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Bioactive compounds' contents, drying kinetics and mathematical modelling of tomato slices influenced by drying temperatures and time

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ABSTRACT

This study investigated the influence of drying temperature, and time on antioxidant activity, phenolic, flavonoid, lycopene and β – carotene contents of tomato slices. It also evaluated the influence of drying process on drying kinetics, moisture diffusivity and activation energy. Oven processed tomato slices had temperature-dependent significant increase in antioxidant activity at 30 and 60 min, phenolic from 30 to 120 min and lycopene contents from 120 to 300 min. Significantly decreased contents of flavonoid and β – carotene were obtained for oven processed tomato slices with increasing drying temperature and time. Page model accurately predicted the drying process of tomato slices. Similarity between experimentally determined moisture ratio and Page predicted moisture ratio was obtained with high correlation (R^2 = 0.9986). Effective moisture diffusivities indicated that drying process of tomato slices was temperature dependent while Arrhenius equation explained the relationship between activation energy and temperature.

1. Introduction

Tomatoes (*Lycopersicon esculentum* L.) are vegetables essentially and widely consumed as components of diets in the world (Rajkumar et al., 2007; Kulanthaisami et al., 2010; Sadin et al., 2014; Coskun et al., 2016). They are nutritionally beneficial and contain antioxidant compounds which play important roles in inhibiting the formation and progression of reactive oxygen species (ROS) that are responsible for degenerative diseases (Elbadrawy and Sello, 2011; Kaur and Aggarwal, 2015; Oberoi and Sogi, 2015; Stratakos et al., 2016). These compounds have been reported to possess anti-inflammatory, antioxidant, anti-cancer activities which stem from synergistic association of antioxidant compounds such as β-carotene, lycopene, vitamins C and E, flavonoids, and phenolic compounds (Dewanto et al., 2002; Olajire and Azeez, 2011). Tomatoes are abundantly rich in carotenoids such as lycopene and β – carotene which are effective quenchers of singlet oxygen and scavengers of peroxyl radicals. They also detoxify free radicals produced during normal metabolism affect DNA and have been implicated in cancer formation (Hiranvarachat et al., 2008; Kulanthaisami et al., 2010; Capanoglu et al., 2010; Abano et al., 2011; Olaiya and Aremu, 2013).

Tomatoes are either eaten raw or processed to reduce their high moisture content which make them highly susceptible to microbial degradation and rottenness, therefore, they need to be preserved. Preservation extends their shelf-life and enhances their storage stability (Azeez et al., 2012; Doymaz, 2014; Sadin et al., 2014; Karam et al., 2016). They are usually preserved using various methods depending on the region of the world and expensiveness of the preservation method. Methods such as drying, canning, salting, use of lemon, freezing are usually used (Elbadrawy and Sello, 2011; Ogundipe et al., 2012; Karam et al., 2016) but concerns have arisen on the availability and retention of essential and beneficial nutrients in tomatoes after being made to undergo different processing conditions without defeating its aim of protection against diseases.

Thermal (drying) processing is widely employed now to process tomatoes into products in cans, sachet and other forms in order to improve their shelf life by reducing moisture content which aids microbial decay (Gupta et al., 2011; Taheri-Garavanda et al., 2011; Doymaz, 2014).

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Different drying processes have been reported in literatures with their advantages and disadvantages on nutritional composition, antioxidant activity, polyphenols and carotenoids (Karam et al., 2016). Methods such as open sun and solar drying (Rajkumar et al., 2007; Kulanthaisami et al., 2010; Deshmukh et al., 2014), convective hot air drying (Guine, 2006; Gaware et al., 2010; Doymaz, 2014; Haq et al., 2018), freeze drying (Chan et al., 2009; Michalska et al., 2016; Neoh et al., 2016), vacuum oven drying (Roberts et al., 2008; AbdulRahman et al., 2015; Neoh et al., 2016), microwave drying (Chan et al., 2009; Darvishi et al., 2012), infrared drying (Sadin et al., 2014; Touil et al., 2014), fluidized bed drying (Gazor and Mohsenimanesh, 2010; Oberoi and Sogi, 2015). Vacuum oven drying offers fast drying rates with low temperature and large mass transfer. It is used to produce materials with high porosity and low apparent density (Karam et al., 2016). Different studies have reported effects of methods, drying temperature and drying time on increase or decrease of antioxidant activity, polyphenols and carotenoids (Dewanto et al., 2002; Nora et al., 2014; Kamiloglu et al., 2014, 2016; Karam et al., 2016; Michalska et al., 2016; Hu et al., 2017).

