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Ultrasound-Assisted Extraction (UAE) of sappan wood (*Caesalpinia sappan* L.): Effect of solvent concentration and kinetic studies

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Abstract

Sappan wood (*Caesalpinia sappan* L.) is a plant that contains many phytochemical constituents such as antioxidant, antimicrobial, antifungal and antiacne that have functional activities. Sappan woods have several phenolic compounds such as brazilin, xanthone, flavones and coumarin. In order to extract the phenolic compounds, Ultrasound-Assisted Extraction (UAE) is considered as green technology and gives better quality products with a higher extraction rate, shorter extraction time and less energy. The research investigated the effect of different ethanol concentrations on the sappan wood's yield and studied the kinetic on its extraction process. Sappan wood was extracted using a type of UAE probe with ethanol concentrations of 50%, 60%, 70%, 80% and 90% (v/v). For the extract was analyzed its yield, Total Phenolic Content (TPC), antioxidant activity, Fourier Transform InfraRed (FTIR) spectroscopy and lees morphology. The kinetic study refers to Peleg's model and was conducted for temperatures of 40 °C, 50 °C and 60 °C. The results showed that the increase of ethanol concentration increased the yield of extract until ethanol was 80% and decreased when the ethanol concentration is higher than 80%. While the TPC slowly decreased, when the ethanol concentration increased. Comparing the UAE and sohxlet methods, UAE gave a higher yield in a shorter time (10.33% in 20 min) than the Soxhlet method (9.67% in 180 min). All the extracts were categorized as high antioxidant material since the IC_{50} points were lower than 50 ppm. FTIR spectroscopy showed that UAE did not change the functional group of the extract, while Scanning Electron Microscope (SEM) pictures showed the more obvious cracked and deep holes of UAE's lees than the Soxhlet's lees. Peleg's model was suitable to describe the extraction kinetics with R^2 higher than 0.93. Regarding both yield and TPC, a mixture of ethanol-water with ethanol 60% (v/v) could be the optimum solvent concentration (10.33% yield with TPC 2.63 mg GAE/g) for UAE of sappan wood.

Keywords: Ethanol; Phenolic compound; Antioxidant activity; Sonocapillary; Extraction rate; Extraction capacity.

Highlights

- Ultrasound-assisted extraction enhances the extraction process in a shorter time
- Lees of ultrasound-assisted extraction has more cracks and deep holes
- Peleg's model is appropriates to describe the sappan wood's UAE process

1 Introduction

People in modern life today tend to have more awareness of consuming healthy and nutritious foods (González de Peredo et al., 2019). Therefore, the consumption of food with additional biological/pharmacological activities such as antioxidant, antimicrobial, antifungal, and antidiabetic also increase tremendously. The use of edible plants that have biological/pharmacological effects is promoted, since they have little side effects (Vankar & Srivastava, 2010). The components of the plant that are responsible for the biological effect on humans usually are secondary metabolites such as phenolic, flavonoid, alkaloid and terpenoid (Wakeel et al., 2019). Sappan wood (*Caesalpinia sappan* L.) is a plant that has been used in the food, beverages and pharmaceutical industries. It is a medicinal plant and grows up in many Asian countries like Sri Lanka, Indonesia, Vietnam and Malaysia. Sappan wood contains many phytochemical constituents (Yim et al., 2019) that have functional activities such as antioxidant, antimicrobial, antifungal and antiacne (Batubara et al., 2010; Muti et al., 2021). Sappan wood is also used as the red dye source, since the extract of sappan wood will give red color. Research on sappan wood resulted in the finding of phenolic compounds such as brazilin, xanthone, flavones and coumarin (Nirmal et al., 2015).

