ORIGINAL ARTICLE

Pulsed electric field energy calculation to damage red galangal (*Alpinia purpurata*, K. Scumm) rhizome slices and its essential oil yield and quality with hydrodistillation

Výpočet energie pulzního elektrického pole pro poškození plátků oddenku červeného galgánu (*Alpinia purpurata*, K. Scumm) a výtěžek a kvalita jeho silice při hydrodestilaci

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Summary

This study aimed to determine the amount of energy to damage the red galangal rhizome sliced cell tissue and the amount and quality of the essential oil obtained by steam-water distillation. This study was a randomized block design, with pulsed electric field (PEF) voltage treatment starting at 1000, 2000, 3000, 4000, and 5000 V and without PEF and repeated three times. The results showed that the voltage between 3000 and 4000 V (E = 120–160 V/cm) or equivalent to 271.5–365.0 kJ/cm^3 had damaged the red galangal rhizome slice cell tissue. The increase in yield due to PEF ranged from 13% to 73%, and there was no change in the value of the refractive index and specific gravity, but there was a change in the chemical composition of the essential oil constituents. The benefits of research with PEF treatment are the increase in yield and shorter distillation time.

Key words: galangal rhizome • hydrodistillation • quality • PEF • energy

Souhrn

Cílem této studie bylo stanovit množství energie, která poškodí buněčnou tkáň plátků oddenku červeného galgánu, a množství a kvalitu silice získaného destilací vodní parou. Studie měla randomizovaný blokový design, přičemž ošetření pulzním elektrickým polem (PEF) začínalo napětím 1000, 2000, 3000, 4000 a 5000 V a bez PEF a opakovalo se třikrát. Výsledky ukázaly, že napětí mezi 3000 a 4000 V (E = 120–160 V/cm) nebo ekvivalent 271,5–365,0 kJ/cm^3 poškodilo buněčnou tkáň plátků oddenku červeného galgánu. Zvýšení výtěžnosti v důsledku PEF se pohybovalo od 13 % do 73 % a nedošlo ke změně hodnoty indexu lomu a specifické hmotnosti, ale došlo ke změně chemického složení složek silice. Přínosem výzkumu s ošetřením PEF je zvýšení výtěžku a zkrácení doby destilace.

Klíčová slova: oddenek galgánu • hydrodestilace • kvalita • PEF • energie

Introduction

Pulsed electric field (PEF) as one of the emerging technologies works based on the potential transmembrane and does not cause damage to the existing chemical components because the increase in temperature is only 9–12 °C during exposure[1]. The potential transmembrane affects the ion gate channel on the cell membrane, and if it lasts for a long time, it affects the porosity. When a PEF device applies a voltage for a certain period to a material to damage cell tissue, the PEF requires specific input energy. Specific input energy requirements will increase when the time of application of PEF is also getting longer[2]. According to Walkling-Ribierio et al.[3], as the electric field strength increases and the application time is longer, the requirement of specific input energy is greater which can cause more damage to the cell tissue. The increase in the applied electric field affects the decrease in the energy required to obtain the maximum level of damage[4].

Cell electroporation is intended so that cells are damaged (broken/porous) without damaging the

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bioactive components[5]. Cells are surrounded by an insulating cell wall membrane made of cellulose, whereas the cytosol (cell contents) and extracellular fluid are electrolytes. At high frequencies, the cytosol, which is a macromolecule, initiates a characteristic relaxation process. Impedance occurs in the microwave range where the liquid dipoles show different dispersions so that the cells experience vibrations[6].

The rupture of the cell membrane of the material occurs due to the energy supplied during the PEF pre-treatment. PEF is an alternative technology with low heat energy, so it is called non-thermal pre-treatment[1]. In the process, the PEF uses 220–240 V and 300 W of power that allows the output voltage of the PEF device to increase to 10000 V so that energy can also be increased. The electrical energy generated from the PEF pre-treatment can be analyzed using a specific input energy calculation. The amount of specific input energy PEF depends on several things such as the anode/cathode distance, room dimensions, voltage (electric field strength), and treatment time[7]. The rupture of the cell wall will result in the liquid in the cell coming out and is called electroporation[8]. The application of PEF is very good for maintaining the product's aromatic ingredients, because the heating treatment results in a loss of 22% of the aromatic material, whereas the PEF treatment loses only 3–9%. Other bioactive ingredients also had no effect due to PEF treatment[9]. The application of a PEF device in the industry not only is very efficient but also improves product quality[10].

