

Drying Kinetics and Mathematical Modelling of Raisin Production by Abrasive and Chemical Pre-Treatment of Grapes

Pawar Dilip Ananda^{1*}, Giri Saroj Kumar¹ & Sharma Ajay Kumar²

¹ICAR-Central Institute of Agricultural Engineering, Bhopal 462 038, Madhya Pradesh, India

²ICAR- National Research Centre for Grapes, Solapur Road, Pune 412 307, Maharashtra, India

Received 28 September 2023; revised 14 January 2024; accepted 15 February 2024

One of the delicious dry fruit, raisin is obtained by drying of grapes with pre-drying treatment. Chemical pre-treatment is most commonly followed for the raisin processing. However, it has drawback like extended drying time and it also triggers the food safety concerns. Various alternatives are being explored for the production of safe raisins. In the present investigation, drying kinetics of grapes and modelling of raisin production have been studied. Grapes were pre-treated with conventional chemical method and novel abrasive method and compared. Treated grapes were dried in tray dryer and solar dryer. Drying kinetics and modelling of experimental data was examined with ten empirical drying equations. Drying rate was higher for grapes treated with abrasive method compared to chemical pre-treatment. Among the different drying conditions, tray drying (55°C) and solar drying (temperature range 43.33 to 58.33°C) was found suitable for superior quality raisin production with drying time of 56.66 h and 78.5 h, respectively. The browning index and firmness of raisins produced using abrasive pre-treatment was to some extent higher compared to chemical treatment whereas yellowness index was found slightly lesser in case of abrasive treated samples. The Modified Handerson-Pebis Model fitted best to predict the drying of abrasive treated grapes, whereas Two term model reported highest goodness of fit for chemically treated grapes. Effective diffusivity for moisture removal of grapes ranged between 1.03×10^{-9} to 5.52×10^{-10} m²/s and was maximum for abrasive treated grapes. Present findings of drying behaviour of grapes and modelling will be useful for the better design of drying systems for production of safe raisins using novel abrasive pre-treatment.

Keywords: Dried grapes, Food safety, Solar drying, Tray drying, Waxy layer

Introduction

Raisin is one of the key dry fruits obtained by controlled drying of grapes using a suitable treatment to grape berry before drying. Being highly delicious in taste, rich in nutritional constituents and proven health benefits, raisins are gaining the market worldwide.^{1,2} Most of the grapes growing countries produce the raisins. Turkey and USA are the major producers of raisins with about 80% of total global raisin production. The other major raisin producers are Iran, India, Argentina, China, Greece, Australia, Afghanistan, and Russia.^{1,3} The worldwide total raisin production has been recorded as 1,237,160 metric tonnes (MT).⁴ India stands at fourth position (1,45,000 MT) after Iran in global raisin production. Some known districts of Maharashtra namely Nashik, Solapur, Sangli, and some regions of Karnataka and Tamil Nadu are the raisin processing area in India. The raisin production of Maharashtra

was increased up to 2.5 lakh tonnes from an average production of 1.8 lakh tonnes.

The three common techniques for drying grapes for making raisins are sun, shade and tray drying.^{1,5} Among these, sun and shade drying are the most prevalent approaches followed by raisin producers.^{6,7} Shade drying is most commonly followed practice by the farmers under Indian conditions. Quality loss due to longer drying times, dust accumulation and infestation by insect, rodents are the issues with sun and shade drying.^{8,9} Hot air drying without pre-treatment is mostly followed in United States of America (USA).¹⁰ Application of solar drying for raisin production has also been studied by some researchers.^{8,11}

Natural drying of grape fruit is hampered by waxy coating on the berry surface.^{5,12} Therefore, pre-treatment before drying is an important operation which dissolves the wax and accelerates moisture migration from grapes during drying. The chemical pretreatment consisting of alkali (Potassium carbonate, sodium carbonate,) and emulsion of oil like

* Author for Correspondence
E-mail: dilip.agroneer@gmail.com

olive oil or ethyl oleate has been proved to be effective which dissolves and/or makes micro fissures to surface cuticle of grape berries and improves the drying rate.^{13,14} The common procedures used by raisin processors in India include immersing grape clusters in solutions made of potassium carbonate (1.5%) and ethyl oleate (2.5%), placing the grapes onto shade drying racks and sporadically spraying the solution. The sulphur fumigation is also followed for enhancing the colour of raisins. However, use of such chemical questions the food safety and disposal of solution after use causes the environmental pollution.^{5,15-17} The use of chemicals is therefore being discouraged with a focus on development of alternate pretreatment method.

A novel industrial scale abrasive pretreatment to grape berries which physically removes grape surface wax has been developed by the authors¹⁶, which avoids synthetic chemicals and is befitting for safe raisin production. Studies on abrasive pretreatment of grape berries before drying have been carried out by various researchers.^{5,12,18-20} Applications of some novel techniques such as ohmic heating²¹, Microwave and pulsed electric field²², high humidity impingement blanching²³ and pulsed vacuum drying¹⁵ have been explored by various researchers. However, the difficulty in scaling up the capacity and prohibiting costs are the challenges of such advance techniques.

Studies on kinetics and mathematical modelling of drying data have been the key interests of the researches working on drying of food crops. The basic models like Henderson and Pebis, Page, Lewis, and exponential Two term are derived using diffusion equation described by Fick's law. Kinetics and mathematical modelling of drying data is useful in understanding of complex drying process, better design of dryers, estimation of times and to generate the equations.^{7,8,24} Most of the studies on drying kinetics of grapes are associated with a chemical pre-treatment. Page^{10,25}, Two term^{9,11}, Midilli^{13,24} are the best fit models for prediction of drying trends of grapes treated with chemicals. So far, the drying behaviour, kinetics and modelling of grapes with abrasive process have not been fully explored. Logarithmic and pages models are found suitable to predict drying behaviour of abraded grapes.¹⁸ The potential of abrasive pretreatment to grapes need be explored further with studies on drying behaviour, mathematical modelling and quality of raisins. This innovative method could ensure food safety by replacing chemicals used in the processing of raisins.

In the present investigation, the modelling and kinetics for drying of grape with both chemical as well as abrasive pretreatment and two drying methods *viz.*, tray drying and solar drying has been studied. This investigation's primary goal is to examine the kinetics and behaviour of grape drying using a unique abrasive approach and compare it to a traditional chemical process. For prediction of the drying process, variety of models suitable for thin layer were identified based on the earlier studies on modelling of grape drying and the models were evaluated using statistical tools for best prediction of data. Some physico-chemical quality parameters of raisins prepared using both chemical and abrasive process were also evaluated. The findings of present investigation could provide advantages of abrasive process of raisin production, better understanding of drying behaviour of grapes with best fit models and hence will be useful in design and development of drying systems for grapes.

Materials and Methods

Materials

Seedless grapes (Cv. *Thompson seedless*) cultivated at ICAR-NRCG, Pune, Maharashtra, were adopted in the research work. Grapes harvested at appropriate maturity (Brix > 23°B, sugar to acid ratio: 20 and uniform pale-yellow colour) were sorted out by removing the damaged or spoiled berries if any.

Pre-treatment

Chemical Pre-treatment

A blend of 1.5 % ethyl oleate, 2.5 potassium carbonate along with water was prepared in a stainless-steel tank. The dipping was done for 4 min and then kept for drying.