Drying kinetics using thin-layer kinetic modelling has been applied to many biological materials such as tomatoes (Rajkumar et al., 2007; Gaware et al., 2010; Sadin et al., 2014; Coskun et al., 2016), watermelon (Oberoi and Sogi, 2015) grape seed (Roberts et al., 2008), *Opuntia ficus-indica* (Touil et al., 2014), ginger (Chan et al., 2009; Deshmukh et al., 2014), mushroom (Doymaz, 2014) for predicting which model best describes the drying process.

The goodness of the fit of these models are expressed and validated by using root square mean error (RMSE) test, Chi square test, correlation coefficient and many others (Roberts et al., 2008). Models such as Midilli, Page, Lewis, Logarithmic, Henderson-Pabis. Page and Midilli models have been employed to describe the drying process in tomatoes (Midilli et al., 2002; Gaware et al., 2010; Sadin et al., 2014; Coskun et al., 2016).

Many studies have reported effects of drying methods, drying temperatures and drying times on tomato and tomato-based products and their drying kinetics but literature is still scanty on the effects of simultaneous drying time and drying temperature as they affect nutritional contents and drying kinetics. Therefore, the study investigates the effects of thermal processing at 50, 60, and 70 °C from 30 to 300 min on antioxidant activity, polyphenolic, carotenoid contents. It also evaluates drying kinetics, moisture diffusivity and activation energy of drying process.

2. Materials and methods

2.1. Reagents

Quercetin, Folin-Ciocalteu's phenol, 2,2-diphenyl-1-picrylhydrazyl (DPPH), $NaCO_3$, $AlCl_3$ and CH_3OH used in the study are of analytical grade from Sigma-Aldrich, Germany.

2.2. Sample collection, preparation and extraction

Raw tomatoes were harvested on a farm in Oke- Osun Osogbo located on 07.44°N and 04.47°E. The samples were rinsed to remove soil and were cut into 4 mm slices.

100 g of 4 mm tomato slices were subjected to thermal treatments using vacuum oven drying (Uniscope SM9053 Surgifriend Medicals England) at different temperatures (50, 60 and 70 °C) with 0.1 ms^{-1} air velocity for 30, 60, 90, 120, 150, 180, 210, 240, 270, 300 min. Extech 45170 type K instrument with 0.001 ms^{-1} sensitivity was used for measuring air velocity.

5 g of both raw and heat-processed tomatoes were blended and extracted with 250 ml of 70% aqueous methanol twice. The first extraction was done with 150 ml, shaken on orbital shaker for 90 min. and filtered using Whatman No 4 filter paper. The residue was further extracted with 100 ml following the previous procedure. Both filtrates were combined and concentrated using rotary evaporator at 40 °C.

2.3. Determination of antioxidant activity, phenolic and flavonoids contents

Antioxidant activity, phenolic and flavonoid contents of tomato slices with and without OD pre-treatment were determined using methods as reported by Azeez et al. (2012).

2.4. GC-FID determination of lycopene and β – carotene contents

The carotenoid content was analysed using modified method of extraction of Takagi (1985). 5 g of tomato was homogenized with 75 ml of acetone and incubated in the dark at room temperature for 1 h after which it was filtered using Whatman No. 4 filter paper. The residue was further extracted three times using the same procedure. The filtrates were combined, concentrated using rotary evaporator at 70 °C, dried over anhydrous sodium sulphate and dissolved in methanol for gas chromatography with flame ionization detector analysis. Dried extract was dissolved in methanol for gas chromatography coupled with flame ionization detector (GC-FID). 1 µl of the methanolic extract was injected into GC (Hewlett-Packard Model 5890, USA) with FID which has AC- 5 column (30 m × 0.25 µm × 0.25 mm id), nitrogen as a carrier gas, a detector section temperature of 320 °C with a split ratio of 20:1 and mode inlet section temperature of 250 °C. The column was initially set at 60 °C, increased at 10 °C/min for 20 min, maintained for another 20 min. and at 15 °C for 4 min and maintained for another 4 min. Concentrations of lycopene and β – carotene were quantified from calibration curves of their standards.

