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Evaluation of mathematical modelings of pineapple juice concentration using different combination techniques

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Abstract

Pineapple juice was concentrated by four different evaporation methods including vacuum (V), vacuum with rotation (VR), ultrasonic atomization assisted vacuum evaporation (UAV) and ultrasonic atomization assisted vacuum evaporation with rotation (UAVR) methods and the temperature were 50, 55 and 60°C for all methods. The pH value, total soluble solid and color parameters (L*, a* and b*) of pineapple juice were measured. The result showed that the pH was not significantly affected by evaporation methods and the temperature. The color parameters were changed by increasing temperature with all evaporation methods. The evaporation times of UAV, VR and UAVR were shorter than V approximately 2.02, 3.59 and 4.89 times, respectively. Midilli model was the best-describing model for pineapple juice evaporation with highest R^2 (≥ 0.982), and lowest X^2 (≤ 0.002) and RMSE (≤0.042) values. The changes of concentration (TSS) during evaporation were described by first order kinetics equation and activation energies (Ea) of pineapple juice concentration were calculated using Arrhenius relationship equation. The Ea of pineapple juice concentration was in the range from 88.188-114.584 kJ/mol·K.

Keywords: Concentration, evaporation, pineapple juice, ultrasonic atomization, vacuum evaporation

1. Introduction

Pineapple is popular tropical fruit in many countries due to its sweet aroma and nice flavor. The pineapple can be processed to various products. In 2017, Thailand exported canned pineapple and pineapple juice about 46.37% and 27.01% of world market shares, respectively (Wattanakul *et al.*, 2020). The pineapple juice contains sugars, minerals, amino acids, vitamins, and polyphenols which contribute to healthy living for human (Bamidele and Fasogbon, 2017). Generally, the juice is often concentrated in order to extend shelf life due to decreasing of water activity (Assawarachan and Noomhorm, 2011).

Concentration process is one of the operations used for component separation to increase the food value. The advantages of concentration process are reduction of transportation, packaging and storage costs due to low volume and water activity of fruit juice (Alves and Coelhoso, 2006). Evaporation is more effective than other concentration methods (reverse osmosis, membrane filtration and freeze concentration) (Thijssen, 1974; Jiao, 2003). However, the limitations of this technique are high energy consumption and lost product qualities such as volatile compound. Vacuum evaporation is considered as an alternative concentration method. The process is performed lower pressure and temperature than conventional evaporation causing less heat energy for removing water (Fellows, 2000). However, it still requires long evaporation time and qualities (flavor and color) of concentrated fruit juice are degraded. (Petrotos and Lazarides, 2001). In order to solve this problem, the other heating techniques were combined with vacuum evaporation system. For instance, microwave and ohmic heating were applied into vacuum evaporation process for reducing the processing time (Assawarachan and Noomhorm, 2008; Icier *et al.*, 2017; Allali *et al.*, 2010).

Ultrasonic atomization is known as the effective liquid atomization process. It produces the uniform micron-sized droplets and is more energy efficient (Mai *et al.*, 2019). The ultrasound wave at high frequency irradiates the liquid to generate the fountain. The fine liquid droplets are generated and ejected from the fountain into the surrounding air at this area (Zhang *et al.*, 2019; Wood and Loomis, 1927). The physical mechanism of ultrasonic atomization is described through the conjunction of cavitation and capillary hypothesis that mentioned to the cavitation inside the liquid mass and instabilities of standing wave on its free surface (Kirpalani and Toll, 2002; Lozano *et al.*, 2017). Ultrasonic atomization has been applied to assist in various processes. Matsuura *et al.*, 2001 used the ultrasonic atomization to separate ethanal from ethanal-water solution at 10˚C. Suzuki *et al.*, (2006) applied the ultrasonic atomization technique for increasing the ratio of two amino acids, tryptophan (Trp) and phenylalanine (Phe) from dilute aqueous solutions. Wangm *et al.*, (2018) studied the effect of ultrasonic atomizing-assisted spray drying on qualities of skimmed milk powder, in which the qualities of skimmed milk powder were improved. Moreover, the ultrasonic atomization was combined with short-wave ultraviolet irradiation in order to inactivate Saccharomyces cerevisiae in tangerine and grapefruit juices (Antonio-Gutiérrez *et al.*, 2017).

