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Araştırma Makalesi Research Article

EXAMINATION OF DRYING KINETICS FOR RED GRAPE POMACE

Erinç KOÇAK, Şeyma UYSAL, Funda TURAN, Fikret PAZIR*, Gülden OVA

Ege University Engineering Faculty Food Engineering Department, 35100, İzmir, Turkey

Keywords

Moisture diffusivity,
moisture ratio,
grape pomace,
drying kinetics,
thin layer

Abstract

In this study, the drying kinetics of red grape pomace processed as a by product during grape juice production of the Black Dimrit grape species was investigated as a function of different drying conditions. Drying process was carried out at temperatures of 40, 50, 60 ve 70 ^{0}C and air velocities of 1.0, 1.4 and 1.8 m/s with an initial sample thickness of 0.75 $\pm$0.2 cm on average until constant weight was attained. The kinetic behaviour of red grape pomace was considered as thin layer drying process. In order to evaluate the effective diffusivity, eleven models of diffusion including Newton, Page, Modified Page, Henderson & Pabis, Logaritmic, Two term, Exponential two term, Diffusion, Modified Henderson & Pabis, Verma and Midilli were then performed. The assessment of the performance was made by the comparison of the coefficients of determination, root of mean square error and reduced chi-square between the observed and predicted moisture ratios. Statistical analysis resulted in the compatibility of Midilli, Two term, Modified Henderson & Pabis and Verma models for the experimental conditions. The effective moisture diffusivity varied from 2.85x10-10 to 1.67x10-9 m2/s over the temperature and air velocity range. Temperature dependence of diffusivity was well reported for the air velocity of 1 m/s by an Arrhenius type relationship. The activation energy of red grape pomace was calculated as 26,26 kJ/mol.

SİYAH ÜZÜM POSASININ KURUTMA KİNETİĞİNİN İNCELENMESİ

Anahtar Kelimeler

Siyah üzüm posası,
nem oranı,
etkin difüzyon katsayısı,
kurutma kinetiği,
ince tabaka

Öz

Bu çalışmada siyah Dimrit cinsi üzümün üzüm suyuna işlendikten sonra arta kalan üzüm posasının farklı sıcaklık ve farklı hava akım hızlarında kurutma kinetiği araştırılmıştır. Kurutma işlemi, 40, 50, 60 ve 70 ^{0}C sıcaklıklarda; 1.0,1.4 ve 1.8 m/s hava akım hızlarında, ortalama kalınlığı 0.75 $\pm$0.2 cm olan, aynı ağırlıktaki üzüm posası örneklerinin tepsili kurutucuya yerleştirilmesiyle yapılmıştır. Üzüm posasının kinetik davranışı ince tabaka kurutma şeklinde değerlendirilmiş ve bu davranışın Newton, Page, Modifiye Page, Henderson ve Pabis, Logaritmik, Çift terimli, Üstelçift, Difüzyon, Modifiye Henderson ve Pabis, Verma ve Midilli olmak üzere onbir farklı modele uyumluluğu incelenmiştir. Bu modellerin uyumluluk derecesi, her deneme için gözlenen ve tahmin edilen nem oranlarının hesaplanmasından sonra regresyon katsayıları, ortalama hata kareler toplamı ve kikare katsayıları karşılaştırılarak saptanmış ve istatistiksel analizler sonucunda Midilli, Çift terimli, Modifiye Henderson ve Pabis, ve Verma modellerinin üzüm posasının kinetik davranışına uyduğu gözlemlenmiştir. İncelenen kurutma sıcaklığı aralığında etkin difüzyon katsayısı (Deff) 2.85x10-10 ve 1.67x10-9 m2/s aralığında değişmekte olup, Difüzyon katsayısının 1.0 m/s hava akış hızı için kurutma sıcaklığı ile ilişkisi Arrhenius teorisi ile doğrulanmıştır. Üzüm posasının aktifleşme enerjisi 26,26 kJ olarak hesaplanmıştır.

