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Research Article

WOUND HEALING POTENTIAL OF *ZINGIBER OFFICINALE* ESSENTIAL OIL

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ABSTRACT

Objectives: The purpose of this study was to evaluate *in vitro* wound healing activity through antioxidant, antibacterial, and fibroblast cell proliferation and migration capabilities of *Zingiber officinale* essential oil (ZEO), as well as to identify its metabolite profile.

Methods: Extraction of essential oil using the hydrodistillation method. Metabolite profile was analyzed using the gas chromatography-mass spectrometry (GC-MS) technique. *In vitro* wound healing activity was evaluated through fibroblast cell proliferation and the fibroblast cell migration using the scratch assay. The antibacterial activity was assessed using the microdilution method against six wound-infecting bacteria, while the ABTS method measured antioxidant activity.

Results: The GC-MS analysis showed citral (15.1%), camphene (14.9%), Z-citral (10.8%), and 1,8-cineole (8.0%) as major compounds. ZEO showed low antioxidant activity (IC50 >250 µg/mL). The antibacterial activity results showed the lowest minimum inhibitory concentration value and minimum bactericidal concentration value against methicillin-resistant *Staphylococcus aureus* at 16 µg/mL. ZEO increased fibroblast cell proliferation to 120% of the control value at a concentration of 1 µg/mL and improved wound closure by 80.52% after 48 h of incubation time at a concentration of 0.1 µg/mL. ZEO has the potential to be utilized as an alternative natural source for wound healing due to its antibacterial effects and ability to stimulate fibroblast cell proliferation and migration.

Keywords: Essential oil, *Zingiber officinale*, Fibroblast cell, Antioxidant, Antibacterial.

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INTRODUCTION

Acute and chronic wound management remains a global challenge [1]. The wound healing process involves hemostasis, inflammation, proliferation, and remodeling. However, high-level oxidative stress and pathogenic bacterial infections can disrupt the healing process, leading to persistent wounds that are challenging to heal [2]. The most frequently found bacterial species infected chronic wound including *Staphylococcus aureus* (SA) (37%), *Pseudomonas aeruginosa* (17%), *Proteus mirabilis* (PM) (10%), *Escherichia coli* (EC) (6%), and *Corynebacterium* spp. (5%) [3]. Current treatment limitations may include increasing risk of antimicrobial resistance in long-term use and the high cost of treatment. This situation encourages the search for new therapeutic alternatives from natural sources that are safer, effective, affordable, and have a dual effect as antibacterial and stimulation of tissue regeneration [4].

Indonesia is rich in natural ingredients from medicinal plants, such as essential oils, whose potential has not been fully explored. Essential oils contain secondary metabolites, including terpenoids (monoterpenes and sesquiterpenes), with aromatic phenolic groups, terpenic ketones, and alcohols showing significant antibacterial, antifungal, and antioxidant effects [5]. The antioxidant capabilities of essential oils can neutralize reactive oxygen species (ROS), shielding tissues against damage caused by oxidative stress. Excessive ROS at the wound site causes cell damage, inhibits cell proliferation, and prolongs the inflammatory phase [6].

Zingiber officinale var. Amarum rhizomes produce essential oils. This species is also known as small ginger. Previous studies on *Z. officinale* rhizome essential oil reported that the essential oil had antioxidant, anti-inflammatory, and antimicrobial activity [7,8]. Another study reported weak antioxidant activity of small ginger [9]. Although many studies have reported regarding antimicrobial and antioxidant activity of *Z. officinale* essential oil, the study focused on the utilization of essential oils derived from this rhizome for wound healing, particularly on fibroblast cell proliferation and migration, remains limited. Therefore, this study aimed to evaluate *in vitro* wound healing activity through antioxidant, antibacterial, and fibroblast cell proliferation and migration capabilities of *Z. officinale* essential oil (ZEO) as well as to identify its metabolite profile.

METHODS

Plant collection

Rhizomes of *Z. officinale* var. Amarum were collected from Padang City, West Sumatra, Indonesia. The rhizomes were sent to Botanist Dr. Nurainas for identification at the Andalas Herbarium, Faculty of Mathematics and Natural Sciences, Andalas University, Padang.

Essential oil extraction

About 10 kg of fresh rhizomes of *Z. officinale* var. Amarum was washed thoroughly. Then, clean rhizomes were cut and extracted by the hydrodistillation method for 6 h. The essential oil was added to anhydrous sodium sulfate to remove the remaining water. The oil was then stored at 4°C until it was used. The characterization of the essential oil was determined, including yield, specific gravity, refractive index, and color.

Essential oil analysis using gas chromatography-mass spectrometry (GC-MS)

Essential oil analysis was performed using GC-MS (Shimadzu GC-MS-QP 2010 SE) and RTX1 column. The GC-MS conditions were set as previously reported in a published article [10]. Compounds were identified using the "WILEY library." The percentage similarity index

was considered to determine compounds with an acceptable value of more than 90%. Furthermore, the fragmentation pattern of each peak was compared with patterns from earlier articles and the National Institute of Standards and Technology Chemistry Webbook.