The extraction of plant bioactive compounds has been reported by many previous researchers using the solid/liquid extraction method. One of the factors that can positively affect the quality and quantity of the extraction results is the level of damage to the cell membrane. Physical, chemical, and biological treatments are used to accelerate the breakdown of cell membranes. PEF is considered a promising method for cellular tissue disruption without affecting the cell components[10]. The specific energy consumption (Q) of plant tissue damage using PEF treatment has been obtained in several studies, usually in the range of 1–15 kJ/kg[11]. Several researchers have previously reported that an amount of 6.4–16.2 kJ/kg is the energy consumption required for potato slice cell tissue[12], 2.5 kJ/kg to damage red beet tissue[13], 3.9 kJ/kg to damage sugar beet tissue[14], and 10 kJ/kg to damage chicory root tissue[15]. The effect of low energy PEF (3–10 J/kg) on the extraction of polyphenols from grape seed has been reported[16]. Specific energy input (Q) has been identified as the main parameter of PEF pre-treatment before the extraction process. Treatment using 32 kJ/kg specific energy for apple juice extraction has been found to increase yield from 71.1% to 76.3%[17]. The specific energy input required for the extraction of the algae suspension (100 g dry weight per kg) is 1 MJ/kg[18]. An increase in the electric field strength (E) results in a decrease in the energy required to induce maximum plant cell tissue damage. The amount of energy received by the material needs to be calculated because it is related to the level of damage and the porosity of the cell wall. The increase in the number of porous cell walls increased the amount of extract obtained.

The application of PEF to determine the integrity of onion cell membranes has been reported by Ersus and Barrett[19], beet tissue cell membrane integrity by Kulshrestha and Sastry[20], apple fruit network by Chalermchat et al.[21] and Bousetta et al.[22], and alfalfa network by Gachovska et al.[4]. The application of PEF before extraction has been widely performed including the extraction of plant bioactive ingredients by Wijngaard et al.[23], orange peel by Lungeo et al.[24], red beet by Loginova et al.[25], mushroom and celery leaf by Kusnadi and Sastry[26], the root of the chicory plant by Loginova et al.[15], chlorophyll extraction of spinach and tomato leaves by Aktas and Yildiz[27], apples by Rawson et al.[28] and Turk et al.[17], and microalgae by Goettel et al.[18]. All of them show a positive influence on the results and the quality of the products obtained. Information to damage red galangal rhizome cell tissue with PEF has not been found so far. Therefore, this research is essential

Fig. 1. Galangal rhizome (a) and Galangal rhizome slices (b)

in science about PEF in tubers, especially galangal rhizomes.

This study aimed to improve the quality and quantity of galangal rhizome essential oil products obtained before distillation, with the finding of the minimum amount of energy required to damage cell membranes[29]. The PEF pre-treatment is expected to reduce energy consumption in the refinery so that production costs to obtain essential oils can be reduced.

Experimental part

Material preparation

Fresh red galangal rhizome was collected from a farmer's garden in Tumpang-Malang Regency, Indonesia with 80 ± 5% water content. Red galangal rhizomes aged 12 months harvested were cleaned of dirt and soil by washing with water and drained (Fig. 1a). Clean rhizomes were sliced 0.5 ± 0.01 cm thick (Fig. 1b).

PEF treatment

The PEF generator is a local product but has been calibrated in a high-voltage laboratory, Faculty of Engineering, Universitas Brawijaya. The PEF generator requires 300 W of electrical power, capable of operating at a voltage of 5 V – 15 kV, frequency 5–15 kHz, and exposure time 5 s – 2 h. The cathode–anode distance can be adjusted from 5 to 40 cm and is made of SS 316 iron with a thickness of 1 mm. The chamber is made of acrylic with a diameter of 12 cm and a thickness of 0.2 mm. The schematic of the PEF tool is presented in Figure 2.

The PEF generator generates an electric field (AC or DC), and the voltage is regulated via a button and detected by a multimeter. The frequency and time of exposure are also set with the desired adjustment knob. Then, the material is placed into the chamber (between the cathode and anode), and the PEF generator is turned on and waited for the specified time. An electric field occurs between the cathode and the anode so that damage/porosity of the cell wall occurs. Furthermore, the material is taken from the chamber and followed by distillation to obtain the essential oil. In this research, DC current was used for the experiment and it carried out as follows: weighed 3000 g of sliced red galangal rhizome in a plastic bag container and then treated with a voltage of 0, 1000, 2000, 3000, 4000, and 5000 V (at a frequency of 5000 Hz, exposure time of 30 min, and cathode/anode distance of 25 cm). Each treatment was repeated three times. It takes 30 min of exposure and 5000 Hz frequency, because based on previous research for materials in the form of sliced rhizomes, the oil results obtained less than 30 min are not optimal.

Microscopic analysis (SEM)

The shape changes of cells in the galangal rhizome slice were observed before and after PEF exposure. Microscopic observations were performed on dry rhizome using a scanning electron microscope (SEM; FEI-Inspect S25-EDAX). Fresh galangal rhizome slices are dried in an oven at 50 °C during 2 × 24 h and transferred to the laboratory. The dry galangal rhizomes were cut 1 × 1 cm and then performed using sputter coating with gold coated SC-2620 (Emitech, France). Other galangal slices after PEF with 3000, 4000, and 5000 V were dried in an oven at 50 °C during 2 × 24 h, transported to the laboratory, and then cut 1 × 1 cm for coating with SC-2620 gold (Emitech). Sample were subsequently observed above.