Abrasive Pre-treatment

Berries of grapes were separated using a grape de-buncher.¹⁷ The damaged and spoiled berries (if any) were sorted out manually and the sample mass of intact berries were washed with potable water. Abrasive pre-treatment equipment developed by the authors¹⁶ was used for abrasive pretreatment of berries. The prepared berry samples were loaded in abrasive pre-treatment system and treated at optimized operating conditions (*viz.*, speed: 15 rpm, time: 3.5 minutes, grape mass: 8.5 kg). Treated samples were further loaded in tray dryer as per the experimental conditions.

Drying Process

Drying of grapes was done in a tray dryer (air velocity: 1.5 m/s) and CIAE-Solar dryer (Length: 12 m, width: 3m, Tray size: 1 m × 1 m, top cover: 200 µm polyethylene sheet). Solar drying experiments were arranged during the period of 27th April 2019 to 3rd May 2019. Some relevant observations on the atmospheric conditions during the experimental period were recorded. During the period of 27th April to 3 May 2019, the average (day time) values were recorded as temperature (°C): 38.75, 39.25, 39, 34.5, 37.25, 36.75, 37.25; Humidity (%): 18.25, 22.5, 12.25, 20.5, 21, 21.75, and 21.5 and Wind velocity (Km/h): 10.75, 8.75, 10, 14.25, 25.5, 12.25, 15.75. The average values of temperature obtained inside the solar dryer were recorded to be 44.33, 49.00, 52.00, 54.33, 55.00, 58.33, 57.67, 57.67, 57.00, 51.00, 50.33, 47.67 and 43.33°C, at an interval of 40 min from 10 am to 6 pm. The grape samples (350 g) with abrasive and chemical pre-treatment were loaded in both the dryers for drying. The initial weight of sample was recorded and observations on weight loss were measured at 40 min interval. In case of solar drying the observations on decrease in weight were recorded (from morning 10.00 h to evening 18 h) and samples were kept in dryer itself during night time with exhaust fans working to prevent the humidity inside the dryer. The temperature inside the solar dryer was also measured using mercury thermometer with simultaneous observations on moisture loss. Grapes were dried till the moisture reaches below 18%. Tray drying was carried out in day time only at same hours as indicated for solar drying. Observations on decrease in weight of samples were recorded in day time only at an interval of 40 minutes whereas in night time the samples were removed from dryer and kept in airtight desiccator overnight. Drying was continued on next day with record of observations on decrease in weight of samples. The observations on decrease in weight during drying were recorded in duplicate.

Drying Kinetics

Initial Moisture Content

Moisture of fresh grapes was measured with air oven method (Make: Jyoti Scientific, New Delhi, Model: JSI-520) at a temperature of 70°C. About 20 g sample of fresh grapes (cut longitudinally) were dried until the weight decrease of sample ceases. Moisture content (db) in triplicate was recorded considering initial and final weight of sample.

Modelling

The Moisture Ratio (MR) was calculated as in Eq. (1)^{24,26} using the moisture at initial, equilibrium and at specific time during drying

$$MR = \frac{M - M_e}{M_0 - M_e} \quad \dots (1)$$

where, M: Moisture at particular time, % db, M₀: Moisture of fresh grapes, % db, M_e: Equilibrium moisture, EMC, % db. The equation of moisture ratio has been further simplified by some investigators^{9,24} considering the fluctuations in different drying parameters. The EMC was considered to be negligible in simplified equation of moisture ratio (Eq. 2).

Therefore,

$$MR = \frac{M}{M_0} \quad \dots (2)$$

Rate of Drying (DR) of samples during drying was measured using Eq. (3).

$$\text{Drying rate, } DR = \frac{M}{t \times DM / 100} \quad \dots (3)$$

where, M is the water removed in unit time t, DM is dry content in sample.

Validation of Experimental Data

Experimental data on change in MR with respect to time of drying was allocated to selected models. The identified models are widely reported in scientific study and used for drying kinetics, (Table 1). These models have been reported to fit for predicting drying of high sugar produce like plums, grapes, apricot, kiwi etc.²⁷ The models were evaluated in (MATLAB and Simulink® software, Online, © 1994–2021 The MathWorks, Inc.) and the values of constant were calculated.

Statistical criteria viz., the Squared R (R²), Error Some of Square (SSE), Root Mean Square Error (RMSE), and chi-square were used to assess each model's performance to fit the data. The SSE, RMSE and squared chi (χ²) were calculated using Eqs, 4–6,^{24,28}

Table 1 — Models fitted to experimental data

S.N.	Model ^{Ref}	Equation
1	Lewis model ²⁴	$MR = a * e^{(-k*t)}$
2	Page's ^{24,25}	$MR = ae^{(-k*t^n)}$
3	Handerson and Pebis ^{9,24}	$MR = a * e^{(-kt)}$
4	Modified Henderson and Pebis ³⁶	$MR = a * e^{(-kt)} + ge^{(-g*t)} + ce^{(-h*t)}$
5	Logarithmic ²⁹	$MR = ae^{(-k*t)} + c$
6	Two term ^{9,24}	$MR = ae^{(-k_0*t)} + be^{(-k_1*t)}$
7	Exponential two term ^{10,24}	$MR = ae^{(-k*t)} + (1 - a)e^{(-k*a*t)}$
8	Verma ^{9,24}	$MR = a * e^{(-k*t)} + (1 - a)e^{(-g*t)}$
9	Approx. diffusion ^{9,24}	$MR = ae^{(-k*t)} + (1 - a)e^{(-k*b*t)}$
10	Parabolic ⁹	$MR = a + bt + ct^2$

$$SSE = \sum_{i=1}^n MR_{exp,i} - MR_{pred,i} \quad \dots (4)$$

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^N (MR_{exp,i} - MR_{pred,i})^2 \right]^{1/2} \quad \dots (5)$$

$$\chi^2 = \frac{\sum_{i=1}^N (MR_{exp,i} - MR_{pred,i})^2}{N-z} \quad \dots (6)$$

where, $MR_{exp,i}$ and $MR_{pred,i}$ are the actual and forecasted values of moisture ratio, N observations recorded, z constants of the equation. The goodness of fit of the equation was judged with maximum R^2 and minimum SSE, RMSE and χ^2 .²⁹

Determination of Moisture Diffusivity (Deff.)

The diffusion of water from grape samples is expressed by Fick’s second law^{8,30} as given in Eq. 7.

$$\frac{dM}{dt} = Deff \cdot \frac{d^2M}{dr^2} \quad \dots (7)$$

The Fick’s law (second) has been stated in Eq. 8 considering the assumptions that, samples are with spherical coordinates, constant moisture diffusion and temperature, and negligible shrinkage of sample.

$$MR = \frac{6}{\pi^2} \sum_{i=1}^{\infty} \frac{1}{n^2} \exp \left(-n^2 \pi^2 \frac{Deff \cdot t}{r^2} \right) \quad \dots (8)$$

where, Deff. is in m^2/s , r is average radius of grape (18 cm, measured as average of 50 berries, Cv. Thompson seedless grapes), n is positive number.