To design novel concentration processes, the understanding of concentration characteristics is important for optimizing and improving the process system. The characteristics of concentrated juice can be explained by using mathematical model (Dincer *et al.*, 2016). Many mathematical models such as Lewis, Henderson and Pabis, Page, Midilli and Logarithmic models were used to study the concentration behavior in various fruit juices such as pineapple juice (Assawarachan and Noomhorm, 2011), pomegranate juice (Goula *et al.*, 2014), apple juice (Bozkir and Baysal, 2017), grape and black carrot juices (Dinçer *et al.*, 2019). Up to now, an information about the effect of ultrasound assisted vacuum evaporation on physicochemical properties and evaporation characteristics of pineapple juice is still limited. Therefore, the objectives of this research were (1) to evaluate the effect of different evaporation techniques (vacuum evaporation (V), vacuum evaporation with rotation (VR), ultrasonic atomization assisted vacuum evaporation (UAV) and ultrasonic atomization assisted with vacuum evaporation and rotation (UAVR) and temperatures (50, 55 and 60°C) on physicochemical properties (pH and color parameters) and (2) to select the most appropriate mathematical model to describe evaporation behavior of pineapple juice based on the goodness of fit of the model.

2. Materials and Methods

2.1 Materials

Pineapple juice was obtained from Malee Group Public Co. Ltd., Thailand. The physiochemical characteristics of pineapple juice such as pH, total soluble solids content (TSS) and color parameters were measured prior to further experiments.

2.2 Evaporation experiments

Pineapple juice (150 ml) was concentrated from initial concentration of 13°Brix to a final approximately 45°Brix by four different evaporation methods (V, VR, UAV and UARV) and three evaporation temperatures (50, 55 and 60°C) as shown in Table 1. The rotary vacuum evaporator was BÜCHI Rotavator R-114, Germany. The schematic of ultrasonic atomization assisted vacuum evaporation system was shown in Figure 1. The ultrasonic atomizer, frequency 1700 kHz, was installed under the round bottom flask.

Table 1 Operating conditions of evaporating pineapple juice.

Evaporation methods	Temperature (°C)	Pressure (mbar)	Rotation speed (rpm)	Frequency of ultrasound wave (kHz)
Vacuum evaporation (V)	50 55 60	70	-	-
Vacuum evaporation with rotation (VR)	50 55 60	70	80	-
Ultrasonic atomization assisted vacuum evaporation (UAV)	50 55 60	70	-	1700
Ultrasonic atomization assisted vacuum evaporation with rotation (UAVR)	50 55 60	70	80	1700

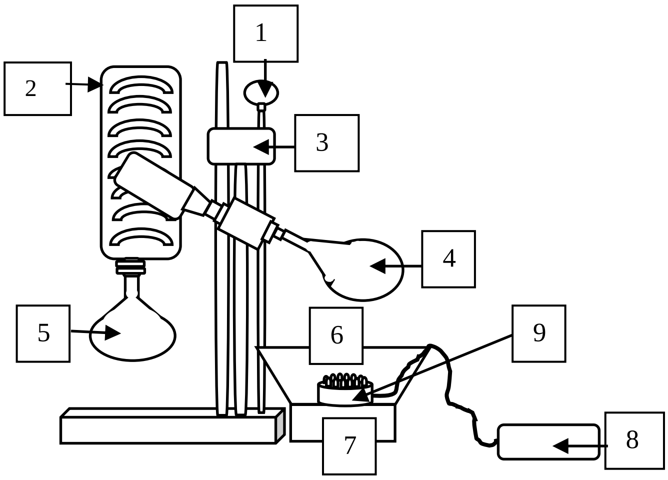

Figure 1 Schematic of ultrasonic atomization assisted vacuum evaporation system. (1) vacuum gauge, (2) condenser, (3) speed controller, (4) round bottom flask, (5) condensed collector, (6) water bath, (7) heater, (8) power supply, (9) ultrasonic atomizer.

2.3 The physicochemical measurements

The physicochemical characteristics of pineapple juice such as pH value, total soluble solid content (TSS) and color parameters were measured. The concentration of pineapple juice was measured at 5 min intervals during evaporation process using the refractometer (ATAGO, Tokyo, Japan). Color parameters were determined using colorimeter (Hunter Lab, CQX32, USA) following CIELAB color space and expressed in terms of L*, a* and b* values. The total color difference (ΔE*) was used to compare the total color changes of evaporated pineapple juice. Browning index (BI) was used to evaluate the intensity of brown color of the product. The ΔE* and BI were calculated by the equation (1) and (2), respectively. (1)

$$\Delta E^* = \sqrt{(L_i^* - L_c^*)^2 + (a_i^* - a_c^*)^2 + (b_i^* - b_c^*)^2} \quad (1)$$

where L*, a* and b* were the lightness, redness and yellowness of pineapple juice. Subscript i and c indicated the values of initial and concentrated juice.

$$BI = \left| \frac{100(x - 0.31)}{0.17} \right| \quad (2)$$

where x was the chromaticity coordinate that calculated from the L*, a*, b* values as following equation:

$$x = \frac{a^* + 1.75L^*}{5.645L^* + (a^* - 3.012b^*)} \quad (3)$$

$$\Delta BI = BI_t - BI_i \quad (4)$$

where BI_i and BI_t were browning index of initial and concentrated pineapple juice, respectively.