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* İlgili yazar / Corresponding author: fikret.pazir@gmail.com

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Yazar Kimliği / Author ID (ORCID Number)
E. Koçak, 0000-0001-9054-4703
Ş. Uysal, 0000-0001-6271-4752
F. Turan, 0000-0003-3451-6745
F. Pazir, 0000-0003-3997-4892
G. Ova, 0000-0002-9161-0212

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1. Introduction

Nowadays, valorization of some agricultural wastes and by products produced during food processing is of particular concern to the world's population due to its economic and environmental aspects, and thus leading to a progressive rise in the awareness of world's society.
Red grape pomace is composed of several parts namely skins, seeds and stalks. It has been considered as a valuable agricultural waste since its composition consists of considerable amounts of tartarate, malate, citric acid, grape seed oil and dietary fibre and hence it is feasible for diverse scientific research and industrial application areas (Arvanitoyannis et al., 2006; Celma et al.,2007). Beyond its commercial value and healthy nutrient composition, its effective recovery is regarded as a significant environmental challenge (Ekici,2011). All these aspects emphasize the requirement of a utilization process of grape pomace at optimal conditions.
The moisture content of red grape pomace varies from 56% to 80% in accordance with the variety, cultivar, type of process (whether it is dried after the removal of the seeds and stalks or as a whole) (Doymaz et al.,2004). Meanwhile, this moisture content must be reduced in order to obtain products with high added value such as anthocyanins, adsorbents and grape seed oil. Therefore, there are a number of studies reported so far in literature in relation to different drying methods of agricultural products such as conventional air drying (Doymaz et al.,2004; Freire et al.,2001;Kaur et al.,2006; Arora et al.,2006; Movagharnejad 2007; Hossain et al.,2007; Jumah et al.,2007; Shiby et al.,2007; Singh et al.,2006), infrared drying (Sharma et al.,2005; Sun et al.,2007), microwave drying (Sutar and Prasad, 2007). It is strongly recommended that the drying temperature should not exceed the upper limits specific to the food type so that it does not cause any damage of the ingredients.
This study aims to evaluate the conformance of several thin layer drying models with the drying process of red grape pomace and to identify the best fitted model. In addition, it intends to calculate effective moisture Diffusivity and Arrhenius activation energy of red grape pomace at different drying temperatures and air velocities.

2. Material and Method

2.1. Material

Freshly produced grape pomace obtained by pressing the Black Dimrit grape species (*Vitis vinifera*) during grape juice processing was provided by Manisa Viticulture Research Institute located in Manisa, the western part of Turkey in July 2016. As soon as it was filled in airtight and light resistant packages, the samples were delivered to the facility of Food Enginnering Department in Ege University and stored at -24^{0}C until drying process. The moisture content of wet grape pomace was determined by means of a vacuum oven (WiseVen VOW-30, Germany) operating at 65^{0}C. The analysis was performed until the achievement of constant weight in triplicate runs. The average moisture content was calculated 67.9% $\pm$ 0.4.

2.2 Drying procedure

In this study, a cabinet dryer (Weintek, Turkey) made of 10 trays and produced by a special design with certain customer specifications was used. For all experiments the tray load capacity was determined and kept constant at 1,66 kg/m^2. The air flow was parallel to the sample. Air inlet temperature and relative humidity was measured by a higrometer (Testo 645, Germany) at time intervals of 1 hour. The samples were spread uniformly on each tray and the average initial thickness of the samples was measured for each tray by a digital calliper. The average sample thickness of twelve experiments was found as 0.75 $\pm$ 0.2 cm.
The moisture loss during drying process was measured by a balance inside the cabinet dryer. The weight of the samples were recorded at 20 minutes intervals until the samples reach constant weight. The drying experiments were performed at 40, 50, 60 ve 70^{0}C and at air velocities of 1.0, 1.4 and 1.8 m/s which can be adjusted by the centrifugal fan. As soon as the samples were placed in the cabinet dryer and the

electrical heater was turned on, the system automatically started to record all the relevant data with respect to drying process.