Antioxidant activity

ABTS solution (7 mM) was mixed with potassium persulfate solution (2.45 mM) and incubated for 16 h at room temperature under dark conditions. The ABTS radical solution formed was then diluted to reach an absorbance value of about 0.70±0.02 at a wavelength of 734 nm. From the 10,000 µg/mL stock solution, a test solution was prepared ranging from 250 to 3.907 µg/mL. Each well of the 96-well plate was filled with 100 µL of the test solution and 100 µL of the ABTS solution. The absorbance was recorded at a wavelength of 734 nm using a microplate reader (BioradxMark®). The assay was performed in three repetitions. Trolox was used as a positive control [9].

The percentage inhibition and half-maximal inhibitory concentration values were calculated using the following equation:

$$\text{Inhibition (\%)} = \frac{(A - B)}{A} \times 100$$

Notes:
A: Absorbance of negative control
B: Absorbance of the sample

Antibacterial activity

Test microorganisms: *Streptococcus mutans* (SE) (ATCC 25175), *Methicillin-Resistant Staphylococcus aureus* (MRSA) (ATCC 43300), *Proteus mirabilis* (PM) IS01 were obtained from the Microbiology Laboratory, University of North Sumatra, Medan, Indonesia. In addition, EC (ATCC 25922) and SA (ATCC 6538) were obtained from the Department of Health Laboratory in Padang. *Enterococcus faecalis* (EF) and *Staphylococcus epidermidis* (SE) were obtained from the Indonesian Food and Drug Administration in Padang, West Sumatra, Indonesia.

Determination of minimum inhibition concentration (MIC) and minimum bactericidal concentration (MBC)

A stock solution of ZEO was prepared at 50 mg/mL in dimethyl sulfoxide (DMSO). Serial two-fold dilutions were made in Mueller-Hinton Broth (MHB) to achieve final test concentrations ranging from 25 to 0.781 mg/mL. Ciprofloxacin was included as a positive control. Next, 50 µL of MHB medium was added to all wells, followed by 50 µL of the test solution. The turbidity of bacterial suspension was set to a similar level as the McFarland 0.5 standard. All wells were filled with 50 µL of the bacterial suspension, except the control wells. The plate was then incubated at 37°C for 18–24 h.

After incubation, 40 µL of 3-(4,5)-dimethylthiazolyl-2-yl)-2-yl)-2,5 2,5-diphenyltetrazolium bromide (MTT) solution was added to each well, achieving a final concentration of 0.5 mg/mL, and the plates were incubated again at 37°C for 30 min. Next, observe the color change (colorless to purple). The test was performed 3 times. The MIC value was determined from the lowest concentration at which no color change occurred. Following this, the solution from each well was removed, and a streak was made on the surface of NA agar, which was incubated at 37°C for 18–24 h to observe bacterial growth. The experiment was also repeated 3 times. The MBC was determined as the lowest concentration at which no bacterial growth was observed [11].

Wound healing activity

Fibroblast proliferation activity

The cell proliferation activity was determined using the MTT test. Each well received 180 µL of a fibroblast cell suspension (containing 10^4 cells/well) and was cultured for 24 h in a CO_2 incubator at 37°C (5% CO_2). The wells received 20 µL of ZEO in DMSO at concentrations of 100, 10, 1, and 0.1 mg/mL. A DMSO-containing Dulbecco's Modified Eagle Medium (DMEM) was used as a negative control in each well. Curcumin serves as a positive control. All plates were incubated for 24–48 h at 37°C with 5% CO_2. Next, each well received 100 µL of MTT (0.5 mg/mL) and was incubated for 4–6 h at 37°C with 5% CO_2. Living cells will respond by producing a purple formazan, which is then dissolved in 100 µL DMSO. The assay was repeated 3 times and measured at a wavelength of 550 nm. The percentage of fibroblast cell proliferation was calculated [12].

Fibroblast cell migration

The scratch assay was used to test fibroblast cell migration. Fibroblast cells were grown in a 24-well plate at a density of 100,000 cells/well until they reached confluence. Linear wounds were made using yellow tips. Wells were washed with 500 µL of Phosphate-buffered saline to remove cellular debris. Each well received 1 mL of each ZEO diluted in DMSO at three different concentrations (10 µg/mL, 1 µg/mL, and 0.1 µg/mL). The negative control was filled with 1 mL of DMEM-containing DMSO. It was incubated at 37°C with 5% CO_2. Cell migration was observed under an inverted microscope after 0, 24, and 48 h of treatment with ZEO. The experiment was repeated 3 times, and the percentage of wound closure was calculated [10].