2.4 The evaporation rate and kinetics of concentration change

Evaporation rate was calculated from equation (5) where condensed water was the weight loss of pineapple juice.

$$\text{Evaporation rate} = \frac{\text{condensed water (g)}}{\text{evaporation time (min)}} \quad (5)$$

The change of total soluble solid content was modeled by zero-order (equation (6)) and first-order (equation (7)) reaction kinetics using SPSS Statistics version 24.0 (IBM Corp, 2016).

$$C = C_0 - k_0 t \quad (6)$$

$$C = C_0 \exp(-k_1 t) \quad (7)$$

where C_0 was initial total soluble solid, C_t was total soluble solid at t minute, k_0 and k_1 were the kinetic constants of zero-order and first-order, respectively.

2.5 Mathematical models of concentrated pineapple juice

The eight of mathematical models including Lewis, Henderson and Pabis, Page, Midilli, Logarithmic, Wang and Sing, linear and Diffusion approximation models, equation (8) - (15) were shown in Table 2. These models were applied to explain the concentration kinetics of pineapple juice. The fitting and parameters in all models were determined using non-linear regression technique in IBM SPSS Statistics version 24.0 (IBM Corp. 2016).

Table 2 The mathematic models applied to concentration of pineapple juice

Model name	Model	Reference	Equation number
Lewis	$MR = \exp(-kt)$	Lewis (1921)	8
Henderson &Pabis	$MR = a\exp(-kt)$	Henderson and Pabis (1961)	9
Page	$MR = \exp(-kt^n)$	Page (1949)	10
Midilli	$MR = a\exp(-kt^n) + b$	Midilli *et al* (2002)	11
Logarithmic	$MR = \exp(-kt) + b$	Sharma *et al* (2005)	12
Wang and Sing	$MR = at^2 + bt + 1$	Sharma *et al* (2005)	13
Linear model	$MR = kt + b$	Sabanci and Icier (2017)	14
Diffusion approximation	$MR = a\exp(-kt) + (1-a)\exp(-kbt)$	Yaldýz and Ertekýn (2001)	15

Note: t is concentration time (min), k, a, n and b are model constants.

$$MR = \frac{m_t - m_e}{m_0 - m_e} \tag{16}$$

where MR was moisture ratio, M_t was moisture content at a specific time and M_e was final moisture content. The moisture content of pineapple juice at time t (M_t) was found from the relation with TSS contents and the weight measured (Eq. (17)) that follow to the study of Sabanci and Icier (2017).

$$m_t = \frac{(1-(TSS_t / 100)) \times M_{a,t}}{(TSS_{ini} / 100) \times M_{a,ini}} \tag{17}$$

where TSS_t was TSS of pineapple juice (%) at time t, TSS_{ini} was initial TSS (%) of pineapple juice, $M_{a,t}$ was weight (g) of pineapple juice at time t and $M_{a,ini}$ was weight (g) of pineapple juice.

The coefficient of determination (R^2), reduced Chi square (χ^2), and root mean square error (RMSE) were used to consider goodness of fit of the model. R^2, X^2 and RMSE were calculated using the equation (18) - (20). The best model to describe evaporation behavior of pineapple juice was chosen due to the highest R^2, the lowest X^2 and RMSE.

$$R^2 = \frac{1-(\text{Residual MR})}{(\text{Correctedtotal MR})} \tag{18}$$

$$\chi^2 = \sum_{i=1}^{N} \frac{(MR_{exp} - MR_{pre})^2}{N - n_p} \tag{19}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (MR_{exp} - MR_{pre})^2}{N}} \tag{20}$$

where MR_{exp} and MR_{pre} are experimental and predicted data, respectively. N and n_p are the number of observation data and number of constants in model, respectively.

2.6 Evaluation of activation energy

The activation energy (E_a) is the energy values for initiation of reaction that calculated from Arrhenius equation.

$$k = k_0 \exp(-\frac{E_a}{RT}) \tag{21}$$

where k is the evaporation rate, k_0 is parameter constant, E_a is the activation energy (kJ/mol), R is the universal gas constant (8.314 J/mol ·K) and T is the absolute temperature (K).