2.5. Drying process kinetics

Many thin-layer drying kinetic models have been used to evaluate the drying processes involved in food materials. Most commonly used models are Logarithmic, Page, Midilli, Lewis, Henderson-Pabis, Wang and Singh equations. They have been fitted to accurately describe the drying processes in tomatoes, grape seeds, watermelon and plum powder (Midilli et al., 2002; Roberts et al., 2008; Gaware et al., 2010; Sadin et al., 2014; Coskun et al., 2016; Michalska et al., 2016).

Moisture content (MC) was determined in tomato slices at different temperatures for different drying time using Eq. (2a) and converted to moisture ratio. Moisture ratio is calculated using Eq. (2b) which is reducible to Eq. (2c) because M_e is usually very low and its removal does not bring significant changes (Sadin et al., 2014)

$$MC = \frac{W_L}{W_i} \times 100 \tag{2a}$$

$$MR = \frac{M_t - M_e}{M_i - M_e} \tag{2b}$$

$$MR = \frac{M_t}{M_i} \tag{2c}$$

where W_i is the initial weight of tomato slices, W_L is the weight loss, M_i is the initial moisture content, M_e is the moisture content at equilibrium and M_t is the moisture contents at a particular time.

Mathematical modelling applied to drying tomato slices in this study are three well known thin-layer dying models; Page, Lewis, Henderson-Pabis.

Page model

$$MR = e^{-kt^N} \tag{3}$$

$$\ln[-\ln(MR)] = \ln(k) + N\ln(t) \tag{3a}$$

where k and N are constants obtainable from the intercept and slope of plot of $\ln[-\ln(MR)]$ against $\ln(t)$

Lewis model

$$MR = e^{-kt} \tag{4}$$

$$\ln(MR) = -kt + 1 \tag{4a}$$

Henderson – Pabis

$$MR = ae^{-kt} \tag{5}$$

$$\ln(MR) = -kt + a \tag{5a}$$

Where the drying constants k and a are obtained from the slope and intercept of the plot of $\ln(MR)$ versus t. The intercept of Lewis equation is 1.

The goodness of fit and similarities between experimentally determined moisture ratio and model predicted moisture ratio were evaluated using correlation coefficient (R^2), root mean square error (RMSE) and chi square test (χ^2). RMSE and χ^2 were calculated using Eqs. (6) and (7)

$$RMSE = \sqrt{\left[\frac{1}{n}\sum_{i=1}^{n}(MR_{exp,i} - MR_{pred,i})\right]} \tag{6}$$

$$\chi^2 = \frac{1}{N-n}\sum_{i=1}^{n}(MR_{exp,i} - MR_{pred,i})^2 \tag{7}$$

Relatively high R^2, and relatively low χ^2 and RMSE suggest the model that best fits the drying process.

2.6. Moisture diffusivity and activation energy

Moisture diffusivity in solids is related to both drying temperature and moisture content. The mechanism of moisture diffusivity is governed by diffusion of liquid as described by Fick's second law (Eq. (8)) and simplified to Eqs. (8a) and (8b) based on assumptions that D_{eff} is constant with negligible external resistance, temperature gradient and shrinkage during drying (Gupta et al., 2011; Darvishi et al., 2012)

$$\frac{\delta M}{\delta t} = \nabla[D_{eff}(\nabla M)] \tag{8}$$

where D_{eff} is effective moisture diffusivity.

