Journal of Engineering Science and Technology
7th EURECA 2016 Special Issue July (2018) 27 - 39

EXTRACTION KINETIC OF *ZIZIPHUS JUJUBA* FRUIT USING SOLID-LIQUID EXTRACTION

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Abstract

Ziziphus jujuba is one of the most common traditional herbs and among the five most valuable herbal plants in China due to the high nutritional and nutraceutical values of bioactive compounds in it. The main aim of this research work was to investigate the effect of temperature on the extraction of bioactive compounds from *Z. jujuba* fruit *via* ultrasound assisted extraction (UAE). Pre-treatment of *Z. jujuba* fruit was done using a convective oven at a temperature of 60°C for 48 hours. UAE was carried out with three different temperatures (40°C, 50°C and 60°C) while the remaining extraction parameters of *Z. jujuba* fruit were acquired from available literature. They were identified as such: extraction time (90 minutes), ultrasound power (70 W) and ratio 1:20 (g/mL). The results indicated that an initial increase in temperature increased the concentration of the crude extract as a result of improved solubility. Further increase negatively impacted the extraction as the concentration began to subside due to thermal degradation. Likewise, the yield of antioxidants showed a similar trend with the change in temperature. Optimum results were achieved at 50°C with maximum antioxidant activity of 93.64%. The kinetics of temperature were also explored in current research by fitting the experimental data to six different extraction kinetic models including First-order kinetic model, Second-order rate equation, Peleg's model, Power law equation, Page's model and Logarithmic model. First-order kinetic model proved to be the best model with the highest R^2 (>0.9934) and lowest *RMSE* (<2.41E-15), indicating that it was best suited to describe the solid-liquid ultrasound-assisted extraction of antioxidants from *Z. jujuba* fruit.

Keywords: Antioxidant, Extraction kinetic, Mathematical modelling, Ultrasound-assisted extraction, *Ziziphus jujube.*

1. Introduction

Medicinal plants that showcase similar properties with pharmaceutical drugs have been exploited since the ancient times [1, 2]. Due to their possession of certain natural bioactive compounds and its medicinal value, they are utilised heavily in traditional medicine to treat handful of chronic diseases [3]. These secondary metabolites are a promising solution to synthetic drugs with scientific reports proven on the success in treating the diseases [4, 5].

Ziziphus jujuba (Z. jujube) Mill. is one of the most common traditional herbs and among the five most valuable herbal plants in China. *Z. jujuba* fruit is well-known and recognized as one of the valuable herbal plants as it contains high nutritional and nutraceutical values of bioactive compounds [6]. Generally, dried *Z. jujuba* fruit is used as food additive and flavouring, however, fresh fruits are also converted into pastes and purees for improved digestion and overall health maintenance [7]. It is also frequently used in the traditional Chinese medicine for the treatment of fatigue, anorexia together with the syndromes of the spleen and hysteria in women. Besides, it has various effects including antimicrobial, anticancer, antioxidant and anti-inflammatory [6]. It is scientifically proven that intake of *Z. jujuba* fruit might improve sleep, nourish the heart and soothe the nerves [8]. Because of these numerous benefits, researchers have developed a keen interest on the extract of *Z. jujuba* fruit .

Studies conducted previously have revealed the antioxidant potential of *Z. jujuba* fruit's crude extract but all of them are mainly focused on the seeds, fruiting bodies, peels and leaves of fruit individually [9]. Therefore, it is worth to study the total antioxidant activity of *Z. jujuba* fruit (fruiting bodies and peel) as a whole in order to use this herbal plant for a development of therapeutics that could be used to prevent diseases.

Extraction of *Z. jujuba* fruit has been accomplished using ultrasonic-assisted extraction (UAE) [10]. Traditional solvent extractions have several drawbacks such as tedious extraction duration, low selectivity and extraction yield [11]. UAE is widely used in the extraction of bioactive compounds as it enables to disrupt the cell walls *via* various mechanisms of cavitation, thereby, increasing the contact between solvent and compounds [12]. Organic solvent are usually costly, environmentally hazardous and require expensive disposal procedures. However, ethanol has relatively low impact to the environment, has a positive net energy balance and it is recognised as Generally Recognised as Safe (GRAS) solvent [13]. For these reasons, ethanol is the preferred choice of solvent for the UAE of bioactive compounds from *Z. jujuba* fruit.