2.7 Statistical analysis

A completely randomized design (CRD), 4 × 3 factorial experiments, was used to study the main factors of evaporation methods (V, VR, UAV and UAVR) and evaporation temperatures (50, 55 and 60°C). Three replications were performed for both evaporation experiments and quality determinations. Statistical analysis was conducted using IBM SPSS Statistics version 24.0 (IBM Corp. 2016). Duncan's multiple range test was applied to compare the difference of variable means between each treatment at 95% confidence interval.

3. Results and Discussion

3.1 Physicochemical characteristics of pineapple juice

The physicochemical characteristics of pineapple juice including pH value, TSS and color parameters were shown in Table 3. The pH of concentrated pineapple juice from four different evaporation methods (V, VR, UAV and UAVR) were in between 3.63 ± 0.12 and 3.79 ± 0.04 and not significant different ($P>0.05$). All evaporation methods affected to decrease of L* values but increase a* and b* values of concentrated juice. Different browning index (ΔBI) were used as indicator of browning reaction. ΔE* values slightly increased with increasing evaporation temperatures. The change of ΔE* in pineapple juice was influenced from non-enzymatic browning reaction. Maillard reaction was the one of non-enzymatic browning reaction that was major causes of color change in the concentrated pineapple juice (Damasceno *et al.,* 2008; Mahmoud *et al.,* 2017). Maillard reaction could be occurred by sugar and amino acid interaction in which the reaction was accelerated by the increasing temperature. This reaction related to 5-Hydroxymethylfurfural (HMF) accumulation and brown pigment formation (Rattanathanalerk *et al.,* 2005). Normally, pineapple juice contains free amino acids and sugars (sucrose, glucose and fructose). By increasing temperature, the sucrose in pineapple juice was easily hydrolyzed to more reducing sugars (glucose and fructose) that were the substrate in Maillard reaction (Garza *et al.,* 1999).

Table 3 The physicochemical characteristics of initial and concentrated pineapple juice using four evaporation methods at different temperatures.

Methods	Temp (°C)	pH	L*	a*	b*	ΔE*	ΔBI
Initial	-	3.79 ± 0.04[a]	90.17 ± 0.29[a]	-0.88 ± 0.04[d]	20.16 ± 0.05[c]	-	-
V	50	3.70 ± 0.04[b]	38.58 ± 0.16[cd]	10.36 ± 0.11[bc]	24.24 ± 0.07[b]	52.96 ± 0.16[ab]	88.99 ± 0.99[a]
	55	3.74 ± 0.02[ba]	38.45 ± 0.67[cd]	10.26 ± 0.30[bc]	23.88 ±0.17[b]	53.04 ± 0.72[a]	87.31 ± 3.60[a]
	60	3.63 ± 0.12[c]	38.33 ± 0.08[cd]	10.27 ± 0.09[bc]	24.17 ± 0.16[b]	53.17 ± 0.08[a]	89.40±0.97[a]
VR	50	3.75 ± 0.01[ba]	38.87 ± 0.09[bcd]	11.02 ± 0.21[a]	24.28 ± 0.07[b]	52.82 ± 0.05[ab]	89.21 ± 0.53[a]
	55	3.77 ± 0.01[ba]	38.44 ± 0.23[cd]	11.15 ± 0.32[a]	24.39 ± 0.09[b]	53.28 ± 0.15[a]	91.92 ± 0.12[a]
	60	3.70 ± 0.02[b]	38.32 ± 0.04[cd]	10.31 ± 0.03[bc]	24.08 ± 0.17[b]	53.19 ± 0.05[a]	89.04 ± 1.15[a]
UAV	50	3.75 ± 0.01[ba]	38.60 ± 0.13[cd]	10.44 ± 0.12[b]	23.98 ± 0.13[b]	52.94 ± 0.16[ab]	87.59 ± 1.44[a]
	55	3.72 ± 0.02[ba]	39.30 ± 0.87[cd]	10.00 ± 0.58[bc]	25.64 ± 1.50[a]	52.32 ± 1.11[ab]	93.83 ± 13.29[a]
	60	3.67 ± 0.05[bc]	38.15 ± 0.08[d]	10.40 ± 0.08[bc]	23.99 ± 0.18[b]	53.38 ± 0.07[a]	89.37 ± 0.85[a]
UAVR	50	3.74 ± 0.02[ba]	38.60 ± 0.08[ab]	10.45 ± 0.10[b]	24.24 ± 0.13[b]	52.96 ± 0.70[ab]	89.08 ± 1.00[a]
	55	3.75 ± 0.01[ba]	39.59 ± 1.38[d]	9.96 ± 0.30[c]	24.72 ± 0.62[b]	51.93 ± 1.35[b]	86.93 ± 3.06[a]
	60	3.72 ± 0.03[ba]	38.41 ± 0.06[cd]	10.14 ± 0.07[bc]	24.27 ± 0.07[b]	53.14 ± 0.06[a]	89.43 ± 0.47[a]

