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Kinetics of mace (*Myristicae arillus*) essential oil extraction using microwave assisted hydrodistillation: Effect of microwave power

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ABSTRACT

Mace essential oil extractions were carried out using hydrodistillation (HD) and microwave assisted hydrodistillation (MAHD). The powers used were varied from 300, 600, and 800 W. The amounts of oil from dew resulted from condensation were measured every 1 min. The condensation was done using 12 °C cold water. From the experimental results, MAHD is seen to be superior to HD. The extraction using MAHD at 800 W stopped after 20 min (8.63% yield), while the one using HD stopped after 73 min (7.03% yield). The power used affected the yields of essential oils obtained. From the various powers used, in 10 min, the yields obtained were 2.68, 4.56, 5.41%, in 15 min 4.12, 6.20, 6.83%, and in 20 min 5.13, 7.39, 6.83% at 300, 600, and 800 W, respectively. It can also be seen that time has a significant effect on the essential oil yields obtained. The main components of the essential oil obtained from HD and MAHD were beta pinene, alpha pinene, myristicin, 4-terpineol, and gamma terpinene. The mechanism of mace essential oil mass transfer using HD and MAHD methods was controlled by intra-particle diffusion following the Fick's law. The diffusion coefficient (*De*) of HD was 4.98×10^{-14} m^2/s and the diffusion coefficients of MAHD were 9.17×10^{-14}, 1.39×10^{-13}, and 1.65×10^{-13} m^2/s at 300, 600, and 800 W, respectively. The empirical correlation of diffusion coefficient and MAHD power can be approximated by $De = 3.02 \times 10^{-15} \times P^{0.5985}$.

1. Introduction

Nutmeg is a native plant of Indonesia which can be widely found in Maluku, Sulawesi, Papua, Sumatera, and Java. According to Al-Rawi et al. (2013), it can be used as a natural flavoring, antifungal, traditional medicine, and essential oil. Mace (*Myristicae arillus*), or nutmeg waste, has an essential oil content of 7–18% which still can be recovered, instead of being disposed (Nowak et al., 2016). Mace essential oil contains monoterpenic compounds like alpha pinene, beta pinene, and sabinene. It also contains aromatic compound like myristicin which is categorized as a monoterpene and aromatic compound, and can be used as anti-inflammatory, anti-carcinogenesis, and neuroprotection (Kiyama, 2017). Anti-inflammatory properties of essential oils can be used as topical oils to relieve joints, nerves, and muscles (Al-Rawi et al., 2013). The compounds in mace can be obtained through extraction method (Dupuy et al., 2013).

Extraction of essential oils can be obtained through conventional or non-conventional methods. Conventional method refers to hydrodistillation (HD), while non-conventional method refers to microwave assisted hydrodistillation (MAHD) which uses microwave as the energy source (Moradi et al., 2018). According to Kumar et al. (2017) and Liu et al. (2018), compared to HD, MAHD is an extraction process that requires a short extraction period, low energy source, and is environmentally friendly. The main factor that affects the performance of MAHD is the microwave power and time used during the extraction (Ranitha et al., 2014). The higher the microwave power, the more the yields will be obtained and the less the time will be used. When a great microwave power is used, the operating temperature will be high, so more yields will be obtained in a relatively short period of time (Leonel, 2015). Extraction temperature also affects the chemical compositions of mace essential oil (Fernández et al., 2001). However, according to Megawati and Murniyawati (2015), at the power of 800 W, less essential oil yields were obtained, while at the power of 600 W, more essential oil yields were obtained. The decrease of essential oil yields is possibly caused by the biodegradation of the oil components. This consideration motivates the study of the effect of power in the extraction using MAHD.

In the extraction of essential oils, the mass transfer of oils from solid

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to liquid undergoes 2 phases. The phases are the oil diffusion from inside of the solid particles to the surfaces (diffusion-controlled model) and the mass transfer from the surfaces to solutions (film-controlled mass transfer model). However, in this study, this mechanism will be approached using one phase. This is essential in extractor design and important to be learned (Shakir, 2017). The extraction using HD and MAHD can be approached using intraparticle-diffusion-controlled model, because the solute on the surface of the materials immediately evaporates along with the solvent, so the mass transfer is faster and negligible (Cassel et al., 2009; Ammar et al., 2014). A diffusion process is affected by several factors; such as particle size, particle surface area, and temperature (Cassel and Vargas, 2006). According to Chaiklahan et al. (2014), the higher the extraction temperature, the higher the diffusion will be. Moreover, according to Cassel et al. (2009) the diffusion coefficients in the essential oils extraction of rosemary, basil, and lavender were 4.36×10^{-11}, 5.96×10^{-11}, and 3.32×10^{-11} m^2/s, respectively. These relatively low values also suggest that the intraparticle controls the overall rate of extraction. This research aims to investigate the effect of HD and MAHD methods on mace essential oil yields, compositions, and to develop an extraction kinetics model based on the assumption of diffusion-controlling. Furthermore, in the extraction using MAHD, the effect of power was also investigated. The diffusion process of mace essential oil in solid was approached by Fick's law with the objective that the value of diffusion coefficient (*De*) obtained can be usefull in the design of industrial-scale extraction systems. Finally, the correlation between diffusion coefficient and power was also investigated.