On simplifying Eq. 8 for long drying condition, the logarithmic form of simplified Fick’s law is given as Eq. 9.

$$\ln MR = \ln \left(\frac{6}{\pi^2} \right) - \left(\frac{\pi^2 Deff \cdot t}{r^2} \right) \quad \dots (9)$$

Plotting $\ln MR$ vs time, the slope, K is given as Eq. (10)

$$K = \frac{\pi^2 Deff.}{r^2} \quad \dots (10)$$

Quality Analysis of Raisins

Using established protocols, the quality attributes of the produced grapes were ascertained. The hot air oven method was used to assess the water content of samples. A sample was dried at 70°C in a hot air oven until it reached a consistent weight. Using the relative CIE L^* , a^* , and b^* from the Hunter-Lab colorimeter (Model: Labscan HunterLab, USA), the browning index of raisins was computed. Changes in values of L^* , a^* , b^* are closely related to browning process. Browning index was calculated using the following equations (11) and (12).^{15,31}

$$BI = 100 \times \frac{(X-0.31)}{0.17} \quad \dots (11)$$

$$\text{where, } X = \frac{(a^* + 1.75L^*)a}{(5.64L^* + a^* - 3.012b^*)} \quad \dots (12)$$

The yellowness index was determined using the values of b^* and L^* using the Eq. (13).

$$YI = 142.86 \frac{b^*}{L^*} \quad \dots (13)$$

The firmness of raisins was measured with texture analyser (Model: TA-XT 2i/TA-XT Plus, Stable Microsystems, UK). p/2 probe was used and operated in compression mode with 5 mm penetration depth. Test and pre-test velocities were maintained at 1 mm/s and 2 mm/s, respectively. Total anthocyanins and phenol content was determined using standard procedure used by Pathare *et al.*³²

Results and Discussions

Drying Curves of Grapes

Changes in Moisture Ratio with Time of Drying

Moisture ratio of grapes changing with time under three temperatures (45, 55 & 65°C) in tray dryer and for two pre-treatments *viz.*, abrasive (A) and chemical (C) is depicted in Fig. 1a. The MR vs time curves in solar dryer for both chemical and abrasion treated grapes are depicted in Fig. 1b. Interruptions in curves of drying in case of solar dryer represents the night period of drying. Water content of grapes before drying was 87.60% (wb). The data showed that, in all tray drying experiments, the moisture ratio dropped faster in the samples treated with abrasive than in the

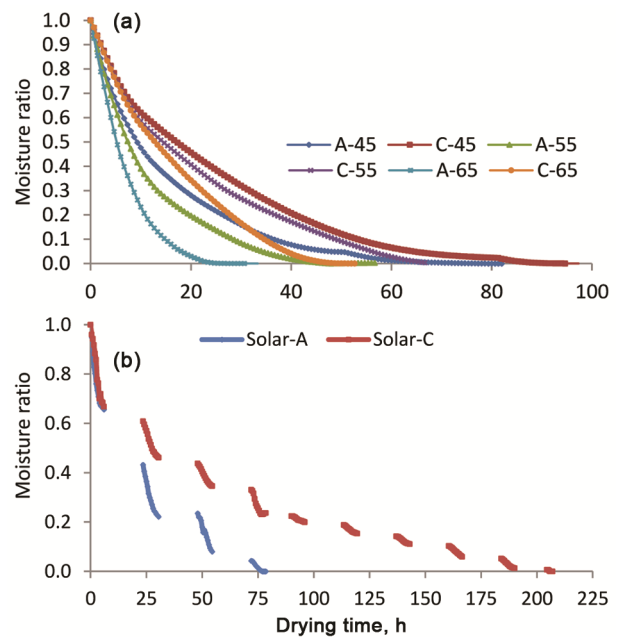


Fig. 1 — Variation in MR with time during different scenarios of grape drying: (a) Tray drying; and (b) Solar drying [A = Abrasive pretreatment, C = Chemical pretreatment].

samples treated with chemical pre-treatment. A like pattern was also noted in the instance of solar drying. It could mean that, in comparison to chemical pre-treatment, the samples treated with abrasion dried more quickly. Among the three drying temperatures of tray drying the decrease in moisture ratio was faster at drying temperature of 65°C followed by 55°C and 45°C. The similar trend was seen for chemical treated samples as well. It is evident that a greater driving force of temperature would result in an increased rate of moisture removal at elevated temperatures of drying. It could also be confirmed from curves that the decrease in moisture ratio was initially higher which further flattened indicating ceasing of water exclusion in drying. Total time was varied with pre-treatment methods, and drying temperature. When samples were dried at 45, 55, 65°C, the overall time required for drying of abrasive pre-treated grapes was reported to be 82, 56.66, and 33.33 hours, respectively. On the other hand, samples that underwent chemical treatment required a total of 95.33, 70.66, and 52.66 hours to dry. The samples dried in solar dryer took 78.5 hours with abrasion before drying and 207 hours with chemical dipping. Conventionally with chemical dipping and shade drying it requires about 13–20 days for the preparation of raisins depending upon environmental conditions. It was discovered that throughout the drying process, the MR of seedless grapes dropped.²⁶ The total drying time was ranged between 51 hours at 50°C to 21 hours at 65°C in an impingement drying at air flow of 5 m/s. Total time of drying the grapes for raisin preparation by chemical treatment and sun drying was 178–228 hours.²⁴ The findings show that employing an abrasive pre-treatment significantly reduces the span of time needed for grapes to dry for making raisins. When grapes were treated with abrasion instead of chemicals before drying, the overall drying time was reduced by 27.77%.⁽¹⁶⁾ Enhanced drying of grapes with abrasive pre-treatment was observed by some researchers.^{5,18–20} Abrasion treatment given to grapes produced a drying curve approaching that of chemically treated samples and the treated grapes reduced 1/3rd of drying time compared to untreated one.¹²

Variations in Drying Rate in Relation to Water Content

Understanding how the drying rate varies with water content allows one to study the kinetics of drying. The drying rate shows how much moisture is extracted from a specific sample mass in a given

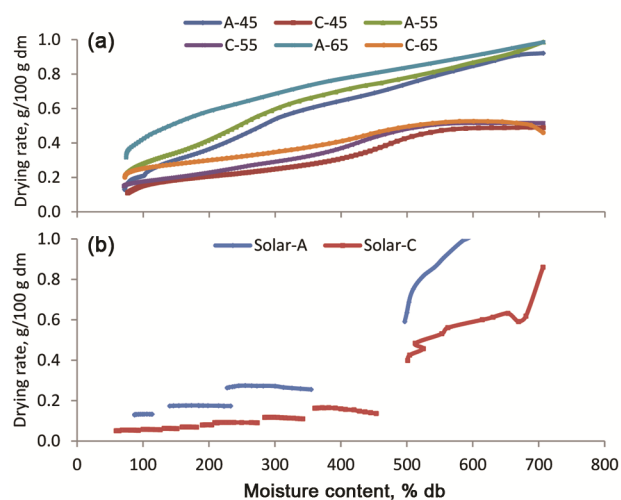


Fig. 2 — Rate of change of drying with water content under different treatments: (a) Tray drying; and (b) Solar drying [A = Abrasive pretreatment, C = Chemical pretreatment].

amount of time. Rate versus water content curves of grapes dried in tray dryer and solar dryer have been plotted in Fig. 2a and Fig. 2b, respectively. Under all experiments, it was noted that the drying rate reduced as the samples' water content dropped. This decrease of drying rate was due to ceasing of moisture removal from grape sample as the drying progress and driving force in the form of moisture difference decreases. It is also understood that in final phase of drying the bound moisture is removed which requires more time to transfer it up to surface and its removal from surface. All the samples of abrasive pre-treatment were dried in falling rate period both in tray and solar dryer (Fig. 2a and 2b). Grape samples treated with chemical pre-treatment were also dried under falling rate period after a small initial constant rate period (up to moisture content of 600%). Drying of grapes occurred under falling rate period in earlier studies.^{9,25,33} The drying of abrasive pre-treated samples was higher under all the experimental conditions compared to chemical pre-treatment. Similar trend could be observed in case of solar dried samples as well. Among the three drying temperatures (45, 55 & 65°C) in tray drying, the drying rate was higher at 65°C, followed by 55°C and 45°C. This trend was observed both in abrasive and chemical pre-treatment.