Note: The browning index of initial pineapple juice, BI_i, is 23.96 ± 0.21. Different superscripts in the same column are significantly different (P≤0.05) by Duncan' multiple range test (n=3).

3.2 Kinetic reaction and evaporation rate of pineapple juice

Figure 2 showed the concentration (TSS) of pineapple juice with evaporation time using V, VR, UAV and UAVR methods at 50, 55 and 60°C. The ranges of evaporation time were 17-210 min. At 50°C of evaporation temperature, the evaporation time of V, VR, UAV and UAVR were 210, 70, 105 and 45 min, respectively. When the temperature was 55 and 60°C, the evaporation times of V, VR, UAV and UAVR were 130, 35, 62 and 26 min and 85, 21, 45 and 17 min, respectively. The evaporation time of UAVR method was shorter than VR, UAV and V methods around 1.3, 2.4 and 4.9 times, respectively. The changes of the pineapple juice concentration followed first order kinetics reaction in which corresponding correlation coefficient (R^2) values were greater than 0.964 as shown in Table 4. This result was similar to concentration in other fruit juices such as blueberry (Elik *et al.,* 2016), mulberry (Fazaeli *et al.*, 2011) and barberry juice (Alizadeh *et al.,* 2020). The evaporation rate constant (k_1) for UAVR method was higher than the others which corresponded to shorter evaporation time. At a same temperature, UAVR method also presented the highest evaporation rate followed by VR, UAV and V methods, respectively. Decreasing evaporation time in UA method was relevant to the small droplet size of the juice using ultrasonic atomizer. Wangm *el at.,* (2018) studied the effect of ultrasonic atomizing-assisted spray drying (UASD) in skimmed milk powder. The particle size of skimmed milk powder using UASD process (2 to 10 μm) was smaller than the particle from high-speed rotating dish spray drying (RDSD) leading to faster water evaporation because of surface area increasement. The obtained small droplets from ultrasonic atomizer would increase both heat contact area and heat transfer rate during evaporation leading to evaporation time reduction (Kudo *et al.,* 2017; Crafton and Black, 2004). In addition, the decreasing of evaporation time using VR method could be implied that the rotation in VR method generated a thin film layer of the juice resulting to increase heat transfer rate in VR method (Leonard and Ramey, 1964). Furthermore, increasing evaporation temperature led to increase evaporation rate. The higher evaporation temperature had more heat energy, leading to increase heat transfer rate and the evaporation occurred faster (Goula *et al.*, 2014). Therefore, the pineapple juice concentration using UAVR method at 60°C provided the shortest evaporation time and highest evaporation rate due to high heat transfer rate from higher evaporation temperature and the combination between ultrasonic atomization with rotation (increasing heat contact area).