Input energy calculation

The specific input energy of PEF in kJ/cm^3 (W_{PEF}) is calculated using Equation [1]. It is calculated by multiplication of voltage in V (U), total duration of PEF (t), the resistance of electrode (Rc), and volume chamber (Vc)[29].

$$W_{PEF} = U \times t \times Rc^{-1} \times Vc^{-1} \quad [1]$$

Distillation

Steam-water distillation was performed for 6 h at a temperature of 120 °C and at a pressure of 1.1 bar,

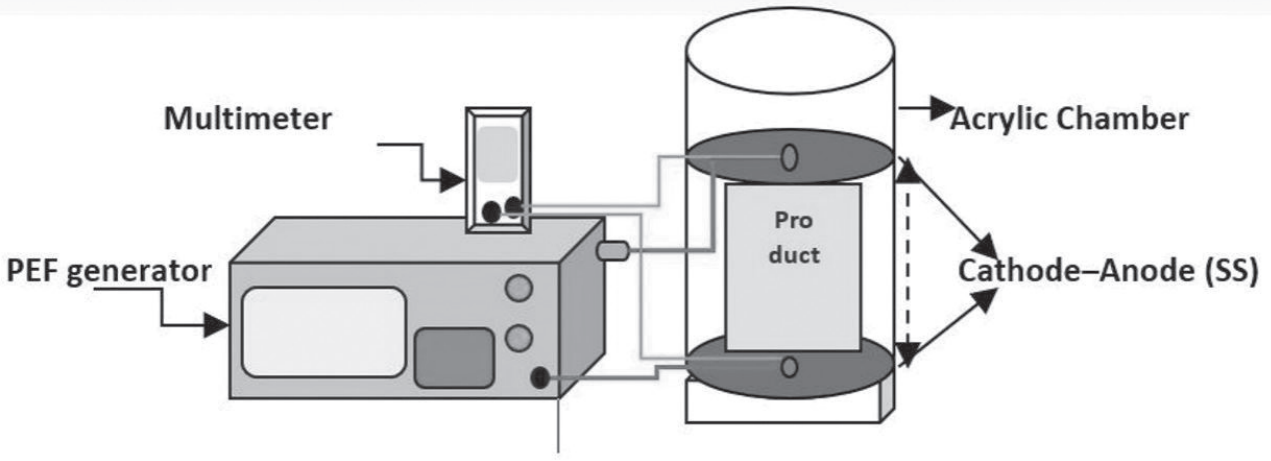

Fig. 2. The PEF generator scheme

and the amount and quality of the galangal essential oil obtained was calculated.

Gas chromatography – Mass spectrometry (GC-MS) analysis

Tests were conducted to determine the phytochemical content of essential oils produced using gas chromatography/mass spectrometry (GC-MS). The analysis was performed by injecting the sample into the instrument with the injection port conditions up to 250 °C, oven temperature up to 60 °C, and increasing periodically to 280 °C. The detector used is a MS with ionization energy of 70 eV, scan mass range (m/z) 28–600, with a detector temperature of 250 °C. The spectrum obtained was matched to the supporting literature. Further identification is carried out by comparing the mass spectra of the tested sample components with a database stored on a computer.

Yield calculation

Samples of raw materials were weighed using an analytical balance and recorded as the weight of the starting material. The results of the final treatment were weighed using an analytical balance and recorded as the weight of the resulting product. The yield of the material can be calculated using the formula as stated in Equation [2][30]:

$$\%\,\text{Yield} = \frac{the weight of the essential oil resulting product(g)}{the weight of matrial(g)} \times 100 \quad [2]$$

Density analysis

Density measurements in essential oils are ideally carried out at a room temperature of ± 20 °C. The following is the procedure for measuring the density of essential oils using a pycnometer based on SNI[30] Equation [3]:

1. Weigh the pycnometer empty and clean.
2. Fill the pycnometer with distilled water then cover it and weigh it.
3. Empty the pycnometer and clean with ethanol.
4. Fill the pycnometer with oil then cover it and weigh it.
5. Determine the density of the essential oil using the following formula:

$$Density = (m2-m)/(m1-m) \quad [3]$$

with:
m – mass pycnometer empty (g),
m1 – mass pycnometer and aquades (g),
m2 – mass pycnometer and essential oil (g).

Refractive index analysis

The determination of the refractive index of essential oils is ideally carried out at a room temperature of 20 °C. The following is the procedure for measuring the density of essential oils using a refractometer[30]:

1. Pour alcohol on the surface of the refractometer prism and wipe with a tissue to make it sterile and clean.
2. Drop the essential oil whose refractive index will be measured on the refractometer prism.
3 Let it stand for a while so that the temperature of the oil and the tool is stable.
4. Read the numbers that appear on the refractometer layer.

