BIODIVERSITAS
Volume 25, Number 10, October 2024
Pages: 3442-3453

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d251006

GC-MS analysis of bioactive compounds in ethanolic extract on different parts of *Ziziphus mauritiana*

LARBENNO PAULOI, RAFIDAH MD SALIM♥, LIEW KANG CHIANG, MURNI SUNDANG, NOR AZIZUN RUSDI, MANDY MAID, SHIRLEY MARYLINDA BAKANSING, JANSHAH MOKTAR
Wood Chemistry Laboratory, Faculty of Tropical Forestry, Universiti Malaysia Sabah. UMS Road, 88400 Kota Kinabalu, Sabah, Malaysia.
Tel.: +60-88-320-000, ♥email: rafidahs@ums.edu.my

Manuscript received: 4 July 2024. Revision accepted: 6 October 2024.

Abstract. *Pauloi L, Salmim RM, Chiang LK, Sundang M, Rusdi NA, Maid M, Bakansing SM, Moktar J. 2024. GC-MS analysis of bioactive compounds in ethanolic extract on different parts of* Ziziphus mauritiana*. Biodiversitas 25: 3442-3453. Ziziphus mauritiana* Lam., a tropical fruit-bearing tree commonly known as *Bidara* tree in Malaysia, has a long and rich history of use in traditional medicine. Cultures across the globe have utilized various parts of the plant, including its leaves, bark, fruit, and roots, to address a wide range of health issues, such as digestive disorders, skin conditions, and inflammatory ailments. This study aimed to comprehensively analyze the bioactive compounds present in different parts of *Z. mauritiana* using Gas Chromatography-Mass Spectrometry. Ethanolic extracts were prepared from the leaves, bark, stem, root, and fruit of the plant, and their chemical compositions were meticulously analyzed. The GC-MS analysis revealed a diverse array of bioactive chemicals belonging to various chemical classes, including organic acids, esters, silanes, and thiodipropionates. Notably, many of these identified compounds have demonstrated promising antibacterial, antioxidant, anti-inflammatory, and anticancer properties in previous scientific studies. The presence of these bioactive substances provides scientific support for the traditional medicinal uses of *Z. mauritiana* and underscores its potential as a valuable source for developing novel therapeutic agents. Further research is warranted to fully elucidate the individual bioactivities and potential synergistic effects of these compounds, paving the way for harnessing the full therapeutic potential of *Z. mauritiana* for improving human health and well-being.

Keywords: Bioactive compounds, ethanolic extract, GC-MS analysis, *Ziziphus mauritiana*

INTRODUCTION

Ziziphus mauritiana Lam., is a tropical fruit tree belonging to the Rhamnaceae family. In Malaysia, *Z. mauritana* is also known as *Bidara* tree. The genus *Ziziphus* encompasses approximately 40 species of prickly shrubs and small trees, exhibiting a diverse array of characteristics. Some species are deciduous, while others maintain evergreen foliage. This variability allows them to thrive in warm-temperate and subtropical regions worldwide. *Z. mauritiana*, in particular, is known for its resilience and adaptability to challenging environmental conditions, such as drought and salinity (Abubakar 2021). Jailani et al. 2020, also mention that this particular species exhibits a notable capacity to acclimate to unfavorable environmental conditions. These trees can reach heights of up to 15 meters, featuring a sturdy trunk that may surpass 40 centimeters in diameter and cascading branches adorned with stipular spines (Yamini and Panigrahi 2024). Their leaves are glossy green on the upper surface and a lighter shade underneath, with a rounded or slightly notched base. The fruit of *Z. mauritiana* is a small, edible drupe, typically measuring between one to five centimeters in length. The fruit's color can vary from yellow-brown to crimson or black, and it has a globose or rectangular shape (Abdallah 2017; Benidir et al. 2020; Adilah et al. 2023). It is known for its remarkable sweetness, often described as sugary, with a texture and flavor reminiscent of dates (Soraya et al. 2022).