2.3 Modelling of Drying Kinetics

For most of the agricultural products, theoretical models related to drying are based on Fick's second law of diffusion. The thin layer drying modelling assumes the shape of the grape pomace as an infinite slab and a uniform temperature distribution in the sample. For the infinite slab geometry, the fractional moisture ratio (M_R) of the sample is computed with Eq.1 given below under the following assumptions: uniform initial moisture distribution, steady diffusivity, negligible external resistance and shrinkage (Crank,1975).

$$M_R = \frac{M - M_e}{M_0 - M_e} = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left(-\frac{(2n+1)^2\pi^2 D_{eff}t}{4L^2}\right) \quad (1)$$

For long drying periods, only the first term of the Eq. (1) can be used (Ramesh et al.,2001; Movagharnejad et al., 2007). Furthermore, equilibrium moisture content (M_e) is negligible unless the ambient relative humidity remains constant. In this case, fractional moisture ratio can be calculated with the following equation:

$$M_R = \frac{M}{M_0} = \frac{8}{\pi^2}\exp\left(\frac{\pi^2 D_{eff}t}{4\,L^2}\right) \quad (2)$$

In Eq. (2), M represents the moisture content at time t (on d.b), M_0, refers to the initial moisture content (on d.b.), D_{eff}, is called effective moisture diffusivity coefficient and L (m) is the half thickness of the infinite slab.

In this study, partially theoretical models derived from Newton's cooling law and Fick's diffusion law by an analogy were examined and these models are described in Table 1.

Table 1. Semi theoretical drying models (Erbay, 2008)

Model	Model equation	Reference
Newton	$M_R = \exp(-kt)$	Lewis, 1921
Page	$M_R = \exp(-kt^n)$	Page, 1949
Modified Page-I	$M_R = \exp[-(kt)^n]$	Overhults et al., 1973
Henderson & Pabis	$M_R = a\exp(-kt)$	Henderson & Pabis, 1961
Logaritmic	$M_R = a\exp(-kt) + c$	Chandra & Singh, 1995
Two-Term	$M_R = a\exp(-k_0t) + b\exp(-k_1t)$	Henderson, 1974
Exponential Two Term	$M_R = a\exp(-kt) + (1-a)\exp(-kat)$	Sharaf-Eldeen et al., 1980
Diffusion	$M_R = a\exp(-kt) + (1-a)\exp(-kbt)$	Kasem, 1998
Modified Henderson & Pabis	$M_R = a\exp(-kt) + b\exp(-gt) + c\exp(-ht)$	Karathanos, 1999
Verma	$M_R = a\exp(-kt) + (1-a)\exp(-gt)$	Verma et al., 1985
Midilli	$M_R = a\exp(-kt^n) + bt$	Midilli et al., 2002

2.4 Statistical assessment

Eleven models are investigated in order to describe the drying behaviour of grape pomace. For each model, the predicted and observed values of fractional moisture ratios changing with time were computed, the coefficient of determination (R^2), Root of square mean error (RMSE) and reduced chi-square coefficients were determined. The best fitted model was chosen under consideration of the highest value of the coefficient of determination and the least RMSE and the least reduced chi-square coefficients (Sarsavadia et al.,1999; Sun et al.,2007; Lahsasni et al.,2004; Faustino et al.,2007). The goodness of fit of the tested mathematical models was performed by SPSS (version 20.0) program using non-linear regression analysis based on Levenberg-Marquardt algorithmus and regression coefficient of determination (R^2) for each trial were computed by SPSS. In order to calculate RMSE and χ^2 values the following equations with the number (3) and (4) were used.

$$\mathrm{RMSE} = \sqrt{\left(\frac{1}{n}x\left[\sum_{n=1}^{n}\left(\mathrm{MR_{pre}} - \mathrm{MR_{obs}}\right)^2\right]\right)} \quad (3)$$

$$\chi^2 = \frac{\sum_{i=1}^{n}\left(MR_{pre} - MR_{obs}\right)^2}{n - z} \quad (4)$$

In Eq. (3) n is identified as the number of observations; MR_{pre} is the predicted moisture ratio; MR_{obs} refers to the observed values of moisture ratio; z is the number of constants in the model equation.