Results and discussion

Microstructure of galangal rhizome

The galangal rhizome slices after being treated with PEF were dried in an oven at 50 °C for 2 × 24 h and then analyzed by SEM. SEM test results of slices of galangal rhizome without and with PEF 3000, 4000, and 5000 V are presented in Figure 3 (a, b, c, d). SEM is a type of electron microscope that can be used to identify the shape of nanoparticles of a material[31]. Based on the results of SEM micrographs, samples without PEF have dense cavities and tend to be closed. At 3000 V voltage treatment, the cell cavity began to open and opened maximally at 4000 V voltage treatment. The cell cavity began to be partially closed when the 5000 V treatment was applied, this was because the cell began to experience damage due to high-voltage application. The electric voltage applied to the material can damage the cell wall due to the electric current[31, 32]. The presence of larger cavities in the PEF-treated material is due to electroporation and joining with each other[33].

The PEF treatment between 3000 and 4000 V has reached stage-2 creation of small metastable hydrophilic pores when the transmembrane potential has increased and stage-3 evolution of the pore population changes in pore number and/or size[34]. During the application of electric pulses to the spherical cell, elastic deformation of the membrane occurs that affects the induced transmembrane potential, the dynamics of the pore formation, and the maximum membrane deformation, also maximum pore opening[35].

Plant plasma membranes are more affected with longer pulses than with short pulses[36]. Plant cell walls are composed of cellulose and other materials such as lignin[37]. The cell wall experiences stress and changes in the pores when given a PEF depends on the electric field strength, frequency, and exposure time[23]. The increase in voltage results in the occurrence of gate ion channel on the cell wall increasing to form pores[38].

Energy calculation

Specific energy input is required to damage the cell wall or tissue before the extraction process is performed. There are several techniques to calculate the specific energy input to the material, including using the formula for the minimum energy required to damage the material per unit weight of the sample[39]. Buckow et al.[40] stated that the energy required to solve the sample can be calculated by the specific energy (Q_{spec}). The energy of the PEF treatment is calculated by Equation [1][29]. The data show

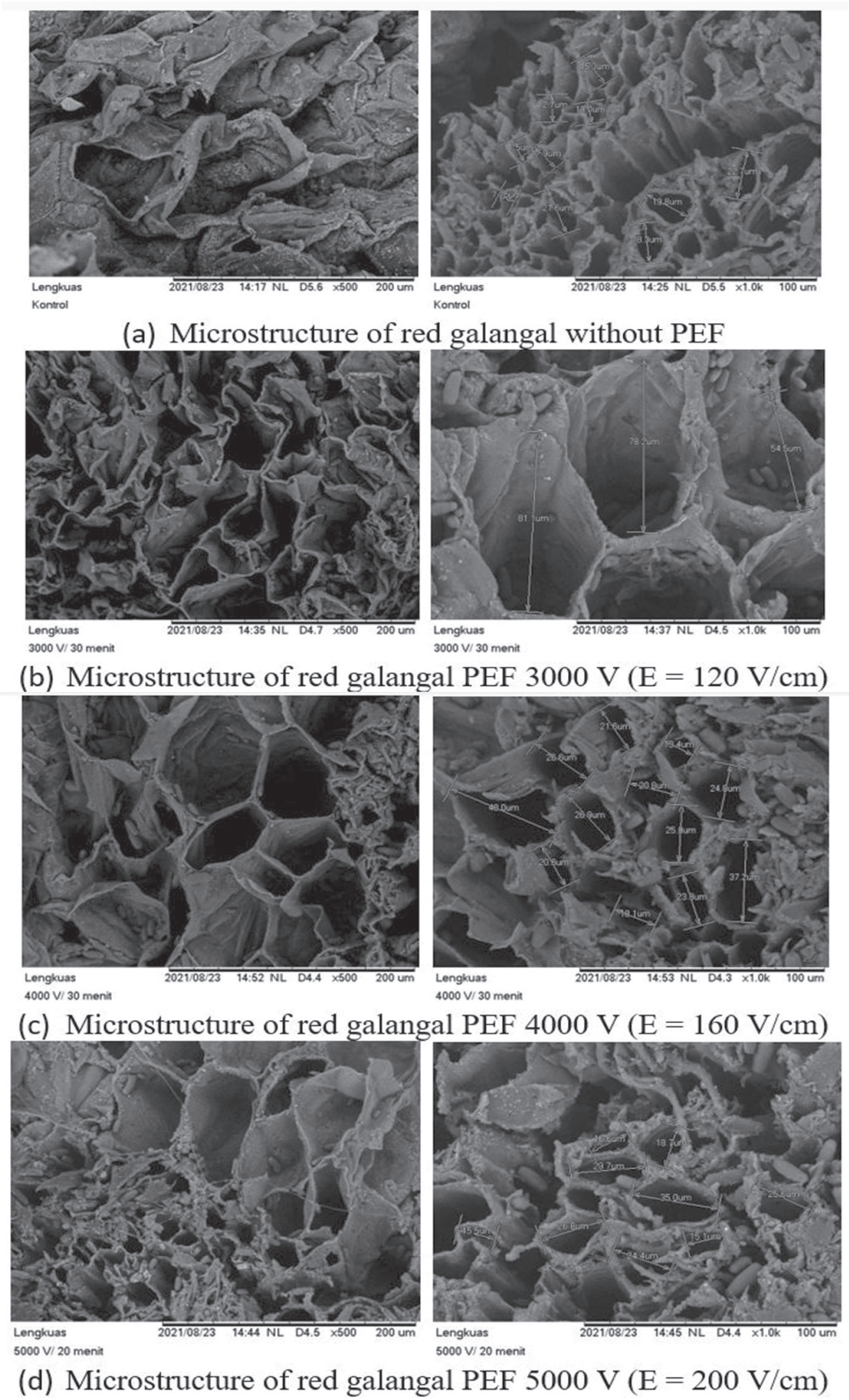

Fig. 3. The microstructure of galangal rhizome

that increasing specific energy input is proportional to the increase in PEF voltage (Table 1).

