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The antibacterial activity and chemical components of Ginger (*Zingiber officinale*) and Phlai (*Zingiber purpureum*) essential oils against *Propionibacterium acnes*

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Abstract

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Zingiber officinale, commonly known as Ginger, and *Zingiber purpureum*, referred to as Phlai, are members of the Zingiberaceae family, extensively utilized in culinary practices and traditional medicinal applications. Nevertheless, there exists a paucity of information regarding their chemical constituents and antibacterial properties. In this work, we aim to elucidate the antibacterial properties and chemical constituents of the essential oils derived from the rhizomes of Ginger and Phlai. The essential oils were obtained through steam distillation. The antibacterial efficacy against *Propionibacterium acnes* DMST 14916 was determined utilizing both the Agar disc diffusion and broth microdilution methodologies. The chemical components of the essential oil were examined via Gas Chromatography-Mass Spectrometry. The Minimum Inhibitory Concentration (MIC) values for the antibacterial activity against *P. acnes* DMST 14916 were 1.56% and 6.25% V/V, respectively, whereas the Minimum Bactericidal Concentration (MBC) values were 3.12% and 25.00% V/V, respectively. The results indicated the presence of 11 distinct chemical constituents in Ginger oil, with the predominant components being 1,8-cineole (13.95%) and geranial (13.49%). In contrast, Phlai oil exhibited 17 constituents, with sabinene (50.83%) identified as the major component.

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1. Introduction

Zingiberaceae is classified under the order of Zingiberales. Annual or perennial rhizomatous herbs are widely distributed in the tropical or subtropical regions with approximately 1,300 species. Interestingly, 300 species under 26 genera have been found only in Thailand [1]. In Thailand, Zingiberaceae has been utilized as food, spice, ornamentals, rituals, dyes, and cosmetics [2].

Different parts of Zingiberaceae, especially the rhizome, have been reported to possess the medicinal properties of essential oils containing several active substances that inhibit many types of bacteria. The essential oil of Phlai (*Z. purpureum*) has various inhibitory effects on common human pathogens, e.g., *Staphylococcus aureus*, *Staphylococcus epidermidis*, *Bacillus cereus*, *Bacillus subtilis*, *Salmonella typhi*, *Pseudomonas aeruginosa*, *Serratia marcescens*, *Escherichia coli,* and *Propionibacterium acnes* [3–5]; Ginger essential oil inhibits *Listeria monocytogenes*, *Staphylococcus aureus*, *Escherichia coli* 0157:H7, and *Salmonella* Typhimurium [6, 7].

Skin is considered the most abundant part of the human body where many Normal flora (Normal microbiota), e.g., *Staphylococcus* sp., *Streptococcus* sp., *Corynebacterium* sp., *Malassezia* sp., and *Propionibacterium* sp., can be found [8]. *P. acnes*, the primary cause of acne, affects people of all ages and genders, with lesions predominantly appearing on the face. Common antibiotics like clindamycin, erythromycin, doxycycline, and tetracycline treat acne, but long-term use drives antibiotic resistance. [9]. To reduce the problem of antibiotic resistance, medicinal plants have been explored for studying their active substances and microbiological activity to further develop herbal products in the field of cosmeceuticals to prevent skin infections through Thai medicinal plants [7, 10, 11]. However, the active substances in such plants vary according to the environment in which they are cultivated. [7, 12, 13].

The suitable geographical location, climate, and cultivation methods result in a greater growth of medicinal plants and the active substances [14], especially the organic cultivation without chemical contaminants, which is more suitable to be used as a component of cosmeceutical products. Loei Province is one of the largest Ginger plantations in the Northeast of Thailand due to market demand and exportation. Ginger and Phlai are locally cultivated for traditional medicine and cuisine; however, scientific research is needed to support their benefits. Therefore, in this study, we investigated the chemical composition and anti-*P. acnes* activity of organically grown Ginger (*Z. officinale*) and Phlai (*Z. purpureum*) essential oils to document the specific components of plants from this region. This is to provide a scientific basis for their traditional use and to promote the integration of local wisdom with modern scientific methods for cosmeceutical product development of indigenous Thai herbs. This is also to offer natural alternatives and to help minimise the problem of antibiotic resistance.