Various parts of *Z. mauritiana*, including its leaves, fruit, roots, and bark, have a long history of use in indigenous ceremonies and traditional medicine. For example, the Malay community uses the leaves for post-mortem rituals, believing they soften the body, strengthen the skin, and slow decomposition (Yusof and Ramli 2021). The fruit and leaves have also been used to address constipation and dandruff (Khan et al. 2015; Prakash et al. 2021). *Z. mauritiana* contains a diverse array of phytochemicals, including berberine, quercetin, kaempferol, sitosterol, and stigmasterol (Yadav et al. 2022). It exhibits various pharmacological properties, such as antioxidant, cytotoxic, antimicrobial, anti-diarrheal, and hepatoprotective effects (Akassh et al. 2020). Studies have also explored its potential sedative, hypotensive, antihyperlipidemic, antihypoxic and hypothermic properties. The plant is abundant in minerals, alkaloids, flavonoids, sterols, tannins, and saponins (Hassan and Abd-Elaziz 2020). Research suggests that *Z. mauritiana* may stimulate hair growth, prevent platelet aggregation, reduce inflammation, promote wound healing, combat obesity, and act as an antibacterial. Regular consumption of *Z. mauritiana* fruit may offer health benefits, such as reducing the risk of cardiovascular disease and metabolic syndrome (Jailani et al. 2020). Despite being underutilized in Malaysia, *Z.*

mauritiana demonstrates therapeutic and dietary promise. *Z. mauritiana* also offers a diverse array of culinary applications. Its sweet and tangy fruit, resembling a miniature apple, is commonly eaten fresh as a snack or incorporated into various desserts such as pies, preserves, and condiments (Rashwan et al. 2020).

The research on *Z. mauritiana* is crucial due to its widespread presence in tropical regions and its introduction to new countries, raising concerns about its potential to become invasive. Studying its ecological adaptability and growth patterns is essential to anticipate and mitigate any ecological impacts. The promotion of *Z. mauritiana* as an underutilized species raises concerns about the potential for further uncontrolled introductions (Maruza et al. 2017). Additionally, recent studies have highlighted its impressive biological activities, such as antioxidant, anti-inflammatory, and anticancer properties. However, there is still limited knowledge about its toxicity, mechanisms of action, and clinical applications, emphasizing the need for further research to explore its medicinal potential. Recent studies on *Z. mauritiana* have primarily focused on its fruit and leaves. However, this study expands the scope by providing detailed information regarding the secondary metabolism element on various parts of *Z. mauritiana*, including the fruit, leaves, stem, bark, and root. It offers crucial insights into the chemical elements present in these different parts, contributing to a more comprehensive understanding of the plant's overall chemical composition.

MATERIALS AND METHODS

Fruit, stems, bark, roots, and leaves were the plant components used. The West Coast Division of Sabah, Malaysia's Tuaran District is where the *Z. mauritiana* materials used in this study were selected: sample 1 (6° 12' 12" N, 116° 13' 52" E), sample 2 (6° 08' 30" N, 116° 13' 07" E) (Figure 1). This species was grown, but the trees that were chosen and the locals were all five years of age or older which is mature enough to bear fruit. The species' taxonomy was determined based on a previous study by Byalt and Korshunov (2021) prior work as a basis. For every genotype, about 200 g of fruits and roots, two resealable, breathable storage bags measuring 20 cm in width by 28 cm in length, and one kg of stem with bark were collected. All collected samples have been transported to the Wood Chemistry Laboratory of Universiti Malaysia Sabah for analysis.

Sample extracts preparation

A range of 2 to 5 centimeters in stem diameter was used to choose mature, healthy stems. Using a hand saw, the medium-sized, healthy branch from another tree was chopped. Using a sharp knife, the branches were chopped to remove the bark. The major taproot was left undisturbed to protect the tree, and the lateral roots which are crucial for nutrient and water absorption were selected. After being sliced into tiny pieces, the bark stems, and roots samples were dried for 48 hours at 60°C in an incubator. The leaves were chosen from the middle and lower parts because they were healthy and devoid of damage, infections, or pests. In the laboratory, tap water was used to wash the leaves. Fruits of *Z. mauritiana* were harvested from the shoots and branches. The sample size of fruits was approximately 60, and the fruits were fully formed and mature. Fruit samples were separated from seeds. Both the leaves and the fruits were dried in an incubator at 45°C for 48 hours. After drying, all samples were ground to a fine powder using an electric blender and mortar. Figure 2 shows that the fine powder of each sample was ready to be extracted. Figure 3 shows the ethanolic extract of different parts of *Z. mauritiana*.

Maceration extraction was a technique involving the immersion of *Z. mauritiana*'s samples in different solvents to extract desired compounds. The solvent penetrates the material, dissolving and absorbing the target constituents, resulting in an extract enriched with the compounds of interest. The maceration method was done according to a previous study (Abubakar 2021). Ground samples weighing 10 g were prepared.