$$MR = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{2n+1}e^{\left(-\frac{(2n+1)^2\pi^2 D_{eff}t}{4L^2}\right)} \tag{8a}$$

$$MR = \frac{8}{\pi^2}e^{\left(-\frac{\pi^2 D_{eff}t}{4L^2}\right)} \tag{8b}$$

The D_{eff} can be calculated from the slope of ln MR against t as shown in Eq. (9)

$$D_{eff} = -\frac{slope4L^2}{\pi^2} \tag{9}$$

D_{eff} varies with temperature and its dependence on drying temperature is explained according to Arrhenius Eq. (10)

$$D_{eff} = D_o e^{\left(-\frac{E_a}{RT}\right)} \tag{10}$$

where D_o is the pre-exponential factor of the Arrhenius equation (m^2/s), E_a is the activation energy (kJ/mol), R is the universal gas constant (8.314 J mol^{-1} K^{-1}), and T is the absolute air temperature (K). The activation energy is determined from the slope of the Arrhenius plot, ln (D_{eff}) against $\frac{1}{T}$.

2.7. Statistical analysis

Data of bioactive compounds were expressed as mean ± standard deviation of four replicates. They were subjected to one-way ANOVA followed by Duncan Multiple Range Test (DMRT) for comparison of their means tested at 95% confidence level using SPSS software.

3. Results and discussion

3.1. Effects of drying temperature and drying time on antioxidant activity

Antioxidant activity of raw and thermally processed tomato slices are presented in Table 1. In comparison with raw tomato, significant improvements in antioxidant activity were obtained for tomato slices that were thermally processed at all temperatures for 30 and 60 min., and for 90 min at 70 °C while comparable antioxidant activity with raw tomato was found for tomato slices thermally processed for 90 and 120 min at 50 and 60 °C, and at 70 °C for 120. Significant decrease in antioxidant activity was recorded for all tomato slices thermally processed at all temperatures from 150 to 300 min compared with raw tomato. Antioxidant activity of tomato slices increased with increasing drying temperature from 50 to 70 °C but decreased as drying time progressed from 30 to 300 min. The trend in our results is similar to previously published results obtained for tomato (Dewanto et al., 2002;

Table 1
Antioxidant activity of raw and thermally treated tomatoes.

Time (min)	Raw	Antioxidant activity (%) Temp (°C)		
	78.82 ± 1.52[a]	50	60	70
30		85.01 ± 1.12[b]	86.68 ± 0.22[b]	89.11 ± 0.29[h]
60		82.23 ± 2.04[b]	83.70 ± 1.25[b]	87.66 ± 0.88[b]
90		77.05 ± 0.82[a]	79.07 ± 1.18[a]	83.46 ± 0.44[b]
120		75.29 ± 0.41[a,c]	75.66 ± 0.09[a,c]	76.43 ± 0.68[a,c]
150		74.17 ± 0.19[c]	74.32 ± 0.43[c]	74.90 ± 0.27[c]
180		70.82 ± 0.35[c]	72.08 ± 0.32[c]	72.83 ± 0.33[c]
210		70.75 ± 3.03[c,d]	71.65 ± 0.86[c]	72.47 ± 0.63[c]
240		66.36 ± 0.63[e]	70.03 ± 0.63[c,d]	70.08 ± 0.04[c,d]
270		59.46 ± 0.94[f]	62.08 ± 1.13[f]	68.70 ± 1.68[d]
300		52.02 ± 0.27[g]	62.83 ± 0.53[f]	66.57 ± 0.17[e]

Data are mean ± standard deviation of four replicates. Data with different superscripts are significantly different ($p < 0.05$).

Kamiloglu et al., 2014; Kamiloglu et al., 2016), *Kappaphycus alvarezii* (Ling et al., 2015), Thai red curry powder (Inchuen et al., 2010), red guava (Nora et al., 2014) and fruit plum powder (Michalska et al., 2016) which showed antioxidant activity increased with increasing drying temperature. The improvements in antioxidant activity with increasing temperature was adduced to the higher antioxidant activity of partially oxidized polyphenols than non-oxidized polyphenol as a result of heat treatment. Also, Nwozo et al. (2015) and Hu et al. (2017) reported similar trend on decrease in antioxidant activity with increasing drying time for leafy vegetable and red rice respectively which was attributed to heat treatment. The significant reduction of antioxidant activity from 150 to 300 min is attributable to the prolong drying time as evidenced in the results of Tomaino et al. (2005) on antioxidant activity of spice essential oils.