Abundant literature exists on the solid-liquid extraction of *Z. jujuba* fruit. However, there is no existing report available regarding the extraction kinetics of *Z. jujuba* fruit. Therefore, there is a need to investigate the extraction kinetics and what drives it. Mathematical modelling is a very useful engineering tool that helps to explain a system and study the effects of different parameters together with making behaviour predictions for future applications [14]. Thus, the objective of this research work is to evaluate the extraction of the bioactive compounds in *Z. jujuba* fruit by ethanolic UAE to obtain high antioxidants. The influence of temperature parameter on the extraction process will be investigated. At the same time, present work also aims to find the best kinetic model suited *via* mathematical modelling to describe the extraction process from *jujuba* fruit.

2. Materials and Methods

2.1. Chemical reagents

Ethanol (99.8% AR grade) and 2, 2-Diphenyl-1-Picrylhydrazyl (DPPH) were purchased from Chemolab Supplies Sdn. Bhd.

2.2. Preparation and pre-treatment of *Z. jujuba* fruit

Dried *Z. jujuba* fruit were purchased from NSK Trade City, Kuchai Lama, Kuala Lumpur. 1 kg of dried *Z. jujuba* seedless fruit was washed with distilled water to remove the dirt accumulated on the surface. Washed and cleaned *Z. jujuba* fruit was cut into slices and was further dried in a convective drying oven (Model UFE-800, Memmert, Germany) at 60°C for 48 hours [15]. The dried samples were ground into fine powder using a cutting mill (Model SM-100, Retsch, Germany). The powder form of the *Z. jujuba* fruit was passed through a 500 µm sieve mesh to remove the chunk particles and ensure uniformity. The powder form of *Z. jujuba* fruit was sealed in a plastic container and stored in dry cabinet for further usage.

2.3. Ultrasound-assisted extraction (UAE) of *Z. jujuba* fruit

UAE of *Z. jujuba* fruit was conducted according to the procedure presented by Li et al. [15]. Ethanol was used as solvent for the extraction of *Z. jujuba* fruit with the solid to solvent ratio of 1:20 g/mL. 18 g of *Z. jujuba* fruit powder was mixed with 360 ml of 99.8% ethanol in a beaker. The sample was immersed in an ultrasonic bath (Elmasonic Model P120H, Singen, Germany) with ultrasonic input power and frequency of 70 W and 37 kHz, respectively. According to a study by Lin & Leng (2018), 70 W combined with 37 kHz of frequency resulted in highest amount of extracted phenolic content from red dates [16]. Extraction was performed at 40°C with occasional swirling during extraction period. Extraction was carried out at two other different temperatures of 50°C and 60°C with three replicates. The extract was sampled at every 5 minutes for 90 minutes. The sample was filtered using Whatman filter paper no. 1 in a rotary flask to obtain supernatants of the sample. The supernatants of filtrate (20 mL) was dried in a rotary vacuum evaporator (Heidolph Model Hei-VAP Precision (HL), Schwabach, Germany) to remove ethanol at 40°C until crude extracts were observed. All of the extraction conditions adopted from previous literature was summarised in Table 1.

Table 1. Optimum extraction parameters for Solid-liquid extraction (SLE) of *Z. jujuba* fruit using UAE. [10]

Ultrasound Power (W)	Type of Solvent	Ratio of Solid to Solvent	Extraction Time (mins.)
70	Ethanol	1:20	90

2.4. Extraction kinetic data collection of *Z. jujuba* fruit

The dried extract obtained after evaporation was weighted using a digital balance (Ohaus PA4102, USA). The extraction yield of *Z. jujuba* fruit was calculated using the weight of a dried extract and volume of *Z. jujuba* fruit extract. The yield was presented in the term of concentration and calculated using Eq. (1). The change of solute concentration in the liquid phase with respect to time during the extraction of *Z. jujuba* fruit was investigated by plotting graph to study the behaviour of extraction [10].

$$C_A = \frac{W_d}{V_e} \qquad (1)$$

where C_A is the concentration of crude extract (g/mL), W_d is the weight of dried extract (g) and V_e is the volume of filtrate of each sample (mL).

