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Bioactive compounds of *Chloranthus officinalis* are successfully characterised as potential dengue antivirals

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ABSTRACT

While *Chloranthus officinalis*, a medicinal plant has been widely used in Rinjani Mountain National Park, its bioactive compounds have not yet been characterised. This study aims to characterise the bioactive compounds of *C. officinalis*. Biocative compounds from *C. officinalis* were extracted with 96% ethanol and analysed by GC-MS; further analysis using Toxtee software was used to determine toxic activity. There were 18 bioactive compounds in *C. officinalis*, five of them (quercetin, terpinen-4-ol, δ-cadinene, α-cadinol, and viridiflorol) have potential candidate dengue antivirals. The toxicity level of Quercetin, Terpinene-4-ol, and Viridiflorol are in class 3 (LD50 values 1500-2000 mg/kg), while δ-cadinene and α-Cadinol are class 4 (LD50 2500-5000 mg/kg). Five potential bioactive compounds in *C. officinalis* have antiviral activity against dengue fever. Overall, these findings indicate that *C. officinalis* contains bioactive compounds with a favourable safety profile for oral consumption, supporting its use in traditional medicine.

Keywords: Bioactive compound, *Chlorantus officinalis*, in-silico, toxicity activity

INTRODUCTION

Dengue virus (DENV) infection is experiencing an outbreak in Indonesia (Alenou et al., 2023; Sazali et al., 2024). According to a World Health Organization report, there has been a dramatic increase in dengue cases in recent years. There are 390 million cases of DENV infection worldwide every year (World Health Organization, 2022). DENV infection causes dengue fever and a high fatality rate. The availability of specific treatments in some areas exacerbates the condition (Sabir et al., 2021). Therefore, developing new antiviral drug candidates is essential.

The study of plants as drug candidates is the focus of growing research (Khoirunnisa & Subarnas, 2023; Salleh et al., 2021). The beberas plant (*Chlorantus officinalis*) is known in traditional medicine around Mount Rinjani National Park (TNGR). *C. officinalis* is a source of antioxidants and bioactive compounds that have the potential to inhibit the growth of bacteria and viruses. Traditionally, *C. officinalis* has been utilised as a fever reducer and anti-inflammatory. According to Rianto et al., (2015) Sembalun community has widely used *C. officinalis* during the COVID-19 pandemic to prevent disease infection (Aini et al., 2025).

The potential of drugs derived from renewable plant materials of *C. officinalis*. The bioactive compounds were known as potential candidates for antiviral drugs, such as quercetin and terpinen-4ol (Salleh et al., 2021; Salim et al., 2023). These compounds exhibit antiviral activity with promising potential as a basis for developing antiviral agents for the treatment of dengue. Previous studies have examined these bioactive compounds based on phytochemical

and computational approaches. Quercetin and tervenol-4-ol have inhibited replication and disrupted dengue virus infection in host cells.

Quercetin and terpinen-4-ol were bioactive compounds with antiviral properties (Sudirman et al., 2016). The ability of terpinen-4-ol to combat specific microorganisms highlights the importance of researching plant-derived compounds in the fight against infectious diseases, such as dengue fever (Sudirman et al., 2016). Therefore, the bioactive compounds were expected to inhibit dengue virus infection, thus having the potential to be developed as antiviral drug candidates.

Despite traditional medicinal use and ethnobotanical recognition, the genus *Chloranthus* were identified as containing 418 compounds (Liu et al., 2022). However, the study did not investigate the role of bioactive compounds from C. officinalis as potential dengue antivirals. Therefore, this research focuses on the phytochemical testing of *C. officinalis* bioactive compounds, including toxicity activity. This study aims to identify bioactive compounds in *C. officinalis* that have potential as drug candidates for dengue fever.

METHOD

Sample collection and identification

Samples of *C. officinalis* were randomly collected from Sembalun Forest, Mount Rinjani National Park. The expedition was conducted in October 2024. *C. officinalis* was found at elevations ranging from approximately 870 to 1,390 meters above sea level, with temperature and humidity conditions around 22°C ± 2°C and 77%, respectively (Syahputra, 2020).

Identification of *C. officinalis* based on clarifying the plant species. The local community recognises *C. officinalis* as "beberas". Additional identification of *C. officinalis* involved examining the morphology of the plant's leaves, stems, and roots. The identification was determined based on the medicinal plant book from TNGR (Rianto et al., 2015). The additional identification of *C. officinalis* involves direct examination by the expert team from TNGR. The *C. officinalis* was approximately 3 kg of leaves, stems, and roots for extraction.