Based on the calculation of the specific energy input (W_{PEF}) and the results of the SEM analysis of the galangal rhizome slices (Figure 3), it can be seen that the tissue damage appears to be massive starting at a voltage between 3000 and 4000 V or equivalent to 271.5–362.0 kJ/cm^3. The PEF exposure time is 30 min because the material is wet, so the water affects the electric field in the chamber. The amount of specific energy input is based on the energy stored in the capacitor and is influenced by voltage, capacitor storage capacity, frequency, and amount of material[1]. The amount of energy received by the material during PEF treatment is influenced by peak stress, total time, resistance, and chamber volume[29]. The minimum energy required to damage cell tissue is determined by voltage, current strength, number of pulses, duration of modality, exposure time, and material flow velocity[17].

The electric voltage applied to the cell causes pores to form in the cell wall[41]. The increase in stress applied to the material is followed by an increase in the specific energy of the input received[42] so that the gap damage is more massive and the material is easily extracted. Furthermore, it is said that the energy per pulse of the electric circuit element at time t_1 is the power integral for each time. The effectiveness of treatment with PEF technology depends on the intensity of the electric field strength and the total energy applied and the characteristics of biological cells such as morphology, electrical conductivity, and chemical composition[43].

The increasing electric field strength and the length of time of the application of PEF are followed by the greater the specific input energy required, resulting in more cell damage[3]. The increase in the applied electric field affects the decrease in the energy required to obtain the maximum level of damage[4]. The greater the specific energy input, the greater the exposure time and the PEF electric field strength.

The higher the applied voltage followed the higher the electric field strength produced, and the processing time can be reduced[2]. Extraction of rose oil obtained an increase of 46% and reduced distillation time with optimal input energy of 10 kJ/kg material[44]. The PEF with an energy of 100 kJ/kg and electric field strength (E) of 5 kV/cm on *Arabidopsis thaliana* cell walls has experienced porosity[45]. Experimental study of the effect of low energy pulsed electric charges (3–10 J/kg) on the extraction of grape seed polyphenols has been carried out by Boussetta et al.[46]. The electric field strength shows a threshold effect, whereas the specific energy input can be applied as a dose parameter. It depends on the type of application and the specific energy input required, and the permeabilization of plant tissue is in the range of 5–10 kJ/kg[47]. The energy requirement for pressing potato slices is 7.5 kJ/kg materials, and the application of PEF before pressing potato slices is more effective than that of pressing without PEF[48]. The amount of specific energy input to damage the cell depends on the cathode–anode distance and the dimensions of the chamber[40]. Damage to the apple slice tissue requires an electric field of 900 V/cm, and the damage to the apple slice tissue is irreversible[21].

Essential oil yield and quality

Damage to the membrane minimizes the energy required to remove the material from the cell so that extraction is efficient, which in turn can increase extraction and obtain large amounts of oil[49]. Red galangal essential oil is an essential oil that can be

Table 1. The energy-specific input

No.	Voltages (V)	Energy (kJ/cm^3)
1.	0	0
2.	1000	90.50431
3.	2000	181.0086
4.	3000	271.5129
5.	4000	362.0172
6.	5000	452.5216

Table 2. Yield, density, and refractive index of red galangal essential oil

PEF treatment	Yield (%)	Density (g/ml)	Refractive index (%)
Control	0.300	0.8682	1.4779
1000 V	0.310	0.8777	1.4783
2000 V	0.317	0.8873	1.4806
3000 V	0.340	0.8812	1.4753
4000 V	0.520	0.8879	1.4824
5000 V	0.410	0.8853	1.4788

obtained from the distillation of red galangal flowers, stems, and leaves[50]. According to Damayanti et al.[51], the demand for red galangal essential oil in the market is very high, because it can be used in aromatherapy.

The compounds in the essential oil of red galangal (*Alpinia purpurata*, K. Schum) consist of 1,8-cineole (40.92%), acetyl chavicol (10.33%), cis β-farnesene (6.91%), l-cayophilene (6.32%), 1-β-bisabolene (3.37%), β-elemene (3.23%), α-pinene (3.20%), β-sesquiphellandrene (2.32%), β-pinene (2.21%), germacrene D (1.90%)[52], and the rest d-pinene, galangin, and eugenol as the cause of the spicy taste of galangal[53]. Cineol (1,8-cineole) is a naturally occurring monoterpene, also known as eucalyptol. This compound is one of the main compounds in many plant essential oils. Cineol has been shown to have therapeutic benefits in inflammatory airway diseases, such as asthma and chronic obstructive pulmonary disease[54].