2. Materials and Methods

Plant samples

The plant samples in this research were Ginger and Phlai, identified by Saensuk S. [15, 16]. The samples were 9-month rhizomes (Fig. 1), cultivated and collected in organic farms in Mueang (17°29'15" N, 101°51'28" E) and Phu Ruea districts (17°28'53" N, 101°16'49" E), Loei Province, Thailand.

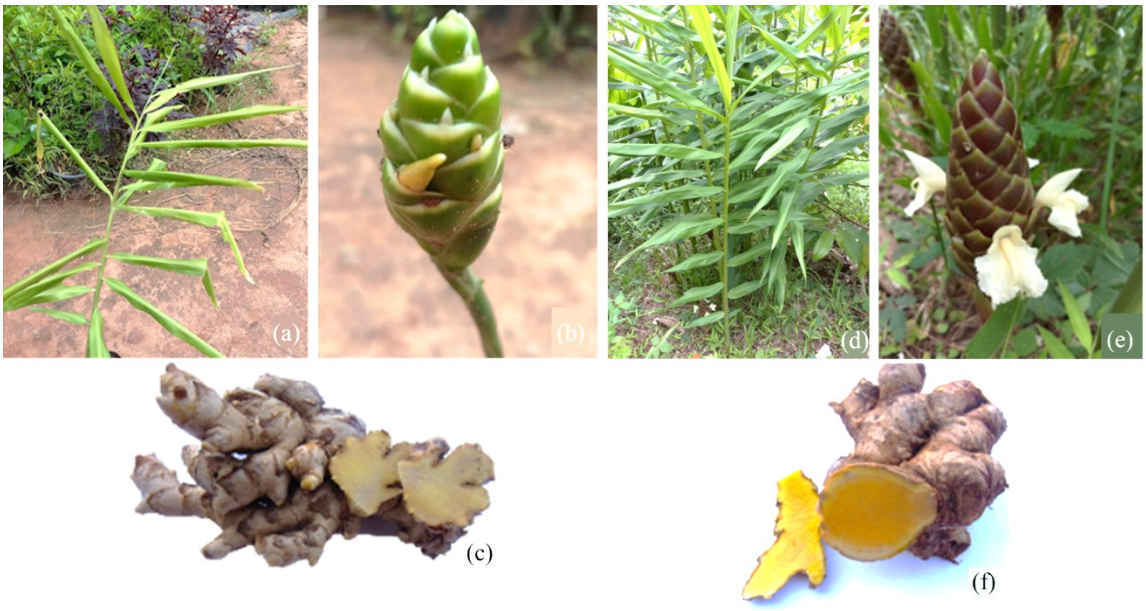

Fig. 1 Ginger leaves (a), flowers (b), rhizomes (c), and Phlai leaves (d),flowers (e), rhizomes (f) from Mueang and Phu Ruea districts, Loei Province.

The extraction of Ginger and Phlai essential oil

The extraction of Ginger and Phlai essential oil were adapted from Nookong *et al.* [17]. The fresh rhizomes of Ginger and Phlai were cleaned and air-dried, then cut into small pieces and finely blended. The 400 g of each *Z. officinale* and *Z. purpureum* were extracted by steam distillation at a controlled temperature of 270 °C. The essential oils were kept ina brown glass bottle until use.

Antibacterial activity for P. acnes DMST 14916 Preparation of essential oils

0.5 mL of Ginger and Phlai essential oils were dissolved in 0.5 mL of 10% Tween 80 to a final concentration of 50% V/V and stored at 4 °C until the next experiment [18].

Bacterial preparation

P. acnes DMST 14916 was obtained from The Protein and Proteomics Research Center for Commercial and Industrial Purposes (ProCCI), Faculty of Sciences, Khon Kaen University. *P. acnes* DMST 14916 was cultured in Brain Heart Infusion (BHI) broth and incubated at 37 °C in anaerobic conditions overnight. The turbidity of the bacterial sample was adjusted to the 0.5 McFarland Standard (approximately 10^6– 10^8 CFU mL^{-1}) [3].