2.5. Antioxidant assay of *Z. jujuba* fruit using DPPH Radical scavenging capacity

The antioxidant activity of *Z. jujuba* fruit was determined using the DPPH according to the procedure of Himaja et al. [17]. 1.9 mg of DPPH was dissolved in 100 ml of ethanol in order to produce 0.1mM of DPPH solution. The solution was prepared in a schott bottle wrapped with aluminium foil to minimise light exposure. 1 ml of DPPH solution was added into 3 ml of crude extract and the sample was then left in a dark room for 30 minutes for reaction to reach completion. The sample absorbance value at 517 nm was measured against a blank using UV spectrometer (Model Genesys 10S, Massachusetts, United States). This test was performed in triplicates to ensure the results were not offset. 3 mL of pure ethanol was used as the blank solution for this test and ethanolic solution of DPPH was used as positive control [18]. The absorbance value of sample was recorded to calculate the radical scavenging activity of *Z. jujuba* fruit. The lower absorbance of sample mixture indicates higher free radical scavenging activities. The DPPH scavenging activity of *Z. jujuba* fruit was quantified using Eq. (2):

$$\text{Scavenging activity (\%)} = [1 - (\frac{A_{sample}}{A_{control}})] \times 100\% \qquad (2)$$

where $A_{control}$ is the absorbance of control DPPH solution and A_{sample} is the absorbance of the test sample.

2.6. Mathematical modelling of SLE of *Z. jujuba* fruit

In this research work, six mathematical models that were commonly applied in modelling for the recovery of solutes from different type of solid materials were used to fit the experimental data and evaluate the entire extraction process. They were identified as First-order kinetic model, Peleg's model, Second-order rate equation, Power law equation, Page's model and Logarithmic model. These models were compared in order to determine the mathematical model that best fits the experimental data.

2.6.1. First-order kinetic model

The first-order kinetic model had been used in extraction kinetic for herbal plants [19]. Therefore, this mathematical model was used to describe the extraction kinetic model of *Z. jujuba* fruit. A kinetic approach based on Fick's law can be written as follows:

$$\frac{dC_A}{dt} = k_L A[C_e - C_t] \qquad (3)$$

where $\frac{dC_A}{dt}$ is the rate of mass transfer of *Z. jujuba* fruit (g/min), k_L represents mass transfer coefficient (cm/min), A is the total surface area of solid (cm^3), C_e represents the solute concentration at equilibrium in the liquid phase (g solute $A.cm^{-3}$) and C_t is the solute concentration in the bulk liquid (g solute $A.cm^{-3}$).

After further derivative, the equation of extraction process of solute from solid into bulk liquid is expressed as below:-

$$C_t = C_e[1 - e^{(-k.t)}] \tag{4}$$

Where C_t is the solute concentration in the bulk liquid (g solute $A.cm^{-3}$), C_e represents the solute concentration at equilibrium in the liquid phase (g solute $A.cm^{-3}$), k_L represents mass transfer coefficient (cm/min), and α is specific surface area of the solid ($cm^3\ g^{-1}$).

2.6.2. Second-order rate equation

The second-order rate law equation provides satisfactory representation of the solid-liquid extraction process [20]. Therefore, this mathematical model was suitable to be used in this research work on the extraction of *Z. jujuba* fruit. The second-order rate equation can be written as:

$$\frac{dC_t}{dt} = k(C_e - C_t)^2 \tag{5}$$

where $\frac{dC_t}{dt}$ is the rate of extraction (g cm^{-3} min^{-1}), k is the rate constant of extraction process, C_e and C_t are the concentration of solute in equilibrium state and at extraction time t respectively (g cm^{-3}).

When $t = 0$, the initial rate of extraction, h can be expressed as:

$$h = kC_e^2 \tag{6}$$

After integrated under the initial and boundary conditions of $t = 0$, and $C_t = 0$ to C_t and rearranging the equation can be written as:

$$C_t = \frac{t}{\left(\frac{1}{h}\right) + \left(\frac{t}{C_e}\right)} \tag{7}$$

2.6.3. Peleg's model

Peleg was widely used to explain the extraction curve for bioactive compounds from medicinal plants due to the shape of sorption curves [21]. The equation is as below:

$$C_t = C_0 + \frac{t}{k_1 + k_2 t} \tag{8}$$

where C_0 is the initial concentration of solute at time t (g/g powder), C_t is the concentration of solute at time t (g/g powder), t is the extraction time (min), k_1 is Peleg's rate constant (min g/mg) and k_2 is the Peleg's capacity constant (g/mg).