Grape Drying Kinetics with Abrasive Pre-Treatment

All the results revealed that grapes treated with abrasive pre-treatment dried faster in comparison to chemically treated samples. It could be confirmed

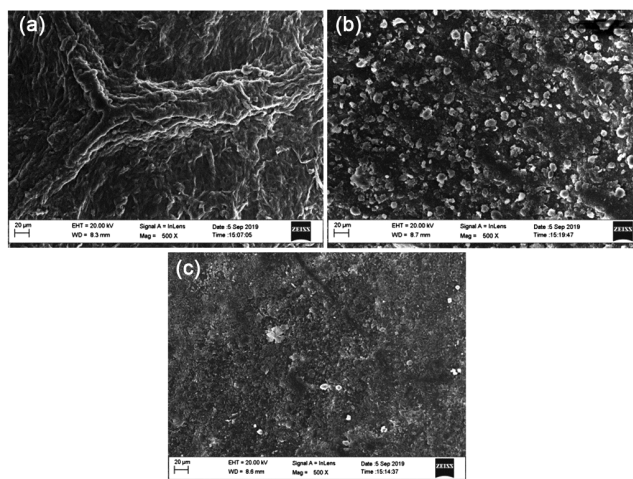


Fig. 3 — Microscopic images of grape peel treated with different methods (Cv. Thompson Seedless): (a) untreated; (b) Chemical; and (c) Abrasive.

from all the curves of drying kinetics presented in Fig. 1 and 2. The obstacle to grapes naturally drying out is the waxy cuticle layer that covers the berries. With an abrasive pre-treatment, this layer is physically removed from the berry surface, but with chemicals, wax dissolves in the liquid compound and then redistributes on berry surface once more during the drying process. This is the reason that the solution of chemicals is sprayed again during the course of drying for 2–3 times to enhance drying process. Complete physical removal of the wax coating permits unhindered continuous moisture diffusion from the grape surface. The pictures of electron microscopy (SEM) clearly show microscopic structure of peel of the grapes with abrasion and chemically treated along with untreated sample (Fig. 3a to 3c). Presence of waxy cuticle layer with its dense network could be observed in Fig. 3a, whereas in case of chemical pretreatment the wax seems to be dissolved and redistributed on the surface (Fig. 3b). Although the cuticle wax network has been disrupted, its re-distribution on the surface poses another challenge to the grape's drying process. The wax was almost removed by abrasive pre-treatment (Fig. 3c) and thus allows continuous moisture migration from the grape berries.

Model Fitting and its Validation

Experimental data on changes in MR with time of drying was fitted to ten identified drying models. The constants of the empirical equations were determined solving non-linear regression equations. The data on fitted models with validation parameters (R^2 , SSE,

PMSE and χ^2) have been tabulated in Table 2 for abrasive pre-treatment and Table 3 for chemical pre-treatment. Model with maximum R^2 value and minimal SSE, RMSE, χ^2 was considered as best fit model. Coefficient of determination (R^2) were more than 0.96 indicating better fit of models for almost all the models except Lewis model in abraded grapes. The SSE, RMSE, and χ^2 values for drying of abraded grapes ranged from 0.000181 to 0.5146, 0.002029 to 0.07226, and 0.00001 to 0.0512, respectively; in contrast, the values for grapes treated chemically varied from 0.003566 to 0.5656, 0.00593 to 0.06727, & 0.000046 to 0.00449. The model Modified Henderson & Pebis followed by Two term resulted highest prediction performance for the tray drying (45, 55, 65°C) in case of abrasive pretreatments and for a temperature of 45°C in case of chemical treatment with maximum values of R^2 and least SSE, χ^2 and RMSE. For a drying temperature of 55 and 65°C in chemically treated grapes respectively, Two term model and Logarithmic model followed by Modified Henderson model provided best fit. In case of solar drying of grapes Modified Henderson and Pebis model was fitted better for abraded grapes whereas Two term model predicted better data for chemically pre-treated grapes. Remaining models such as Pages, two term, logarithmic, Verma and diffusion models were also provided good fit with higher coefficient of determination and minimum errors. Plots of experimental and anticipated values (using the Modified Henderson-Pebis and Two-Term Model) for various experimental settings are shown in Figs. 4a to 4d. The predicted moisture ratio versus drying rate curves is almost coincide with experimental curve showing the best fit of models.

Among the previous studies on mathematical modelling of grapes, there is diversity in the best fitting of model depending upon the experimental conditions. Modified Henderson and Pebis are best fit models for grape under sun drying.⁷ Higher number of data points leads to increased accuracy of Modified Henderson and Pebis Model.³⁴ Two term model has been reported to be better to predict grape drying.^{5,9,11.}

Effective Moisture Diffusivity (Deff.)

Deff. of grape samples dried at different experiments varied between 2.06×10^{-10} to 6.88×10^{-10} m²/s (Table 4). The results of diffusivity conformed normal range reported for food materials.^{8,24} Grapes dried using an abrasive pretreatment had a higher Deff. than grapes dried using a chemical pretreatment.

Table 2 — Fitting and validation of models for the drying of abrasion treated grapes