3.2. Effects of drying temperature and drying time on phenolic and flavonoid contents

Phenolic contents of raw and thermally processed tomato slices are presented in Table 2. Significant increase in phenolic contents was obtained for tomato slices that were thermally processed at all temperatures for 30, 60, 90 and 120 min compared to raw while comparable phenolic contents of thermally processed tomato with raw were obtained at all temperatures for 150 min. Significant decrease in phenolic contents was recorded at all temperatures and drying time above 150 min compared to raw. As reported for antioxidant activity of tomato slices, phenolic contents increased significantly with increasing drying temperature and decreased with drying time. This suggests that the effects of heat treatment on increased phenolic contents could have led to the increase in the antioxidant activity from 30 to 90 min because phenolic contents have been reported to aid antioxidant activity in vegetables (Olajire and Azeez, 2011).

Increase in phenolic contents with drying temperature and drying time from 30 to 120 min. as obtained in this study is in consonance with the results on tomato and ginger (Gumusay et al., 2015), leafy vegetables (Nwozo et al., 2015) and red rice (Hu et al., 2017). The increase was related to the increase in the release of bound phenolics from the cell wall as a result of heat treatment that breaks down the ester between phenolic and cell wall. Decrease in total phenolic with increasing drying time at all temperatures could be due to the long drying time which has been reported to destroy some phenolic compounds (Li et al., 2007; Garau et al., 2007; Inchuen et al., 2010; Gupta et al., 2011; Ling et al., 2015).

Effects of drying temperatures and drying time on flavonoid contents are presented in Table 2. Significant improvements in flavonoid contents were found for tomato slices processed at all temperatures for 30 min while content significantly reduced at all temperatures for drying time above 30 min. The trend in this study at 30 min which shows increase in flavonoid content with increasing temperature and decreasing with the drying time is similar to results obtained for tomato (Dewanto et al., 2002; Kamiloglu et al., 2014; Kamiloglu et al., 2016), Irish brown seedweed (Gupta et al., 2011) and red rice (Hu et al., 2017). Our results are also in agreement with report of Neoh et al. (2016) who found that short time drying preserved flavonoid content of Malaysian red seaweed better. Ling et al. (2015) equally noted that long time drying reduced total flavonoid content of *Kappaphycus alvarezii*.

3.3. Effects of drying temperature and drying time on lycopene and β – carotene

The results of influence of drying temperature and drying time on lycopene and β – carotene contents as determined by GC-FID are presented in Table 3. Comparable lycopene contents of heat processed and raw tomato slices were obtained at 60 min for all temperatures and became significantly increased with drying temperature and drying time from 120 to 300 min while β – carotene contents decreased significantly with drying temperature and drying time.

Our results are in agreement with the previous results on tomatoes (Shi and Maguer, 2000; Dewanto et al., 2002; Kamiloglu et al.,

Table 2
Effects of thermal treatments on phenolic and flavonoid contents of tomato.