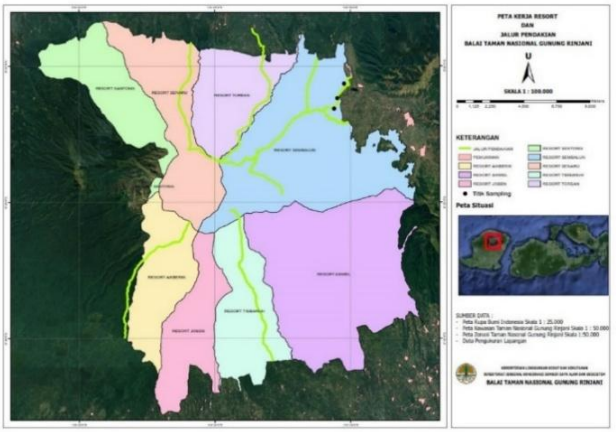


Figure 1. The sampling location for *Chloranthus officinalis* in the Sembalun Forest Area, East Lombok.

Sample preparation

All fresh plant parts were thoroughly cleaned before being finely chopped, crushed, and ground. Approximately 500 g of macerated sample powder was prepared for extraction. The total dry weight of the sample powder was obtained from oven drying at 50°C for 4 days. The sieving process yielded approximately 824 grams of leaf simplicia, 815 grams of stem simplicia, and 432 grams of root simplicia. The maceration process required approximately 500 grams each for the leaves and stems, and around 250 grams for the roots.

Sample extraction

The extraction process begins with ethanol maceration at room temperature. Approximately 500 grams of simplicia from the leaves and stems are dissolved in 750 mL of 96% ethanol. Around 250 grams are needed for the roots, using 500 mL of 96% methanol as the solvent. The maceration process is conducted for 4 cycles of 24 hours each. The macerated solution is then filtered to obtain the filtrate and residue. The filtrate was concentrated using a rotary evaporator. Extractions were carried out at a pressure of 75 mbar at a temperature of 45°C. The extract solution is ensured to be ethanol-free.

Qualitative phytochemical analysis of *C. officinalis*

Alkaloid Assay: qualitative tests designed to identify alkaloids within a sample. Initially, the sample was extracted with methanol solvent. Tests of the extract solution revealed a solution rich in alkaloids. A method involves treating the solution in a test tube with specific reagents, including Mayer's, Wagner's, and Dragendorff's. These reagents interact with alkaloids, producing distinct colour changes: Mayer's reagent yields a creamy white precipitate, Wagner's reagent forms a reddish-brown precipitate, and Dragendorff's reagent produces an orange-to-red precipitate (Ciuca & Racovita, 2023).

Flavonoid Assay: The sample extract is solubilized in 3 mL of methanol in a test tube for 2 minutes. The resultant solution is subsequently transferred to another test tube. A strip of magnesium metal is then introduced, followed by three drops of concentrated hydrochloric acid (HCl). The presence of flavonoids is confirmed by the appearance of a reddish colouration in the solution (Dymek & Mroczek, 2021).

Steroid Assay: The sample is extracted with 3 mL of chloroform in a test tube for approximately 2 minutes. The extract is then transferred to another test tube. Two mL of concentrated sulfuric acid (H_2SO_4) is carefully added along the side of the test tube. The formation of a reddish-brown ring at the interface of the two phases, which turns red, indicates the presence of steroids (Utami et al., 2024).

Volatile compound analysis of *C. officinalis*

Gas chromatography-mass spectrometry (GC-MS) was used to identify volatile compounds. The ethanol extract was evaporated using a rotary evaporator until a concentrated, solvent-free filtrate was obtained, which appeared greenish-black for the stems and reddish-brown for the roots. The final ethanol extract was fractionated and yielded 5 mL of hexane fraction (Jogdand et al., 2022).

A hexane fraction sample was required to analyze volatile compounds. The chromatography instrument used GC-MS HP 6890 system. The sample was injected into a capillary-type GC-MS column, model number Agilent 19091S-433 HP-5MS 5% Phenyl Methyl Siloxane with a length of 30 meters, an inner diameter of 250 µm, and a film thickness of 0.25 µm. The oven temperature is set between 100-220°C. The temperature ramp rate is 15°C per minute, and the flow rate is 1.0 mL per minute. Helium gas, pressurized at 10.5 psi with a flow rate of 140 mL per minute and a split ratio of 1:50, is used to propel the volatile compounds of the sample.