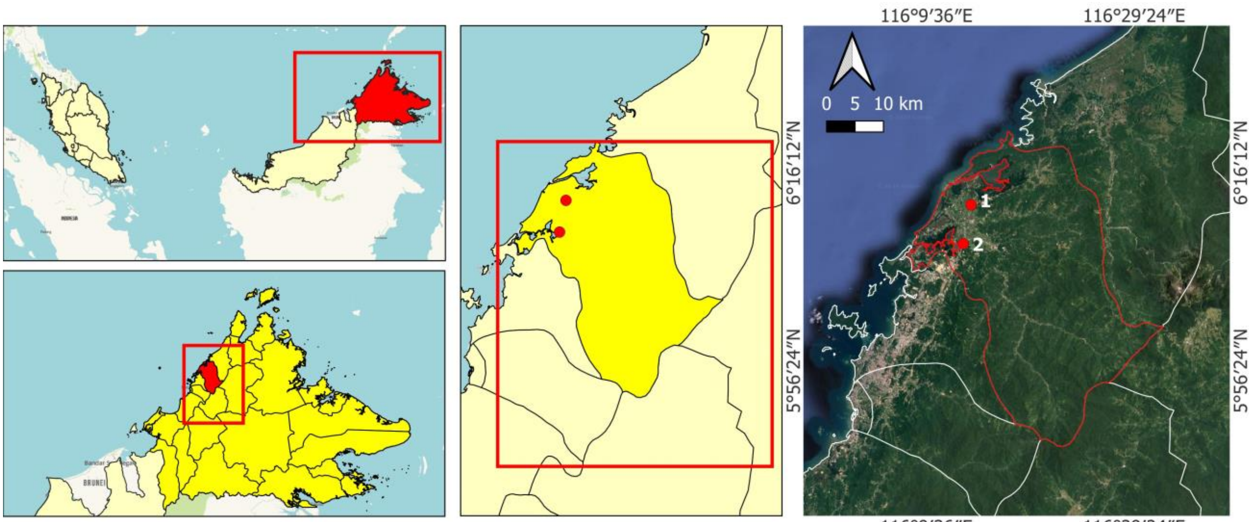

Figure 1. Red arrows show the exact location of *Ziziphus mauritiana* samples in Tuaran, Sabah, Malaysia: sample 1: (6° 12' 12" N, 116° 13' 52" E), sample 2 (6° 08' 30" N, 116° 13' 07" E)

Ten (10) g of each part of the samples were extracted individually in 100 mL of 80% methanol in a 500 mL conical flask. Then, the conical flasks that contained the mixture, which were powdered samples and solvent, were covered with parafilm. All the samples were placed in a water bath machine for 48 hours at 30°C with 80 rpm. Then, the mixtures were filtered through Whatman No. 1 filter paper to separate the solid waste and extract solutions from the samples. The final extracted solutions were placed into a glass container and stored in a cool place until further analysis. Figure 2 shows that the fine powder of each sample was ready to be extracted. Figure 3 shows the ethanolic extract of different parts of *Z. mauritiana*.

Gas Chromatography-Mass Spectrometry (GC-MS) analysis

The different parts of *Z. mauritiana* were analyzed using GC-MS, following standard protocols for phytochemical analysis as outlined by Kushwaha et al. 2019. 10 mg of dried extract samples were diluted with 10 mL of 99.99% ethanol, resulting in a final concentration of 1 mg/mL, which was used for testing (Figure 3). Each sample analysis was performed in triplicate to ensure reproducibility, providing technical replicates for statistical validation. The GC-MS analysis was conducted using a Perkin Elmer Turbo Mass Spectrophotometer equipped with a Perkin Elmer tester. The chromatographic column employed was a Perkin Elmer Elite 5 capillary column (30 meters × 0.25 mm, film thickness 0.25 mm) composed of 95% dimethylpolysiloxane. Helium, at a flow rate of 0.5 mL per minute and with a purity of 99.99%, was used as the carrier gas. The injection volume was set at 1 µL, with the injector temperature maintained at 250°C. The oven temperature was initially set at 110°C, then ramped at 5°C per minute to 200°C, followed by another ramp of 5°C per minute to a final temperature of 280°C. This final temperature was held isothermally for 5 minutes. The total run time for each analysis was 16 minutes. The transfer line to the Mass Spectrophotometer was held at 200°C, while the source temperatures remained at 100°C and 80°C, respectively. The peak areas of the identified compounds were analyzed using Perkin Elmer Turbo Mass software. Compound identification was performed by comparing the mass spectra with the NIST (National Institute of Standards and Technology) library. All experimental procedures, including sample preparation and analysis, were performed at the Centre for Instrumentation and Science Services, Universiti Malaysia Sabah, Kota Kinabalu.