Time (min)	Phenolic content (mg quercetin/g of extract)				Flavonoid content (mg quercetin/g of extract)			
	Raw	Temp (°C)			Raw	Temp (°C)		
	250.19 ± 0.98^{a}	50	60	70	85.85 ± 0.64^{a}	50	60	70
30		352.31 ± 0.85^{b}	359.37 ± 0.27^{b,c}	365.88 ± 0.26^{c}		92.73 ± 0.23^{b}	92.04 ± 0.19^{b}	92.54 ± 0.78^{b}
60		320.45 ± 0.64^{d}	325.51 ± 0.24^{d}	327.39 ± 0.32^{d}		83.86 ± 0.41^{a}	82.83 ± 0.53^{a}	82.58 ± 0.86^{a}
90		305.26 ± 0.47^{e}	311.33 ± 0.63^{e}	317.17 ± 0.97^{e}		78.83 ± 0.93^{a}	77.06 ± 0.44^{a}	72.23 ± 0.13^{c}
120		275.29 ± 0.78^{g}	287.72 ± 0.35^{f}	284.34 ± 0.54^{f}		66.05 ± 0.58^{c}	58.21 ± 0.61^{d}	57.48 ± 0.76^{d}
150		248.71 ± 0.77^{a}	259.38 ± 0.22^{a}	266.59 ± 0.97^{h}		55.26 ± 0.27^{d}	55.07 ± 0.97^{d}	52.55 ± 0.15^{d,e}
180		240.01 ± 0.65^{i}	240.47 ± 0.43^{i}	241.34 ± 0.62^{i}		52.88 ± 0.72^{d,e}	52.06 ± 0.18^{d,e}	51.08 ± 0.92^{d,e}
210		237.97 ± 0.57^{i}	238.06 ± 0.16^{i}	237.33 ± 0.73^{i}		48.74 ± 0.98^{e}	44.29 ± 0.57^{e}	40.03 ± 0.53^{f}
240		215.47 ± 0.27^{j}	216.05 ± 0.25^{j}	221.03 ± 0.41^{j}		48.38 ± 0.32^{e}	36.21 ± 0.31^{f}	33.87 ± 0.17^{f}
270		213.44 ± 0.09^{j}	217.60 ± 0.07^{j}	213.45 ± 0.64^{j}		31.43 ± 0.33^{f,g}	36.54 ± 0.38^{f}	37.61 ± 0.67^{f}
300		205.31 ± 0.02^{k}	205.59 ± 0.32^{k}	204.22 ± 0.24^{k}		25.14 ± 0.44^{g}	25.39 ± 0.69^{g}	29.81 ± 0.23^{f,g}

Data are mean ± standard deviation of four replicates. Data with different superscripts are significantly different ($p < 0.05$) for both phenolic and flavonoid contents.

Table 3
Effects of thermal treatments on lycopene and β – carotene contents.

Time (min)	Lycopene contents (μg/100 g)				β – carotene contents (μg/100 g)			
	Raw	Temp (°C)			Raw	Temp (°C)		
	24.42 ± 0.66^{a}	50	60	70	82.04 ± 0.16^{a}	50	60	70
60		25.18 ± 0.76^{a}	25.52 ± 1.19^{a}	25.93 ± 0.23^{a}		74.02 ± 0.14^{b}	72.12 ± 0.31^{b}	71.18 ± 0.54^{b}
120		27.04 ± 0.12^{b}	27.04 ± 0.45^{b}	27.07 ± 0.73^{b}		72.78 ± 0.70^{b}	71.55 ± 0.56^{b}	68.25 ± 0.18^{c}
180		27.24 ± 0.01^{c}	27.11 ± 0.55^{c}	27.13 ± 0.83^{c}		55.27 ± 0.34^{e}	55.03 ± 0.09^{e}	54.86 ± 0.94^{e}
240		29.48 ± 0.28^{c}	29.52 ± 0.84^{c}	29.91 ± 0.57^{c}		52.21 ± 0.11^{e}	50.84 ± 0.78^{f}	50.69 ± 0.15^{f}
300		30.63 ± 0.43^{c}	31.05 ± 0.14^{d}	30.52 ± 0.34^{c}		47.23 ± 0.31^{g}	46.45 ± 0.20^{g}	48.27 ± 0.67^{g}

Data are mean ± standard deviation of four replicates. Data with different superscripts are significantly different ($p < 0.05$) for both lycopene and β – carotene contents.

2014). The increase in lycopene contents is related to drying time and drying temperature which result from the improved extractability of bioaccessible lycopene released from cell matrix. Heat treatment converts cis-lycopene conformation to trans conformation which increases its detection and subsequently its higher quantity (Jorge et al., 2014).

Decrease in β – carotene contents in tomato slices in this study is similar to previously reported result for red bell pepper (Leong and Oey, 2012), red guava (Nora et al., 2014), papaya (Udomkun et al., 2015) that drying temperature and drying time affected β – carotene contents.