Extraction is the common process used to take the phytochemical compound in plants. The process usually uses hydrothermal treatment with agitation (Sharma & Dash, 2022), maceration, cold freezing and Soxhlet extraction (Chemat et al., 2017). These conventional methods were reported to have lower extraction efficiency, time-consuming, higher temperature and need higher energy (Liao et al., 2021). Nowadays trend in the extraction method is selecting a new, rapid and safe method. Ultrasound-Assisted Extraction (UAE) is one of the new methods that is considered sustainable and green technology (Sharma & Dash, 2022). UAE generates the cavitation phenomena, where the implosion of a cavitation bubble on the surface of solute produces micro-jetting. In fact, micro-jetting causes the cell-surface rupture and allows solute disseminates into a solvent. Ultrasound application will also reduce external barriers in the mass transport step of extraction (Alcántara et al., 2020) and this makes the loosing of phytochemical compounds happen easily since UAE will enhance the cell-wall rupture (Herrera-pool et al., 2021). Since UAE gives a higher extraction rate, the extraction time needed can be shortened. The shorter extraction time will impact the reduction of energy and extraction cost. Reduction of energy or power consumption leads to a reduction in carbon dioxide emission. Lower CO_2 emission can be explained through the calculation of coal and fuel needed that must be combusted to produce energy (Chemat et al., 2017). These conditions make the UAE a green extraction method. Moreover, it is stated that acoustic cavitation produced from UAE increases the mass transfer and allows operation at moderate temperatures and shorter extraction times (Fraterrigo Garofalo et al., 2022; José Aliaño González et al., 2021). These conditions preserve structural and bioactive properties, avoid the degradation of phytochemical compounds and make the UAE a suitable method for thermal labile components (Fernando et al., 2021; Sharma & Dash, 2022). Several studies about UAE of phytochemical compound were done for blackcurrant (José Aliaño González et al., 2021), black jamun pulp (Sharma & Dash, 2022), mangrove leaves (Audah et al., 2018), mulberry (Insang et al., 2022), leaves waste of *Syzygium cumini* (L.) (Mahindrakar & Rathod, 2022), cereal brans (Milićević et al., 2021) and *Empetrum nigrum* L. (Gao et al., 2021).

Besides the safe and rapid extraction method, the tendency of people to their health also makes the choice of green solvent in the extraction process increases. The choice of solvent is one important factor affecting the extract gained. The solvent will affect the solute solubilization since this process is related to the attractions and repulsions of solute and solvent (Jacotet-Navarro et al., 2018). Green solvents are safer than petrochemical ones and usually come from bio-based solvents. This kind of solvents are prepared from biomass or waste compounds and are considered less toxic, renewable and biodegradable components (del Pilar Sánchez-Camargo et al., 2020). Phenolic compounds are mostly polar compounds, therefore it is better to choose polar solvents for extraction. Among many polar solvents that are common for the extraction process, water and ethanol are considered green solvents. Water is a renewable material that is non-toxic and also non-flammable (Anuar et al., 2021), while ethanol is a low toxic material that is also renewable and biodegradable. The combination of ethanol and water as an extraction solvent is a better choice, since it has been reported that binary solvents made from mixture of water and organic solvent give higher efficiency than single solvents (Saifullah et al., 2020). The use of an ethanol-water mixture with different concentrations as a solvent may be investigated to get better extraction results. On the other hand, to the best of our knowledge, there is still limited research investigating the ethanol-water concentration on the extracted characteristic of the UAE of sappan wood.

Studies about extraction kinetics are also an important point to analyze the efficient extraction process. The kinetic study can help the process optimization, process design and also scaling up for industrial applications (Sharma & Dash, 2022). The kinetic study results on the mass transfer constant and diffusion coefficient which are important parameters of the extraction. In the extraction of phytochemical compounds, the kinetic study will give an understanding of the relationship between time and phytochemical content in extract and also equilibrium concentration at steady state condition. Peleg's model has been adapted from the moisture sorption curve to the extraction process since there is a similarity between extraction and shape of the sorption curve (Milićević et al., 2021). Peleg's model had been used to investigate the kinetic studies of phenolic compound extraction from cereal brans (Milićević et al., 2021), *Plectranthus amboinicus* (Lour.) Spreng (Zahari et al., 2020) and leaves waste of *S. cumini* (Mahindrakar & Rathod, 2022). Although the kinetic study is an important point in the extraction process, it can be seen that the UAE kinetic study of phytochemical compounds from sappan wood has not been reported. Thus, this research investigated the effect of different ethanol concentrations on the extract characteristic of the UAE of sappan wood and also studies the kinetic on its extraction process.