Table 2 shows that the average yield of red galangal essential oil ranges from 0.30% to 0.52%. The highest yield was obtained at a 4000 V voltage treatment of 0.52%. The lowest yield was obtained at a 1000 V voltage treatment of 0.30%, this is similar to the research of Yajun et al.[55]. This event is due to the potential difference between the inside and the outside of the cell membrane that becomes larger due to electrostatic forces disintegrating organelles and cellular structures and an increase in the release of volatile substances in the material[56]. The intensity of the stress applied to the material that is too large will harm the distillation results, one of which is a decrease in yield[57]. The application of the PEF method as a pre-treatment in the extraction process is very good for the industry[11].

Refractive index measurements were carried out to identify the purity of the oil[58]. The higher the refractive index, the better the oil quality[59]. There was no significant difference between the value of the refractive index and specific gravity between no PEF and PEF treatment; however, there was a slight increase in PEF treatment (Table 2). The more long-chain components such as sesquiterpenes or functional groups that contain oxygen, the more difficult the incoming light will be to refract[60]. Pre-treatment of PEF with higher voltage shows a decrease in the refractive index[61]. Pre-treatment of PEF with higher voltage can cause the pores of the cell membrane to open so that the oil is extracted more optimally and produces a higher refractive index[62].

The density of essential oils is one of the benchmarks that can be used as a measure of quality[63]. According to Ospina et al.[64], the density of essential oils is related to the composition of compounds contained in the oil itself. The average density of red galangal essential oil ranged from 0.8682 to 0.8879 g/ml. The highest density was obtained at a 4000 V treatment of 0.8879 g/ml. The lowest density was obtained in the control treatment of 0.8682 g/ml (Table 2).

Pre-treatment of PEF with higher voltage can cause the pores of the cell membrane to open so that the oil is extracted more optimally and produces a higher refractive index[62]. However, in this study, it showed a decrease in the refractive index at 5000 V treatment that could be due to the cell membrane having been severely damaged so that volatile compounds were lost and produced oil and the density was smaller than 4000 V. The results of the test with GC-MS obtained several chemical components in the distillation of galangal oil without PEF (control), PEF 1000 V, PEF 2000 V, PEF 3000 V, PEF 4000 V, and PEF 5000 V and based on 20 chemical components that have an average % area above 1%, as presented in Table 3.

GC-MS analysis

The application of PEF to biological cells resulted in electroporation of the cell wall membrane and increased cell wall permeability and facilitated the release of intracellular compounds[65]. The degree of disintegration of the cell wall appears to be highly dependent on the PEF exposure time and the electric field strength (E). At long PEF exposure times, a smaller electric field is required, as is the effect of pulse duration on PEF efficiency in sugar beet[11]. The change of the chemical component of essential oil with PEF treatment of the galangal rhizome is presented in Table 3.

The percentage of the macro component of patchouli oil decreased, but the micro component increased, this indicates an increase in quantity due to PEF treatment in patchouli oil extraction. Changes in the chemical components of patchouli essential oil also occurred due to the electrochemical reaction, namely isomerization, resulting in a decrease in macro components and an increase in micro components[66]. Judging from the composition of volatile compounds, PEF is a technology to improve the quality of aromatic compounds[7]. Boussetta et al.[46] stated that the PEF treatment is influenced by several operating parameters such as the duration and strength of the electric field. The results of Garde-Cerdan et al.[67] showed that the effect of applying PEF differed depending on the plant variety, but the aromatic profile of the studied material was not affected in any way at low electric fields. PEF increases antioxidant activity due to the formation of derivative compounds[68].

Pataro et al.[69] stated that the PEF pre-treatment of tomato peels at a field strength of 0.5–5 kV/cm (specific energy input 0.5–20 kJ/kg) reveals that lycopene is the main carotenoid extracted and there is no degradation/isomerization phenomenon. Isomerization is a process of changing the configuration of atoms or groups of atoms in space. In complex compounds, isomerism occurs in complexes with a structure of two substituents or two kinds of ligands. Substituents can be located next to or opposite each other. If the substituent groups are located next to each other, then the isomer is a Cis isomer; otherwise, if the substituents are opposite each other, the isomer that occurs is a Trans isomer. PEF affects the VIT-C conformation, which induces the VIT-C isomer

to change the enol form to the keto form. In addition, PEF treatment did not damage VIT-C[70].

The application of a pulsed electric field (PEF) at high voltages tended to change the amount of several components of the volatile oil compounds (Table 3). Changes in the chemical components of red galangal rhizome oil due to the application of PEF occurred at the application of energy above 90 kJ/cm^3. Previous researchers showed that the application of PEF with an energy of 20 kJ/kg on herbal plants resulted in the instability of the material so it required lower energy. The application of 10 kJ/kg energy obtained aroma and chemical composition of essential oils better than 20 kJ/kg[71]. The application of PEF with an energy of 10 kJ/kg and 20 kJ/kg and a distillation time of 0.5 h to 2.5 h, also resulted in changes in the yield and chemical components of rose flower oil[72].