In silico analysis of toxicity and Lethal Dose-50 (LD50)

The toxicity parameters of bioactive compounds were analyzed to determine the safety of the drug candidates for oral and dermal use. ADME (Absorption, Distribution, Metabolism, and Excretion) analysis was conducted virtually using the swissADME free access server (http://www.swissadme.ch/index.php) (Tahya & Karnelasatri, 2021). This server can analyze parameters such as physicochemical properties, lipophilicity, water solubility, pharmacokinetics, drug-likeness, and medicinal chemistry.

In this study, a toxicity assay was performed using the ProTox web server and Toxtree software. The ProTox web server freely predicts multiple toxicity endpoints for a specific compound, including acute toxicity, hepatotoxicity, carcinogenicity, cytotoxicity, immunotoxicity, mutagenicity, and specific pathogen toxicity targets.

RESULTS AND DISCUSSION

Ethnobiological study of *C. officinalis*

Samples of *C. officinalis* were obtained from the vicinity of the hiking trails on Mount Rinjani. Locally known as "Beberas," this plant is believed

to possess medicinal properties according to ethnobiological knowledge. It is traditionally used to alleviate fever, pain, and infections. Information from the local community around Mount Rinjani National Park indicates that *C. officinalis* played a crucial role in defending against viral infections during the COVID-19 pandemic (Katha & Begum, 2021).

C. officinalis is processed as a traditional medicinal remedy, typically prepared as a tea. In specific cases, people experience high fever, abdominal pain, or wound infections, the remedy involves boiling one, three, or five fresh leaves. However, *C. officinalis* is important to avoid using in large amounts or continuously, as it can lead to dizziness if taken excessively and frequently (Oktavia et al., 2020). Consequently, a precise safe dosage for human consumption has not yet been established.

C. officinalis is a shrub species that extensively covers the forest floor. The morphological structure of this plant resembles that of herbaceous species because the entire stem—from the apex to the root—is enveloped in green epidermal tissue. However, the plant possesses a relatively rigid woody structure composed of cellulose, lignin, and various hemicelluloses.

The leaves of *C. officinalis* are categorized as pinnately veined with pointed tips, it's measure approximately 15–19 cm in length and 5–6 cm in width. The entire stem of the plant is covered by green epidermal tissue. A distinctive feature of this species is its stem, which possesses prominent nodes. The roots of *C. officinalis* are fibrous and serve an additional role as pathways for shoot development during vegetative growth.

C. officinalis emits a distinctive aroma from all parts. The essential oil's aroma intensifies significantly when the leaves are crushed, producing a dark green liquid. Due to the aroma, the local community traditionally utilizes *C. officinalis* as an ingredient in beverages. The stems also have the same aroma as the leaves, although it is not as strong as the aroma of the crushed leaf. This is because the plant's stems are composed of wood and cork tissue in the central part of the stem.

Figure 2. *C. officinalis* was obtained from the Sembalun Forest, Mount Rinjani National Park. The characteristic features of *C. officinalis* include prominent nodes on the stems and all boundary epidermis covered in green.

The roots of *C. officinalis* exhibit a distinctive camphor-like odour. Therefore, the local population has not extensively utilised the roots for beverages or traditional medicines. Superficially, the roots exude a calming, spice-like aroma. Additionally, the roots of *C. officinalis* can play a role in vegetative propagation, as evidenced by the emergence of new shoots at the root tips on the forest floor.

Bioactive compound in *Chloranthus officinalis*

Qualitative phytochemical analysis of *Chloranthus officinalis* was performed using reagent color indicators. The study identified various compounds, including alkaloids, flavonoids, polyphenols, saponins, terpenoids, steroids, and tannins. These naturally occurring chemicals are known for their antioxidant properties, maintaining and preventing cellular metabolic disorders. The phytochemical tests indicated that *Chloranthus officinalis* contains several types of secondary metabolites, as detailed in Table 1.