2. Materials and research methods

2.1. Materials preparation

Fresh mace (500 g) was obtained from a jamu store called "DAMI on MT. Haryono (Mataram) street, Semarang. Before being used, the mace was deburred and sieved into 150 mesh size. The solvent used was distilled water obtained from Laboratorium Riset, Chemical Engineering Department of Universitas Negeri Semarang.

2.2. Mace extraction

In this research, the mace essential oil extractions were conducted using HD and MAHD methods with varied microwave powers. The solvent used was 150 and 200 mL and the mace was 30 and 40 g for HD and MAHD methods, respectively. In the extraction using HD, the heating process utilized an energy source from heating mantle EMX 5000 S-CE, while microwae oven (Samsung ME731 K, wavelenght 2450 MHz) was used in the extraction using MAHD.

In HD and MAHD methods, the vapor leaving the extraction chamber containing steam and essential oils was passed through a condensor (Liebig; diameter of 4.1 cm; length of 30 cm; surface area of 15 cm^2) and was then collected in a burrette to measure the essential oil volume obtained. The essential oil volume was observed every 1 min until the essential oil volume practically did not increase. The obtained essential oil was taken using a dropping pipette to measure its density and chemical compounds using Gas Chromatography-Mass Spectrometry (GC–MS). The GC–MS analysis of each sample was carried out on a GC Clarus® 680-MS Clarus® SQ 8 T series GC–MS system (USA). The columns used was an Elite-5MS capillary column (inside diameter of 0.25 mm, with the length of 30 m, the film thickness of 0.25 μm), and the stationary phase of diphenyl dimethyl-polysiloxane. Pure Helium gas (99.999%) was used as the carrier gas with a constant flow rate (1 mL/min). The column temperature was initially programmed at 70 °C and increased at 5 °C/min to 240 °C. Injector and detector temperatures were 250 °C. The ionization energy was 70 eV with a scan time of 0.2 s and a mass range of 50–300 AMU. The management of the GC–MS system, parameter settings for GC and mass spectrometry, and

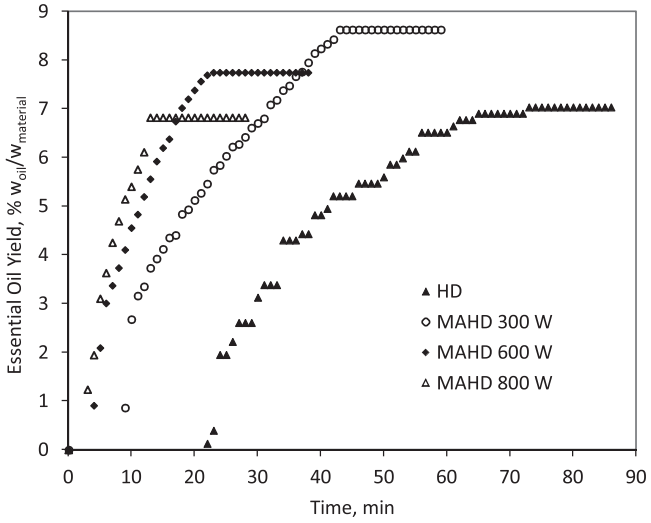

Fig. 1. Extraction yield as a function of time for the hydrodistillation (HD) (under condition: weight of raw material = 30 g, volume of solvent = 150 mL, size of material = 150 mesh) and microwave assisted hydrodistillation (MAHD) of essential oil of mace (under condition: weight of raw material = 40 g, volume of solvent = 200 mL, size of material = 150 mesh).

data receipt and processing were performed using Turbomass GC–MS software (USA). The compounds were identified using two methods. One of the methods was based on a comparison of their mass spectra with data in NIST (National Institute of Standards and Technologies), CAS (Chemical Abstracts Service), TSCA (Toxic Substances Control Act), and EINECS (European Inventory of Existing Commercial Chemical Substances). The other one was by comparison of their retention indices (RI) with those reported in the literature for Elite-5MS column. Diluted samples (1/100 v/v, in ethanol) of 1 μL was injected in the split mode with a split ration 100:1. The relative percentage of the chemical constituents in crude extracts from mace essential oil was expressed as percentage by peak area normalization.

2.3. The extraction kinetic using diffusion-controlled model

The mass balance equation of mace essential oil is written as in Eq. (1). It is assumed that the extracted particles' shape is spherical.

$$\frac{1}{De}\frac{\partial C}{\partial t} = \frac{\partial^2 C}{\partial r^2} + \frac{2}{r}\frac{\partial C}{\partial r} \tag{1}$$

In which C is the concentration of oil at the position of r and time of t. The initial conditions are expressed as follows:

$$C_{(r,0)} = C_0$$

$$C_{(R,t)} = 0$$

Eq. (1) was solved using the method of separation of variables as in Megawati et al. (2013). The analytical solution is as in Eq. (2) and then the integration with respect to position gives the amount of oil remaining in the particle. Finally, the oil fraction (x) can be obtained as in Eq. (3). The value of β (1/min) is defined as in Eq. (4), while n = number of term in the series, De = diffusion coefficient (m^2/min), R = radius of mace, and t = diffusion time (min).

$$C_{(r,t)} = \frac{2C_0R}{\pi}\sum_{n=0}^{n=\sim}\frac{(-1)^n}{n}\frac{sin\left(\frac{n\pi r}{R}\right)}{r}e^{\left(\frac{n\pi}{R}\right)^2 De.t} \tag{2}$$

$$x_{cal} = 1 - \frac{6}{\pi^2}\sum_{n=1}^{n=\sim}\frac{1}{n^2}e^{(-\beta n^2 t)} \tag{3}$$