2 Materials and methods

2.1 Material

The raw material used for this research was sappan wood from Ungaran Central Java, in Indonesia. Ethanol as solvent was obtained from Bratachem, while aquadest was obtained from UD. Mitra Karya Semarang Central Java. Reagent 1,1-diphenyl-2-picryl-hydrazyl (DPPH), Folin-Ciocalteu's phenol reagent and Gallic acid were purchased from Sigma Aldrich, while methanol, sodium carbonate and ascorbic acid were obtained from Merck.

2.2 Ultrasound-Assisted Extraction (UAE)

The sappan wood was sieved and grounded until passed 20 mesh (0.78 mm) screening. Ten gram of sappan wood was mixed with 150 mL solvent and extracted using ultrasound-assisted extractor for 20 min and at 50 °C. Ultrasound apparatus used was a type of Ultrasonic Cell Disruptor TUE-500 probe with a frequency 20-30 kHz. Ethanol water mixtures were used as solvents with ethanol concentrations of 50%, 60%, 70%, 80% and 90% (v/v). After extraction, the solution was filtered using a vacuum pump and the solvent was separated using a rotary evaporator (Heidolph, Hei-VAP Andvantage) to get the extract. The yield of the extract was counted using Equation 1.

$$yield = \frac{mass\ of\ extract\ gained}{mass\ of\ raw\ material\ used}\ x100\% \quad (1)$$

2.3 Total Phenolic Content (TPC) analysis

The total phenolic content of the extract was analyzed using Folin-Ciocalteu's method (Arsiningtyas, 2021) with slight modification. Extract 0.1 g was added with methanol until 10 mL. The solution was taken 0.2 mL and added with aquadest and 1 mL of Folin-Ciocalteau's reagent. The solution was shaken and added with 3 mL Na_2CO_3 20%. The solution was incubated for 2 h at room temperature. Absorbance was analyzed using UV-Vis spectrophotometer (Genesis 10S) at 765 nm. Gallic acid was used as the standard for the calibration curve

2.4 IC_{50} antioxidant analysis

Antioxidant analysis was measured using DPPH Free Radical Scavenging Activity. For this analysis 1 mL of sample was added with 4 mL 0.05 mM DPPH in methanol. The solution was incubated in a dark place for 30 minutes. Absorbance was measured at 515 nm using UV-Vis spectrophotometer. The inhibition was calculated using Equation 2.

$$inhibition\ (\%) = \frac{A_0 - A_S}{A_0} \times 100 \tag{2}$$

where A_0 was absorbance of blank (without extract) and A_s was absorbance with extract. The IC_{50} was calculated using linier regression of the samples (Arsiningtyas, 2021). Ascorbic acid was used as the positive control.

2.5 Fourier Transform InfraRed (FTIR) analysis

Fourier Transform InfraRed (FTIR) was used to analyze the spectra of extracts to observe the functional group that exists. Samples were analyzed using Perkin Elmer FTIR spectrometer between wavelengths of 400 to 4000 nm.

2.6 Conventional extraction method

For comparison, it was also conducted Soxhlet extraction for 180 min consisting of 10 g of sappan wood with 150 mL ethanol of 60% as solvent. The extract was also analyzed as well as its yield, TPC, antioxidant activity and IR spectrum.

2.7 Morphology of sappan wood surface

In order to investigate the effect of the ultrasound-assisted extraction on the rupture of the sappan wood, a Scanning Electron Microscope (SEM) was used to analyze the morphology of the residual of UAE method (for 60% of ethanol concentration) and residual of Soxhlet extraction. Samples were analyzed using JEOL Type JSM 6510 LA.