3. Results

In this section of this study, the drying kinetics of red grape pomace were examined. The best fitted statistical model or models for the kinetic behaviour in each trial were determined and the level of the goodness of fit was indicated.

3.1. The Relationship between fractional Moisture Ratio, Drying Temperature, Air Velocity and Drying Time

The moisture ratio (MR) of red grape pomace versus drying time (h) within the temperature range between 40^0C and 70^0C for different air velocities of 1.0 , 1.4 and 1.8 m/s was plotted and shown in Figure 1., Figure 2. and Figure 3., respectively.

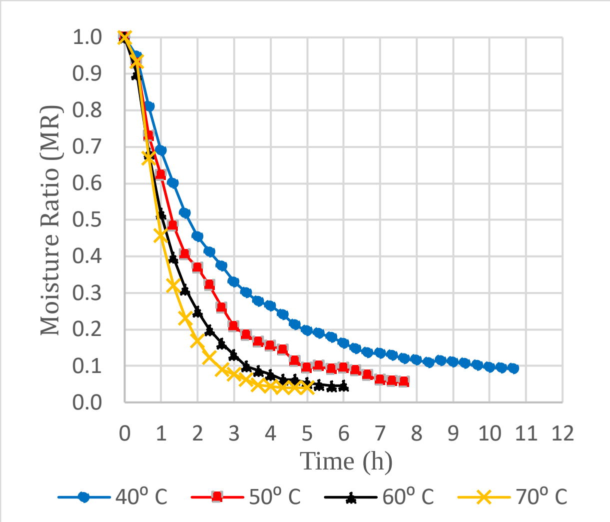

Figure 1. Experimental Moisture ratios of grape pomace at different drying temperatures (air velocity=1.0 m/s)

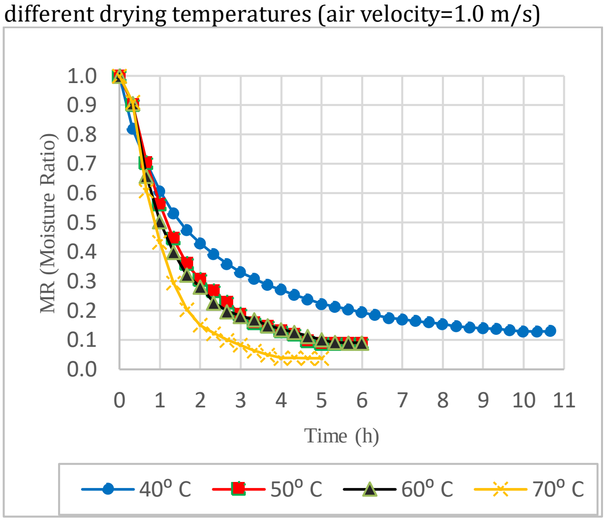

Figure 2. Experimental Moisture ratios of grape pomace at different drying temperatures (air velocity=1.4 m/s)