Table 1. Qualitative phytochemical analysis of *Chloranthus officinalis.*

Secondary Metabolites	Reactant	Parameter		
		Leaf	Stem	Root
Alkaloid	Mayer	++	-	-
	Wagner	+	-	-
	Dragendroff	+	-	-
Flavonoid	HCl high concentration + magnesium powder	+++	++	+++
Steroid	Klorofom+ Asetat Anhidrida and H_2SO_4 high concentration	++	+	+

Explanation:
- : Not detected
+ : Weakly detected
++ : Moderately detected
+++ : Strongly detected

The phytochemical test results indicated variations in the secondary metabolites present in *C. officinalis*. The alkaloid test was positive when all reagents were used, whereas no alkaloids were detected in the stem and root samples with three specific reagents. Alkaloid reaction in the phytochemical assay of the extract was evidenced by a change in color to orange. Alkaloids are recognized as secondary metabolites that can serve as antimicrobial and antifungal agents (Oktavia et al., 2020; Heinrich et al., 2021). Numerous studies have shown that alkaloids can act as RNA antivirals. Alkaloids interact with the ACE2 receptor, preventing viruses from attaching to and entering human cells (Leka et al., 2026; Yamin et al., 2024).

Flavonoids were identified using a high-concentration HCl reagent and magnesium powder. The flavonoid test results showed a colour change to yellow, orange, or red. The extract of the plant *C. officinalis* yielded a positive. The result was evidenced as an orange colouration. This indicator is attributed to the reduction of the benzopyrone nucleus present in the flavonoid structure (Dias et al., 2021; Zandavar & Babazad, 2023). The beneficial properties of flavonoid compounds include antioxidant, antimicrobial, and anticancer activities. As antioxidants, flavonoids are capable of scavenging free radicals that damage cellular structures (Roy et al., 2022; Shamsudin et al., 2022). The important role of flavonoids was demonstrated in NS4B-receptor binding. Therefore, flavonoids in *C. officinalis* have the potential to inhibit flavivirus infections, including dengue virus.

Volatile compounds of *C. officinalis*

The hexane fractionation extract of *C. officinalis* was processed to test specific bioactive compounds, a volatile compound analysis approach using GC-MS (Jogdand et al., 2022; Georgieva et al., 2022). The GC-MS analysis revealed approximately 28 bioactive compounds. However, not all bioactive compounds were fully detected in the instrument library. Therefore, 21 bioactive compounds were detected, as indicated on the chromatogram.

All compounds were transformed into constituent compounds for analysis as potential drug candidates. Screening of the 21 compounds identified in the GC-MS analysis was conducted only on those with a Peak Report TIC value (peak area) above 1% (Shah et al., 2021). Based on Table 2, 18 compounds meet the standard of peak area above 1%.

Table 2. GC-MS compound identification

Peak Report TIC				
Peak	R. Time	Constituent Compounds	Molecular Weight (gr/mol)	High Area (%)
1	10,696	α-Pinene	166.22	2.1
2	10,825	Germacrene D	210.39	8.5
3	11,33	Bicyclogermacrene	204.35	2.6
4	11,377	Terpinen-4-ol*	154.24	16.1
5	11,464	δ-Cadinene*	204.18	7.8
6	11,527	α-Terpineol	154.24	1.2

Peak Report TIC				
Peak	**R. Time**	**Constituent Compounds**	**Molecular Weight (gr/mol)**	**High Area (%)**
7	11,668	α-Calacorene	200.32	1.5
8	11,75	δ-Elemene	204.18	1.2
9	11,835	Germacrene B	204.35	8.6
10	11,928	α-Cubebene	204.35	1.2
11	11,985	Elemol	222.36	2.1
12	12,225	Spathulenol	220.35	1.2
13	12,296	Caryophyllene oxide	220.35	7.2
14	12,365	β-Elemene	-	1.8
15	12,495	Quercetin*	254.23	6.8
16	12,545	β-Caryophyllene	-	3.2
17	12,591	Viridiflorol*	222.37	5.8
18	14,684	α-Cadinol*	222.36	8.5

GC-MS analysis of the *C. officinalis* revealed several important compounds as potential drug candidates. The category of drug candidate compounds based on GC-MS analysis includes those with different retention times (Wahyuni et al., 2022), characterized by molecular weights below 300 g/mol, chromatogram peak heights around 200,000, and peak areas above 1%. These GC-MS analysis criteria identified five candidate drug compounds: quercetin, terpinen-4-ol, δ-cadinene, α-cadinol, and viridiflorol.