The C_0 can be omitted when the initial concentration of solute is zero and this equation now is named as modified Peleg's equation, which is shown as below:

$$C_t = \frac{t}{k_1 + k_2 t} \tag{9}$$

where C_t is the concentration of solute at time t (g/g powder), t is the extraction time (min), k_1 is Peleg's rate constant (min g/mg) and k_2 is the Peleg's capacity constant (g/mg).

2.6.4. Power law equation

Power law model is one of the useful empirical equations for SLE and had been successfully used for extraction of polysaccharides from a medicinal fungus [21]. The power law equation can be written as:

$$C_t = Bt^n \tag{10}$$

where C_t is the concentration of solute at extraction time t (g cm^{-3}), B represents the rate constant of extraction process, t is extracted time (min) and n is Power-law component (<1).

2.6.5. Page's model

Page's model was commonly used in drying kinetic, however, there was satisfactory representation of solid-liquid extraction process [22]. The Page's model equation can be written as:

$$C_t = e^{(-kt^n)} \tag{11}$$

Where C_t is the concentration of solute at extraction time t (g cm^{-3}), k and n are the Page's constant and t is the extracted time (min).

2.6.6. Logarithmic model

Logarithmic model was successfully applied for the SLE of polyphenols from soybeans and herbs [22, 23]. The logarithmic model can be written as below:

$$C_t = a \log t + b \tag{12}$$

where C_t is the concentration of solute at extraction time t (g cm^{-3}), a and b represent the logarithmic model constants and t is the extraction time (min).

2.7. Statistical analysis and model validation

All the experiments were performed in triplicates and the results were represented in the form of mean $\pm$ standard deviation (*SD*). The values of model parameters had been calculated with GRG Nonlinear solving method using SOLVER incorporated in Microsoft Excel 2010. Four parameters, coefficient determination (R^2), root mean square error (*RMSE*), reduced chi-square (χ^2) and mean absolute error (*MAE*) were used to determine the goodness of fit of the models to the experimental data. The best model describing the SLE characteristics of *Z. jujuba* fruit was chosen with the one has highest value of R^2 and the least value *RMSE*, χ^2 and *MAE*.

Coefficient determination (R^2) is a statistical measure of how close the experiment data are to the fitted regression line [20]. The formula for R^2 is written as below:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(C_{exp,i} - C_{pre,i})^2}{\sum_{i=1}^{n}(C_{exp,i} - \bar{C})^2} \tag{13}$$

where n is number of samples, $C_{exp,i}$ and $C_{pre,i}$ represent experimental and predicted concentration of *Z. jujuba* fruit, respectively and $\bar{C}$ is the mean value of all experimental data.

The root mean square error (*RMSE*) is used to measure the differences between data predicted by a model and the experimental data [23]. Eq. (2.15) was used to calculate the *RMSE* of the experiment data.

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (C_{pre,i} - C_{exp,i})^2} \quad (14)$$

where *N* represents the number of observations, $C_{exp,i}$ and $C_{pre,i}$ represent experimental and predicted concentration of *Z. jujuba* fruit, respectively.

Reduced Chi-square (χ^2) is a statistical test commonly used to compare experimental data with the data that obtain from models [24]. Eq. (15) is the equation used to obtain the value of χ^2.

$$\chi^2 = \sum \frac{(C_{exp,i} - C_{pre,i})^2}{N-n} \quad (15)$$

where $C_{exp,i}$ and $C_{pre,i}$ represent experimental and predicted concentration of *Z. jujuba* fruit respectively, *N* is the number of observations and *n* is number constants.

Mean absolute error (*MAE*) is a measure of prediction accuracy of a forecasting method in statistics. In another words, it is the average over the verification sample of the absolute values of the differences between the forecast and corresponding observation. *MAE* is one of the useful measures which is widely used in model evaluations [25]. The equation of *MAE* is shown as below:

$$MAE = \frac{1}{n} \sum_{i=1}^{N} \left| C_{exp,i} - C_{pre,i} \right| \quad (16)$$

where $C_{exp,i}$ and $C_{pre,i}$ represent experimental and predicted concentration of *Z. jujuba* fruit, respectively and n indicates the number of model constants.