2.8 Kinetic studies

Studies about the kinetic of sappan wood extraction used Peleg's kinetic model. This model evaluates the relationship between time and the yield of extraction. For extraction of phytochemical compound, Peleg's model was stated in Equation 3.

$$C_t = C_o + \frac{t}{K_1 + K_2 t} \tag{3}$$

Where C_t is the extraction yield at time t, C_0 is the extraction yield at time t = 0, t is the time of extraction, K_1 is rate constant and K_2 is capacity constant. Since at t = 0 the C_0 is zero, then Equation 3 can be simplified into Equation 4

$$C_t = \frac{t}{K_1 + K_2 t} \tag{4}$$

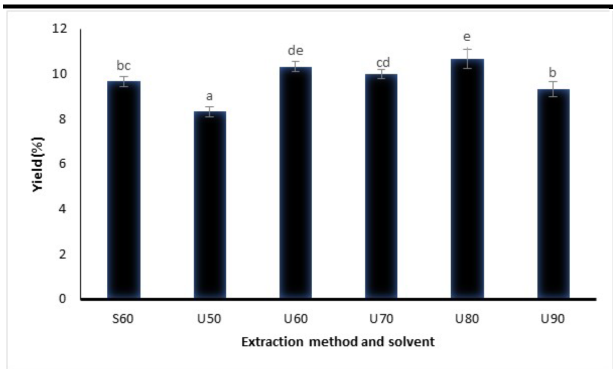
The reciprocal value of K_1 represents the initial rate constant B_0, while the reciprocal value of K_2 represents equilibrium capacity C_e (Milićević et al., 2021). The K_1 and K_2 constants were calculated using a nonlinear regression model with solver in Microsoft Excel.

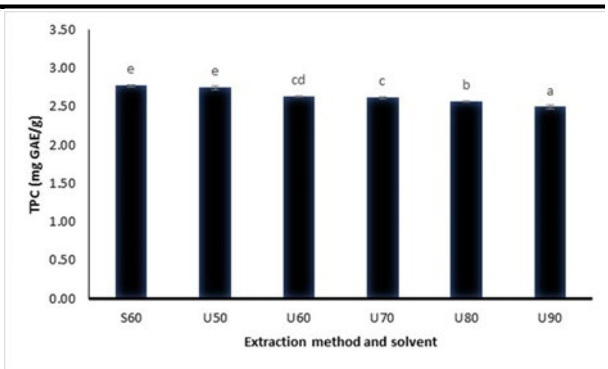
Ten gr of sappan wood powder was extracted using ethanol 60% with 15 mL solvent/g solute. Temperatures were set at 40 °C, 50 °C and 60 °C. Samples were analyzed for their TPC analysis every 10 minutes from t:0 until t:60 minutes. The data collected were fitted to the model that has been described in Equation 4.

3 Results and discussions

3.1 Effect of ethanol concentration on yield, TPC and antioxidant activity, comparison between UAE and Soxhlet method

The effect of ethanol concentration on the yield and TPC of the extract was shown in Figure 1, while the antioxidant activity which is expressed in IC_{50} number was shown in Table 1.





(a) (b)

Figure 1. Effect of ethanol concentration on yield and TPC of extract: (a). Yield, (b). TPC Data are related to the mean with SD, S = Soxhlet (with ethanol v/v%), U = UAE (with ethanol v/v%). Different letter indicates significant difference ($p < 0.05$ by Duncan's test).