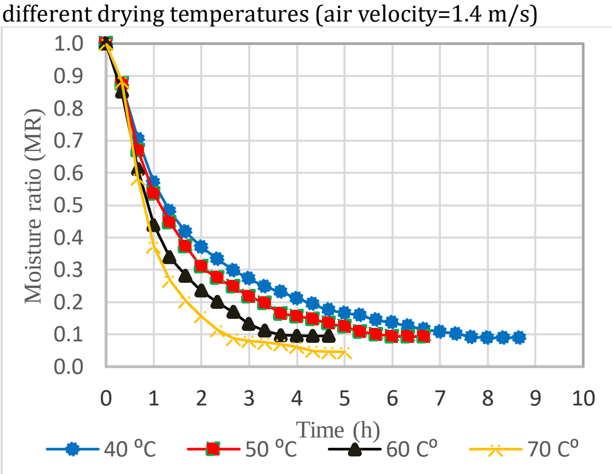

Figure 3. Experimental Moisture ratios of grape pomace at different drying temperatures (air velocity=1.8 m/s)

In these figures, the fractional moisture ratio declines with time. It can be concluded that it is not possible to observe a distinct constant rate drying period for all these cases and the whole drying process probably took place during the falling rate period. As one might expect, the higher the drying temperature, the shorter the drying time and the lower the final moisture ratio.

3.2 Evaluation of Kinetic Models

It might be pointed out that four different models (Midilli, Two term, Modified Henderson & Pabis, Verma) are able to describe the kinetic behaviour of grape pomace most conveniently. Seven experiments were best fitted to the model Midilli ($0.991 < R^2 < 0.998$) , three experiments showed good agreement with Two Term ($0.996 < R^2 < 0.999$) , while the goodness of fit was verified by Modified Henderson & Pabis ($R^2= 1$) and Verma ($R^2= 0.999$) each for one experiment. This data indicates that Midilli is the best fitted model that could succesfully present the kinetic behaviour of red grape pomace 58.3% of the drying experiments. This result is in agreement with the research in the past. Several studies reported that Midilli can be selected as the most appropriate kinetic model for hawthorn at drying temperatures of 50, 60, 70 ^{0}C and air velocities of 0.5; 0.9 and 1.3 m/s (Aral & Beşe, 2016) ; for coriander at the drying microwave power outputs of 180, 360, 540, 720 and 900 W (Sarımeseli, 2011) ; for Murta berries at 40,50 and 60^{0}C by convectional air drying in addition to infrared drying at 400 and 800 W (Puente-Diaz et al., 2013); for spearmint at 40, 45, 50 and 55 ^{0}C by air velocity of 0.8, 1.0 ,1.2 and 1.5 m/s (Ayadi et al., 2014); for mushroom at 55^{0}C by convectional isothermal drying (Guo et al., 2014). In contrast to these findings, it was reported by some studies conducted with sour cherry that Verma and modified logistic kinetic models were determined as the most convenient semi theoretical models which describe the kinetic behaviour most satisfactorily at drying temperatures 50, 60 and 70 ^{0}C by convectional air drying and at microwave power levels of 120,150 and 180 W by hybrid drying (Horuz et al., 2017). In our study, it was found that Verma model best fits to the kinetic behaviour of grape red pomace at 70 ^{0}C and air velocity of 1 m/s. This issue verifies that our findings might be in agreement with the literature.

It can be pointed out that the goodness of fit for 40 ^{0}C was verified by Two-Term and Modified Henderson & Pabis, for 50 ^{0}C by Midilli and Two-Term; for 60 ^{0}C only by Midilli and for 70 ^{0}C by Midilli and Verma models. Moreover, at constant air velocity, there is no statistical significance among the models Midilli, Two-Term, Modified Henderson & Pabis, Verma and Difusion models. Though, logaritmic model indicated the lowest goodness of fit in comparison to the other models. The statistical evaluation of the kinetic models is shown in Table 2.

In contrast to our results, it was reported that logaritmic model most satisfactorily described the kinetics of red grape pomace which was dried at 70, 90 and 110^{0}C with the air velocity of 1.2 m/s. The other models that were examined are Henderson & Pabis and Page (Doymaz & Akgün, 2009). The reason for this discrepancy might be the difference of the carbohydrate content arising from the raw material. Water binding capability of grape pomace depends on its sugar composition and whether it undergoes a fermentation process before drying or not. Hence, the kinetic behaviour might be influenced by the change in the carbohydrate content.