3. Results and Discussion

3.1. Effect of extraction temperature on concentration of crude extract from *Z. jujuba* fruit

The temperature of extraction was varied in the range from 40°C to 60°C to evaluate the effect of this parameter on the concentration of crude extract from *Z. jujuba* fruit. Extraction temperature had significant effects on the concentration of crude extract from *Z. jujuba* fruit as observed from Fig. 1. The concentration of crude extract from *Z. jujuba* fruit displayed a rapid linear increase within the first 15 minutes. The trend reduced to a slower extraction rate until it reached equilibrium. The application of higher temperature resulted in softening and swelling of the fruit’s tissues increasing the diffusion rate and overall mass transfer of the extracting solvent into the raw material [18]. The maximum concentration of crude extract of 0.02234 g/mL was obtained at 50 °C. However, the figure showed that elevation of temperature to 60°C had lowered the concentration of solute until the equilibrium concentration was reached at 0.0224 g/mL. The results showed that the compounds in *Z. jujuba* fruit had degraded due to the high extraction temperature during the process of SLE. Previous findings of corroborate with present study that high temperature resulted in the degradation of bioactive compounds from *Piper betle* and Wild sage [26, 27].

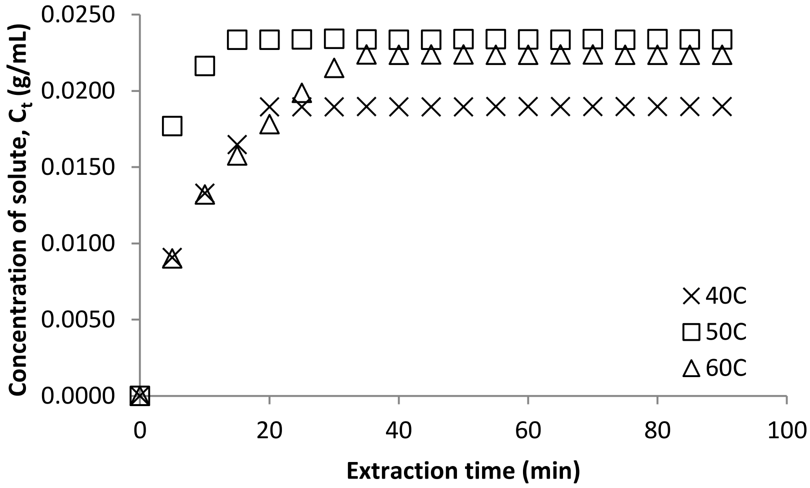

Fig. 1. Effect of temperature on concentration of crude extract from *Z. jujuba* fruit.

3.2. Effect of temperature on DPPH radical scavenging activities

DPPH radical method is a widely used assay to evaluate the free radical scavenging activities based on colour change of the reagent from purple to yellow. The discoloration of DPPH reagent denotes the potential of free radical scavenging of the sample [28]. Table 2 shows the DPPH radical scavenging activities of *Z. jujuba* fruit for the temperature ranged of 40°C to 60°C. The DPPH radical scavenging activities of *Z. jujuba* fruit increased with the increase of extraction temperature from 40°C to 50°C. This might due to the increased solubility and diffusion coefficient of antioxidants compounds in *Z. jujuba* fruit [29]. However, further elevation of temperature to 60°C reduced the DPPH radical scavenging activities of *Z. jujuba* fruit. Similar observations were also made by Li et al. [30] who reported the decrease of antioxidant activity might due to degradation of bioactive compounds at increased temperature [30]. Furthermore, it had been reported that high temperature reduced cavitation effects and mass transfer intensity and led to a decreased extraction [31].

Based on the results in Table 2, the highest DPPH radical scavenging activities (93.64%) was achieved for *Z. jujuba* fruit with the extraction temperature of 50°C and extraction time of 15 minutes. It was observed that the absorbance of this sample was low (0.035 nm) mainly because of the high radical scavenging by hydrogen donation [28].

Table 2. DPPH scavenging activities of antioxidant in *Z. jujuba* fruit.

Temperature (°C)	Radical Scavenging Activity (%)
40	90.38 ± 0.15[a]
50	93.64 ± 0.15
60	92.44 ± 0.24

[a] Values are expressed as percentage mean of triplicate determination (*n*=3) ± standard deviation.