From Figure 1, it can be seen that UAE has obtained a higher yield in a shorter time when compared with Soxhlet method. UAE with ethanol 60% (U60) had a yield of 10.33 ± 0.217% when compared with Soxhlet method (S60) which had a yield of 9.67 ± 0.23%. The extraction yield of Soxhlet was approximately equal to the UAE method, but it can be noticed that UAE was conducted in a shorter time. In this research, UAE was conducted for 20 min while the Soxhlet method was conducted within 180 min. Moreover, the Soxhlet method uses a higher temperature (in this research is around 85 °C) compared with UAE temperature at 50 °C, since on the Soxhlet method, the solvent must reach its boiling point during the extraction process. The high temperature could destroy the extract, especially for the thermal labile components. A similar result was reported by Liao et al., (2021) that extracted flavonoids from peanut shells. It was mentioned that UAE conducted at 55 °C and 80 min had a higher yield than the Soxhlet extraction that was conducted at 98 °C and 320 min. Comparing the TPC content, the Soxhlet (S60) have slightly obtained higher TPC content (2.77 mg GAE/g) than U60 (2.63 mg GAE/g), however, if counted both yield and TPC, U60 still had higher overall result (10.33% and 2.63 mg GAE/g of U60 and 9.67% and 2.77 mg GAE/g of S60). Therefore, the advantages of using UAE compared with the conventional method are the shorter extraction time with lower temperature.

UAE can accelerate the extraction process due to acoustic cavitation phenomena, where acoustic cavitation resulted in the micro-jetting. Micro-jetting affects the cell wall peeling and promotes particle breakdown that increases extraction yield (Fernando et al., 2021). UAE has been reported in some works with several mechanisms. The possible mechanisms involved are fragmentation, erosion, capillarity, detexturation and sonoporation (Chemat et al., 2017). Fragmentation usually happens in the initial sonication step, mainly because of particle collisions that are resulted from the collapsing of cavitation bubbles. The reduction of particle size by ultrasound increases the surface area of the solid which results in higher mass transfer. Erosion enhances the solvent accessibility to the plant tissues and therefore enhances the solubilisation. Sonocapillary effect deals with deep penetration of solvent into the pores of tissue that contributes to the higher solvent absorption at the beginning of extraction, while sonoporation usually uses high ultrasound frequencies for cell uptake in molecules or for cell destruction.

The use of different solvent concentrations also had an impact on the yield of the extract. The use of ethanol 50% (v/v) in UAE had the lowest yield, and the yield increased with the increase of ethanol content in the solvent mixture. But after 80% of ethanol concentration, yield decreased. The highest yield was reached on U80 shown in Figure 1. It can be seen that the yield of U60 and U80 was not significantly different since both results had the same letter on the analysis. This result was expected since phenols contain hydroxyl groups that are more soluble in polar solvents (Brahmi et al., 2022). Water as a polar solvent is not preferred to extract phytochemical compounds but water in an organic solvent can increase the extraction yield (Liao et al., 2021) since water will act as a swelling agent and touch the surface of the solute (Anuar et al., 2021). It will make cell swelling and greater pores formed for improving the diffusion of phenolic compounds (Mahindrakar & Rathod, 2022). The use of ethanol has several advantages compared with other organic solvent. It is considered a sustainable solvent, has low toxicity, safer and tolerable when applied to agricultural products (Brahmi et al., 2022). Thereby ethanol become one of the preferable solvent used combined with UAE method.

The solvent mixture affects the polarity of the solvent and thus affects the extraction process. Solvent solubility is not the only main parameter for the extraction process, since solvent solubility does not impact the diffusion of targeted component in the plant matrix. Besides solvent solubility, it must also be considered the mass transport phenomena in extraction. Mass transport happens through a complex interaction between solvent, plant material and targeted compound (Jacotet-Navarro et al., 2018). The phenolic content of sappan wood is located in the interior part of the wood, therefore solvent must pass through the wall and membrane that it is more difficult to achieve for pure ethanol than for a water-ethanol mixture. The use of UAE had the highest TPC for 50% of ethanol. When the ethanol concentration increases, the TPC slowly decreases. Gao et al. (2021) revealed that the ethanol concentration between 50-64% had the highest TPC, and it will decrease after 65% of ethanol concentration. Another research stated that an ethanol concentration of 60% to 80% as a good extraction solvent of antioxidants from rosemary (Jacotet-Navarro et al., 2018), while Liao et al., (2021) got ethanol 70% as the best concentration for extracting flavonoids from peanut shell This slight difference might be related to the phenolic compounds that can be different in each plant, so it needs different solvent polarity for maximizing the process. Although UAE 50% ethanol had the highest TPC, it could be noted that it had the lowest yield result. Combining both yield and TPC result, U80 actually had the highest total result (10.67% and 2.57 mg GAE/g). However, this result only slightly differed with U60 (10.33% and 2.63 mg GAE/g). The use of ethanol 80% as solvent needs more ethanol than ethanol 60% and it will affect the extraction cost. Therefore the most possible optimum solvent concentration regarding the yield and TPC was 60% of ethanol concentration.