Antibacterial activity of essential oil against P. acnes

Antibacterial activity against *P. acnes* DMST 14916 of Ginger and Phlai essential oils was determined by the standard Agar disc diffusion method, adapted from Sebiomo *et al.* [19]. The turbidity of bacterial suspension was adjusted by using McFarland standard No. 0.5 (Himedia®, Himedia Laboratories Pvt. Ltd., India) to obtain bacterial

cells about 1×10^8 CFU mL^{-1}, spread on BHI agar, and left for 3–5 minutes. 20 µL of each of the 50% V/V of Ginger and Phlai essential oils were dropped onto a sterile paper disc (diameter of 6 mm) and allowed to dry for 3–5 minutes. The paper discs were placed on BHI agar and incubated at 37 °C for 72 h in anaerobic conditions. In addition, 50 µg mL^{-1} of Clindamycin (Clinda-M®, RPC International CO., Ltd, Thailand) and 10% Tween 80 (Acros Organics™, ThermoFisher Scientific, USA) were applied as a control. Each sample was tested in triplicate. The diameter of the inhibition zone in millimeters (mm) was recorded [3, 20].

The Minimum Inhibitory Concentration (MIC)

P. acnes DMST 14916 was cultured in BHI broth and adjusted to turbidity equal to McFarland standards No. 0.5 (10^6 – 10^8 CFU mL^{-1}). The Minimum inhibitory concentration (MIC) of Ginger and Phlai essential oils was determined by using broth microdilution [20, 21], two-fold serial dilution of Ginger and Phlai essential oils in a 96-well plate. The concentrations were in the range of 50.00–0.19 % V/V, with BHI broth (Himedia®, Himedia Laboratories Pvt. Ltd., India) and 0.05 mg mL^{-1} Clindamycin as control, then incubated at 37 °C for 72 h in anaerobic conditions. Each sample was tested in triplicate. Subsequently, 20 µl of 10 mg mL^{-1} resazurin solution (Alfa Aesar™, Thermo Fisher Scientific, USA) was added. The 96-well plates were incubated for 1 h. The MIC value, the minimum inhibitory concentration (MIC), was read in the well where resazurin remained blue [22].

The Minimum Bactericidal Concentration (MBC)

The wells that remained blue in 96-well plates were inoculated onto BHI agar and then incubated at 37 °C for 72 h under anaerobic conditions for the determination of the MBC value. Each sample was tested in triplicate. The inoculation from the concentration that shows the absence of bacterial growth was interpreted as the MBC value [23].

The chemical components of essential oil from Ginger and Phlai rhizomes

Two milliliters of the obtained essential oil were transferred into a vial for analysis. The chemical composition of the oils was determined using a gas chromatography-mass spectrometry (GC-MS) system (Agilent Technologies model 7890B) coupled with a Triple Quadrupole Mass Selective Detector (model 7000D). The injection port temperature was maintained at 230 °C, while the oven temperature program started at 50 °C and was increased at a rate of 4 °C per minute until reaching 230°C. Mass spectrometric detection was conducted in scan mode using an electron ionization source at 70 eV, covering a mass range of 40–400 amu. Separation was achieved using an HP-5MS capillary column (30 m × 0.25 mm internal diameter, with a film thickness of 0.25 µm). Helium was employed as the carrier gas at a pressure of 10.0 psi, with a flow rate of 1.2 mL min^{-1} and an average linear velocity of 40 cm s^{-1}. The split injection ratio was set at 20:1.

Statistical analysis

The inhibition zone, MIC, and MBC values were calculated as mean ± SD.

3. Results and Discussion

Ginger and Phlai have been utilized for culinary purposes and in traditional medicinal practices for an extensive period. The essential oils are incorporated as a component in numerous cosmetic formulations, reflecting their therapeutic efficacy concerning human dermal conditions and their antimicrobial properties. Beyond the suppression of bacterial proliferation, these substances also serve as a complementary therapeutic approach to mitigate the challenge posed by bacterial resistance to antibiotics.