3.3. Comparison of kinetics models

The experimental concentration of crude extract from *Z. jujuba* fruit was fitted into the mathematical models discussed in section 2.6. In order to study the extraction kinetics of *Z. jujuba* fruit, the concentration curves of crude extract from *Z. jujuba* fruit were plotted as a function of extraction time (from 0 to 90 minutes) and the results are shown in Fig. 2. The curves represented the experimental and predicted data obtained from the mathematical models. Based on Fig. 2, First-order kinetic model was found to be the best fitted extraction model for *Z. jujuba* fruit.

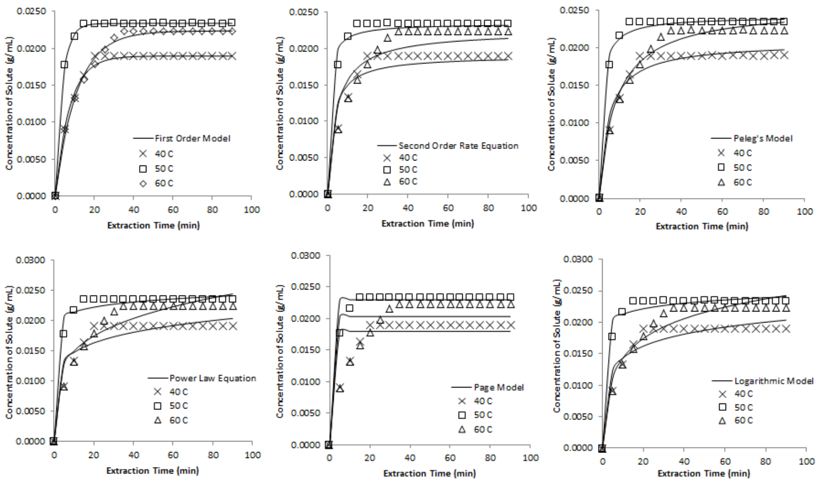

Fig. 2. Comparison of kinetic extraction of *Z. jujuba* fruit fitted to the First-order kinetic model, Second-order rate equation, Peleg's model, Power law equation, Page's model and Logarithmic model respectively. (Symbols - experimental data, lines - model fitting curves)

The goodness of fit was evaluated on the basis of coefficient determination (R^2), root mean square error (*RMSE*), reduced chi-square (χ^2) and mean absolute error (*MAE*). A high value of R^2 and a low value of *RMSE*, χ^2 and *MAE* indicate good fit. Table 3, Table 4 and Table 5 show the R^2, *RMSE*, χ^2 and *MAE* values for all six mathematical models at extraction temperature of 40°C, 50°C and 60°C, respectively. Only a handful of models exhibited good fitting performance to the experimental data. First-order kinetic model was proven as the best fitted model for the experimental data of 50 °C with the highest value of R^2 (0.9995) and lowest *RMSE* (5.01×10^{-27}), χ^2 (1.95×10^{-26}) and *MAE* (4.26×10^{-26}) among the mentioned models. The fitting accuracy of experimental data was in the order of First-order kinetic model > Peleg's model > Second-order rate equation > Logarithmic model > Power law equation > Page's model.

Table 3. Modelling of solid-liquid extraction of *Z. jujuba* fruit at 40°C.

Model	Model Constants	R^2	χ^2	*RMSE*	*MAE*
1	k = 0.1348; C_e = 0.019	0.9935	6.19E-16	2.41E-15	5.26E-15
2	h = 0.0070; C_e = 0.019	0.9227	1.63E-08	6.36E-08	1.39E-07
3	k_1 = 221.7122; k_2 = 48.2493; C_0 = 0	0.9658	8.51E-07	3.32E-06	7.24E-06
4	B = 0.0104; n = 0.1476	0.8978	2.55E-06	9.93E-06	2.16E-05
5	k = 4.0197; n = 0.0010	0.7082	7.27E-06	2.84E-05	6.18E-05
6	a = 0.0063; b =0.0080	0.9139	2.14E-06	8.37E-06	1.82E-05

1: First-order kinetic model, 2: Second-order rate equation, 3: Peleg's model, 4: Power law equation, 5: Page's model and 6: Logarithmic model.

Table 4. Modelling of solid-liquid extraction of *Z. jujuba* fruit at 50°C.