3.4. Drying kinetics modelling

The initial moisture content of tomato slices was 89.6 g water/g dry sample which decreased to 3.584, 0.894 and 0.418 g water/g dry sample for tomato slices processed at 50, 60 and 70 °C respectively for 300 min. Drying curves of 4 mm tomato slices processed at 50, 60 and 70 °C from 30 to 300 min are presented in Fig. 1. Moisture ratio decreased with increasing drying temperature and drying time. Drying rates were higher at 30 min but gradually decreased as time progressed from 30 to 300 min. This trend is similar to results of Roberts et al. (2008) and Sadin et al. (2014) which indicates that more radiation energy is absorbed by the water at the tomato surface initially resulting into faster drying.

Moisture ratios at different temperature and drying time were fitted to three models (Lewis, Page and Henderson-Pabis equations) to define which model suitably fits the description of the drying process. The results of constants obtained from the plots of Eqs. (3a), (4a) and (5a) are presented in Table 4. The correlation coefficients (R^2) of drying rate constants (k) follows Page (0.9972) > Henderson – Pabis (0.9917) > Lewis (0.9836). R^2 reduces with increasing temperature and drying rates increased with increasing temperature. This is similar to results of Roberts et al. (2008) for Concord pomace and Gazor and Mohsenimanesh (2010) for Canola. Drying rate constants obtained in this study are in close agreement with those obtained for tomato by Sogi et al. (2003) and for Concord pomace by Roberts et al. (2008).

RMSE, χ^2 and R^2 of the three thin layer drying kinetics models employed are presented in Table 4.1. Page model had the highest R^2 (0.9981) with the lowest RMSE, and χ^2 and therefore was the best fit because the goodness of fit is established by the closeness of R^2 to 1 and the closeness of both RMSE and χ^2 to zero. Thus, Page model was chosen as the most suitable model to describe the drying process of 4 mm tomato slices. This is in agreement

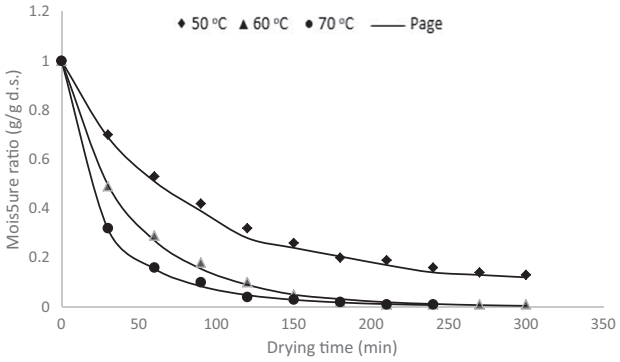

Fig. 2. Drying curves of experimental moisture ratio and Page model predicted moisture ratio of 4 mm tomato slices.

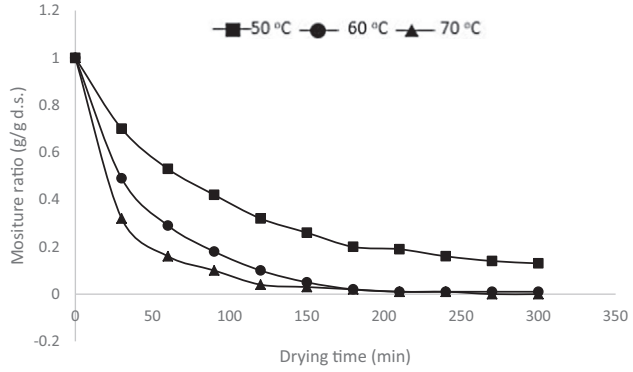

Fig. 1. Drying curves of 4 mm tomato slices at different temperatures.

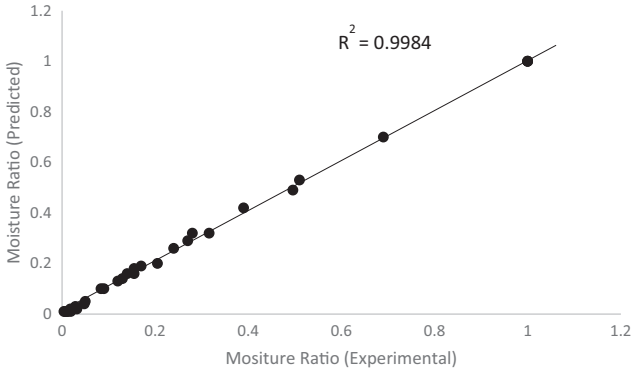

Fig. 3. Correlation between Page predicted and experimental moisture ratio.