RESULTS AND DISCUSSION

Many compounds were identified in the ethanolic extract of different parts of *Z. mauritiana* by GC-MS analysis. The active principle using retention time (RT), area (%), and molecular formula are presented as follows.

Roots

In Figure 4 of GC-MS chromatogram analysis of compounds identified in *Z. mauritiana* root, several compounds were detected. Among them, three major compounds stand out based on their relative peak areas. The first major compound identified is dimyristyl thiodipropionate, which appears at retention times of 23.97 and 27.85 minutes, constituting significant peak areas of 5.83% and 64.65% (Blue arrow), respectively. The second major compound is propanoic acid, 3,3'-thiobis-, ditetradecyl ester, detected at retention times of 23.88 and 24.06 minutes, with peak areas of 10.52% and 13.89% (Red arrow), respectively.

Figure 2. Powdered of different parts of *Ziziphus mauritiana*

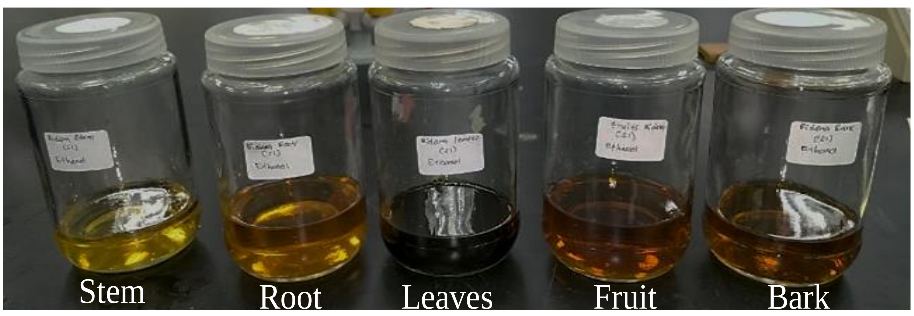

Figure 3. Ethanolic extracts of different parts of *Ziziphus mauritiana*

Lastly, the third major compound is 2-propenoic acid, pentadecyl ester, observed at a retention time of 11.279 minutes with a peak area of 3.14% (Black arrow). While 2-propenoic acid, pentadecyl ester present in lower abundance compared to the other major compounds, its presence is notable and contributes to the complexity of the sample composition.

Table 1 shows the phytochemical profiles obtained in the root of *Z. mauritiana*, four dominant compounds identified by GC-MS have biological activities that can contribute medicinally. From Table 1 shows one such compound is dimyristyl thiodipropionate, which is used as a secondary stabilizer and antioxidant in combination with phenolic antioxidants for polymers (Diamante et al. 2010). Dimyristyl thiodipropionate is a commonly used antioxidant and stabilizer in various industries. Its primary function is to inhibit or slow down oxidation processes, which can lead to the degradation of materials such as polymers, plastics, and other organic substances. Specifically, dimyristyl thiodipropionate works by scavenging free radicals, which are highly reactive molecules that can initiate and propagate oxidation reactions. Another compound, 2-propenoic acid, pentadecyl ester, also known as pentadecyl acrylate, belongs to the family of acrylate esters. It has potential as an anticancer agent (Sahu et al. 2023) and exhibits known biological activities such as antimicrobial and antioxidant properties, including health-promoting benefits (Khromykh et al. 2022).