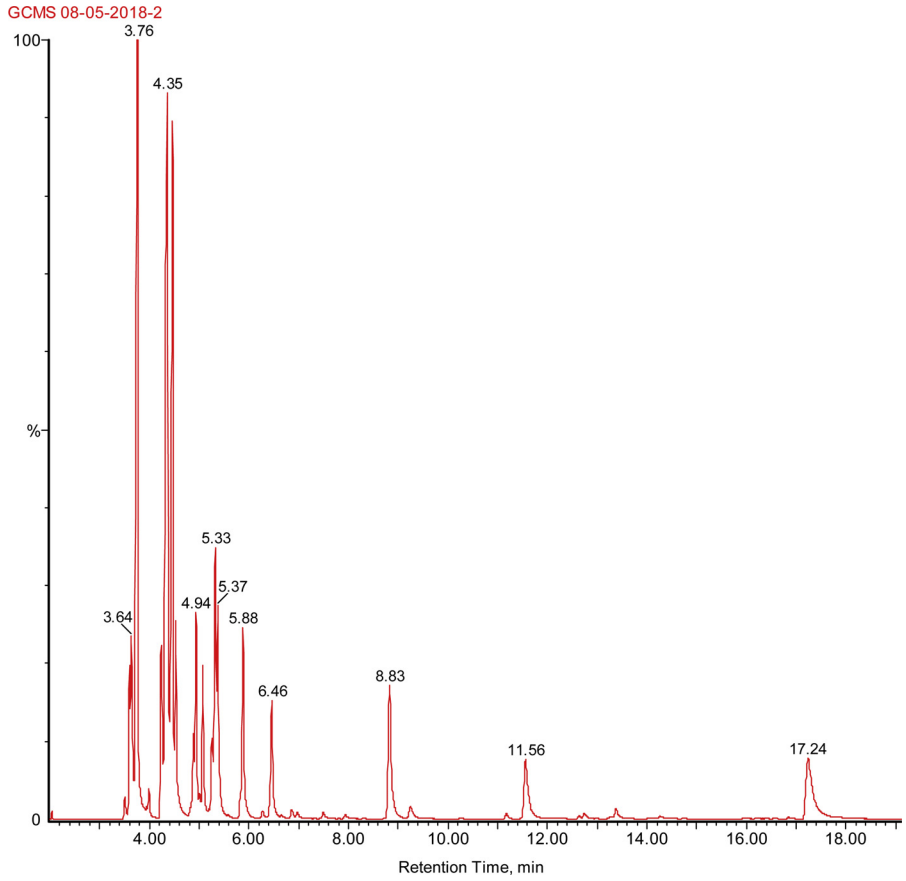

Fig. 2. The chromatography of mace essential using hydrodistillation (HD).

$$\beta = \frac{\pi^2 De}{R^2} \quad (4)$$

In this research, data on oil fraction (x_{data}) will be obtained. The experimental data showed that in a period of initial time, the oil fraction is practically zero. This phenomenon suggests that the diffusion takes place after the wall of cells containing oils have been degraded. The time needed for degradation until the essential oil diffused out for the first time was called t_{deg}. Consequently, in the calculation, the time value (t) must be corrected into t_{data} - t_{deg}. The values of t_{deg} and β were evaluated by trial and error in such a way that the minimum Sum of the Squares of the Errors (SSE) between the calculated and experimental values of oil fraction (x) was obtained. Mathematically, the SSE was defined as in Eq. (5). The computations were conducted using Microsoft Excel.

$$SSE = (x_{data} - x_{cal})^2 \quad (5)$$

Based on the previous discussion, diffusion coefficient (De) is influenced by temperature, or indirectly, by the microwave power applied. In this research, the effect of power on diffusion will be correlated with empirical equation as depicted in Eq. (6), with P = power (W), a and b = constants. The constant values of a and b will be evaluated using curve-fitting method.

$$De = a \, . P^b \quad (6)$$

3. Results and discussion

3.1. Effect of extraction methods on the essential oil efficiency

In Fig. 1, the effect of process on extraction time in HD and MAHD methods was depicted. Mace essential oil extraction using MAHD needed 43 min at 300 W and 13 min at 800 W, while the one using HD needed 73 min. In MAHD method, the extraction time was reduced by 42.85% for 300 W and 82.19% for 800 W. In the research conducted by Moradi et al. (2018), rosemary essential oil extraction using HD method needed 90 min, while the one using MAHD only needed 30 min. In other words, by using MAHD method, the extraction time was reduced by 67%. This indicates that MAHD method is faster than HD method (Megawati and Murniyawati, 2015).

The yields of mace essential oil extractions using HD and MAHD methods were also depicted in Fig. 1. The total yields of mace essential oil extraction using HD method was 7.03%, while MAHD 8.63%. According to Golmakani and Rezaei (2008), the yields of *Thymus vulgaris* L. essential oil extracted using MAHD was greater (2.44%) after 75 min of extraction process, while HD was 2.39% after 240 min. According to Ismiyarto and Muastika (2009), the yield of mace essential oil extraction is in the range of 7–18%. The yield differences in raw material essential oils are influenced by climate, soil fertility, and geography, which affect the composition of the materials used (Saputro et al., 2016). In MAHD method, less energy is required, because the extraction process can be done in a relatively short period of time. In MAHD, the energy used was 756 kJ, while HD 1095 kJ. This is in line with the research conducted by Moradi et al. (2018), which stated that rosemary extraction using MAHD required 324 kJ, while HD 81,000 kJ.