In addition, the application of PEF to essential oils will influence the quality of the oil. This is an important

Table 3. Chemical component of red galangal essential oil and its changes after PEF treatment

No	Control (non-PEF)		PEF 1000 V		PEF 2000 V	
	Component	**% area**	**Component**	**% area**	**Component**	**% area**
1	Eucalyptol	27.35	Eucalyptol	27.35	Eucalyptol	15.86
2	β-Farnesene	11.64	β-Myrcene	18.18	Alloaromadendrene	7.40
3	β-Pinene	8.70	β-Pinene	8.70	Phenol, 4-(2-propenyl)-, acetate	6.62
4	Chavicol	6.40	β-Farnesene	11.64	β-Pinene	5.86
5	Terpinene-4-ol	4.31	Phenol, 4-(2-propenyl), acetate	6.39	α-Cadinol	5.76
6	Cis-Ocimene	4.01	3-Cyclohexen-1-ol, 4-methyl-1-(1-methylethyl)	4.31	(1R,2S,6S,7S,8S)-8-Isopropyl-1-methyl-3-methylenetricyclo [4.4.0.02,7]decane	5.19
7	Germacrene D	3.51	Cis-Ocimene	4.01	Caryophyllene	4.64
8	Caryophyllene	3.20	Germacrene D	3.32	Cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, [1S-(1. alpha.,2.beta.,4.beta.)]-	4.12
9	Nerolidol	3.03	Caryophyllene	3.20	Octadecane, 1-chloro-	3.02
10	β-Elemene	2.98	Cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, [1S-(1alpha, 2beta,4. beta)]	2.98	1-Isopropyl-4,7-dimethyl-1,2,3,5,6,8a-hexahydronaphthalene	2.95
11	α-Terpineol	2.70	α-Terpineol	2.69	3-Cyclohexen-1-ol, 4-methyl-1-(1-methylethyl)-, (R)-	2.44
12	Globulol	2.45	Globulol	2.45	(1R)-2,6,6-Trimethylbicyclo[3.1.1] hept-2-ene	2.31
13	Methyl eugenol	2.13	Benzene, 1,2-dimethoxy-4-(2-propenyl)- (CAS)	2.13	τ-Muurolol	2.07
14	γ-Terpinene	1.93	Bicyclo [3.1.0] Hexane, 4-Methylene-	1.71	L-α-Terpineol	1.95
15	β-Myrcene	1.82	Nerolidol A (Cis or Trans)	1.54	cis-α-Bergamotene	1.88
16	Sabinene	1.71	Phenol, 2-methoxy-4-(1-propenyl)- (CAS)	1.51	2,6,10-Dodeca trien-1-ol, 3,7,11-trimethyl-, acetate, (E,E)-	1.79
17	Isoeugenol	1.51	Nerolidol	1.49	β-Bisabolene	1.61
18	Patchouli alcohol	1.39	Patchouli alcohol	1.39	γ-Terpinene	1.44
19	β-Cedrene	1.14	1,4-Cyclohexa diene,1Methyl-4	1.32	Methyleugenol	1.44
20	Torreyol	1.08	β-Cedrene (CAS)	1.14	β-Myrcene	1.02

criterion since the atomic chains C_{14} to C_{24} are sensitive to energy above 10 kJ/kg[72]. The change in eucalyptol composition was affected by the application of high voltages. The quality of essential oils followed the trend of changing yields. At the energy input of 10 kJ/kg and 20 kJ/kg, the amount of distilled components according to their volatility also differs[66]. The essential oils obtained from the PEF treatment with energy less than 10 kJ/kg tended to have the same trend in the values of the chemical components[73]. The investigated compound of *A. purpurata* rhizome oil showed a significant difference (Table 3) at the application of energy above 90 kJ/cm^3. Despite the differences in the structure of the chemical profile of *A. purpurata*, the changes in chemical components of *A. purpurata* oil had the same tendency to increase. It was consistent with the application of PEF to roses (*Rosa alba* L.)[73].