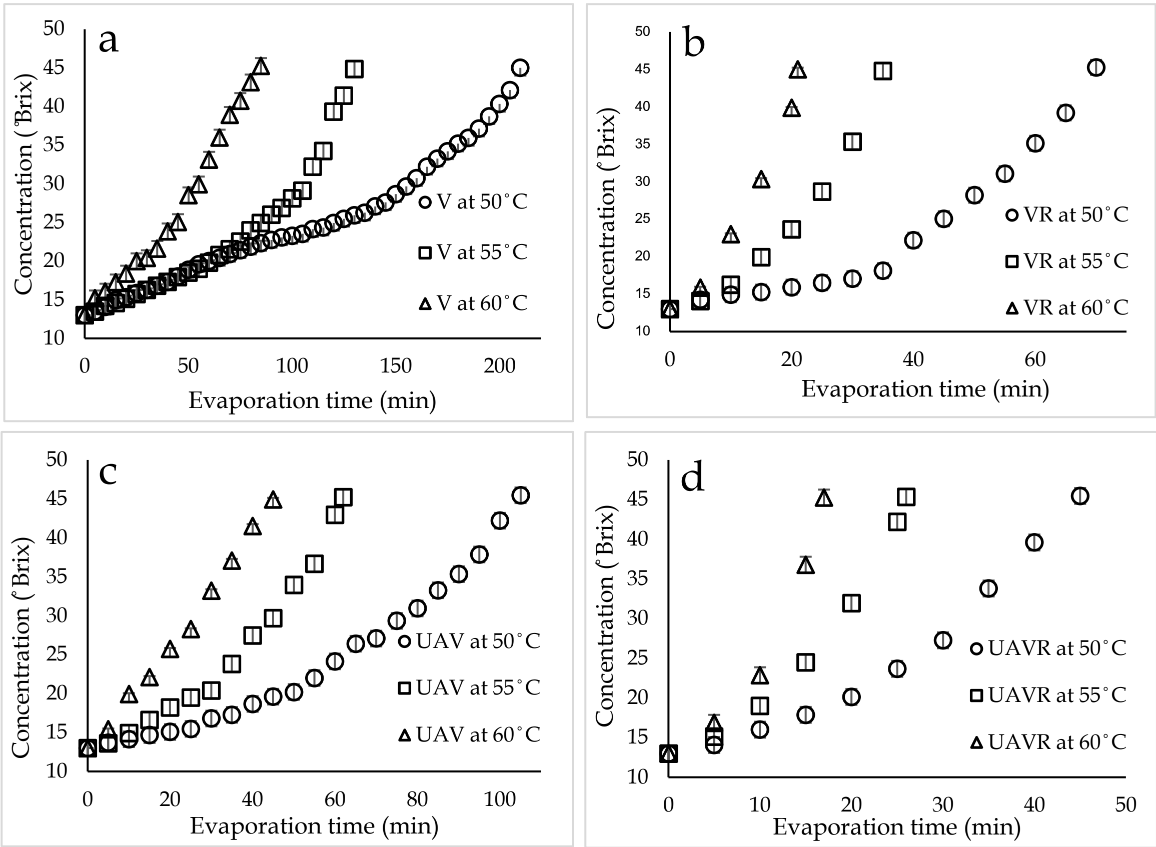

Figure 2 The concentration of pineapple juice using four different evaporation methods at 50, 55 and 60°C. (a) vacuum; (b) vacuum with rotation; (c) ultrasonic atomization assisted vacuum evaporation; (d) ultrasonic atomization assisted vacuum evaporation with rotation.

3.3 Activation energy

The activation energies of pineapple juice concentration were ranged from 88.188-114.584 kJ/mol·K (Table 4). The UAVR method showed lower activation energy than V, UAV and VR methods around 1.30, 1.17 and 1.16, respectively. The result of activation energy directly affected to the evaporation rate constant (k_1). The lower activation energy indicated the higher evaporation rate constant (k_1). In table 4, UAVR method provided the lowest activation energy due to highest evaporation rate constant. The results implied that water in juice was rapidly evaporated by UAVR method.

Table 4 Evaporation time, evaporation rate and kinetic parameters of first order equation for concentration of pineapple juice during different concentration processes.

Concentration Method	Temperature (°C)	Evaporation rate (g water/min)	Kinetic parameters			Activation energy	
			k_1(min^{-1})	C_0	R^2	K_0	E_a (kJ/mol)
V	50	0.51 ± 0.01[k]	0.005 ± 0.000	13.664 ± 0.137	0.989	2 × 10^{16}	114.584
	55	0.83 ± 0.01[j]	0.010 ± 0.000	11.358 ± 0.251	0.964		
	60	1.27 ± 0.01[h]	0.018 ± 0.001	13.653 ± 0.146	0.994		
VR	50	1.44 ± 0.02[g]	0.020 ± 0.002	10.454 ± 0.329	0.971	2 × 10^{14}	98.346
	55	3.03 ± 0.02[d]	0.039 ± 0.005	11.252 ± 0.254	0.993		
	60	5.19 ± 0.10[b]	0.060 ± 0.033	12.327 ± 0.323	0.994		
UAV	50	1.01 ± 0.01[i]	0.012 ± 0.001	11.342 ± 0.155	0.990	6 × 10^{14}	103.094
	55	1.73 ± 0.01[f]	0.022 ± 0.002	11.586 ± 0.195	0.992		
	60	2.39 ± 0.03[e]	0.038 ± 0.003	14.930 ± 0.304	0.987		
UAVR	50	2.39 ± 0.03[e]	0.031 ± 0.003	11.470 ± 0.222	0.993	6 × 10^{12}	88.188
	55	4.29 ± 0.04[c]	0.058 ± 0.008	11.569 ± 0.240	0.996		
	60	6.32 ± 0.07[a]	0.083 ± 0.015	11.062 ± 0.525	0.986		