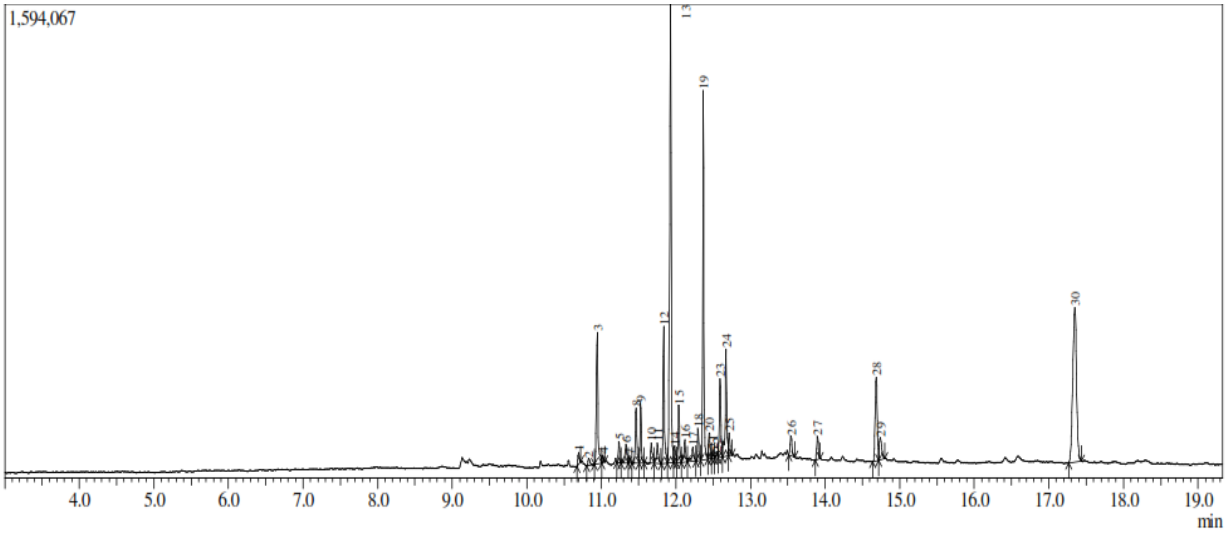
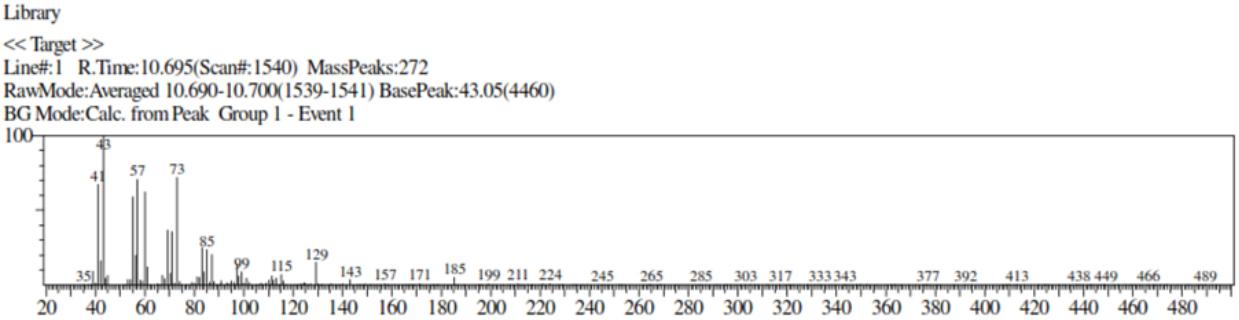
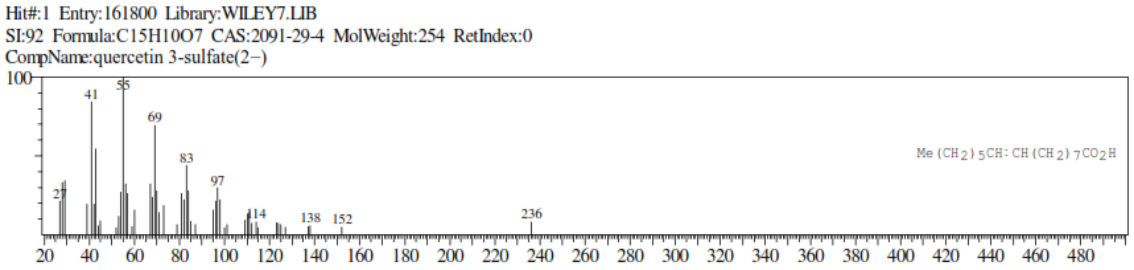