S. No	Model Name	Drying	Model parameters	Validation parameters			
				R ²	SSE	RMSE	χ ²
1	Lewis	45°C	K : 0.05316	0.8901	0.5146	0.06468	0.00418
		55°C	k : 0.06328	0.9468	0.2020	0.04904	0.00238
		65°C	k : 0.10680	0.9757	0.06365	0.03604	0.00127
		SD	k : 0.04509	0.9332	0.2715	0.07091	0.00494
2	Page	45°C	k : 0.1514; n : 0.6653	0.9847	0.07095	0.02422	0.00058
		55°C	k : 0.1313; n : 0.7519	0.9916	0.03183	0.01958	0.00038
		65°C	k : 0.1439; n : 0.8749	0.9838	0.04239	0.02972	0.00087
		SD	k : 0.1165; n : 0.7245	0.9696	0.1235	0.04827	0.00229
3	Henderson and pebis	45°C	a : 0.8079; k : 0.041	0.9395	0.2834	0.0482	0.00262
		55°C	a : 0.8711; k : 0.05398	0.9696	0.1153	0.03726	0.00157
		65°C	a : 0.9633; k : 0.1025	0.9772	0.05989	0.03532	0.00125
		SD	a : 0.8547; k : 0.03805	0.9724	0.1122	0.04602	0.00247
4	Modified Henderson and pebis	45°C	a : 0.5616; k : 0.03748; b : 0.4333; g : 0.163; c : 0.01716; h : -0.01836	0.9996	0.002019	0.004154	0.00002
		55°C	a : 0.5567; k : 0.03849; b : 0.00001841; g : -0.1392; c : 0.4649; h : 0.1693	0.9993	0.002746	0.005896	0.00004
		65°C	a : 0.031999; k : -0.03263; g : 0.8153 b : -0.09635; c : 1.047; h : 0.1357	0.9999	0.000181	0.002029	0.00001
		SD	a : 0.8047; k : 0.03602; b : 0.08221; g : 21.61; c : 0.2617; h : 0.9251	0.9785	0.08731	0.04221	0.00219
5	Logarithmic	45°C	a : 0.08373; k : 0.0718; c : 0.1052	0.9961	0.01814	0.0123	0.00018
		55°C	a : 0.8704; k : 0.08227; c : 0.09588	0.9966	0.01307	0.01263	0.00017
		65°C	a : 0.9667; k : 0.1423; c : 0.08191	0.9986	0.003586	0.008735	0.00012
		SD	a : 0.8787; k : 0.03415; c : -0.03385	0.9735	0.1076	0.0455	0.00249
6	Two term	45°C	a : 0.2463; k ₀ : 0.01269 b : 0.7326; k ₁ : 0.0956	0.9982	0.008154	0.008278	0.00007
		55°C	a : 0.3419; k ₀ : 0.02468 b : 0.6615; k ₁ : 0.1203	0.9981	0.007279	0.00948	0.00009
		65°C	a : 0.01745; k ₀ : -0.05057 b : 1.014; k ₁ : 0.1258	0.9997	0.0008891	0.004396	0.00004
		SD	a : 0.805; k ₀ : 0.03603 b : 0.2627; k ₁ : 0.932	0.9785	0.08731	0.04138	0.00177
7	Exponential two term	45°C	a : 0.2618; k : 0.1545	0.9498	0.232	0.04379	0.00190
		55°C	a : 0.2615; k : 0.1857	0.9846	0.05844	0.02653	0.00070
		65°C	a : 0.3864; k : 0.2002	0.9875	0.03271	0.02611	0.00067
		SD	a : 0.1389; k : 0.2859	0.9621	0.154	0.05391	0.00285
8	Verma <i>et al.</i>	45°C	a : 0.273; k : 0.01425; g : 0.1032	0.998	0.009125	0.00872	0.000075
		55°C	a : 0.3336; k : 0.02418; g : 0.1182	0.9981	0.007298	0.009434	0.00009
		65°C	a : 0.008692; k : -0.07131; g : 0.1183	0.999	0.002634	0.007486	0.00005
		SD	a : 0.2008; k : 0.6876; g : 0.03584	0.9782	0.08848	0.04125	0.00167
9	Approximation of diffusion	45°C	a : 0.7271; k : 0.1032; b : 0.1381	0.998	0.009125	0.00872	0.000075
		55°C	a : 0.6666; k : 0.1182; b : 0.2046	0.9981	0.007298	0.009434	0.00009
		65°C	a : 0.9913; k : 0.1183; b : -0.6027	0.999	0.002634	0.007486	0.00005
		SD	a : -0.3382; k : 0.04527; b : 0.9975	0.9332	0.2715	0.07226	0.00512
10	Parabolic	45 °C	a : 0.7427; b : -0.02251; c : 0.0001899	0.9329	0.3105	0.05086	0.00311
		55 °C	a : 0.8167; b : -0.03372; c : 0.0003907	0.9631	0.1401	0.04133	0.00209
		65 °C	a : 0.8856; b : -0.06594; c : 0.001336	0.9752	0.06503	0.0372	0.00163
		SD	a : 0.8039; b : -0.02078; c : 0.0001394	0.9608	0.1596	0.05541	0.00374

Quality Analysis of Raisins

The data on quality parameters of raisins prepared under different conditions is presented in Table 5. Moisture content of prepared raisins ranged between 16.38 ± 0.13 and 17.03 ± 0.03 %, db and without any statistical difference. Studies reported grapes dried

until the moisture reaches till 14.79 to 24.93%.²⁵ Browning index of the raisins varied between minimum of 23.14 ± 0.10 to maximum 36.46 ± 0.06 . The raisins prepared with abrasive pretreatment had slightly higher browning index in comparison to chemical pre-treatment (Fig. 5). Additionally, it was

Table 3 — Fitting and validation of models for the drying of chemical treated grape

S. No	Model Name	Drying temperature, °C/ Drying method	Model Parameters	Validation parameters			
				R ²	SSE	RMSE	χ ²
1	Lewis	45	k : 0.03122	0.9785	0.1562	0.03316	0.00109
		55	k : 0.03651	0.9838	0.08801	0.02895	0.00083
		65	k : 0.04656	0.9976	0.01165	0.01222	0.00015
		SD	k : 0.01838	0.9163	0.5656	0.06727	0.00449
2	Page	45	k : 0.05802; n : 0.829	0.9961	0.0285	0.01422	0.00020
		55	k : 0.06161; n : 0.8475	0.998	0.01099	0.01028	0.00011
		65	k : 0.0473; n : 0.995	0.9976	0.01159	0.01227	0.00015
		SD	k : 0.07049; n : 0.6858	0.9700	0.203	0.04047	0.00162
3	Henderson and pebis	45	a : 0.9097; k : 0.0281	0.9911	0.06463	0.02141	0.00051
		55	a : 0.9206; k : 0.03324	0.9947	0.0289	0.01667	0.00034
		65	a : 0.9921; k : 0.04615	0.9977	0.0112	0.01206	0.00014
		SD	a : 0.8217; k : 0.01485	0.9751	0.1681	0.03681	0.00160
4	Modified Henderson and pebis	45	a : 0.8932; k : -0.02851; b : 0.0001451;	0.999	0.007459	0.007379	0.00006
		55	g : -0.063; c : 0.1423; h : 0.4039 a : 16.74; k : 0.1936; b : 0.9196; g : 0.03287; c : -16.69; h : 0.1928	0.9974	0.01392	0.0118	0.00017
		65	a : 0.9857; k : 0.04585; b : 0.03538; g : 0.768; c : 0.03756; h : 16.61	0.9978	0.01078	0.01215	0.00019
		SD	a : -0.1084; k : 0.02399; b : 0.8002; g : 0.01349; c : 0.3805; h : 0.0363	0.9849	0.1022	0.02918	0.00089
5	Logarithmic	45	a : 0.8851; k : 0.03485; c : 0.06331	0.9967	0.02395	0.01308	0.00019
		55	a : 0.8999; k : 0.03726; c : 0.03853	0.9957	0.02319	0.01501	0.00026
		65	a : 0.006; k : 0.0435; c : -0.02322	0.998	0.009812	0.01136	0.00013
		SD	a : 0.8205; k : 0.002023; c : 0.1496	0.9751	0.168	0.03696	0.00161
6	Two term	45	a : 0.002129; k ₀ : -0.03552; b : 0.9338; k ₁ : 0.0307	0.9972	0.02033	0.01209	0.00017
		55	a : 0.1787; k ₀ : 0.2874; b : 0.8557; k ₁ : 0.03089	0.9993	0.003586	0.00593	0.000046
		65	a : 0.9858; k ₀ : 0.04585; b : 0.03557; k ₁ : 0.7736	0.9978	0.01078	0.01199	0.00015
		SD	a : 0.7518; k ₀ : 0.01358 b : 0.329; k ₁ : 0.5363	0.9877	0.08305	0.02609	0.00073
7	Exponential two term	45	a : 0.1839; k : 0.1391	0.9951	0.03549	0.01586	0.00025
		55	a : 0.1485; k : 0.208	0.999	0.00522	0.007085	0.000049
		65	a : 1.221; k : 0.04857	0.9976	0.01155	0.01225	0.00015
		SD	a : 0.1646; k : 0.09449	0.9517	0.3262	0.05129	0.00261
8	Verma <i>et al.</i>	45	a : 0.1701; k : 0.1798; g : 0.02577	0.9953	0.3422	0.0153	0.00024
		55	a : 0.8518; k : 0.0308; g : 0.2302	0.9991	0.004847	0.00686	0.000046
		65	a : 0.9876; k : 0.04594; g : 0.554	0.9977	0.01096	0.01201	0.00014
		SD	a : 0.7515; k : 0.01357; g : 0.4233	0.987	0.08785	0.02673	0.00071
9	Approximation of diffusion	45	a : 0.1706; k : 0.1788; b : 0.144	0.9953	0.03422	0.01563	0.00024
		55	a : 0.1485; k : 0.2293; b : 0.1342	0.9991	0.004847	0.00686	0.000046
		65	a : 0.01247; k : 0.5585; b : 0.08225	0.9977	0.01096	0.01201	0.00014
		SD	a : 0.2485; k : 0.4234; b : 0.03206	0.987	0.08785	0.02673	0.00071
10	Parabolic	45	a : 0.8735; b : -0.01961; c : 0.0001258	0.9907	0.06727	0.02192	0.00059
		55	a : 0.8789; b : -0.02312; c : 0.0001761	0.9868	0.07167	0.02638	0.00083
		65	a : 0.9409; b : -0.03329; c : 0.0003317	0.9965	0.01682	0.01488	0.00026
		SD	a : 0.7608; b : -0.007842; c : 0.00002149	0.9553	0.302	0.04955	0.00290