RESULTS AND DISCUSSION

Physical characteristics

The essential oil of *Z. officinale* var. amarum (ZEO) is shown in Fig. 1. ZEO has a golden yellow color with a characteristic odor. The physical characterization of ZEO is presented in Table 1, which includes yield, specific gravity, refractive index, and color. ZEO extracted by hydrodistillation was 0.423% v/w. Previous research on ginger oil varies depending on its origin. The results of this study differed, with ginger in India containing 1.26% v/w [13]. However, it is not much different from the essential oil obtained from ginger in Saudi Arabia and China, at 0.2% w/v and 0.14% v/w, respectively [14].

The specific gravity and refractive index measurements determine the quality of the essential oil. In the current study, the specific gravity was 0.9049 g/mL, and the refractive index was 1.4778. These results contrast with the Indonesian National Standard for Ginger Oil (SNI: 06-1312-1998), which stated that the specific gravity of ginger essential oil was in the range of 0.8720–0.8890 g/mL. On the other hand, SNI released the refractive index of ginger essential oil in the range of 1.4853–1.4920 [15]. Chemical composition influences the refractive index and specific gravity of essential oils. The presence of larger molecules, such as oxygenated aromatic compounds, results in a higher specific gravity for the substance. Furthermore, the presence of water in the essential oil will affect its refractive index [16].

Chemical component of *Z. officinale* var. amarum essential oil

The chemical component of ZEO is listed in Table 2. GC-MS analysis revealed the presence of 24 chemical compounds in ZEO, accounting

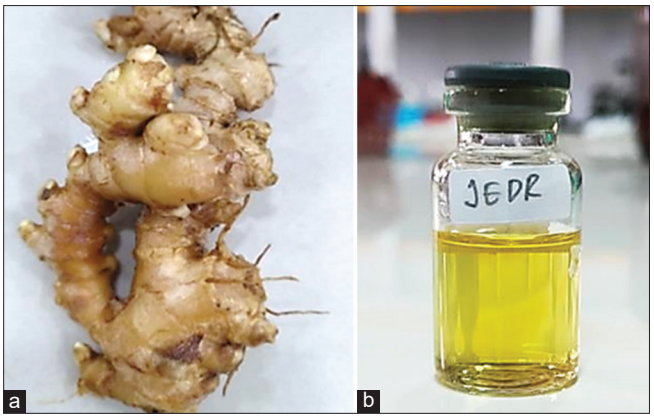

Fig. 1: (a) Rhizome of *Zingiber officinale var. Amarum*, (b) Essential oil of *Z. officinale*

Table 1: Physical characterization of ZEO

essential oil	Yield (%) v/w	Color	Specific mass (g/mL 25°C)	Refractive index (25°C)
Zingiber officinale Var. Amarum	0.42	Golden yellow	0.9049±0.00	1.4778±0.00

*Data presented as mean±standard deviation, ZEO: *Zingiber officinale* essential oil

Table 2: Chemical composition of ZEO

No.	Chemical compound	Retention time	Percentage of relative area
1	α-pinene	3.3	2.9
2	Camphene	3.5	14.9
3	β-myrcene	4.08	1.9
4	L-Phellandrene	4.38	0.3
5	Cymol	4.69	0.2
6	1,8-cineole	4.88	8
7	1,4,6-heptatriene, 2,3,6-trimethyl-	6.38	0.7
8	Linalool	6.53	1.3
9	Camphor	7.61	0.3
10	Endo-Borneol	8.61	3.5
11	6-Methyl-5-hepten-2-one	9.11	0.7
12	α-Terpineol	9.53	1.2
13	Z-citral	11.4	10.8
14	Geraniol	12.38	3.8
15	Citral	12.73	15.1
16	α-fenchyl acetate	13.85	1.9
17	Neryl acetate	18.8	3.2
18	Ar-Curcumene	23.71	3.5
19	Zingiberene	24.49	5.4
20	β-bisabolene	25.11	2.6
21	β-sesquiphellandrene	25.65	2.9
22	Nerolidol	27.17	0.2
23	α-Cedrol	29.06	1.2
24	Trans-Caryophyllene	31.65	0.2
Total (%)			86.7
Hydrocarbon monoterpene			20.5
Oxygenated monoterpene			29.5
Hydrocarbon sesquiterpene			13.6
Oxygenated sesquiterpene			15.9
Others			20.5

Compounds listed in order of elution; Identification based on mass spectral match (similarity index>90%). ZEO: *Zingiber officinale* essential oil

for 86.7% of the total constituents. Oxygenated monoterpene group compounds significantly contributed to ZEO, accounting for 29.5%, followed by hydrocarbon monoterpene group compounds at 20.5% and oxygenated sesquiterpene compounds at 15.9%. The main compounds were citral (15.1%), camphene (14.9%), z-citral (10.8%), and 1,8-cineole (8.0%). These results showed differences in the major compounds reported in Pahang, Malaysia, namely neral (10.75%), geranial (13.88%), and α-zingiberene (18.56%) [17]. In addition, the results of this study differed from those of the main compounds of ginger oil in Thailand and China, namely Ar-curcumene (15.57%), nerolidol (14.32%), followed by eucalyptol (9.06%), and limonene (8.58%) [18].