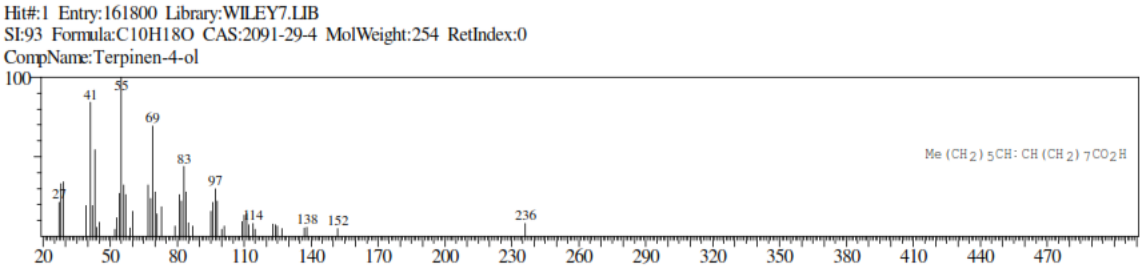
Figure 3. Chromatogram of GC-MS analysis of *C. officinalis* based on hexane fractionation



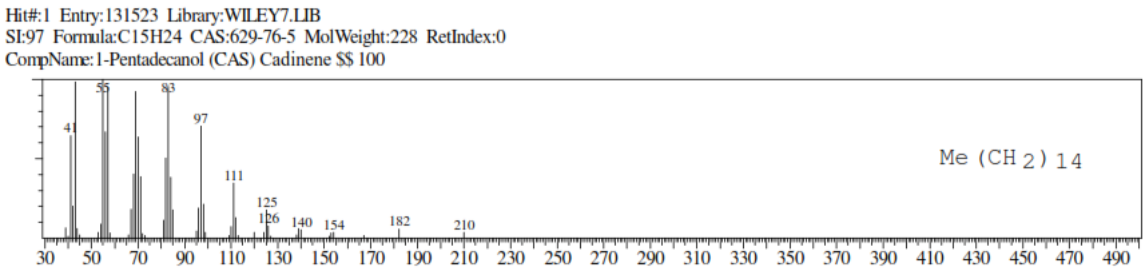
Standard target library instrument



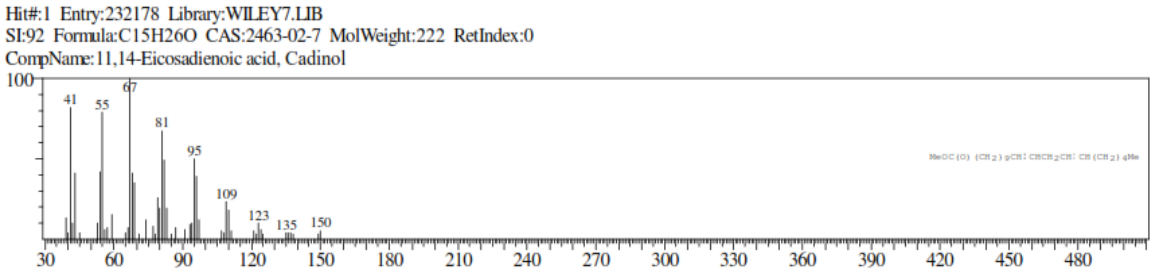
Quercetin



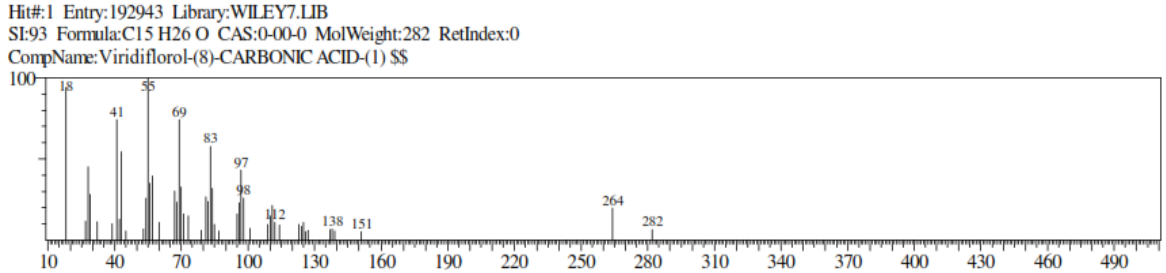
Terpinen 4-ol



Cadinene



Cadinol



Viridiflorol

Figure 4. Target drug candidate compounds adapted to target library chromatography in the *C. officinalis* plant.