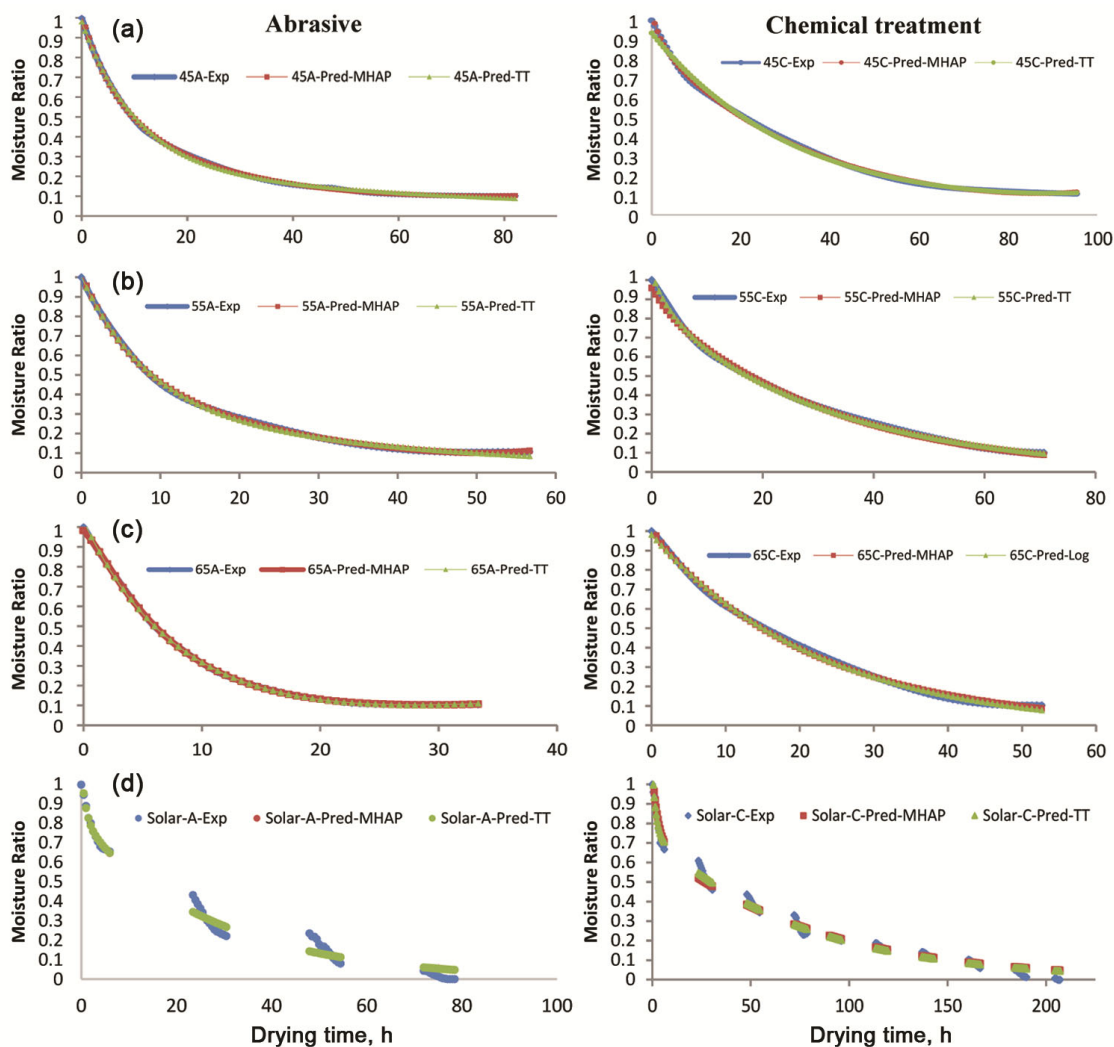


Fig. 4 — Experimental vs projected moisture ratio (MR) for drying of grapes under different scenario: (a) 45°C (Tray drying); (b) 55°C (Tray drying); (c) 65°C (Tray drying); and (d) Solar drying [Exp = Experimental values; Pred-MHAP = Predicted values by Modified Henderson and Pebis Model; Pred-TT = Predicted values by Two-term Model; Log = Logarithmic Model; A = Abrasive pre-treatment; C = Abrasive pre-treatment].

Table 4 — Effective diffusivity of moisture of grape samples dried under different conditions

Pre-treatment	Temperature of drying, °C	Deff., m ² /s
Abrasive	45	3.61×10 ⁻¹⁰
	55	5.52×10 ⁻¹⁰
	65	1.03×10 ⁻⁹
	SD	1.03×10 ⁻⁹
Chemical	45	3.61×10 ⁻¹⁰
	55	4.64×10 ⁻¹⁰
	65	5.15×10 ⁻¹⁰
	SD	3.10×10 ⁻¹⁰

seen to have risen with increase in drying temperatures. The yellowness index of raisins varied from minimum of 76.17 ± 0.76 (for raisins prepared with abrasive pre-treatment at 65°C) to minimum of

95.20 ± 1.01 (for chemical pre-treatment and dried at 45°C in hot air dryer). Abrasive pretreatment at 45 and 55°C and solar dryer resulted into yellowness index of 91.17 ± 0.96, 82.90 ± 0.36, 83.97 ± 0.75, respectively. In case of abrasive pre-treatment except a temperature of 65°C in hot air drying, all other drying resulted into raisin of good color in the form of yellowness index. The firmness of the raisins treated with abrasive pretreatment was slightly higher than that of chemical treated. Temperature of drying showed noteworthy effect on firmness ($p < 0.05$) value reporting maximum firmness of 15.13 ± 0.05 N for the raisins prepared at 65°C with abrasive pretreatment. Factors like temperature, time of drying; pretreatment determines the texture of raisins.