Furthermore, this study suggests the most satisfactory kinetics models Two-term, Midilli and Verma for the air velocity of 1 m/s; Midilli and Modified Henderson & Pabis for the air velocity of 1.4 m/s and Two term and Midilli for the air velocity of 1.8 m/s.

In the highlight of this knowledge the models that gave better results, the kinetics coefficients used in these models and the effective moisture diffusivity which will be calculated in the following section are described in Table 3.

3.3 Evaluation of Effective Moisture Diffusivity and Arrhenius type equation

The effective moisture diffusivity (Deff) is computed by plotting experimental drying data in terms of ln(M_R) versus time (Lomauro et al.,1995; Doymaz and Akgün 2009). From Equation (5), a plot of ln(MR) versus time gives a straight slope of α, where;

$$\alpha = \frac{\pi^2 D_{eff}}{4L^2} \qquad (5)$$

D_{eff} indicates effective diffusivity coefficient, L is the half-thickness of the infinite slab. The values of effective diffusivity coefficients are given in Table 4. These values range between 2.849 x 10^{-10} m^2/s and 1.674 x 10^{-09} m^2/s. The highest value (D_{eff}) was obtained for the experiment where drying temperature is 70 ^{0}C and air velocity is 1.4 m/s. The findings are in agreement with the results of early studies focusing on the kinetic behaviour of different agricultural products and wastes. Doymaz and Akgün (2009) found D_{eff} value as 0.855-2.17 x 10^{-09} m^2/s between 70-110 ^{0}C drying temperatures. In another previous research, the D_{eff} value of coconut pomace was calculated 0.702-3.326 x 10^{-09} m^2/s at drying temperatures of 65-75 ^{0}C [24]. The effective moisture diffusivity was reported in another study at 65-75 ^{0}C for apple pomace as 3.47-6.47 x 10^{-09} m^2/s (Sun et al.,2007).

In order to analyze the effect of temperature on the effective diffusion coefficient, Equation (6) was used which is also defined as Arrhenius equation and given below (Lopez et al.,2007; Srikiatden et al.,2006).

$$D_{eff} = D_0 \exp\left(-\frac{E_a}{R\,(T+273{,}15)}\right) \qquad (6)$$

Using this formula, for the air velocity of 1 m/s, ln (D_{eff}) -1/T (absolute temperature in K) was plotted and the linearity of Arrhenius equation was shown in Figure 4. given below.

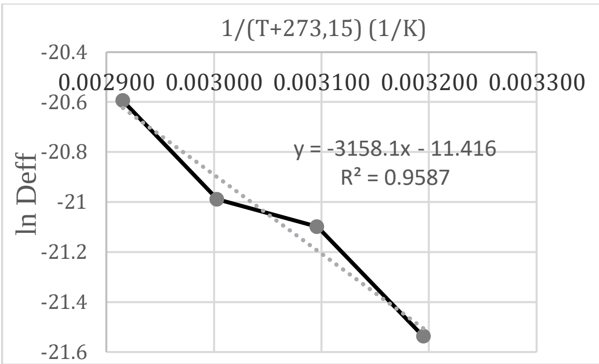

Figure 4. Arrhenius type relationship between effective Diffusivity (D_{eff}) (m^2/s) and Temperature (1/K) in red grape pomace