Phytochemical analysis of *C. officinalis* extract revealed several secondary metabolite compounds as potential drug candidates (Wulandari et al., 2024). Based on various preliminary tests, secondary metabolites such as alkaloids, flavonoids, and steroids were identified. Alkaloids were found only in the leaves, although the color change was not pronounced. In contrast, flavonoid and steroid compounds were detected in the leaves, stems, and roots. Therefore, the leaves of *C. officinalis* hold significant potential as drug candidates. The results of the phytochemical tests ensure the safety of using this candidate plant as a drug (Ambrose et al., 2022; Chaachouay & Zidane, 2024). The secondary metabolite compounds were further tested for toxicity activity.

Table 3. Bioactive compound screening of *C. officinalis* indicates potential as a source of antiviral drug candidates

R. Time	Constituent Compound	Molecular Weight	Peak Area (%)
11,377	Terpinen-4-ol	254.24 gr/mol	16.1
11,464	δ-Cadinene	204.18 gr/mol	11.8
12,495	Quercetin	254.23 gr/mol	6.8
12,591	Viridiflorol	222.37 gr/mol	5.8
14,684	α-Cadinol	222.36 gr/mol	8.5

Five candidate drug compounds are known to have molecular weights below 300 g/mol; the smaller the molecular weight, the greater the likelihood that the compound will efficiently reach cellular targets (Rupa et al., 2017). The peak area indicates values above 1%, showing that these five bioactive compounds are present in significant concentrations in the sample. Chromatogram peaks reach 200,000 mV, and the bioactive compounds were accurately at GC-MS instrument. Therefore, molecular screening meets the criteria for candidate drug compounds. *C. officinalis* was developed as a therapeutic agent against the dengue virus.

GC-MS analysis of *C. officinalis* detected quercetin, which is likely to contribute as an antioxidant and antimicrobial agent. Several compounds possess antifungal and antibacterial capabilities. Screening specific compounds is expected to inhibit viral activity in human infections; bioactive compounds have been obtained from *C. officinalis*, as shown in Table 2.

GC/MS analysis of the *C. officinalis* extract in this study revealed the presence of quercetin, terpinen-4-ol, δ-cadinene, α-cadinol, and viridiflorol. Compared to other flavonoids, quercetin significantly inhibited the DENV NS2B-NS3 protease and prevented DENV-2 virion assembly. Quercetin formed a total of six hydrogen bonds with key residues—Ala164, Asn152, Lys74, Asn167, Leu149, and Gly87 (Salim et al., 2023; Thagriki, 2022).

Quercetin inhibits viral replication by targeting viral enzymes, such as the NS2B-NS3 protease and the RNA-dependent RNA polymerase (RdRp) (Renantha et al., 2022). Quercetin has antioxidant and immunomodulatory properties, reducing pro-inflammatory cytokines that exacerbate dengue infection. Terpinen-4-ol disrupts viral lipid membranes through surfactant activity. It exhibits immunostimulatory and anti-inflammatory effects that can enhance the host's immune response (Hasan et al., 2025). δ-Cadinene is lipophilic, allowing interaction with the viral membrane and disrupting virus-cell fusion. Potential as a viral enzyme inhibitor through hydrophobic interactions. α-Cadinol has antiviral activity through the disruption of viral protein structure. α-Cadinol is anti-inflammatory effects that support the control of excessive immune responses during dengue infection. Viridiflorol is known to have antimicrobial and antiviral activity. This compound is expected to

have the potential to inhibit the adsorption or penetration of viruses into target cells.

In-Silico analysis of toxicity activity and Lethal Dose-50

Natural bioactive compounds were required to undergo a series of standard analyses to be considered safe drug candidates. The initial evaluation involves assessing the properties of ADME (Absorption, Distribution, Metabolism, and Excretion)(Sutapa et al., 2018). This analysis aims to determine the pharmacokinetic profile of the drug candidate compound.

The study conducts an ADME analysis to evaluate the pharmacokinetic profiles of bioactive compounds. Virtual ADME predictions are performed using the freely accessible SwissADME tool (http://www.swissadme.ch/index.php). This server enables comprehensive analysis and prediction of several essential pharmacokinetic parameters, including physicochemical properties, lipophilicity, water solubility, pharmacokinetics, drug-likeness, and aspects of medicinal chemistry.