Table 5 — Quality of raisins prepared under different drying conditions and pretreatments [A = Abrasive pretreatment, C = Chemical pretreatment]

Drying method	Temp. °C	Moisture content, % db		Browning index		Yellowness Index, IY		Overall sensory score	
		A	C	A	C	A	C	A	C
HAD	45	16.77±0.04 ^a	17.03±0.03 ^a	26.75±0.09 ^a	23.14±0.10 ^c	91.17±0.96	95.20±1.01	8.45±0.29 ^a	8.45±0.48 ^a
	55	16.48±0.22 ^a	16.88±0.18 ^a	32.32±0.04 ^b	29.41±0.13 ^f	82.90±0.36	86.17±0.96	8.46±0.28 ^a	8.23±0.29 ^d
	65	16.38±0.13 ^a	17.01±0.23 ^a	36.46±0.06 ^c	31.75±0.12 ^g	76.17±0.76	80.21±0.75	7.94±0.22 ^b	7.87±0.30 ^e
SD	40-57	16.86±0.13 ^a	16.94±0.52 ^a	27.23±0.03 ^d	24.16±0.08 ^h	83.97±0.75	86.93±0.60	8.66±0.33 ^c	8.36±0.39
HAD		Total anthocyanins, mg/kg		Phenol content, mg/g		Firmness, N			
		A	C	A	C	A	C		
	45	7.16±0.08 ^a	7.29±0.23 ^a	0.157±0.014 ^a	0.139±0.004 ^a	11.56±0.06 ^a	10.07±0.07 ^e		
	55	6.83±0.22 ^a	7.14±0.13 ^a	0.142±0.012 ^a	0.127±0.011 ^a	13.04±0.05 ^b	11.34±0.02 ^a		
	65	6.39±0.16 ^{b*}	6.87±0.13 ^{ab*}	0.137±0.005 ^a	0.126±0.001 ^{ab*}	15.13±0.05 ^c	12.23±0.05 ^f		
SD	40-57	7.15±0.17 ^a	7.22±0.11 ^c	0.140±0.003 ^a	0.130±0.003 ^a	11.64±0.05 ^a	10.55±0.06 ^f		

A: Abrasive pretreatment, C: Chemical pretreatment



Fig. 5 — Raisins (Tray drying at 55°C) from different pretreatments: (a) abrasive; and (b) chemical pretreatment.

Hardness of raisin was varied from 4.04 ± 0.20 N to 6.33 ± 0.13 N⁽¹⁸⁾ whereas it was as high as 30.07 N⁽²⁰⁾ for the raisins prepared from different grape varieties and with abrasive pretreatment. The firmness of raisins with different drying temperature-time combinations was ranged from 21.0 N to 68.9 N.⁽³⁵⁾

There was no significant variation ($p>0.05$) observed in the total anthocyanins and Phenol content of the raisins prepared at different conditions. The values of total anthocyanins ranged between 6.83 ± 0.22 to 7.29 ± 0.23 mg/kg whereas that of phenol content varied from 0.126 to 0.157 mg/g. The values were slightly on lower side in the raisins prepared at higher drying temperatures. The overall sensory score reported minimum of 7.87 ± 0.3 for the raisins prepared with chemical pretreatment at 65°C and it was maximum of 8.66 ± 0.33 for solar dried raisins with abrasive pretreatment. Essence of chemical and darker color at higher drying temperature might have resulted to lower sensory score of raisins prepared with chemical pretreatment and dried at higher drying temperature (65°C).

Conclusions

Drying kinetics and modelling of grapes with novel abrasive pre-treatment was studied with comparison of chemical process comprising of a liquid blend of ethyl oleate and potassium carbonate. When grapes were treated with abrasive rather than a chemical technique, the rate of drying increased. Abrasion removes the waxy layer physically in all and hence triggers the constant removal of water from grapes. Modified Handerson-Pebis and Two term model reported highest goodness of fit for abrasive and chemical pre-treatment, respectively. The diffusivity for moisture removal of grapes dried under all the experiments varied between 1.03×10^{-9} to 5.52×10^{-10} m²/s and it was maximum for abraded grapes. Abrasion treatment did not have any adverse effect on the quality parameters of the raisins, rather it could avoid the residues of the chemicals and produce safe raisins. The findings of this research would be useful for effective design of dryers and processing systems for production of raisins with novel abrasive process.

Acknowledgement

Present work is the output of a collaborative project between ICAR-CIAE, Bhopal, MP, India and ICAR- NRCG, Pune, India. Project No. 801, Project title: Technology package for production of quality grape raisins. Authors are thankful to ICAR-NRCG, Pune, India for providing the raw material for the experiment and quality analysis of raisins.

References

- 1 Wang J, Mujumdar A S, Wang H, Fang X M, Xiao H W & Raghavan V, Effect of drying method and cultivar on sensory attributes, textural profiles, and volatile characteristics of