3.2. Effect of different microwave powers on yield

From Fig. 1, it is depicted that power plays and important role in the essential oil yields production. The first phenomenon, in 10 min, the yields obtained at 300, 600, and 800 W were 2.68, 4.56, and 5.41%. It can be concluded that the higher the power, the more the yields obtained will be. The second phenomenon, in 15 min, the yields obtained were 4.12, 6.20, and 6.83%. This result is in line with the research

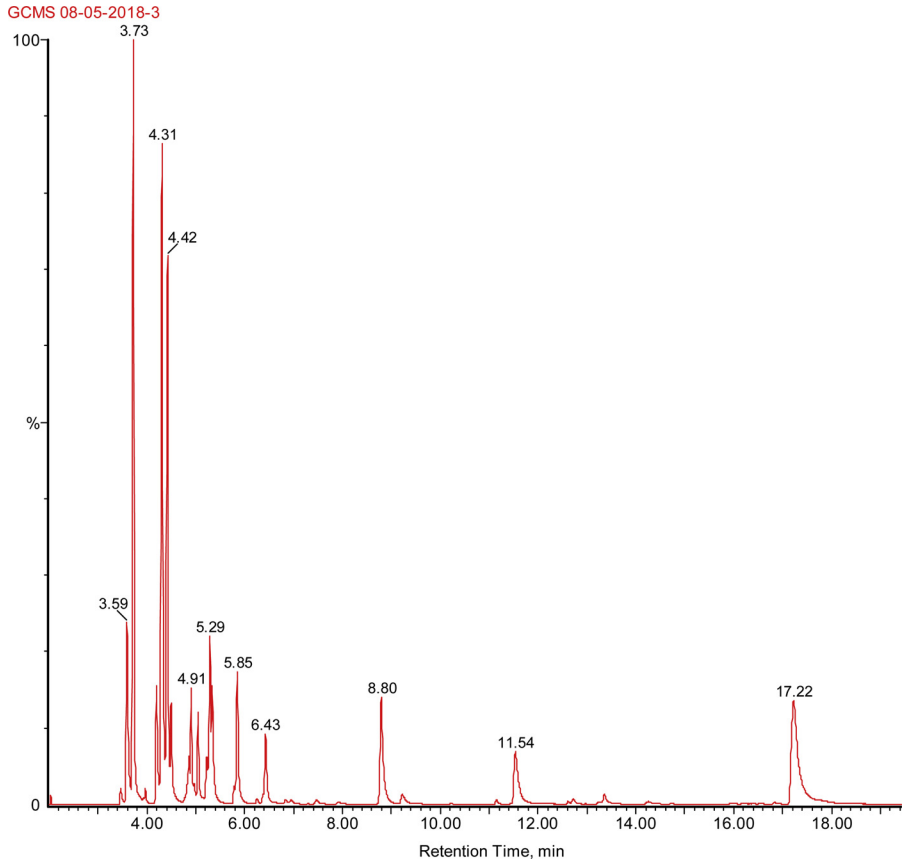

Fig. 3. The chromatography of mace essential oil using microwave assisted hydrodistillation (MAHD) at 300 W.

conducted by Erliyanti and Rosyidah (2017), which stated that frangipani essential oil extractions at 300–600 W, the highest yield was produced at 600 W, as many as 1.16%. The operating temperature increases as the power gets higher. Temperature rises are a result of the materials and solvents' ability to absorb microwave energy. The higher the power, the higher the energy absorbed by the materials will be. The energy absorbed is converted into heat so that more yields will be produced (Leonel, 2015). The last phenomenon, in 20 min, the yields obtained were 5.13, 7.39, and 6.83%. The yield obtained at 800 W was less than the one at 600 W. It is presumed that at 800 W, the more degradation of oil compounds occurs. It can be suspected also that the condensor's surface area (diameter of 4.1 cm, length of 30 cm, surface area of 15 cm^2) was not enough to provide heat transfer area needed for complete condensation. Larger condensors are suggested, such as the liebig condensors with a diameter of 4.1 cm which are longer than the one used in this research (30 cm); they were 40 cm (surface area of 20 cm^2) and 50 cm (surface area of 25 cm^2). In addition, another type of condenser (Graham condenser), can also be considered, because they have a larger surface area.Therefore, at 800 W, the mace essential oil extraction will be better if it is operated using condensors with a diameter of 4.1 cm and length of 40 or 50 cm. Theoretically, a longer condenser presents a greater surface area and longer path length that vapors must get past in order to escape into the atmosphere. Thus, a longer condenser is preferable for a more volatile liquid. Moreover, at 800 W, between 13–20 min, the essential oil obtained was constant (6.83%), whereas at 13 min and 300 and 600 W, the essential oil yield obtained was only 3.74 and 5.56%, respectively. Therefore, at 800 W, after 13 min, lots of the extracted essential oil escaped and there was no more yield. In this condition, Moradi et al. (2018) suggested that extraction using MAHD should be operated quicky using high power otherwise loss of volatile compounds would result.