Table 1. Detail of compounds identified in *Ziziphus mauritiana* root

Compounds	RT (min.)	Area (%)	MF	MW (g/mol)	Biological activities
2-(Oxan-3-yl) ethanamine	3.05	0.69	$C_7H_{15}NO$	129.19	Antimicrobial therapies (Campana et al. 2020)
1-Dodecanol	8.51	0.60	$C_{12}H_{26}O$	186.33	Antiviral application (Katz et al. 1991).
Phosphinous bromide, methylenebis[[2,4,6-tris(1-methyl ethyl) phenyl] methylene]]	8.58	0.23	$C_{33}H_{42}BrP$	585.10	Antibacterial and antifungal properties (Srinivasulu et al. 2008)
2-Propenoic acid, pentadecyl ester	11.28	3.14	$C_{18}H_{34}O_2$	282.50	Anticancer (Sahu et al. 2023)
Propanoic acid, 3,3'-thiobis-, ditetradecyl ester	23.88	10.52	$C_{34}H_{66}O_4S$	571.00	Antioxidant and antimicrobial agent (Tumosienė et al. 2016)
Dimyristyl thiodipropionate	23.97	5.83	$C_{34}H_{66}O_4S$	571.00	Antimicrobial and anti-inflammatory activities (Sucheta et al. 2017)
Propanoic acid, 3,3'-thiobis-, ditetradecyl ester	24.06	13.89	$C_{34}H_{66}O_4S$	571.00	Antioxidant and antimicrobial agent (Tumosienė et al. 2016)
3,6-Dioxaoctanedioic acid, Bis[9-(ethoxycarbonyl)nonyl] ester	24.51	0.22	$C_{30}H_{54}O_{10}$	574.70	Exhibit antimicrobial activity (Mukovoz et al. 2018)
Dimyristyl thiodipropionate	27.85	64.65	$C_{34}H_{66}O_4S$	571.00	Antimicrobial and anti-inflammatory activities (Sucheta et al. 2017)
Hexadecanoic acid, tetradecyl ester	30.56	0.23	$C_{30}H_{60}O_2$	452.80	Pest management and antibacterial properties (Tewari et al. 2015; Shaaban et al. 2021)

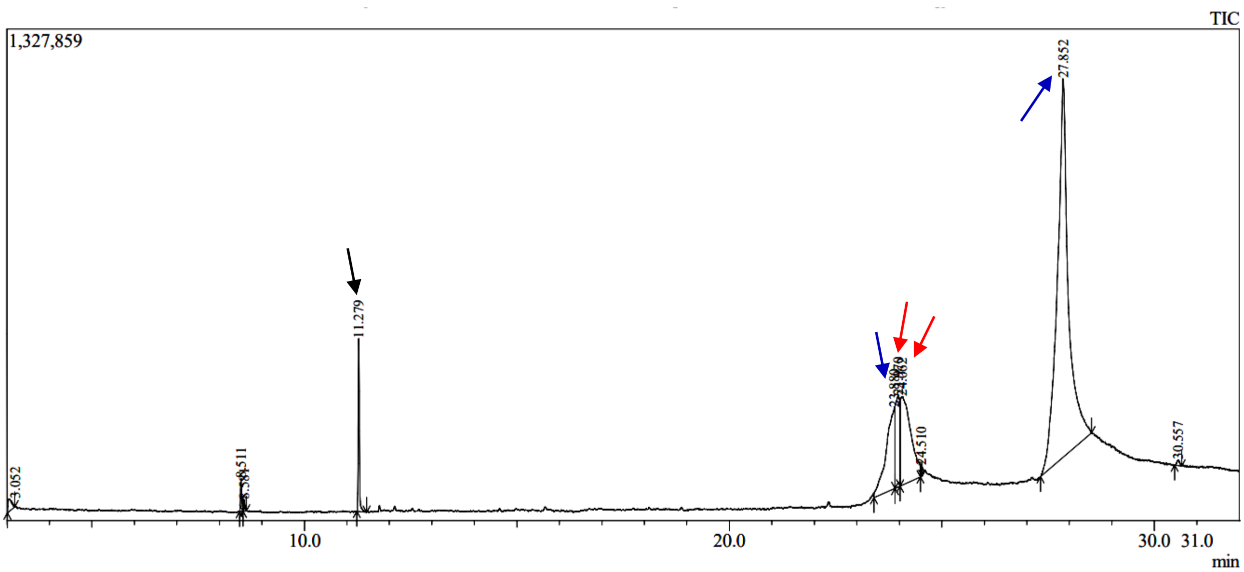

Figure 4. Gas chromatogram of chemical ingredients of ethanol extract of *Ziziphus mauritiana* root