The essential oils derived from Ginger and Phlai demonstrated notable antibacterial activity against *P. acnes* DMST 14916. The Ginger and Phlai essential oils, when administered at concentrations of 50% V/V, exhibited inhibition zones measuring 15.00±4.58 mm and 13.67±0.58 mm, respectively (Table 1). Furthermore, the clindamycin at a concentration of 50 µg mL^{-1} yielded an inhibition zone of 6.00±1.00 mm (Fig. 2).

Table 1 Inhibition zone of Ginger and Phlai essential oils against *P. acnes* DMST 14916.

Essential oil and antibiotic	Inhibition zone (mm) ± S.D.
Ginger	15.00±4.58
Phlai	13.67±0.58
Positive control: Clindamycin 50 µg mL^{-1}	6.00±1.00
Negative control: 10% Tween 80	0.00

* Mean±S.D.; n = 3

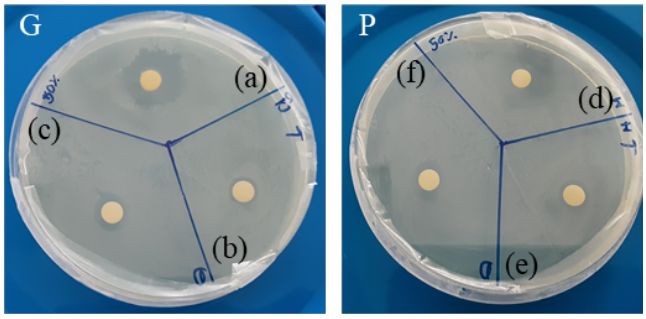

Fig. 2 Inhibitory activity against *P. acnes* DMST 14916 of Ginger (G) essential oil (a), tween 80 (b), clindamycin (c), and Phlai (P) essential oil (d), tween 80 (e), clindamycin (f) using agar disc diffusion method.

The antibacterial activity of Ginger and Phlai essential oils against *P. acnes* was evaluated using Minimum Inhibitory Concentration (MIC) and Minimum Bactericidal Concentration (MBC) assays. The MIC values for both Ginger and Phlai essential oils were found to be 1.56% and 6.25% V/V, indicating that both oils were effective at

inhibiting bacterial growth at these concentrations (Table 2). After streaking cultures from MIC test wells onto BHI agar, the absence of bacterial growth following 72 h of incubation was recorded as the MBC. The MBC values for both Ginger and Phlai essential oils were determined to be 3.12% and 25.00% V/V, respectively (Fig. 3). The findings indicated that Ginger essential oil demonstrated superior antibacterial efficacy when compared to Phlai essential oil, as determined through the MIC and the MBC.

Table 2 Antibacterial activity of Ginger and Phlai essential oils against *P. acnes* DMST 14916.

Essential oil and antibiotic	Concentration (% V/V)	
	MIC	MBC
Ginger	1.56	3.12
Phlai	6.25	25.00
Positive control: Clindamycin 50 µg mL^{-1}	-	-
Negative control: 10% Tween 80	+	+

Note: + growth, - no growth

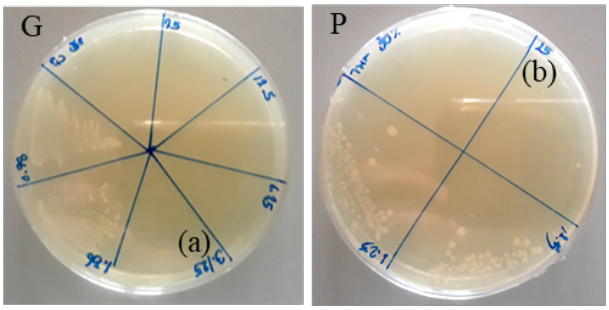

Fig. 3 The Minimum Bactericidal Concentration (MBC) of Ginger (G), 3.12% V/V (a) and Phlai (P), 25.00% V/V (b) showed no visible bacterial growth using the streak plate method.