3.4 Mathematical models of pineapple juice concentration

The evaporation data of each method were processed by nonlinear regression techniques. Eight mathematical models including Lewis, Henderson and Pabis, Page, Midilli, Logarithmic, Wang and Sing, linear and Approximation of diffusion model (Table 5) were applied. The goodness of fit of eight different models were tested to select the best model in order to describe pineapple juice concentration behavior. The R^2, X^2 and RMSE were used as criteria for selecting the best model. The results of fitting were presented in Table 5 where the R^2, X^2 and RMSE ranged from 0.873 to 1.000, 0.000 to 0.016 and 0.000 to 0.113, respectively. The results showed that Midilli model was the best model for pineapple juice concentration owing to provide the highest R^2 value (0.982 to 1.000) and the lowest X^2 (0.000 to 0.002) and RMSE (0.000 to 0.042). Figure 3 showed the moisture ratio comparison between experimental and predicted data from Midilli model in which R^2, $X^2$and RMSE were 0.9929, 0.0004 and 0.0015, respectively. Midilli model was also the best prediction model for concentration of other fruit juices such as sour cherry (Sabanci and Icier, 2017), grape, pomegranate and black carrot juices (Dinçer *et al.*, 2019).

Table 5 Statistical compatibility results of mathematical models to the experimental data including the change of moisture ratio of pineapple juice concentration and predicted model constants.

Models	Methods	Temperatures (°C)	Coefficient and statistical analysis					R^2	χ^2	RMSE
			k	n	a	b	C			
Lewis	V	50	0.011	-	-	-	-	0.979	0.001	0.038
		55	0.013	-	-	-	-	0.941	0.005	0.069
		60	0.029	-	-	-	-	0.968	0.003	0.052
	VR	50	0.023	-	-	-	-	0.873	0.014	0.113
		55	0.053	-	-	-	-	0.925	0.010	0.095
		60	0.102	-	-	-	-	0.946	0.009	0.086
	UAV	50	0.017	-	-	-	-	0.927	0.007	0.085
		55	0.031	-	-	-	-	0.936	0.007	0.026
		60	0.063	-	-	-	-	0.988	0.001	0.034
	UAVR	50	0.043	-	-	-	-	0.934	0.008	0.086
		55	0.078	-	-	-	-	0.936	0.009	0.089
		60	0.115	-	-	-	-	0.930	0.012	0.098
Henderson and Pabis	V	50	0.010	-	0.989	-	-	0.979	0.002	0.038
		55	0.014	-	1.067	-	-	0.949	0.004	0.064
		60	0.029	-	0.998	-	-	0.968	0.003	0.051
	VR	50	0.026	-	1.090	-	-	0.886	0.013	0.107
		55	0.056	-	1.096	-	-	0.939	0.010	0.085
		60	0.107	-	1.061	-	-	0.951	0.010	0.080
	UAV	50	0.019	-	1.106	-	-	0.943	0.006	0.074
		55	0.035	-	1.103	-	-	0.951	0.006	0.072
		60	0.064	-	1.024	-	-	0.989	0.001	0.034
	UAVR	50	0.047	-	1.089	-	-	0.946	0.002	0.077
		55	0.083	-	1.075	-	-	0.944	0.009	0.082
		60	0.119	-	1.048	-	-	9.993	0.016	0.097
Page	V	50	0.010	1.007	-	-	-	0.979	0.002	0.038
		55	0.002	1.398	-	-	-	0.975	0.002	0.045
		60	0.018	1.123	-	-	-	0.972	0.003	0.048
	VR	50	0.001	1.913	-	-	-	0.962	0.004	0.061
		55	0.006	1.737	-	-	-	0.994	0.001	0.026
		60	0.019	1.679	-	-	-	0.996	0.001	0.023
	UAV	50	0.001	1.628	-	-	-	0.989	0.001	0.032
		55	0.004	1.562	-	-	-	0.988	0.002	0.036
		60	0.043	1.125	-	-	-	0.992	0.001	0.027
	UAVR	50	0.006	1.618	-	-	-	0.990	0.001	0.033
		55	0.012	1.701	-	-	-	0.993	0.001	0.029
		60	0.019	1.762	-	-	-	0.985	0.004	0.026

Table 5 (Continued)