Model	Model Constants	R^2	χ^2	*RMSE*	*MAE*
1	k = 0.2790; C_e = 0.0234	0.9996	5.01E-27	1.95E-26	4.26E-26
2	h = 0.0246; C_e = 0.0234	0.9818	2.98E-09	1.16E-08	2.53E-08
3	k_1 = 58.1056; k_2 = 41.4335; C_0 = 0	0.9906	2.95E-07	1.15E-06	2.51E-06
4	B = 0.0188; n = 0.0543	0.9709	9.12E-07	5.09E-06	7.75E-06
5	k = 3.7741; n = 0.0543	0.9311	2.15E-06	8.40E-06	1.83E-05
6	a = 0.0029; b =0.0184	0.9722	8.70E-07	3.39E-06	7.40E-06

1: First-order kinetic model, 2: Second-order rate equation, 3: Peleg's model, 4: Power law equation, 5: Page's model and 6: Logarithmic model.

Table 5. Modelling of solid-liquid extraction of *Z. jujuba* fruit at 60°C.

Model	Model Constants	R^2	χ^2	*RMSE*	*MAE*
1	k = 0.0902; C_e = 0.0224	0.9934	2.63E-12	1.03E-11	2.24E-11
2	h = 0.0051; C_e = 0.0224	0.9187	5.93E-08	2.31E-07	5.04E-07
3	k_1 = 318.4472; k_2 = 39.2443; C_0 = 0	0.9805	7.45E-07	2.91E-06	6.33E-06
4	B = 0.0089; n = 0.2235	0.9213	3.00E-06	1.17E-05	2.55E-05
5	k = 3.8964; n = 0.0010	0.5886	1.57E-05	6.12E-05	1.33E-04
6	a = 0.0104; b =0.0039	0.9471	2.02E-06	7.86E-06	1.71E-05

1: First-order kinetic model, 2: Second-order rate equation, 3: Peleg's model, 4: Power law equation, 5: Page's model and 6: Logarithmic model.

4. Conclusions

This research work investigated the effect of extraction temperature on the concentration of crude extract from *Z. jujuba* fruit. The concentration of crude extract increased with increasing temperature, however, it began to reduce when the temperature was elevated to 60ºC. This shows that the compounds in *Z. jujuba* fruit degraded due to the high extraction temperature during the process of SLE. The highest concentration of 0.02234 g/mL was obtained at 50ºC.

The antioxidants of *Z. jujuba* fruit also exhibited a trend mirroring the results of the crude extract. The highest DPPH radical scavenging activities (93.64%) was achieved for *Z. jujuba* fruit with extraction temperature of 50°C and extraction time of 15 minutes respectively. The results proved that *Z. jujuba* fruit could be a good natural source of producing antioxidants.

Kinetic modelling was used to study the effect of temperature on the SLE of *Z. jujuba* fruit. First-order kinetic model, Second-order rate equation, Peleg's model, Power law equation, Page's model and Logarithmic model were used to fit the experimental data. The results showed that temperature had significant effects on the concentration of crude extract from *Z. jujuba* fruit. Based on the extraction models, First-order kinetic model was the best fitted model with the experimental data with the highest value of R^2 (0.9995) and lowest values of *RMSE* (5.01×10^{-10}), χ^2 (1.95×10^{-10}) and *MAE* (4.26×10^{-10}) compared to other models.

Acknowledgement

The authors would like to acknowledge Taylor's University Lakeside for providing financial support under two research grants (TRGS/MFS/1/2016/SOE/ 004 and TRGS/MFS/1/2017/SOE/008).

Nomenclatures

$A_{control}$	Absorbance of control DPPH solution
A_{sample}	Absorbance of test sample
C_t	Concentration of solute at any given time, g solute A.cm^{-3}
C_o	Initial concentration of solute, g solute A.cm^{-3}
C_e	Equilibrium concentration of solute, g solute A.cm^{-3}
R^2	Coefficient of determination
W_d	Weight of dried extract, g
V_e	Volume of filtrate of each sample, mL

Greek Symbols

χ^2	Reduced chi-square

Abbreviations

DPPH	2,2-diphenyl-1-picrylhydrazyl
GRAS	Generally Recognised as Safe
MAE	Mean Absolute Error
RMSE	Root Mean Square Error
SD	Standard Deviation
SLE	Solid-Liquid Extraction
UAE	Ultrasound-Assisted Extraction
UV	Ultraviolet

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