From Table 1, it can be seen that all of the extracts had antioxidant activity higher than ascorbic acid. This means that the antioxidant activity of the extract is still lower than commercial antioxidants, although the difference is just slightly. IC_{50} shows the ability of the material to scavenge 50% DPPH. The IC_{50} below 50 ppm is considered a strong antioxidant (Arsiningtyas, 2021). The IC_{50} of Soxhlet extraction is the highest and it means the lowest antioxidant activities, although it gives the highest TPC. TPC may consist of many phenolic contents that might have another biological function besides antioxidant properties.

Table 1. Antioxidant activity of sappan wood extract.

Extraction Method	Solvent	IC_{50} (ppm)
UAE	Ethanol 50%	3.271
	Ethanol 60%	3.873
	Ethanol 70%	3.994
	Ethanol 80%	3.837
	Ethanol 90%	3.372
Soxhlet	Ethanol 60%	6.516
Ascorbic acid (as standart)		3.150

3.2 FTIR spectra

FT-IR spectroscopy was performed to investigate the functional groups present in each extract. Figure 2 shows the FT-IR spectra for each extract. It can be seen that all of the extracts have almost the same functional group. There are several peaks present such as peaks at 1040 cm^{-1}, 1400 cm^{-1}, 1600 cm^{-1} and 3200 cm^{-1}. The peak at 1040 cm^{-1} corresponds to the ring of phenolic compounds, while peaks at 1600 cm^{-1} refer to C=C bond (Hasrudin et al., 2020). In addition to that, another peak was showed at 3200 cm^{-1} which refers to –OH group of alcohol and peak at 1400 cm^{-1} that refers to C=O group. The presence of C=O group indicates the existence of brazilein component that is produced from the oxidation of brazilin (Ngamwonglumlert et al., 2020). According to Mahindrakar & Rathod (2022), UAE will not destroy the functional group present in phenolic compound.

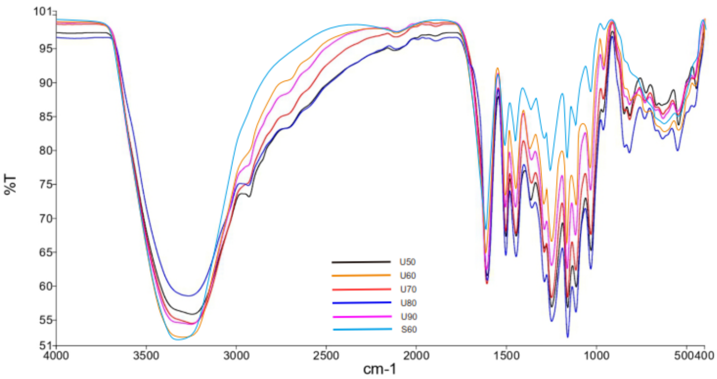


Figure 2. FTIR spectra of extract.