Table 4. ADME profile of bioactive compounds of the plant *C. officinalis*

Bioactive Componds	ADME Profile			
	Lipophilicity	Solubility	Pharmacokinetics	Druglikeness
Quercetin	1.63 iLOGP	-3.16 ESO	High	Fulfilled
Terpinen-4 ol	2.51 iLOGP	-2.78 ESO	High	Fulfilled
δ-Cadinene	3.34 iLOGP	-4.54 ESO	Low	Fulfilled
α-Cadinol	3.15 iLOGP	-3.26 ESO	High	Fulfilled
Viridiflorol	3.11 iLOGP	-3,57 ESO	High	Fulfilled

Based on the SwissADMET assay, the candidate drug compounds were found to have molecular weights less than 500 g/mol; quercetin has shown the highest molecular weight at 302.24 g/mol. This indicates that the candidate drug compounds in this study meet the standard molecular weight criteria for drugs (Kamble & Mitkar, 2023). Additionally, the solubility parameter for non-polar compounds was satisfied, with the target lipophilicity below 5 LOGP. The compound δ-Cadinene demonstrated the highest lipophilicity value of 3.34 iLOGP.

Pharmacokinetic and druglikeness parameters were evaluated based on tests of drug candidate compounds under simulated human body conditions (Bitew et al., 2021). Furthermore, the drug candidate compound is ideally expected to exhibit druglikeness similar to common types of drugs. Based on the SwissADME assay, pharmacokinetic parameters indicated that the drug candidate compound was highly suitable for oral administration. The druglikeness parameters of the drug candidate compound demonstrated consistency with common types of drugs for therapeutic applications.

A toxicity assay was conducted using the ProTox Web Server and Toxtree software. The ProTox web server predicts various toxicity endpoints for specific compounds, including acute toxicity, hepatotoxicity, carcinogenicity, cytotoxicity, immunotoxicity, mutagenicity, and target toxicity toward specific pathogen types (Rizkuloh et al., 2021). Toxicity testing of *Chloranthus officinalis* is necessary to ascertain safe dosages and toxicity thresholds within the human body. Based on the toxicity assays from the ProTox web server, it can be confirmed that several target compounds are well-tolerated by vital organs, as demonstrated in Table 5.

Table 5. Validation LD50 accuracy for *C. officinalis* was performed using the ProTox predictive approach.

Compunds	Formulala	LD50 mg/kg	Toxicity Class	Accuracy
Quercetin	$C_{15}H_{10}O_7$	1590	4	100%
Terpinen-4 ol	$C_{10}H_{18}O$	1016	4	100%
δ-Cadinene	$C_{15}H_{26}$	5000	3	91.83%
α-Cadinol	$C_{15}H_{26}O$	2830	3	96.55%
Viridiflorol	$C_{15}H_{26}O$	2000	4	81.25%

The interpretation of LD50: A lower LD50 value indicates that a compound is more toxic in the human body. In contrast, a higher LD50 value implies that the compound is safer for development as a drug candidate. According to Table 4, quercetin, terpinene-4-ol, and viridiflorol are classified as class 4, with LD50 values ranging between 1500-2000 mg/kg. In contrast, δ-cadinene and α-cadinol are classified as class 3, exhibiting LD50 values ranging from 2500-5000 mg/kg.

The Protox web server analysis indicates that the toxicity of the five candidate drug compounds remains within safe limits for oral consumption. The standardized LD50 values are considered safe, as they exceed the 200–300 mg/kg body weight threshold specified in Annex 2c: OECD/OCE and prediction of acute toxicity (LD50) for Novichoks (Noga et al., 2023) Consequently, the compounds from *C. officinalis* are deemed safe for development as oral drug candidates based on an in-silico approach.

This study was limited to in silico toxicity screening of phytochemicals derived from *C. officinalis*. Ligand–protein binding interactions were not presented. The research focused solely on toxicity assessment of compounds identified through phytochemical profiling and GC–MS analysis. Therefore, the predictive nature of the in silico approach cannot yet be considered a substitute for biological validation.

CONCLUSION

Phytochemical analysis of *Chloranthus officinalis* revealed a significant presence of bioactive and antioxidant compounds, including alkaloids, flavonoids, and steroids. The analysis results demonstrated the presence of bioactive compounds, including quercetin, terpinen-4-ol, δ-cadinene, α-cadinol, and viridiflorol. Based on bioinformatics predictions, these bioactive compounds exhibit a preliminary safety profile as potential drug candidates. Their LD50 values fall within the established threshold, specifically around 200–300 mg/kg. For instance, quercetin, terpinene-4-ol, and viridiflorol show LD50 values of 1500-2000 mg/kg. In contrast, δ-cadinene and α-cadinol demonstrate significantly higher LD50 values, around 2500-5000 mg/kg. Lipophilicity and drug-likeness analyses reveal that the characteristics of these bioactive compounds are similar to those of existing drugs.

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