisen B., Barrett D.M., Stroeve P., Concentrated solar drying of tomatoes. Energy for Sustainable Development. **19**, 47–55(2014).
39. Andritsos N., Dalampakis P., Kolios N., Use of geothermal energy for tomato drying. Oregon Institute of Technology Geo-Heat Center Bulletin. (2003).
40. Santerre C.R., Cash J. N.,Vannorman D.J., Ascorbic acid/citric acid combinations in the processing of frozen apple slices. J. Food Sci., **53,** 1713 – 1716(1988).
41. Sapers G.M., Browning of foods: control by sulfites, antioxidants, and other means. Food Tech. Chicago. **47,** 75–84(1993).
42. Abu-Shahba M.S., Mansour M.M., Mohamed H.I., Sofy M.R., Comparative cultivation and biochemical analysis of iceberg lettuce grown in sand soil and hydroponics with or without microbubbles and macrobubbles. J. Soil Sci. Plant Nutri., **21**(1), 389-403(2021).
43. Sharma, R.R., Pal R.K., Asrey R., Sagar V.R., Dhiman M.R., Rana M.R., Pre-harvest fruit bagging influences fruit color and quality of apple cv. Delicious. Agri. Sci. **4**, 443–448(2013).
44. Ali A., Muhammad M., Sijam K., Siddiqui Y., Effect of chitosan coating on the physicochemical characteristics of Eksotika II papaya (*Carica papaya* L.) fruit during cold storage. J. Food Chem. **124,** 620-625(2011).
45. Echeverria E., Ismail M., Sugar unrelated to brix changes in stored citrus fruits. Hort Sci. **25**, 710-716(1990).
46. Yaman O., Bayoindirli L., Effects of an edible coating and cold storage on shelflife and quality of cherries. Lebnsm. Wiss. Und. Technol. **35**,146-150(2002).
47. Malundo T.M.M., Shewfelt R.L. & Scott J.W. 1995. Flavour quality of fresh tomato (*Lycopersicon esculentum* Mill.) as affected by sugar and acid levels. Postharvest Biol. Technol. **6**,103–110.
48. Sajid M., Basit A., Ullah I., Tareen J., Asif M., Khan S., Ali Q.S., Gilani S.A.Q., Zeb S., Nawaz M.K., Efficiency of calcium chloride ($CaCl_2$) treatment on post-harvest performance of pear (*Pyrus communis* L.). Pure Appl. Bio. **8**(2), 1111-1125(2019).
49. Jiang Y., Li Y., Effects of Chitosan coating on postharvest life and quality of longan fruit. Food Chem., **73**,139–143(2001).
50. Valverde J.M., Valero D., Romera D.M., Fabian N., Guillean C., Castillo S. & Serrano M. 2005. Novel

edible coating based on *Aloe veragel* to maintain table grape quality and safety. J. Agric. food Chem. 53:7807–7813.

51. Srinu B., Vikram K.B., Rao L.V., Kalakumar B., Rao T.M., Reddy A.G., Screening of antimicrobial activity of *Withania somnifera* and *Aloe vera*plant extracts against food borne pathogens. J. Chem. Pharmaceutical Res., **4**(11), 4800-4803(2012).
52. Conway W. S., The effects of postharvest infiltration of calcium, magnesium, or strontium on decay, firmness, respiration and ethylene production in apples. J. Am. Soc. Hort. Sci. **112** (2), 300-3031(987).
53. Joseph O.I., Emmanuella B.T., Babatunde H.J., Hyginus I.C., Effect of Drying Methods on the Quality of Tomato and Pepper Powder. B.A.O.J. Food Sci. Tec., **1**, 008(2017).
54. Sofy M.R., Aboseidah A.A., Heneidak S.A., Ahmed H.R., ACC deaminase containing endophytic bacteria ameliorate salt stress in *Pisum sativum* through reduced oxidative damage and induction of antioxidative defense systems. Environ. Sci. Pollut. Res., (2021b).
55. Sharaf A.E.M., Farghal I.I., Sofy M.R., Response of broad bean and lupin plants to foliar treatment with boron and zinc. Australian J. Basic Appl. Sci. **3,** 2226-2231(2009).
56. Emese J., Nagymat P. F., The stability of Vitamin C in different Beverages. British Food J. **110**(3), 296-309(2008).
57. AjibolaV. O., Babatunde O.A., Sulemain S., The effect of storage methods on the Vitamin C content in some Tropical fruit juices. Int. J. Agr. Policy Res. **1**(7),197-2004(2009).
58. Hussein J.B., Sanusi M.S., Filli K.B., Evaluation of Drying Methods on the Content of Some Bio-Actives (Lycopene, β Carotene and Ascorbic Acid) of Tomato Slices. African J. Food Sci., **10**(12), 359-367(2016).
59. Correia A.F.K., Loro A.C., Zanatta S., Spoto M.H.F., Vieira T.M.F.S., Effect of Temperature, Time, and Material Thickness on the Dehydration Process of Tomato. Int. J. Food Sci. (**970724**), 1-7(2015).
60. Sofy A.R., Sofy M.R., Hmed A.A., Dawoud R.A., Refaey E., Mohamed H.I., El-Dougdoug N.K., Molecular characterization of the Alfalfa mosaic virus Infecting *Solanum melongena* in Egypt and the control of its deleterious effects with melatonin and salicylic acid. Plants **10**, 459(2021c).
61. Mohamed H. I., Aly A.A., Mansour M.T.M., El-Samawaty A.M.A., Association of oxidative stress components with resistance to flax powdery mildew. Tropical Plant Pathol. **37**(6),386-392(2012).
62. Abd El- Rahman S. S., Mohamed H. I., Application of benzothiadiazole and *Trichoderma harzianum* to control faba bean chocolate spot disease and their effect on some physiological and biochemical traits. Acta Physiol. Plant. **36**(2), 343-354(2014).
63. Sofy M., Mohamed H., Dawood M., Abu-Elsaoud A., Soliman M., Integrated usage of arbuscular mycorrhizal and biochar to ameliorate salt stress on spinach plants. Arch. Agron. Soil Sci. https://doi.org/10.1080/03650340.2021.1949709(2021d).
64. Aly A.A., Mansour M.T.M., Mohamed H.I., Abd-Elsalam K.A, Examination of correlations between several biochemical components and powdery mildew resistance of flax cultivars. Plant Pathol. J. **28** (2),149-155(2012).
65. Aly A.A., Mohamed H. I., Mansour M.T.M., Omar M.R., Suppression of powdery mildew on flax by foliar application of essential oils. J. Phytopathol. **161**,376–381(2013).
66. Abd El- Rahman S. S., Mazen M. M., Mohamed H. I., Mahmoud N. M., Induction of defense related enzymes and phenolic compounds in lupine (Lupinus albus L.) and their effects on host resistance against Fusarium wilt. European J. Plant Pathol. **134**,105–116(2012).
67. Hanif M., Khattak M. K., Ali S.A., KhanM., Ramzan M., Amin M., Aamir M., Impact of drying temperature and slice thickness on retention of vitamin C in tomatoes (Diospyros Kaki L.) Dried by a flat plate solar collector" Pak. J. Food. Sci. **25**(2),66-70(2015b).
68. Hanif M., Khattak M.K., Ali S.A., Khan M., Ramzan M., Amin M., Aamir M., Impact of drying temperature and slice thickness on retention of vitamin c in persimmon (*Diospyros kaki* L.) dried by a flat plate solar collector" Pak. J. Food sci., **25**(2), 66-70(2015c).