3.3. Effect of extraction time on yield

From Fig. 1, it can be seen that extraction time also affects the yields obtained from extractions using HD and MAHD methods. The first phenomenon, at 300 W, the first drop of essential oil was obtained at 9 min and the yield kept increasing until 42 min (8.64%). The second, at 600 W, the first drop of essential oil was obtained at 4 min and the yield kept increasing until 22 min (7.75%). The last one, at 800 W, the first drop of essential oil was obtained at 3 min and the yield kept increasing until 13 min (6.83%). These phenomena explains that the longer the extraction time, the more the yields of essential oils will be. However, at a certain time, the yields will be constant. This phenomenon occurs, because the oil amounts in the material become small, while the boiling point increases (Ariyani et al., 2008). A similar research was conducted by Ranitha et al. (2014), at the beginning of the extraction, the yields of lemongrass essential oil increased quickly, but at a certain time, it became slower and became constant. In addition, this phenomenon also occured in the mace extraction using HD, in which in 30–40 min, the yields of mace essential oil increased quickly and after 73 min of extraction process, it became constant.

3.4. Effect of extraction methods on the essential oil compositions

The results of chromatography analysis of the mace essential oil by HD is given in Fig. 2 as well as by MAHD method is given in Figs. 3–5 for power microwave of 300, 600, and 800 W, respectively. Meanwhile, the chemical components for each method are listed in Tables 1–4. The main components of mace essential oil from HD method are beta pinene (57.089%), alpha pinene (22.228%), myristicin (5.386%), gamma terpinene (5.353%), and 4-terpineol (5.157%). However, the main components from MAHD method at 800 W are beta pinene (35.489%), alpha pinene (25.433%), myristicin (8.353%), 4-terpineol (6.757%),

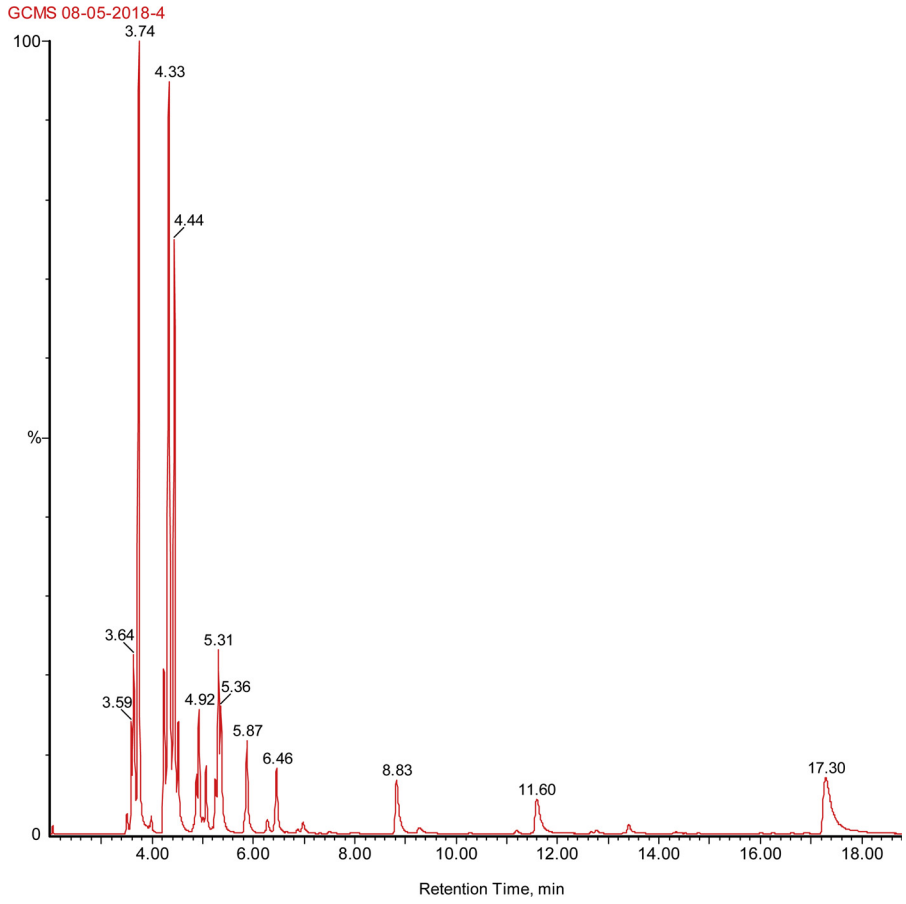

Fig. 4. The chromatography of mace essential oil using microwave assisted hydrodistillation (MAHD) at 600 W.

and gamma terpinene (4.711%). Then, the compositions comparison of the mace essential oil obtained by four methods were depicted in Table 5. As shown in the table, it can be seen that the compositions were qualitatively similar. However, they were quantitatively different. This is caused by the presence of compounds which have undergone oxidation process, hydrolysis, or other chemical reactions (Ranitha et al., 2014). According to Nowak et al. (2016), the main components of mace essential oil are monoterpene hydrocarbons, a few oxygenated monoterpenes, and aromatic compounds. The monoterpene hydrocarbons compounds in mace essential oil are alpha pinene, beta pinene, sabinene, 3-carene, alpha terpinene, limonene, beta phellandrene, gamma terpinene, and alpha terpinolene and the oxygenated monoterpenes is 4-terpineol. Aromatic compounds, according to Kiyama (2017), can be used as anti-inflammatory, anti-carcinogenesis and neuroprotection.