The essential oil from the rhizomes of Ginger and Phlai is effective in inhibiting the effect and bactericidal activity of *P. acnes*,a gram-positive bacterium commonly found in hair follicles that releases lipase to digest sebum, causing inflammation and acne. According to the MIC and MBC values of this research, it was indicated that Ginger essential oil was more effective than Phlai in inhibiting *P. acnes*.

The antibacterial activity of Ginger essential oil was high when compared to the previous study of Zu *et al*. [24], which determined the antibacterial activity of a commercial Ginger essential oil against *P. acnes* CMCC 65002 by using Broth microdilution with both the MIC and MBC of 0.25% V/V. Moreover, Phlai obtained from steam distillation exhibited the antibacterial activity of Phlai essential oil against *P. acnes* 14916 by using the Agar dilution method with the MIC of 4% V/V. [12]. The above experiment results indicated that both the extraction method and the inhibitory activity test method were correlated with the antibacterial efficacy of the plant essential oils.

In addition, Ginger and Phlai essential oils also provided the inhibitory effects against other normal flora that cause skin infections, including *Staphylococcus epidermidis, Staphylococcus aureus*, *Streptococcus mutans, Escherichia coli*, and *Pseudomonas aeruginosa*, with MICs and MBCs ranging from 50–100 µL mL^{-1} and >100 µL mL^{-1}, respectively, and *Listeria monocytogenes, Staphylococcus aureus, Escherichia coli* 0157:H7*, Salmonella* Typhimurium*,* and *Pseudomonas aeruginosa*, with MICs and MBCs ranging from 2.30–9.40 µL mL^{-1} and 4.70–18.70 µL mL^{-1}, respectively [7].

Furthermore, Verma *et al*. [5] reported the antibacterial activity of Phlai essential oils against eight pathogenic bacteria (Gram-positive: *Staphylococcus aureus* (MTCC 96), *Staphylococcus epidermidis* (MTCC 435), and *Streptococcus mutans* (MTCC 890); Gram-negative: *Klebsiella pneumoniae* (MTCC 109), *Pseudomonas aeruginosa* (MTCC 741), *Escherichia coli* (MTCC 723), *Escherichia coli* (DH5α), and *Salmonella* Typhimurium (MTCC 980), with MICs ranging from 125–500 µg mL^{-1}.

Essential oils inhibit bacteria through their hydrophobic constituents, which integrate into the lipid bilayer of bacterial cell walls. This disrupts membrane integrity, causing uncontrolled permeability and cell death [25]. Moreover, Phlai essential oil exhibits potent antibacterial activity against six extensively drug-resistant (XDR) strains of *Acinetobacter baumannii*, an opportunistic pathogen associated with hospital-acquired infection, with MIC of 5 mg mL^{-1}. It also exhibited synergistic effects in combination with various antibiotic classes, including aminoglycosides, tetracyclines, fluoroquinolones, and folate pathway inhibitors. Furthermore, it demonstrates inhibitory effects against opportunistic pathogens, including *Pseudomonas aeruginosa, Staphylococcus aureus, Candida albicans,* and *Cryptococcus neoformans* [26]. The findings may serve as a basis for the development of alternative strategies to inhibit other antibiotic-resistant microorganisms.

On the other hand, Ginger essential oil exhibited the antifungal activity against *Aspergillus niger* PTCC (Persian Type Culture Collection) 5154*, Aspergillus fumigatus* PTCC 5009*, Aspergillus flavus* PTCC 5004*, Aspergillus ochraceus* PTCC 5017*, Penicillium citrinum* PTCC 5304*,* and *Penicillium chrysogenum* PTCC 5271 [27]. Phlai essential oil exhibited antifungal activity against *Candida albicans* (ATCC 14053) and *C. albicans* (MTCC 1637), with MIC 250 µg mL^{-1} [5].