Environmental conditions, including geographic and climatic variations, greatly influence the chemical composition of essential oils [19]. Significant differences in growing location elevation can cause simultaneous changes in relative temperature, humidity, water level, wind speed, and radiation rate. Thus, environmental changes can affect various ecophysiological responses in plants [20].

Antioxidant activity

The percentage inhibition of antioxidants is displayed in Table 3. The study on the antioxidant activity of ZEO revealed that it did not

Table 3: The percentage inhibition of ABTS radical scavenging activity of ZEO

Concentration (μg/mL)	% Inhibition			
	1	2	3	Mean±SD
15.625	5.79	5.79	4.59	5.39±0.74
31.25	4.83	5.43	5.43	5.23±0.35
62.5	5.79	5.56	5.79	5.70±0.14
125	6.64	6.16	5.56	6.12±0.55
250	7.73	8.21	7.73	7.89±0.28

Values are mean % inhibition±SD of n=3 independent experiments.
ZEO: *Zingiber officinale* essential oil, SD: Standard deviation

exhibit significant antioxidant properties. At the highest concentration of 250 μg/mL, the inhibition percentage of ZEO was only 7.89%. This percentage decreased to between 5.26% and 6.12% at lower concentrations. In contrast, the positive control, Trolox, demonstrated moderate antioxidant activity. An extract or essential oil was considered effective as a radical scavenger if the inhibition percentage exceeds 50% at the test concentration [21]. The chemical composition of ZEO was primarily composed of citral, camphene, and 1,8-cineol, which were known to exhibit weak antioxidant activity; however, they are likely to be more effective as antimicrobial and anti-inflammatory agents (Gutiérrez-Pacheco *et al*., 2023; Barras *et al*., 2024) [22].

Antibacterial activity

The MIC and MBC values for ZEO are displayed in Table 4. In general, lower MIC and MBC levels indicated a greater ability to inhibit or eliminate bacterial growth [23].

Based on Table 4, the ZEO has an MIC of approximately 16–125 μg/mL. MRSA bacteria had the lowest MIC value (16 μg/mL), followed by SE and *SM* at 52 μg/mL. Meanwhile, the highest MIC was observed in PM and EC bacteria at 125 μg/mL. However, when compared to ciprofloxacin as a positive control, the inhibitory power of ZEO was still weak. On the other hand, the lowest MBC was also observed in MRSA bacteria at 16 μg/mL. In contrast, the highest MBC was observed in the bacteria EF, PM, and EC. These findings suggest that ZEO was more effective against Gram-positive bacteria than against Gram-negative bacteria.

The MIC/MBC ratio was calculated to determine the bactericidal or bacteriostatic effect of the compound. Antimicrobials are typically regarded as bactericidal if the MIC/MBC ratio is ≤4 and bacteriostatic if the ratio is>4 [24]. The ratios for ZEO toward the entire test organisms were <4, as described in Table 5. It means ZEO has a bactericidal effect on all test microorganisms.

This finding aligns with earlier studies demonstrating that ginger essential oil exhibits antibacterial properties, particularly against Gram-positive bacteria [25]. The antibacterial activity in this study was higher than previously reported, namely, ZEO had MIC values of 1.0 mg/mL and 2.0 mg/mL against SA and EC bacteria, respectively [26].

The antibacterial properties of ZEO may be influenced by its chemical composition, which includes citral, camphene, and 1,8-cineol. Essential oils contain hydrophobic substances that can interact with and be absorbed by cell membranes. Once these components enter bacterial cells, they bind to hydrophobic protein sites, leading to alterations in the membrane structure. This can cause changes in permeability and fluidity of cell membranes, loss of critical intracellular components, impairment of nutrient uptake, and, eventually, cell lysis [27].

Wound healing activity

The results of fibroblast cell proliferation are listed in Table 6. ZEO stimulated fibroblast cell proliferation at low-to-moderate

Table 4: MIC and MBC value

Bacteria	ZEO (µg/mL)		Ciprofloxacin (µg/mL)	
	MIC	MBC	MIC	MBC
Staphylococcus *aureus*	62.5	125	0.015	0.015
MRSA	16	16	0.023	0.047
Staphylococcus epidermidis	31.25–62.5	62.5–125	0.015	0.015
Enterococcus faecalis	62.5	125	0.011	0.023
Proteus mirabilis	125	125	0.094	0.188
Escherichia coli	125	125	0.038	0.075
Staphylococcus mutans	31.25–62.5	125	0.047	0.047

MIC: Minimum inhibitory concentration, MBC: Minimum bactericidal concentration, ZEO: *Zingiber officinale* essential oil, MRSA: Methicillin-resistant *Staphylococcus aureus*

Table 5: MIC/MBC ratios of ZEO against test organisms

Sample	SE	MRSA	SA	EF	PM	EC	SM
ZEO	2	1	2	2	1	1	2

MRSA: Methicillin-resistant *Staphylococcus aureus*, SA: *Staphylococcus aureus*, EF: *Enterococcus faecalis*, PM: *Proteus mirabilis*, EC: *Escherichia coli*, MIC: Minimum inhibition concentration, MBC: Minimum bactericidal concentration, ZEO: *Zingiber officinale* essential oil, SM: *Streptococcus mutans*