Table 2. Statistical Evaluation of Kinetic Models for Red Grape Pomace

Model	Drying Temperature (^{0}C)	Air velocity (m/s) 1			1.4			1.8		
		R^2	RMSE	χ^2	R^2	RMSE	χ^2	R^2	RMSE	χ^2
MIDILLI	40	0.996	0.01493	0.000254	0.779	0.08208	0.007666	0.995	0.01722	0.000353
	50	0.995	0.01989	0.000483	0.997	0.01631	0.000355	0.996	0.01685	0.000360
	60	0.997	0.01476	0.000280	0.992	0.02431	0.000773	0.995	0.02072	0.000620
	70	0.996	0.02117	0.000648	0.995	0.02361	0.000805	0.993	0.02455	0.000822
TWO TERM	40	0.997	0.01266	0.000182	0.999	0.00566	0.000036	0.998	0.01079	0.000139
	50	0.994	0.02071	0.000524	0.995	0.01941	0.000502	0.997	0.01452	0.000267
	60	0.994	0.02196	0.000620	0.991	0.02556	0.000854	0.993	0.02330	0.000706
	70	0.982	0.04527	0.002960	0.984	0.04087	0.002413	0.985	0.03653	0.001820
	40	0.997	0.05074	0.003146	1.000	0.00464	0.000025	0.998	0.01079	0.000146
MODIFIED HENDERSON	50	0.994	0.02071	0.000555	0.996	0.09158	0.013419	0.997	0.03891	0.002213
& PABIS	60	0.995	0.08133	0.009922	0.992	0.16969	0.044503	0.994	0.02484	0.001146
	70	0.987	0.25810	0.123715	0.987	0.10376	0.019994	0.987	0.04305	0.003089
VERMA	40	0.996	0.01537	0.000260	0.999	0.00588	0.000038	0.998	0.25916	0.076324
	50	0.993	0.02350	0.000483	0.991	0.02646	0.000862	0.996	0.01607	0.000307
	60	0.991	0.02793	0.000936	0.989	0.02871	0.001001	0.992	0.02503	0.000814
	70	0.999	0.01219	0.000193	0.979	0.04629	0.002786	0.979	0.04345	0.002360
DIFFUSION	40	0.996	0.01536	0.000260	0.999	0.00591	0.000038	0.998	0.01198	0.000163
	50	0.993	0.02350	0.000639	0.991	0.02646	0.000862	0.996	0.01607	0.000307
	60	0.991	0.02786	0.000932	0.989	0.02871	0.001001	0.992	0.02503	0.000814
	70	0.976	0.05050	0.003315	0.979	0.04605	0.002756	0.990	0.03047	0.001160
PAGE	40	0.986	0.02949	0.000925	0.994	0.01672	0.000298	0.990	0.02394	0.000623
	50	0.988	0.02963	0.000966	0.991	0.02638	0.000795	0.989	0.02703	0.000827
	60	0.993	0.02494	0.000700	0.979	0.03919	0.001741	0.989	0.03035	0.001088
	70	0.990	0.03305	0.001291	0.988	0.03505	0.001452	0.982	0.04026	0.001870
MODIFIED PAGE	40	0.986	0.02949	0.000926	0.994	0.01672	0.000298	0.990	0.02394	0.000623
	50	0.988	0.02963	0.000966	0.991	0.02638	0.000795	0.989	0.02703	0.000827
	60	0.991	0.51791	0.301765	0.979	0.03919	0.001741	0.989	0.03035	0.001088
	70	0.990	0.03305	0.001291	0.988	0.03505	0.001452	0.982	0.04025	0.001870