The chemical constituents present in the essential oils of Ginger and Phlai were elucidated utilizing gas chromatography-mass spectrometry (GC-MS) techniques. The analytical of GC-MS chromatogram are presented in Table 3 and Fig. 4, 17 distinct chemical constituents in varying concentrations within the Ginger essential oil, with the three predominant constituents identified as 1,8-cineole (13.95%), geranial (13.49%), and zingiberene (11.04%) along with Neral (9.52%), β-bisabolene (6.31%), α-curcumene (6.10%), β-sesquiphellandrene (4.81%). The Phlai essential oil demonstrated the presence of 11 chemical constituents (Table 4). The first three significant chemical constituents

identified were sabinene (50.83%), terpinene-4-ol (17.08%), and (*E*)-1-(3,4-dimethoxyphenyl) butadiene (DMPBD) (5.19%), γ-terpinene (5.04%). The chemical compositions detected in Phlai essential oil were also markedly distinct from those of Ginger essential oil.

The chemical constituents and quantities of Ginger essential oil identified in this investigation significantly differed from prior research. Kamal *et al*. [28] analyzed essential oils extracted from fresh ginger rhizomes cultivated in Thailand, which revealed 19 chemical constituents and predominant constituents, including Ar-curcumene (15.57%), eucalyptol (9.06%), and 3-carene (8.63%), markedly distinct from the ginger samples sourced from China. China's fresh ginger rhizomes exhibit 34 chemical constituents. The predominant constituents include curcumene (8.69%), limonene (8.58%), and camphene (7.68%). The sample pre-treatment (fresh, oven-dried,
sun-dried) influenced both the varieties and relative abundances of active chemicals. In contrast, Kiran *et al.* [29] indicated that fresh rhizomes from Northeast India were primarily composed of zingiberene (22.06%), geranial (11.21%), and camphene (9.52%). These findings indicate compositional variation by origin and processing. The variation in active substances appears to be associated with differences in the cultivation environment.

However, Ginger contains an extensive array of bioactive constituents, including both phenolic and terpene compounds [30, 31]. The major phenolic compounds found in ginger are predominantly gingerols, shogaols, and paradols. The primary polyphenolic constituents in fresh ginger are comprised of 6-gingerol, 8-gingerol, and 10-gingerol. Other phenolic constituents identified in ginger encompass quercetin, zingerone, gingerenone-A, and 6-dehydrogingerdione [32]. Moreover, terpenes are recognized as the principal constituents in ginger essential oils, which consist of β-bisabolene, α-curcumene, zingiberene, α-farnesene, and β-sesquiphellandrene [33].

Additionally, the principal chemical constituents of Phlai oil established in this research were sabinene (50.83%), terpinene-4-ol (17.08%), (*E*)-1-(3,4-dimethoxyphenyl) butadiene (5.19%), γ-terpinene (5.04%), and α-terpinene (2.83%).
This differs from the identification of active components in Phlai essential oil obtained from other provinces in northeastern Thailand, where the primary chemical constituents were determined to be sabinene (38.52%), terpinene-4-ol (19.98%), sabinene hydrate (5.22%), ρ-cymene (2.49%), β-mycrene (2.23%), and terpinyl acetate (2.00%) [34]. In addition, Wang *et al*. [35] reported that the fresh Phlai rhizomes in Yunnan of China consisted of primary chemical constituents including sabinene (48.14%), terpinene-4-ol (0.26%), γ-terpinene (6.74%), α-terpinene (4.31%), β-thujene (3.44%), and α-phellandrene (2.73%). These findings reveal the variability in both the quantity and types of chemical constituents present in the essential oils of these two botanical specimens, which are likely influenced by maturity at harvest, growth conditions, and the geographic location of cultivation [36].

Ginger and Phlai are botanical species that are amenable to global cultivation, particularly in regions such as India, China, and Australia. The variation in types and concentrations of chemical constituents within Ginger and Phlai exhibits significant disparities based on geographical location [13, 37, 38], indicating that both the cultivation locale and agricultural practices may exert influence on the type and quantity of chemical constituents, as well as the antibacterial properties of the phytochemicals present in these plants. Sunlight exposure and cultivation duration critically influence essential oil composition and antioxidant activity [39].