3.4 Morphology of sappan wood surface

Morphologies of sappan wood surface after extraction were shown in Figure 3, where Figure 3a was related to the morphology of UAE's surface, while Figure 3b was associated with the Soxhlet extraction's surface. According to Figure 3, it was shown that sappan wood cells had been damaged after the extraction process with both methods. Plant tissues became rough and cracked. In Figure 3b, the damage could be due to the solvent when it dissolved the cell wall (Khandare et al., 2021). This allows components inside the cell to flow to the solvent. Figure 3a showed more ruptured cells that implied UAE gave more impact on the cell wall. The damage of the ultrasound effect was more visible than in the Soxhlet method. The cell rupture of UAE method was also deeper since the roughness in Figure 3a is more visible than in Figure 3b. In Figure 3a, it was also shown several deep holes that may be attributed to the sonocapillary effect of UAE. This effect causes deep penetration of solvent into plant tissues and makes the loosing of the targeted compound becomes easier (Chemat et al., 2017). In wood, secondary metabolites including phenolic compounds are usually located in the heartwood part, which is the inner part of wood (Arisandi et al., 2019; Ravber et al., 2015) and therefore it is hard to achieve by the solvent. Sonocapillary effect of UAE will create deep holes that allow solvent to reach this part. This result was in accordance with (Mahindrakar & Rathod, 2022) that showed the lees of *S. cumini* leaves with cracked and porous. It was also formed the deep and distinct holes as the effect of sonication. Another similar result also found in SEM picture of citrus peel surface where the UAE gave intense rupture on cell wall compared with conventional extraction (Khandare et al., 2021).

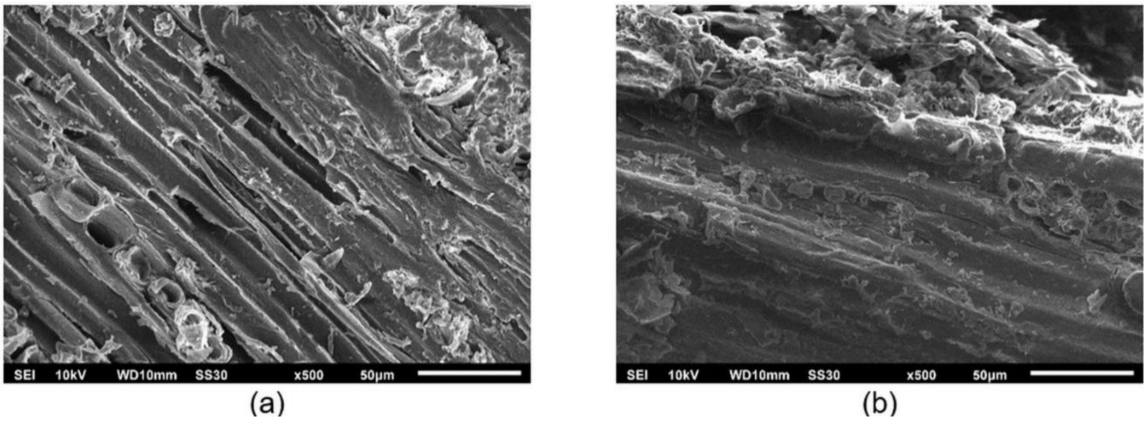


Figure 3. Morphologies of sappan wood surface after extraction for (a). UAE method (U60), (b). Soxhlet method (S60).

3.5 Kinetic studies

Data regarding the TPC of extract varies with time as shown in Figure 4 that shows both the experimental data and also the fitted model of Peleg. The unlined curve resembles the experimental data, while the smooth line represents the Peleg's model. Regarding Figure 4, it can be concluded that the TPC contents in extracts were increasing since the initial time and after reaching the highest point than it decreases. The maximum points were reached at times between 40 and 50 minutes and it showed that equilibrium has been achieved (Zahari et al., 2020). The time needed for the equilibrium state is a bit longer than for thymol extraction from *P. amboinicus* leaves since the equilibrium time was reached at 40 minutes (Zahari et al., 2020), and from *S. cumini* leaves the equilibrium time was reached at 20 minutes (Mahindrakar & Rathod, 2022). The possible reason for this result might be associated with the fact that the material used of sappan was the wood part which is harder in structure and stronger in bonds. Secondary metabolites such as phenolic compound usually are stored in heartwood, which is located inside of the trunk (Arisandi et al., 2019). The equilibrium time needed in UAE was shorter than conventional extraction method which usually varies from 3-6 hours.