EXPONENTIAL TWO TERM	40	0.989	0.09873	0.010377	0.953	0.04465	0.002296	0.987	0.02798	0.000851
	50	0.991	0.02668	0.000783	0.992	0.02466	0.000695	0.992	0.02354	0.000619
	60	0.992	0.02610	0.000767	0.984	0.03495	0.001384	0.991	0.58889	0.409839
	70	0.994	0.02569	0.000780	0.990	0.03156	0.001177	0.979	0.04345	0.002179
HENDERSON & PABIS	40	0.974	0.04023	0.001723	0.937	0.05335	0.003053	0.966	0.04440	0.002142
	50	0.988	0.03051	0.001024	0.992	0.02577	0.000759	0.980	0.03719	0.001546
	60	0.993	0.05859	0.000667	0.976	0.04274	0.002070	0.988	0.03099	0.001135
	70	0.980	0.04615	0.002517	0.983	0.04149	0.002034	0.982	0.04033	0.001877
NEWTON	40	0.972	0.04153	0.001778	0.888	0.07145	0.005264	0.958	0.04994	0.002598
	50	0.987	0.03069	0.000987	0.991	0.02646	0.000747	0.978	0.03848	0.001563
	60	0.991	0.02791	0.000825	0.976	0.04274	0.001941	0.988	0.03112	0.001049
	70	0.971	0.05523	0.003305	0.977	0.04797	0.002493	0.979	0.04345	0.002023
LOGARITMIC	40	0.745	0.12603	0.017473	0.738	0.10955	0.013200	0.760	0.11874	0.016023
	50	0.781	0.12821	0.019032	0.995	0.01941	0.000477	0.781	0.56995	0.385748
	60	0.768	0.14107	0.023880	0.764	0.13280	0.021451	0.993	0.02330	0.000706
	70	0.981	0.06617	0.005692	0.983	0.04142	0.002230	0.711	0.16109	0.032436

Table 3. Model Coefficients, Best fitted Models and calculated Effective Moisture Diffusivities at different Drying Temperatures and Air Velocities for Grape Pomace

Air velocity (m/s)	**Drying temperature (^{0}C)**	**Model**	**Model coefficients**							**Effective Moisture Diffusivity (D_{eff}) (m²/s)**
			a	k	n	b	c	g	h	
1	40	Two-term	0.158	k_0= 0.055 k_1= 0.49	-	0.88	-	-	-	4.426 x 10^{-10}
	50	Midilli	1.025	0.524	1.063	0.01	-	-	-	6.863 x 10^{-10}
	60	Midilli	1.02	0.659	1.183	0.009	-	-	-	7.664 x 10^{-10}
	70	Verma	1.305	1.022	-	-	-	72.13	-	1.137 x 10^{-09}
1.4	40	Modified Henderson & Pabis	0.533	0.665	-	0.357	0.109	0.109	2.273	4.781 x 10^{-10}
	50	Midilli	1.019	0.6	1.118	0.016	-	-	-	6.697 x 10^{-10}
	60	Midilli	1.027	0.695	1.087	0.02	-	-	-	4.713 x 10^{-10}
	70	Midilli	1.024	0.859	1.379	0.015	-	-	-	1.674 x 10^{-09}
1.8	40	Two-term	0.389	k_0= 0.181 k_1= 0.9	-	0.633	-	-	-	2.849 x 10^{-10}
	50	Two-term	0.738	k_0= 0.785 k_1= 0.12	-	0.188	-	-	-	5.108 x 10^{-10}
	60	Midilli	1.016	0.811	1.109	0.021	-	-	-	1.198 x 10^{-09}
	70	Midilli	1.024	0.938	1.299	0.015	-	-	-	1.092 x 10^{-09}

4. Discussion and Conclusion

Red grape pomace was dried at different temperatures 40, 50, 60 ve 70 ^{0}C and different air velocities of 1, 1.4 and 1.8 m/s until constant weight was attained. Drying takes place in falling rate period. It may be claimed that selected drying temperatures are statistically significant for drying times whereas air velocity seemes to have no effect on drying time. The ambient relative humidity inside the cabinet dryer and the removable moisture content of the samples strongly correlate with drying temperature. Experimental values are in accordance with the expected values resulted from several semi-empirical models such as Midilli, Two-Term, Modified Henderson & Pabis and Verma and hence the kinetic behaviour of red grape pomace was described by these models most satisfactorily. The effective moisture diffusivity is directly proportional to drying temperature. However, it is nearly impossible to find out a linearity between air velocity and effective moisture diffusivity. The linear relationship of effective moisture diffusivity with drying temperature was confirmed by the Arrhenius equation and the activation energy of grape pomace was calculated 26.26 kJ/mol.

Conflict of Interest

No conflict of interest was declared by the authors.

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