1,8-cineole is the predominant constituent that was found in Ginger in this research. This chemical was also called eucalyptol and is dominantly found in several aromatic plants [40]. 1,8-cineole has been documented to inhibit a variety of Gram-positive bacteria, including *Staphylococcus aureus* (PTCC1431), Methicillin-resistant *Staphylococcus aureus* (MRSA), *Streptococcus pyogenes, Micrococcus flavus*, and Gram-negative bacteria, including *Escherichia coli* O157:H7*, Klebsiella pneumoniae, Pseudomonas aeruginosa,* and *S.* Typhimurium [41–46]. 1,8-cineole could inhibit biofilm formation and reduce the pathogenicity of bacteria [42, 45] and also increase the permeability of the bacterial cell membrane, causing ion leakage and cell death. [47]

Sabinene was identified as the major constituent of Phlai essential oil, reaching a maximum of 50.83%. However, Terpene compounds, including sabinene, α-terpinene, α-pinene, and α-terpinolene, exhibited weak antibacterial activity against Methicillin-Susceptible *S. aureus* (MSSA) and Methicillin-Resistant *S. aureus* (MRSA) with MICs ranging from 1,024–2,048 μg mL^{-1} [48]. Although Park *et al*. [49] investigated the inhibitory effects of sabinene on *Streptococcus mutans* growth, Sabinene exhibited inhibitory effects on bacterial growth and adhesion, resulting in inhibition of the biofilm formation of bacteria.

Nevertheless, the antibacterial activity of essential oils may be due to the synergistic effect of all compounds in the essential oil. As reported, the potency of plant extracts may be lost when separated, or in some plant essential oils, the secondary compounds may have synergistic effects and be more effective than the predominant constituent. Bassolé & Juliani [50] reported that the combination of phenolic monoterpenes and phenylpropanoids, including the combination of 1,8-cineole and aromadendrene, α-pinene and linalool, and linalool and terpinene-4-ol, results in the enhancement of antimicrobial efficacy of essential oil. Accordingly, essential oils from Ginger and Phlai from Loei Province constitute promising bioactive alternatives for antibacterial applications against human pathogens. Moreover, their development can be advanced by integrating scientific evidence with indigenous knowledge to formulate Thai herbal cosmeceutical products, maximizing the utility of plant essential oils.

Table 3 Chemical components of Ginger (*Z. officinale*) extracted from fresh rhizome.

Components	Retention time (RT)	Area (%)
1,8-cineole	8.733	13.95
geranial	16.778	13.49
zingiberene	23.838	11.04
camphene	6.325	10.20
neral	15.746	9.52
β-bisabolene	24.200	6.31
α-curcumene	23.430	6.10
β-sesquiphellandrene	24.660	4.81
α-pinene	5.918	3.49
borneol	13.114	1.86
β-myrcene	7.500	1.54
α-terpineol	13.960	1.15
linalool	10.929	1.0
geraniol	16.140	0.83
nerolidol	25.796	0.40
eudesmol	28.259	0.27
ar-tumerone	28.660	0.16

Table 4 Chemical components of Phlai (*Z. purpureum*) extracted from fresh rhizome.

Components	Retention time (RT)	Area (%)
sabinene	7.06	50.83
terpinene-4-ol	13.59	17.08
(*E*)-1-(3,4-dimethoxyphenyl) butadiene (DMPBD)	27.73	5.19
γ-terpinene	9.59	5.04
α-terpinene	8.25	2.83
α-pinene	5.90	2.43
β-sesquiphellandrene	24.63	2.25
α-terpinolene	10.53	0.91
α-thujene	5.72	0.80
α-terpinyl acetate	19.22	0.27
zingiberene	23.78	0.25