In Table 5, it can be seen that the oxygenated monoterpene and aromatic compounds (myristicin and 4-terpineol, etc.) increased in MAHD method, while the monoterpene hydrocarbons (beta pinene, alpha pinene, gamma terpinene, etc.) decreased. The oxygen content in essential oils produced using MAHD is higher than the one using MD. According to Moradi et al. (2018), scent, taste, and the amount oxygen in essential oils can be used to determine their quality. Oxygenated monoterpenes contribute in to the aroma of essential oils. Therefore, a high amount of oxygen in essential oils produced using MAHD shows a better quality than the ones produced using HD.

3.5. Effect of power on the composition of mace essential oil produced using MAHD

The differences in extraction powers produced different amounts of main components. The powers used will result in temperature rises during the extraction process which causes changes in the composition of essential oils (Liu et al., 2018). From Table 5, it can be seen that mace essential oil extraction at 300 W produced 5 main components; they were beta pinene (34.69%), alpha pinene (18.40%), myristicin (12.12%), menthene (5.74%), and 4-terpineol (5.49%). At 600 W, only three main components were indicated; they were beta pinene (37.59%), alpha pinene (24.01%), and myristicin (12.12%). However, at 800 W, five main components were indicated; they were beta pinene (35.49%), alpha pinene (25.43%), myristicin (8.35%), 4-terpineol (6.76%) and gamma terpinene (4.71%). According to Saputro et al. (2016), the chemical compounds in mace essential oil are alpha pinene (19.77%), beta pinene (14.77%), sabinene (12.77%, and myristicin (13.83%).

Overall, beta pinene was the component that was indicated in all power variations. This component was most commonly found in the oil extraction at 600 W, which was 37.59%. Two other main components indicated in all samples were alpha pinene and myristicin. From five main components, beta pinene, alpha pinene, gamma terpinene, and menthene are categorized as monoterpene hydrocarbons, while 4-terpineol is oxygenated monoterpene and myristicin is an aromatic compound. The high amount of aromatic compound in nutmeg results in its “warm” taste and disctinctive scent. Meanwhile, monoterpenes have antiseptic, anti-inflammatory and anti-toxic properties (Kiyama, 2017).

3.6. Kinetics of mace essential oil extraction

The calculation of oil fraction using series solution was conducted using number of term of $n = 20$, while the average radius of mace powder was taken to be $R = 7.5.10^{-5}$ m. The density (ρ) of the mace essential oil at 300, 600, and 800 W were 0.767, 0.73, and 0.71 g/mL. According to Saputro et al. (2016), the density value of mace essential

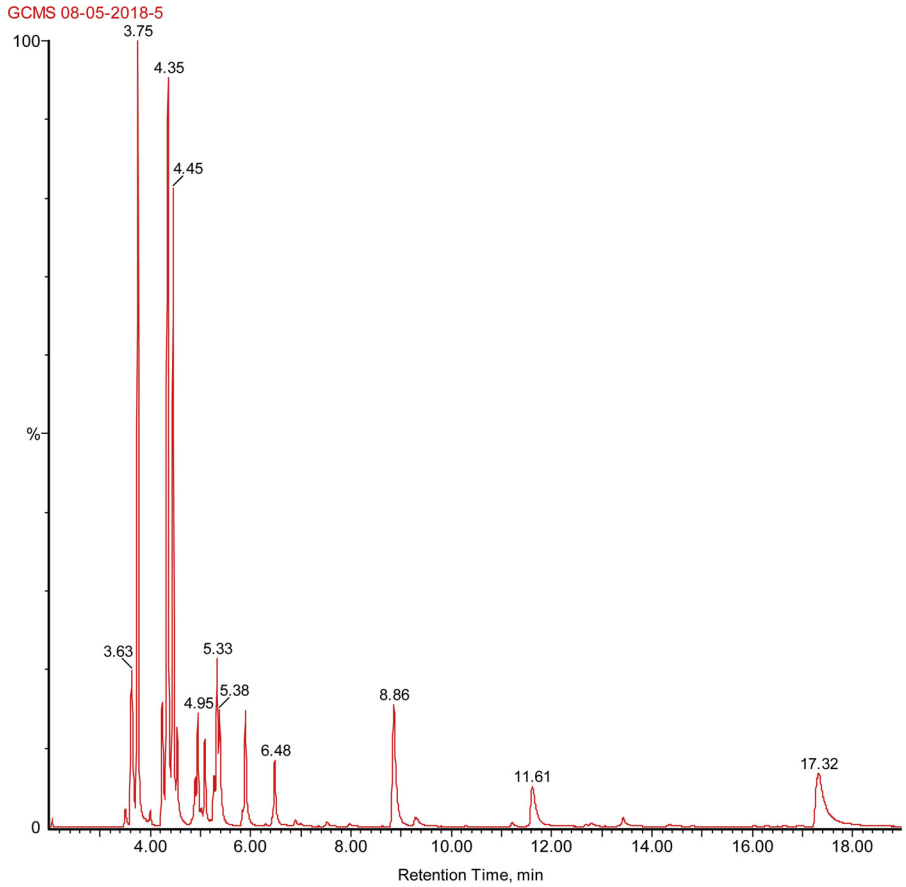

Fig. 5. The chromatography of mace essential oil using microwave assisted hydrodistillation (MAHD) at 800 W.

Table 1
The GC/MS analysis results (%) of mace essential oils extracted using hydrodistillation (HD).