Table 4
Empirical constants of the Page, Lewis, Henderson–Pabis equations.

Temp (°C)	Page equation			Lewis equation		Henderson-Pabis equation		
	k (min^{-1})	N	R^2	k (min^{-1})	R^2	k (min^{-1})	a	R^2
50	0.009095	0.9329	0.9952	0.009806	0.9836	0.009971	0.027028	0.9917
60	0.02237	0.8882	0.9919	0.016996	0.9725	0.017223	0.32011	0.9862
70	0.04076	0.6977	0.9785	0.017158	0.9423	0.018158	0.019102	0.9707

Table 4.1
Model Prediction evaluation.

Temp (°C)	Page equation			Lewis equation			Henderson-Pabis equation		
	RMSE	χ^2	R^2	RMSE	χ^2	R^2	RMSE	χ^2	R^2
50	0.001376	0.000183	0.9981	0.0128	0.003613	0.9963	0.173	0.3759	0.9962
60	0.008832	0.0000975	0.9949	0.1026	0.01195	0.9423	0.231	0.0670	0.9707
70	0.007237	0.00006984	0.9962	0.2727	0.07435	0.9870	0.129	0.0166	0.9932

Table 5
Effective moisture diffusivity and activation energy.

Temp (°C)	D_{eff} (m^2/s) × 10^{-8}	Do (m^2/s) × 10^{-6}	Ea (kJ mol^{-1})	R^2
50	2.53			0.9836
60	3.21	7.31	31.19	0.9423
70	5.00			0.9635

with modelling of drying kinetics of tomato slices reported by (Rajkumar et al., 2007). The comparison between the drying curves of experimentally determined moisture ratio (MR) at different temperatures and Page model predicted moisture ratio are presented in Fig. 2. To further validate the result, Page predicted MR against experimentally determined MR shows high similarity (R^2 = 0.9984) as presented in Fig. 3.

3.5. Effective moisture diffusivity and activation energy

The results of effective moisture diffusivity (D_{eff}) and activation energy are presented in Table 5. The D_{eff} increased with increasing drying temperature (Abano et al., 2011; Gupta et al., 2011; Darvishi et al., 2012). The values of D_{eff} are within the range of 10^{-12} to 10^{-8} m^2/s that has been reported for food products such as tomato (Gaware et al., 2010; Abano et al., 2011; Coskun et al., 2016) carrot (Darvishi et al., 2012; Haq et al., 2018), Canola (Gazor and Mohsenimanesh, 2010), ginger (Deshmukh et al., 2014) and white button mushroom (Doymaz, 2014).

The activation energy obtained for drying tomato slices was 31.19 kJ mol^{-1} and its falls within the range of activation energy for food products. It is agreement with the results of tomato slices by Sadin et al. (2014) and Cab Franc grape seed by Roberts et al. (2008).

Temperature dependent effect on D_{eff} is represented by the equation below

$$D_{eff} = 7.31 \times 10^{-6} e^{\left(\frac{-3751.67}{T}\right)}$$

4. Conclusion

The study has reported effects of drying temperature and drying time on antioxidant activity, phenolic, flavonoid, lycopene, β – carotene contents of tomato slices. It also evaluated drying kinetics with thin-layer kinetic models, moisture diffusivity and activation energy. Antioxidant activity, phenolic and lycopene contents increased with increasing in temperature and decreased with increasing drying time while flavonoid and β – carotene contents decreased with increasing temperature and drying time. Three models were used to predict the drying process of tomato slice and Page model accurately predicted the drying process. This is confirmed with the goodness of fit described by highest correlation coefficient and lowest root square mean error and chi square values. Good agreement between experimentally determined moisture ratio and Page predicted moisture ratio was obtained with high correlation (R^2 = 0.9986). Effective moisture diffusivity showed drying process of tomato depended on the drying temperature while Arrhenius equation explained the relationship between activation energy which falls within reported value for food materials and drying temperature.

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