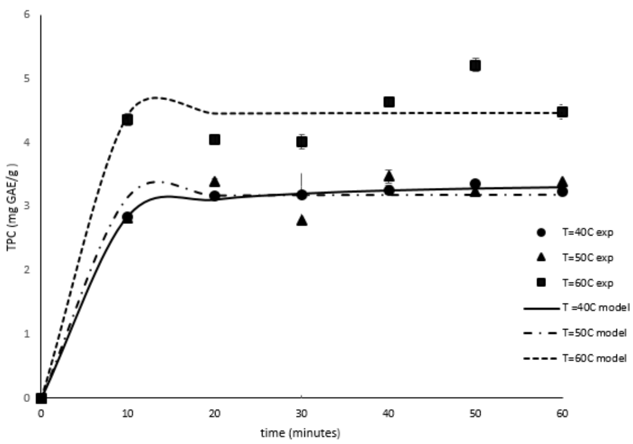


Figure 4. Extraction kinetic studies of total phenolic content from sappan wood.

Temperature plays an important role in the extraction process. The increase in temperature will change the extractant properties and thus affect the solubility of the targeted compound. An increase in temperature will increase vapor pressure and make transient cavitation occurs. This cavitation presents high power and intensity, therefore diffusion of solvent to the matrix happens easily. This will result in a higher extraction yield in a shorter time (Mahindrakar & Rathod, 2022). However, if the temperature increases too highly, although the cavitation bubbles are formed more frequently, the cavitation intensity is lower due to the low pressure difference between the inner and outer bubbles.

The kinetics of extraction shown in Figure 4 shows that extraction is rapid in the first 10 minutes. It correlated with the process mechanism where mass transfer resistance controlled the rate (Milićević et al., 2021). Prolongation time after 40 and 50 minutes does not have a significant effect due to phenolic content already extracted in large amounts. The Peleg's constant was tabulated in Table 2. Constant K_1 is related to B_0 and it relates to initial extraction rate, while K_2 corresponds with C_e or maximum extraction capacity. The K_1 was lower for the lower temperature and increased with the increase in temperature. Temperature can speed up the extraction process and it shows from the constant B_0 which is higher in 50 °C and 60 °C. K_2 is related to maximum extraction capacity and it was shown that a temperature of 60 °C had the highest C_e. Peleg's model was fitted to the data and it can be seen from the R^2 values which were above 0.93 (Milićević et al., 2021) for the three temperatures.

Table 2. Peleg's Constant and Parameter.

Temperature (ºC)	K_1 (min g/mg GAE)	B_0 (mg GAE/g min)	K_2 (g/mg GAE)	C_e (mg GAE/g)	R^2
40	0.5668	1.7641	0.2930	3.4124	0.998
50	0.0351	28.4846	0.3127	3.1975	0.951
60	0.0140	71.4770	0.2237	4.4697	0.946

4 Conclusion

Ultrasound-Assisted Extraction (UAE) increased the yield of extraction for a shorter time, when compared to the 9.67% yield for 180 minutes in the Soxhlet method and 10.33% yield for 20 minutes in UAE. The yield increased with the increase of ethanol content in the solvent mixture. But after 80% ethanol concentration, yield decreased. All the extracts were categorized as high antioxidant material since the IC_{50} points were lower than 50 ppm. FTIR spectroscopy showed that UAE did not change the functional group of the extract, while Scanning Electron Microscope (SEM) picture showed more obvious cracked and deep holes for UAE's surface than the Soxhlet's surface. Peleg's model was suitable to describe the extraction kinetics, where the initial extraction rate and maximum extraction capacity will increase when the temperature increases. Regarding the yield and TPC result, a mixture of ethanol-water with 60% (v/v) ethanol concentration might be the optimum solvent concentration (10.33% and 2.63 mg GAE/g) for UAE of sappan wood.

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