PEF 3000 V		PEF 4000 V		PEF 5000 V	
Component	**% area**	**Component**	**% area**	**Component**	**% area**
Eucalyptol	29.03	Chavicol	9.04	Eucalyptol	12.21
α-Terpineol	14.18	Eucalyptol	8.99	Chavicol	9.84
Terpinene-4-ol	11.12	β-Farnesene	8.67	β-Farnesene	6.71
Chavicol	8.88	α-Cadinol	7.85	α-Cadinol	6.68
β-Pinene	7.89	β-Copaene	6.52	Caryophyllene	6.01
γ-Terpinene	2.77	Caryophyllene	5.77	Cadina-1(6),4-diene	5.13
γ-Elemene	2.63	Cadina-1(6),4-diene	5.24	β-Elemene	4.47
Diacetone alcohol	2.47	β-Elemene	4.89	β-Copaene	4.45
α-Pinene	2.33	γ-Elemene	4.73	α-Terpineol	3.97
trans-Isopiperitenol	2.17	α-Terpineol	3.74	Terpinene-4-ol	3.59
trans-Carveol	1.78	Terpinene-4-ol	3.19	1-Chloroocta decane	3.56
Isoterpinolene	1.66	Methyleugenol	2.84	β-Pinene	3.43
β-Myrcene	1.63	cis-α-Bergamotene	2.39	Methyleugenol	3.13
α-Terpinene	1.49	α-Farnesene	2.12	cis-α-Bergamotene	2.03
Carveol	1.45	β-Pinene	2.06	β-Bisabolene	1.93
trans-Sabinyl acetate	1.34	Farnesyl butanoate	2.02	Farnesyl butanoate	1.81
cis-p-Mentha-2,8-dien-1-ol	0.82	Globulol	1.83	Dihydrogalangal acetate	1.79
Fenchol	0.74	Bis(2-Ethylhexyl) phthalate	1.60	Bis(2-Ethylhexyl) phthalate	1.50
α-Phellandrene	0.71	Dihydrogalangal acetate	1.37	Spathulenol	1.41
Linalool	0.64	α-Bisabolol	1.28	Junenol	1.40

The main components in essential oils are monoterpenes that act as taste and odor givers where monoterpenoids, sesquiterpenoids, diterpenoids, triterpenoids, tetraterpenoids, and polyterpenoids are part of terpenoid compounds (one of the secondary metabolites). The characteristics of monoterpenes and sesquiterpenes are volatile, diterpene compounds are less volatile, and triterpenes are non-volatile[74]. The main compounds contained in each treatment have differences. Eucalyptol, chavicol, α-terpineol, terpinene-4-ol, and β-pinene compounds are monoterpenes. Meanwhile, β-farnesene, α-cadinol, caryophyllene, and β-copaene compounds are classified as sesquiterpene compounds.

Based on Table 3, there are five main compound components contained in red galangal essential oil without PEF pre-treatment: eucalyptol 27.35%, β-farnesene 11.64%, β-pinene 8.70%, chavicol 6.40%, and terpinene-4-ol 4.31%. Treatment of PEF 1000 V contained five main compounds: eucalyptol 27.35%, β-myrcene 11.64%, β-pinene 8.70%, β-farnesene and phenol, 4-(2-propenyl) 6.40%, and phenol, 4-(2-propenyl)-acetate 4.31%. The 2000 V treatment contained five main compound components: eucalyptol 15.86%, alloaromadendrene 7.40%, phenol, 4-(2-propenyl)-, acetate 6.62%, β-pinene 5.86%, and α-cadinol 5.76%. At the 3000 V treatment, there are five main compounds: eucalyptol 29.03%, α-terpineol 14.18%, terpinene-4-ol 11.12%, chavicol 8.88%, and β-pinene 7.89%. At the 4000 V treatment, there were five main compounds: chavicol 9.04%, eucalyptol 8.99%, β-farnesene 8.67%, α-cadinol 7.85%, and β-copaene 6.52%. In the 5000 V treatment, there were five main compounds: eucalyptol 12.21%, chavicol 9.84%, β-farnesene 6.71%, α-cadinol 6.68%, and caryophyllene 6.01%. GC-MS analysis of *A. purpurata* essential oil revealed the presence of 42 essential oil components with -pinene, and -caryophyllene being the main constituents[75]. The *A. purpurata* extracted by chloroform contained an unstable lambda diterpene, lambda-8[17], 12-diene-15, 16-dial, and alkaloid piperine[76]. Based on the results, the application of PEF at 4000 V or 362 kJ/cm^3 energy could change the volatile compound of essential oil. It decreased the yields due to the evaporation of the volatile compounds during distillation. The decreased volatile compound in *A. purpurata* extract could be avoided by applying PEF in the energy range of 100–200 kJ/cm^3. The quality of *A. purpurata* essential oil was determined by volatile compounds such as terpene alcohol (terpineol) which determine the aromatic properties of essential oil. There is a wealth of scientific evidence supporting the wide application of galangal in food and its medicinal properties, such as antiviral, cardiovascular, and neuroprotective properties, along with preclinical and clinical studies with galangal bioactive compounds[77].

Conclusion

The conclusion that can be conveyed in this study is that the PEF treatment of red galangal rhizome slices can damage cell tissue at a voltage between 3000 and 4000 V or equivalent to 271.5–365.0 kJ/cm^3. Essential oil yield increased between 13% and 73% compared to no PEF treatment, so it is very prospective to be developed. There was no significant change in the density and refractive index of essential oils produced without PEF compared to PEF treatment. There was a decrease in the amount of some chemical components that make up essential oils, but most of them increased in the number of components and even formed or there were new components that were also distilled by PEF treatment. In the future, the application of PEF is very good for obtaining high yields; however, it is necessary to find the optimum conditions so that no changes in chemical components occur.

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