Peaks	Retention Time (min)	Compound	Concentration (%)
1	3.599	3-Menthene	2.304
2	3.639	1R-α-Pinene	3.205
3	3.764	1R-α-Pinene	19.023
4	4.239	Sabinene	3.216
5	4.354	β-Pinene	21.331
6	4.469	β-Pinene	13.619
7	4.534	β-Pinene	2.139
8	4.94	3-Carene	2.567
9	5.075	α-Terpinene	2.487
10	5.33	Limonene	4.795
11	5.375	Phellandrene	2.885
12	5.88	γ-Terpinene	5.353
13	6.46	Terpinolene	3.310
14	8.831	4-Terpineol	5.157
15	11.562	Safrene	3.223
16	17.239	Myristicin	5.386

Table 2
The GC/MS analysis results (%) of mace essential oils extracted using microwave assisted hydrodistillation (MAHD) at 300 W.

Peaks	Retention Time (min)	Compound	Concentration (%)
1	3.589	3-Menthene	5.740
2	3.729	1R-α-Pinene	18.397
3	4.199	Sabinene	3.227
4	4.314	β-Pinene	19.663
5	4.424	β-Pinene	13.322
6	4.499	β-Pinene	1.707
7	4.91	3-Carene	1.912
8	5.045	α-Terpinene	2.092
9	5.29	Limonene	3.468
10	5.34	β-Thujene	2.810
11	5.85	γ-Terpinene	3.449
12	6.43	Terpinolene	2.779
13	8.796	4-Terpineol	5.492
14	11.537	Safrene	3.827
15	17.224	Myristicin	12.115

oil is between 0.70 and 0.90 g/mL. Diffusion-controlled model can describe essential oils extraction mechanism using HD and MAHD methods, as depicted in Fig. 6. The data presented were in the region of increasing yield only, not the constant region. The calculation results showed that the time of cell wall degradation (t_{deg}), in the extraction using HD (22.42 min) was very long compared to the ones using MAHD (2.8–8.24 min). The time of cell wall degradation in essential oil extraction of mace uses MAHD at 300, 600, and 800 W were 8.24, 3.97, and 2.8 min, respectively. These results indicated that microwave degrades oil cell walls faster than conventional heating equipment and the higher the microwave power, the shorter the cell wall degradation time. According to Moradi et al. (2018), higher and lower power of microwave due to high intensity of heating to the mixture and possibility of oil cell degradation and low speed of essential oil extraction was left out.

In addition, the calculation results showed that the diffusion coefficient (*De*) of mace extraction using HD is less than the one using MAHD. Therefore, it can be concluded that mass transfer of mace essential oil extraction using HD is lower than the extraction done using MAHD. In addition, the higher the power used, the higher the diffusion will be (see Table 6). This means that the extraction process will be faster. Moreover, according to Leonel (2015), an extraction process will be done quickly if the temperature used is high. In MAHD, the higher

Table 3
The GC/MS analysis results (%) of mace essential oils extracted using microwave assisted hydrodistillation (MAHD) at 600 W.

Peaks	Retention Time (min)	Compound	Concentration (%)
1	3.594	3-Menthene	1.707
2	3.639	1R-α-Pinene	4.284
3	3.739	1R-α-Pinene	19.728
4	4.234	Sabinene	4.395
5	4.334	β-Pinene	23.754
6	4.444	β-Pinene	13.834
7	4.519	Myrcene	1.731
8	4.925	3-Carene	2.084
9	5.065	α-Terpinene	1.419
10	5.31	Limonene	3.919
11	5.36	β-Thujene	2.374
12	5.87	γ-Terpinene	3.651
13	6.455	Terpinolene	2.541
14	8.831	4-Terpineol	3.123
15	11.597	Safrene	3.048
16	17.304	Myristicin	8.408

Table 4
The GC/MS analysis results (%) of mace essential oils extracted using microwave assisted hydrodistillation (MAHD) at 800 W.

Peaks	Retention Time (min)	Compound	Concentration (%)
1	3.634	1R-α-Pinene	6.056
2	3.749	1R-α-Pinene	19.377
3	4.239	Sabinene	3.235
4	4.354	β-Pinene	21.145
5	4.454	β-Pinene	14.344
6	4.95	3-Carene	1.917
7	5.09	α-Terpinene	1.995
8	5.335	Limonene	3.480
9	5.385	β-Thujene	2.485
10	5.895	γ-Terpinene	4.711
11	6.48	Terpinolene	2.636
12	8.856	4-Terpineol	6.757
13	11.612	Safrene	3.509
14	17.319	Myristicin	8.353

Table 5
Chemical components of mace essential oil extracted using hydrodistillation (HD) and microwave assisted hydrodistillaion (MAHD).

Component	(Concentration, %)			
	HD	MAHD 300 W	MAHD 600 W	MAHD 800 W
3-Menthene	2.304	5.740	1.707	-(173)
1R-α-Pinene (150)	22.228	18.397	24.012	25.433
Sabinene (163)	3.216	3.227	4.395	3.235
β-Pinene (165)	57.089	34.692	37.588	35.489
Myrcene (166)	–	–	1.731	–
3-Carene (170)	2.567	1.912	2.084	1.917
α-Terpinene (173.5)	2.487	2.092	1.419	1.995
Limonene (176)	4.795	3.468	3.919	3.480
β-Thujene (151)	–	2.810	2.374	2.485
Phellandrene (171)	2.885	–	–	–
γ-Terpinene (174)	5.353	3.449	3.651	4.711
Terpinolene (173)	3.310	2.779	2.541	2.636
4-Terpineol (209)	5.157	5.492	3.123	6.757
Safrene (156)	3.223	3.827	3.048	3.509
Myristicin (276)	5.386	12.115	8.408	8.353

the power used, the higher the extraction temperature will be. In a research conducted by Megawati et al. (2013), the extraction of cubeb seeds using MAHD at 800 W resulted in the diffusion coefficient of 2.12×10^{-11} m^2/s. The difference in diffusion coefficient was caused by the materials' properties, density, and porosity.