Table 6: Percentage of fibroblast cell proliferation

Sample	% of proliferation (mean±SD)			
	0.1 µg/mL	1 µg/mL	10 µg/mL	100 µg/mL
ZEO	119±16.44	120±6.51	102±10.69	66±14.22
Curcumin	137±3.51	136±5.7	124±5.13	51±4.51

Data presented as mean±SD of n=3 independent experiments. SD: Standard deviation

concentrations, with the highest proliferation at a concentration of 1 µg/mL, reaching 120%. However, at the highest concentration (100 µg/mL), fibroblast cell proliferation decreased to 66%, suggesting potential cytotoxicity at high doses. Curcumin, used as a positive control, was also toxic to fibroblast cells at 100 µg/mL; however, it showed an increase in fibroblast cell proliferation at lower concentrations. The morphology of fibroblast cells after treatment with ZEO is shown in Fig. 2. The statistical analysis using a one-way analysis of variance (ANOVA) showed that ZEO, the positive control, and curcumin had a significant effect on fibroblast cell proliferation ($p<0.05$). Furthermore, a Tukey *post hoc* test was conducted to determine group differences between ZEO, curcumin, and the control, which showed that ZEO at concentrations of 0.1–10 µg/mL did not differ significantly from the control in increasing fibroblast cell proliferation, as indicated by a shared letter between these two groups.

The results of fibroblast cell migration are listed in Table 7 and Fig. 3.

The results showed that ZEO can enhance the migration process of fibroblasts. At 24 h, the wound closure rate ranged from 37.46% to 42.64%, with the highest effect observed at a concentration of 10 µg/mL, at 42.64%. After 48 h, all concentrations showed a significant increase in wound closure, ranging from 76.77% to 80.52%. The highest effect was observed at a concentration of 0.1 µg/mL, with an efficacy of 80.52%. This demonstrates that ZEO can effectively accelerate wound closure, particularly within 48 h, with optimal effects observed at low-to-moderate concentrations. Positive control curcumin showed a lower percentage of wound closure compared to ZEO. The statistical analysis using a one-way

Table 7: Percentage of wound closure after 24 and 48 h treatment with ZEO

Sampel	Concentration (µg/mL)	% of wound closure (mean±SD)	
		24 HRS	48 HRS
ZEO	0.1	41.71±1.43	80.52±2.45
	1	37.46±2.43	76.77±4.30
	10	42.64±6.77	80.31±1.76
Curcumin	0.1	31.62±0.22	62.62±5.99
	1	25.44±1.41	59.41±2.48
	10	22.57±2.64	51.95±0.5

Data presented as mean±SD of n=3 independent experiments. ZEO: *Zingiber officinale* essential oil var. amarum of essential oil, HRS: Hour, SD: Standard deviation

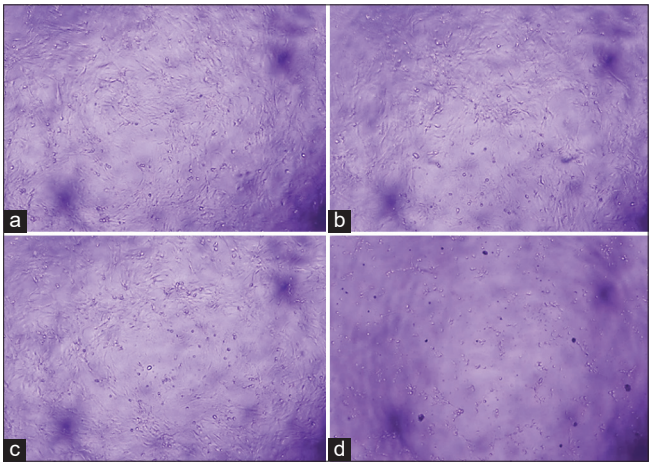

Fig. 2: (a) Fibroblast cell treated with 0.1 µg/mL *Zingiber officinale* essential oil, (b) 1 µg/mL, (c) 10 µg/mL, (d) 100 µg/mL. Scale bar=100 µm

ANOVA showed that ZEO, the positive control, and curcumin had a significant effect on fibroblast cell migration ($p<0.05$). Furthermore, a Tukey *post hoc* test was conducted to determine group differences between ZEO, curcumin, and the control, which showed that ZEO at concentrations of 0.1–10 µg/mL differs significantly from the control and curcumin in triggering fibroblast cell migration, as indicated by the lack of a shared letter between these two groups.

Some essential oils and terpenes may accelerate wound closure by stimulating the movement of fibroblasts and epithelial cells, although dosage can influence this effect. At specific dosages, they may inhibit cell migration [28]. This is thought to be influenced by the content of ZEO, which contains the main compounds citral, camphene, and 1,8-cineol, as well as other compounds that have antimicrobial and anti-inflammatory properties, thereby working synergistically in their role of stimulating fibroblast proliferation and migration [7].