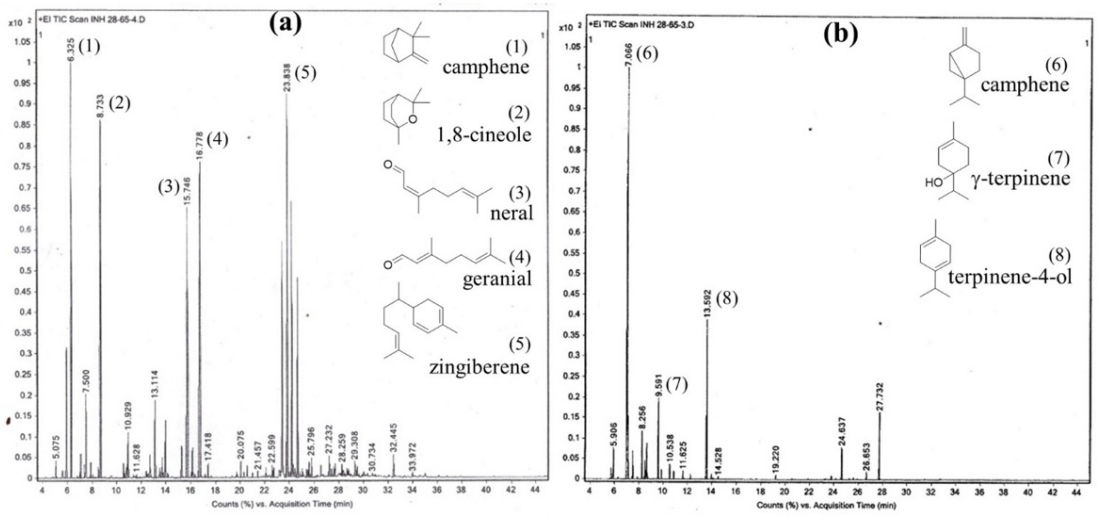

Fig. 4 GC-MS chromatograms showing the chemical constituents of essential oils extracted from Ginger (*Z. officinale*) (a) and Phlai (*Z. purpureum*) (b).

4. Conclusion

The essential oils demonstrated significant antibacterial activity against *Propionibacterium acnes*, the bacterium responsible for acne. Ginger oil exhibited a Minimum Inhibitory Concentration (MIC) of 12.5 mg mL^{-1} and a Minimum Bactericidal Concentration (MBC) of 25 mg mL^{-1}, while Phlai oil showed MIC and MBC values of 48.75 mg mL^{-1} and 195 mg mL^{-1}, respectively. The essential oils extracted from Ginger and Phlai were found to contain the predominant components 1,8-cineole (13.95%) and sabinene (50.83%), respectively. These results indicate that both essential oils, particularly Ginger oil, possess effective antibacterial properties and may serve as natural alternatives to synthetic antibiotics.

The study confirms the potential of Thai medicinal plants as sources of bioactive compounds for dermatological applications. In addition to their therapeutic benefits, the use of locally sourced herbal materials supports the development of natural, sustainable skincare products. Looking ahead, the findings provide a scientific foundation for community-based innovation, enabling the transformation of indigenous herbal knowledge into value-added commercial products. This approach promotes the sustainable use of natural resources and aligns with the principles of Creative Science by encouraging grassroots entrepreneurship and health-oriented local industries.

5. Suggestions

5.1 Development of Thai herbal cosmeceutical products from Ginger and Phlai , along with evaluation of the antibacterial activity of the formulated products.

5.2 Investigation of the antibacterial properties of other Zingiberaceae family plants indigenous to Loei Province.

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7. Declaration of generative AI in scientific writing

AI techniques were utilised for enhancing readability and language quality.

8. Credit author statement:

Pornchanok Boonlub: Conceptualization; Methodology; Writing-Original draft preparation; Visualization; Writing - Reviewing and Editing.

Bunliang Suphim: Methodology; Data curation; Investigation; Visualization.

Kiti Tanmuangpak: Conceptualization; Validation.

Piyapong Choomsri: Data curation; Supervision.

Napatsorn Wongpriaw: Methodology; Data curation; Investigation.

9. Research involving human and animal rights

Not applicable

10. Ethics Approval and Consent to Participate

Not applicable

11. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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