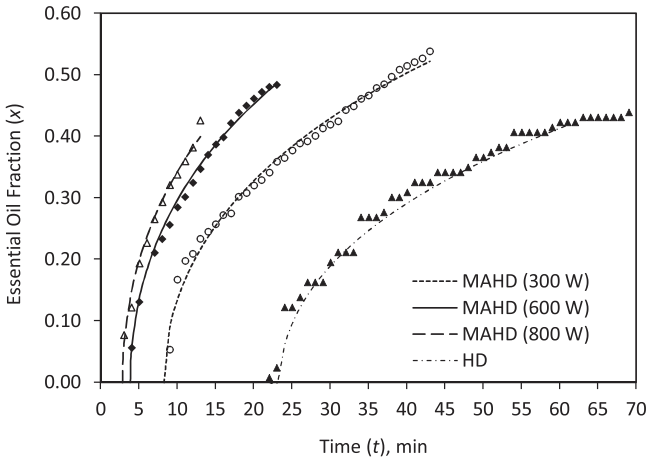

Fig. 6. The comparison of data (symbols) and mace essential oil calculation result (lines) using hydrodistillation (HD) (under condition: weight of raw material = 30 g, volume of solvent = 150 mL, size of material = 150 mesh) and microwave assisted hydrodistillation (MAHD) (under condition: weight of raw material = 40 g, volume of solvent = 200 mL, size of material = 150 mesh).

Table 6
Diffusion coefficient (*De*) and time degradation (t_{deg}) of mace essential oil using hydrodistillation (HD) (under condition: weight of raw material = 30 g, volume of solvent = 150 mL, size of material = 150 mesh) and microwave assisted hydrodistillaion (MAHD) (under condition: weight of raw material = 40 g, volume of solvent = 200 mL, size of material = 150 mesh).

Method	*De* (m^2/sec)	t_{deg} (min)
HD	4.98×10^{-14}	22.42
MAHD 300 W	9.17×10^{-14}	08.24
MAHD 600 W	1.39×10^{-13}	03.87
MAHD 800 W	1.65×10^{-13}	02.80

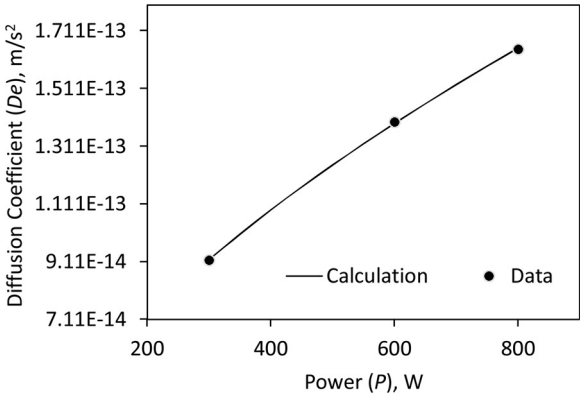

Fig. 7. The correlation between diffusivion coefficient (*De*) of mace essential oil and power (*P*) of microwave oven.

3.7. Correlation between power and diffusion coefficient (De)

Literature study shows that the correlation between power (*P*) used in mace essential oil extraction and diffusion coefficient (*De*) has not been intensively investigated yet. In this research, an empirical correlation between power used and diffusion coefficient was developed. This equation can be applied to estimate the value of *De* at various powers used. The correlation obtained was by $De = 3.02 \times 10^{-15} \times P^{0.5985}$. The goodness of the empirical correlation can be observed in Fig. 7.

4. Conclusions

The extraction of mace essential oil using microwave assisted hydrodistillation (MAHD) is seen to be more efficient than the one done using hydrodistillation (HD). MAHD produced 8.62% essential oils in 42 min, while HD only 7.03% in 73 min. Moreover, MAHD requires less energy (756 kJ) compared to HD (1095 kJ). The higher the power used, the more essential oil yields will be obtained. In 10 min, at 300, 600, and 800 W, the yields obtained were 2.68, 4.56, 5.41%, while in 20 min, the yields obtained were 5.13, 7.39, 6.83%. The main components in the oil obtained using both methods were beta pinene, alpha pinene, myristicin, gamma terpinene, and 4-terpineol. In all power variations used, beta pinene was the most common component. In MAHD, oxygenated monoterpenes and aromatic compound of the mace essential oil were more commonly found compared to HD. The extraction kinetics with diffusion-controlled model can describe the mass transfer of mace extraction well. The diffusivion coefficient (*De*) obtained at 300, 600, and 800 W were 9.17×10^{-14}, 1.39×10^{-13}, and 1.65×10^{-13} m^2/s, respectively. The empirical correlation between diffusion coefficient and power was $De = 3.02 \times 10^{-15} \times P^{0.5985}$.

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