- grape raisins, *Dry Technol*, **39** (2021) 495–506, doi: <https://doi.org/10.1080/07373937.2019.1709199>.
- 2 Zemni H, Sghaier A, Khiari R, Chebil S, Ben Ismail H, Nefzaoui R & Lasram S, Physicochemical, phytochemical and mycological characteristics of italia muscat raisins obtained using different pre-treatments and drying techniques, *Food Bioproc Tech*, **10** (2017) 479–490, doi: <https://doi.org/10.1007/s11947-016-1837-4>.
 - 3 Sharma A K & Adulse P G, Raisin production in India, *National Research Centre for grapes*, (2007) 1–5.
 - 4 Statista, <https://www.statista.com/statistics/205021/global-raisin-production/>, (assessed on March 2022).
 - 5 Adiletta G, Russo P, Senadeera W & Di Matteo M, Drying characteristics and quality of grape under physical pretreatment, *J Food Eng*, **172** (2016) 9–18, <https://doi.org/10.1016/j.jfoodeng.2015.06.031>.
 - 6 Jairaj K S, Singh S P & Srikant K, A review of solar dryers developed for grape drying, *Sol Energy*, **83** (2009) 1698–1712, <https://doi.org/10.1016/j.solener.2009.06.008>.
 - 7 Togrul I T & Pehlivan D, Modelling of thin layer drying kinetics of some fruits under open-air sun drying process, *J Food Eng*, **65** (2004) 413–425, <https://doi.org/10.1016/j.jfoodeng.2004.02.001>.
 - 8 Cakmak G & Yildiz C, The drying kinetics of seeded grape in solar dryer with PCM-based solar integrated collector, *Food Bioprod Process*, **89** (2011) 103–108, <https://doi.org/10.1016/j.fbp.2010.04.001>.
 - 9 Yaldyz O & Ertekyn C, Thin layer solar drying of some vegetables, *Dry Technol*, **19** (2001) 583–597, <https://doi.org/10.1081/DRT-100103936>.
 - 10 Doymaz I, Drying kinetics of black grapes treated with different solutions, *J Food Eng*, **76(2)** (2006) 212–217, <https://doi.org/10.1016/j.jfoodeng.2005.05.009>.
 - 11 Hamdi I, Kooli S, Elkhadraoui A, Azaizia Z, Abdelhamid F & Guizani A, Experimental study and numerical modeling for drying grapes under solar greenhouse, *Renew Energy*, **127** (2018) 936–946, <https://doi.org/10.1016/j.renene.2018.05.027>.
 - 12 Di Matteo M, Cinquanta L, Galiero G & Crescitelli S, Effect of a novel physical pretreatment process on the drying kinetics of seedless grapes, *J Food Eng*, **46(2)** (2000) 83–89, [https://doi.org/10.1016/S0260-8774\(00\)00071-6](https://doi.org/10.1016/S0260-8774(00)00071-6).
 - 13 Bingol G, Roberts J S, Balaban M O & Devres Y O, Effect of dipping temperature and dipping time on drying rate and color change of grapes, *Dry Technol*, **30(6)** (2012) 597–606, <https://doi.org/10.1080/07373937.2011.654020>.
 - 14 Patidar A, Vishwakarma S & Meena D, Traditional and recent development of pretreatment and drying process of grapes during raisin production: A review of novel pretreatment and drying methods of grapes, *Food Frontiers*, **2(1)** (2021) 46–61, <https://doi.org/10.1002/fft2.64>.
 - 15 Wang J, Mu W S, Fang X M, Mujumdar A S, Yang X H, Xue L Y & Zhang Q, Pulsed vacuum drying of Thompson seedless grape: Effects of berry ripeness on physicochemical properties and drying characteristic, *Food Bioprod Process*, **106** (2017) 117–126, <https://doi.org/10.1016/j.fbp.2017.09.003>.
 - 16 Pawar D A, Giri S K, Sharma A K & Kotwaliwale N, Effect of abrasive pre-treatment on drying rate of grape berries and raisin quality, *J Food Process Preserv*, **45(9)** (2021a), e15746, <https://doi.org/10.1111/jfpp.15746>.
 - 17 Pawar D A, Giri S K & Sharma A K, Development and performance evaluation of grape debunching machine for production of raisins and stem less table grapes, *J Food Process Eng*, **44(12)** (2021b) e13898, <https://doi.org/10.1111/jfpe.13898>.
 - 18 Adiletta G, Senadeera W, Liguori L, Crescitelli A, Albanese D & Russo P, The influence of abrasive pretreatment on hot air drying of grape, *Food Sci Nutr*, **6(3)** (2015) 355–364, doi: 10.4236/fns.2015.63036.
 - 19 Senadeera W, Adiletta G, Di Matteo M & Russo P, Drying kinetics, quality changes and shrinkage of two grape varieties of Italy, *Appl Mech Mater*, **553**, (2014) 362–366, <https://doi.org/10.4028/www.scientific.net/AMM.553.362>.
 - 20 Thakur A K, Saharan V K & Gupta R K, Drying of ‘Perlette’ grape under different physical treatment for raisin making, *J Food Sci Technol*, **47** (2010) 626–631, <https://doi.org/10.1007/s13197-010-0095-0>.
 - 21 Salengke S & Sastry S K, Effect of ohmic pretreatment on the drying rate of grapes and adsorption isotherm of raisins, *Drying Technol*, **23(3)** (2005) 551–564, <https://doi.org/10.1081/DRT-200054131>.
 - 22 Dev S R S, Padmini T, Adedeji A, Garipey Y & Raghavan G S V, A comparative study on the effect of chemical, microwave, and pulsed electric pretreatments on convective drying and quality of raisins, *Drying Technol*, **26(10)** (2008) 1238–1243, <https://doi.org/10.1080/07373930802307167>.
 - 23 Bai J W, Sun D W, Xiao H W, Mujumdar A S & Gao Z J, Novel high-humidity hot air impingement blanching (HHAIB) pretreatment enhances drying kinetics and color attributes of seedless grapes, *Innov Food Sci Emerg Technol*, **20** (2013) 230–237, <https://doi.org/10.1016/j.ifset.2013.08.011>.
 - 24 Doymaz I, Sun drying of seedless and seeded grapes, *J Food Sci Technol*, **49** (2012) 214–220, <https://doi.org/10.1007/s13197-011-0272-9>.
 - 25 Pangavhane D R, Sawhney R L & Sarsavadia P N, Effect of various dipping pretreatment on drying kinetics of Thompson seedless grapes, *J Food Eng*, **39(2)** (1999) 211–216, [https://doi.org/10.1016/S0260-8774\(98\)00168-X](https://doi.org/10.1016/S0260-8774(98)00168-X).
 - 26 Xiao H W, Pang C L, Wang L H, Bai J W, Yang W X & Gao Z J, Drying kinetics and quality of Monukka seedless grapes dried in an air-impingement jet dryer, *Biosyst Eng*, **105(2)** (2010) 233–240, <https://doi.org/10.1016/j.biosystemseng.2009.11.001>.
 - 27 Doymaz I & Pala M, The effects of dipping pretreatments on air-drying rates of the seedless grapes, *J Food Eng*, **52(4)** (2002) 413–417, [https://doi.org/10.1016/S0260-8774\(01\)00133-9](https://doi.org/10.1016/S0260-8774(01)00133-9).
 - 28 Bozkir H, Effects of hot air, vacuum infrared, and vacuum microwave dryers on the drying kinetics and quality characteristics of orange slices, *J Food Process Eng*, **43(10)** (2020) e13485, <https://doi.org/10.1111/jfpe.13485>.
 - 29 Vega-Galvez A, Lemus-Mondaca R, Tello-Ireland C, Miranda M & Yagnam F, Kinetic study of convective drying of blueberry variety O’Neil (*Vaccinium corymbosum* L.), *Chil J Agric Res*, **69(2)** (2009) 171–178.

- 30 Celma A R, Lopez-Rodriguez F & Blazquez F C, Experimental modelling of infrared drying of industrial grape by-products, *Food Bioprod Process*, **87(4)** (2009) 247–253, <https://doi.org/10.1016/j.fbp.2008.10.005>.
- 31 Pathare P B, Opara U L & Al-Said F A J, Colour measurement and analysis in fresh and processed foods: A review, *Food Bioproc Technol*, **6** (2013) 36–60, <https://doi.org/10.1007/s11947-012-0867-9>.
- 32 Mnari A B, Harzallah A, Amri Z, Dhaou Aguir S & Hammami M, Phytochemical content, antioxidant properties, and phenolic profile of Tunisian raisin varieties (*Vitis vinifera* L.), *Int J Food Prop*, **19(3)** (2016) 578–590, <https://doi.org/10.1080/10942912.2015.1038720>.
- 33 Tulasidas T N, Raghavan G S V & Norris E R, Microwave and convective drying of grapes, *Trans ASAE-Am Soc Agric Eng*, **36(6)** (1993) 1861–1866.
- 34 Onwude D I, Hashim N, Janius R B, Nawi N M & Abdan K, Modeling the thin-layer drying of fruits and vegetables: A review, *Compr Rev Food Sci Food Saf*, **15(3)** (2016) 599–618, <https://doi.org/10.1111/1541-4337.12196>.
- 35 Rybka A C P, De Freitas S T, Figueireto Neto A & Biasoto A C T, Central composite rotatable design approach to optimize Italia raisin drying conditions, *Comunicata Scientiae Horti J*, **6(4)** (2015) 454–462, <https://doi.org/10.14295/cs.v6i4.993>.