A study stated that incorporating ginger essential oil and garlic oil with neomycin base as nano-emulsions showed an effective and able to accelerate wounds' healing and inflammation in a rat model [29]. In contrast, curcumin, the isolated compound from *Curcuma longa* Linn., has wound-healing properties through anti-inflammatory, antioxidant, and anti-infectious properties. Besides, curcumin also enhances collagen deposition, tissue remodeling, fibroblast proliferation, granulation tissue formation, and vasculature density.

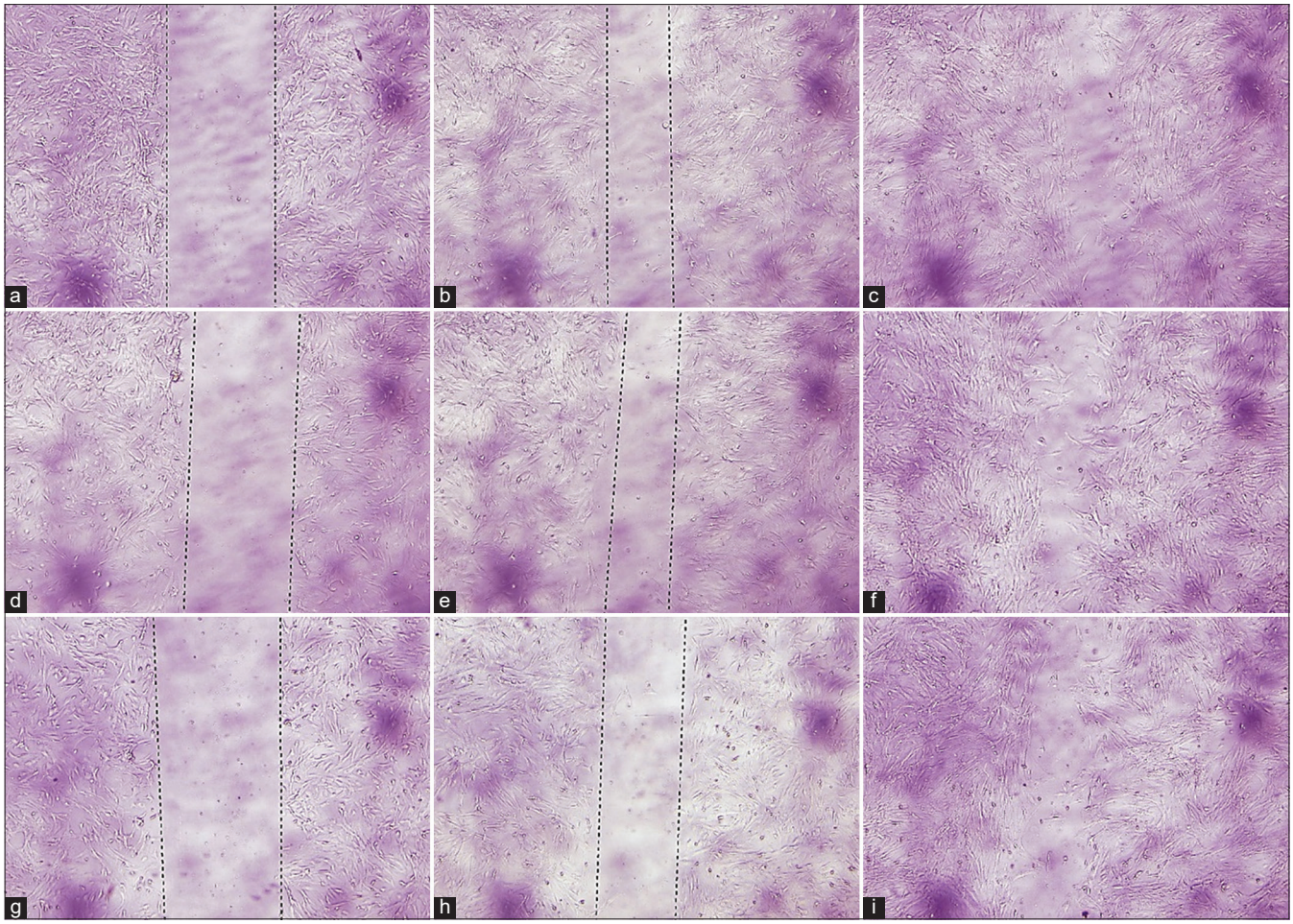

Fig. 3: Representative images of scratch wounds treated with *Zingiber officinale* essential oil. Top row (a-c): 0.1 µg/mL at (a) 0 h, (b) 24 h, (c) 48 h. Middle row (d-f): 1 µg/mL at (d) 0 h, (e) 24 h, (f) 48 h. Bottom row (g-i): 10 µg/mL at (g) 0 h, (h) 24 h, (i) 48 h. Black dashed lines indicate wound margins. Scale bar=200 µm

CONCLUSION

Essential oil from Z. officinale var. amarum exhibited good antibacterial activity against Gram-positive bacteria, displaying a bactericidal effect. The ZEO enhanced the proliferation and migration of fibroblast cells at the lowest concentration and exhibited cytotoxicity at higher concentrations. However, this oil did not show antioxidant activity. Z. officinale var. amarum essential oil has the potential to be developed as a nature-based wound-healing active ingredient, due to its mechanism as an antibacterial agent and its enhancement of fibroblast cell proliferation and migration.