Models	Methods	Temperatures (°C)	Coefficient and statistical analysis					R^2	χ^2	RMSE
			k	n	a	b	c			
Linear	V	50	0.004	-	-	0.830	-	0.957	0.003	0.054
		55	0.007	-	-	0.957	-	0.997	0.000	0.016
		60	0.011	-	-	0.838	-	0.966	0.003	0.053
	VR	50	0/015	-	-	1.012	-	0.975	0.002	0.046
		55	0.030	-	-	0.837	-	0.992	0.001	0.030
		60	0.047	-	-	0.959	-	0.979	0.005	0.055
	UAV	50	0.010	-	-	0.983	-	0.993	0.001	0.026
		55	0.016	-	-	0.968	-	0.989	0.001	0.033
		60	0.021	-	-	0.821	-	0.912	0.011	0.093
	UAVR	50	0.023	-	-	0.977	-	0.993	0.001	0.028
		55	0.039	-	-	0.973	-	0.992	0.001	0.033
		60	0.059	-	-	0.989	-	0.999	0.000	0.009
Diffusion approximation	V	50	0.198	-	0.170	0.053	-	0.979	0.002	0.037
		55	0.026	-	-43.619	0.982	-	0.973	0.003	0.047
		60	2.049	-	0.003	0.014	-	0.968	0.003	0.051
	VR	50	0.052	-	-84.162	0.988	-	0.941	0.007	0.077
		55	0.122	-	-67.708	0.984	-	0.989	0.002	0.036
		60	0.231	-	-53.906	0.978	-	0.994	0.002	0.029
	UAV	50	0.038	-	-56.146	0.983	-	0.983	0.002	0.040
		55	0.067	-	-58.656	0.984	-	0.983	0.001	0.014
		60	0.095	-	-28.774	0.984	-	0.992	0.002	0.027
	UAVR	50	0.093	-	-63.622	0.984	-	0.984	0.003	0.043
		55	0.171	-	-70.752	0.985	-	0.987	0.003	0.039
		60	0.265	-	-104.725	0.989	-	0.978	0.007	0.054

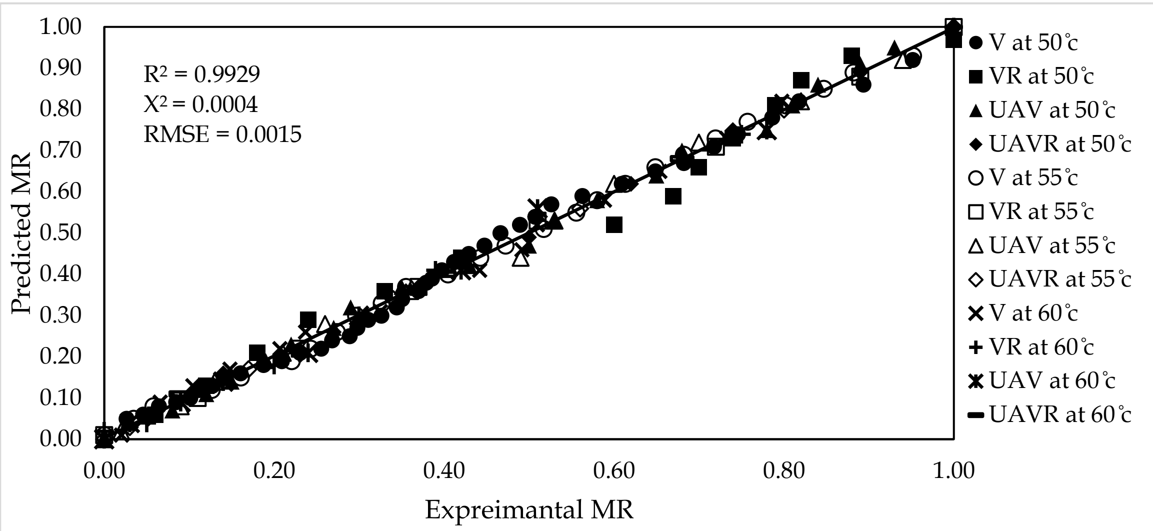

Figure 3 The moisture ratio comparison between experimental and predicted data from Midilli model of different evaporation methods.

4. Conclusion

The application of ultrasonic atomization or rotation into the vacuum evaporation system did not affected both pH and color parameters. While, the increasing evaporation temperature caused to increase total ΔE* and ΔBI values. The rotation and ultrasonic atomization could decrease the evaporation time for concentration process. The results showed that UAVR method and higher temperature provided the shortest evaporation time and highest evaporation rate compared with other methods. Midilli model was the best fit for predicting concentration changes in pineapple juice.

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