AUTHORS' CONTRIBUTION

Conceptualization: Suryati Syafri, Senti Dwi Suryani, and Dachriyanus Hamidi; Data curation: Suryati Syafri; Investigation: Suryati Syafri and Senti Dwi Suryani; Methodology: Suryati Syafri and Dachriyanus Hamidi; Supervision: Suryati Syafri, Dachriyanus Hamidi, Faridah Yusof, and Irwandi Jaswir; Writing-original draft: Suryati Syafri, Senti Dwi Suryani; Writing-review and editing: Suryati Syafri, Dachriyanus Hamidi, Faridah Yusof, Irwandi Jaswir.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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REFERENCES

1. Nussbaum SR, Carter MJ, Fife CE, DaVanzo J, Haught R, Nusgart M. An economic evaluation of the impact, cost, and medicare policy implications of chronic nonhealing wounds. Value Health. 2018;21(1):27-32. doi: 10.1016/j.jval.2017.07.007, PMID 29304937
2. Okur ME, Karantas ID, Şenyiğit Z, Üstündağ Okur N, Siafaka PI. Recent trends on wound management: New therapeutic choices based on polymeric carriers. Asian J Pharm Sci. 2020;15(6):661-84. doi: 10.1016/j.ajps.2019.11.008, PMID 33363624
3. Bessa LJ, Fazii P, Di Giulio M, Cellini L. Bacterial isolates from infected wounds and their antibiotic susceptibility pattern: Some remarks about wound infection. Int Wound J. 2015;12(1):47-52. doi: 10.1111/iwj.12049, PMID 23433007
4. Vitale S, Colanero S, Placidi M, Di Emidio G, Tatone C, Amicarelli F. Phytochemistry and biological activity of medicinal plants in wound healing: An overview of current research. Molecules. 2022;27(11):3566. doi: 10.3390/molecules27113566, PMID 35684503
5. Sumi MJ, Zaman SB, Imran S, Sarker P, Rhaman MS. A review on the ethnopharmacological importance and biochemical composition of medicinal plants within the Zingiberaceae family. Plant Sci Today. 2024;11(1):275-86. doi: 10.14719/pst.3514
6. Hunt M, Torres M, Bachar-Wikstrom E, Wikstrom JD. Cellular and molecular roles of reactive oxygen species in wound healing. Commun Biol. 2024;7(1):1534. doi: 10.1038/s42003-024-07219-w, PMID 39562800
7. Mahboubi M. *Zingiber officinale* Rosc. Essential oil, a review on its composition and bioactivity. Clin Phytosci. 2019;5(1):6.

8. Mao QQ, Xu XY, Cao SY, Gan RY, Corke H, Beta T. Bioactive compounds and bioactivities of ginger (*Zingiber officinale* Roscoe). Foods. 2019;8(6):185.
9. Syafri S, Hafiz A, Syofyan S, Alen Y, Hamidi D. FT-IR fingerprinting analysis for classification of west Sumatra small ginger (*Zingiber officinale* roscoe) essential oil and its antioxidant activity. Trop J Nat Prod Res. 2024;8(2):6081-6.
10. Syafri S, Putri RS, Jaswir I, Yusof F, Alen Y, Syofyan S. Analysis of turmeric (*Curcuma longa* linn) essential oil from different growing locations using Ftir/Gc-Ms spectroscopy coupled to chemometrics and its wound healing activities. Int J Appl Pharm. 2024;16(1):152-9. doi: 10.22159/ijap.2024.v16s1.33
11. Suryati, Dachriyanus, Jaswir I, Yusof F. Chemical profiling and antibacterial activity of Javanese turmeric (*Curcuma xanthorriza*) essential oil on selected wound pathogen. In: Advances in Health Sciences Research (Iccscp). Vol. 40. Netherlands: Atlantis Press; 2021. doi: 10.2991/ahsr.k.211105.042
12. Husni E, Hamidi D, Pavvellin D, Hidayah H, Syafri S. Metabolite profiling, antioxidant, and *in vitro* wound healing activities of *Citrus medica* L. and C*itrus x microcarpa* Bunge peels and leaves essential oils. Prospects Pharm Sci. 2024;22(4):122-30. doi: 10.56782/pps.250
13. Kumar Sharma P, Singh V, Ali M. Chemical composition and antimicrobial activity of fresh rhizome essential oil of *Zingiber officinale* roscoe. Pharmacogn J. 2016;8(3):185-90. doi: 10.5530/pj.2016.3.3
14. Al-Dhahli AS, Al-Hassani FA, Mohammed Alarjani K, Mohamed Yehia H, Al Lawati WM, Hejaz Azmi SN. Essential oil from the rhizomes of the Saudi and Chinese *Zingiber officinale* cultivars: Comparison of chemical composition, antibacterial and molecular docking studies. J King Saud Univ Sci. 2020;32(8):3343-50. doi: 10.1016/j.jksus.2020.09.020
15. Standardisasi B. Standar nasional Indonesia minyak Jahe. In: Standar Nasional Indonesia 16-1312. Indonesia: Nasional Republik Indonesia; 1998.
16. Muderawan IW, Mudianta IW, Martiningsih NW. Physicochemical properties, chemical compositions and antioxidant activities of rhizome oils from two varieties of *Kaempferia galanga*. Indones J Chem. 2022;22(1):72-85. doi: 10.22146/ijc.66348.
17. Abdullahi A, Khairulmazmi A, Yasmeen S, Ismail IS, Norhayu A, Sulaiman MR. Phytochemical profiling and antimicrobial activity of ginger (*Zingiber officinale*) essential oils against important phytopathogens. Arab J Chem. 2020;13(11):8012-25. doi: 10.1016/j.arabjc.2020.09.031
18. Kamal GM, Nazi N, Sabir A, Saqib M, Zhang X, Jiang B. Yield and chemical composition of ginger essential oils as affected by inter-varietal variation and drying treatments of rhizome. Separations. 2023;10(3):186.
19. Figueiredo AC, Barroso JG, Pedro LG, Scheffer JJ. Factors affecting secondary metabolite production in plants: Volatile components and essential oils. Favour Fragr J. 2008;23(4):213-26. doi: 10.1002/ffj.1875
20. Jugreet BS, Suroowan S, Rengasamy RR, Mahomoodally MF. Chemistry, bioactivities, mode of action and industrial applications of essential oils. Trends Food Sci Technol. 2020 Apr;101:89-105. doi: 10.1016/j.tifs.2020.04.025
21. Apak R, Özyürek M, Güçlü K, Çapanoğlu E. Antioxidant activity/capacity measurement. 1. Classification, physicochemical principles, mechanisms, and electron transfer (ET)-based assays. J Agric Food Chem. 2016;64(5):997-1027. doi: 10.1021/acs.jafc.5b04739, PMID 26728425
22. Gutiérrez-Pacheco MM, Torres-Moreno H, Flores-Lopez ML, Guadarrama NV, Ayala-Zavala JF, Ortega-Ramírez LA. Mechanisms and applications of citral's antimicrobial properties in food preservation and pharmaceuticals formulations. Antibiotics (Basel). 2023;12:1608.
23. Barras BJ, Ling T, Rivas F. Recent advances in chemistry and antioxidant/anticancer biology of monoterpene and meroterpenoid natural product. Molecules. 2024;29(1):279. doi: 10.3390/molecules29010279
24. Appiah T, Boakye YD, Agyare C. Antimicrobial activities and time-kill kinetics of extracts of selected Ghanaian mushrooms. Evid Based Complement Alternat Med. 2017;2017:4534350. doi: 10.1155/2017/4534350, PMID 29234399
25. López EI, Balcázar MF, Mendoza JM, Ortiz AD, Melo MT, Parrales RS. Antimicrobial activity of essential oil of *Zingiber officinale* Roscoe (Zingiberaceae). Am J Plant Sci. 2017;8(7):1511-24. doi: 10.4236/ajps.2017.87104
26. Wang X, Shen Y, Thakur K, Han J, Zhang JG, Hu F. Antibacterial activity and mechanism of ginger essential oil against *Escherichia coli* and *Staphylococcus aureus*. Molecules. 2020;25(17):3955. doi: 10.3390/molecules25173955, PMID 32872604
27. Da Silva BD, Bernardes PC, Pinheiro PF, Fantuzzi E, Roberto CD. Chemical composition, extraction sources and action mechanisms of essential oils: Natural preservative and limitations of use in meat products. Meat Sci. 2021 Feb;176:108463. doi: 10.1016/j.meatsci.2021.108463, PMID 33640647
28. Salas-Oropeza J, Rodriguez-Monroy MA, Jimenez-Estrada M, Perez-Torres A, Castell-Rodriguez AE, Becerril-Millan R. Essential oil of *Bursera morelensis* promotes cell migration on fibroblasts: *In vitro* assays. Molecules. 2023;28(17):6258. doi: 10.3390/molecules28176258, PMID 37687087
29. Ibrar M, Ayub Y, Nazir R, Irshad M, Hussain N, Saleem Y. Garlic and Ginger essential oil-based neomycin nano-emulsions as effective and accelerated treatment for skin wounds' healing and inflammation: *In-vivo* and *in-vitro* studies. Saudi Pharm J. 2022;30(12):1700-9. doi: 10.1016/j.jsps.2022.09.015