Phosphinous bromide, methylenebis[[2,4,6-tris(1-methylethyl) phenyl] methylene]], a compound containing phosphorus, aligns with the theme of phosphorus-containing metabolites with biological activities. Phosphorus compounds play crucial roles in biological processes, acting as nucleic acids, coenzymes, and metabolic intermediates (Wohlgemuth 2023). Additionally, phosphoryl prodrugs, which involve phosphorus-containing compounds, are essential in drug development to enhance pharmacokinetic profiles (Kirby and Dowd 2021). Pentadecyl esters of certain compounds have shown potential biological activities, as evidenced by research studies. For instance, the synthesis of oxygenated derivatives of propenylbenzenes, including isosafrole and anethole, resulted in compounds with antimicrobial, antioxidant, and anticancer activities (Ekiert and Szopa 2023). Propanoic acid, 3,3'-thiobis-, and its ditetradecyl ester derivative contain a thiobis moiety, which has shown potential biological activities in various studies. The synthesis of 1,2,4-triazole derivatives containing a propanoic acid moiety demonstrated significant anti-inflammatory effects, reducing the release of inflammatory cytokines like TNF-α and IFN-γ (Paprocka et al. 2023). Additionally, the 3-[5-(1H-indol-3-ylmethylene)-4-oxo-2-thioxothiazolidin-3-yl]-propionic acid exhibited anti-inflammatory and anti-allergic activities, reducing the levels of IgE, IgA, IgM, IL-2, and TNF-α (Sapijanskaitė-Banevič et al. 2023). The presence of the ethoxycarbonyl group in 3,6-dioxaoctanedioic acid, Bis[9-(ethoxycarbonyl) nonyl] ester suggests potential biological activities (Wang et al. 2024). This is supported by research on related compounds like 3,9-dioxatetraasteranes, which have shown promising biological properties. Studies have demonstrated that 3,9-dioxatetraasteranes exhibit antiproliferative activity against cancer cell lines, indicating their potential as inhibitors (Ratto and Honek 2024). Thus, the roots of *Z. mauritiana* contain various compounds that have antifungal and antibacterial properties.

Leaves

Figure 5 shows GC-MS chromatogram analysis of compounds identified in *Z. mauritiana* leaves, several compounds were detected, but three major compounds stand out due to their relative peak areas. The first major compound identified is cyclononasiloxane, octadecamethyl-, which appears at a retention time of 17.70 minutes and constitutes a significant peak area of 87.55% (Blue arrow). The second major compound is cyclodecasiloxane, eicosamethyl-, detected at a retention time of 18.94 minutes with a peak area of 3.97% (Red arrow). Lastly, the third major compound is octasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13,15,15-hexadecamethyl which observed three times at retention time of 19.05, 19.44 and 20.60 minutes with total peak area of 2.98% (Black arrow).

From the phytochemical profiles obtained in the leaves (Table 2), three dominant compounds identified by GC-MS in the ethanolic extract of *Z. mauritiana* leaves have biological activities that can contribute medicinally (Table 2). These compounds, cyclononasiloxane, octadecamethyl-, cyclodecasiloxane, eicosamethyl-, and octasiloxane, possess antifungal, antioxidant, and antimicrobial properties (Jasim et al. 2015; Suriani 2016; Mohamed et al. 2022). Cyclononasiloxane, octadecamethyl- also finds uses in the food and pharmaceutical industries, as well as in traditional medicine in some regions. 2-Propenoic acid, tridecyl ester is reported to have antimicrobial and pharmacological properties (Sangeetha et al. 2015; Seenivasan 2018).

Table 2. Detail of compounds identified in *Ziziphus mauritiana* leaves

Compounds	RT (min.)	Area (%)	MF	MW (g/mol)	Biological activity
Octadecanoic acid, 2-(octadecyloxy)ethyl ester	12.88	1.02	$C_{38}H_{76}O_3$	581.00	Natural antimicrobial agent (Sudharsan et al. 2011)
2-Propenoic acid, tridecyl ester	14.27	1.74	$C_{16}H_{30}O_2$	254.41	Anticancer (Sahu et al. 2023)
1,9-Dioxa-5-thianonane, 3,7-bis (9-borabicyclo [3.3.1] non-9-yl) trideca-2,6,10-trione	14.46	0.97	$C_6H_{12}O_2S$	148.23	These complex structures not commonly found in biological systems
Pentadecafluorooctanoic acid, dodec-2-en-1-yl ester	14.65	0.85	$C_{20}H_{23}F_{15}O_2$	580.40	PFOA is widely utilized in surfactants, firefighting foams, and polymer additives, contributing to its industrial significance (Kishor et al. 2021)
Cyclononasiloxane, octadecamethyl-	17.70	87.55	$C_{18}H_{54}O_9Si_9$	667.40	Cosmetics and personal care products due to its desirable properties (Montiel et al. 2019)
Cyclodecasiloxane, eicosamethyl-	18.94	3.97	$C_{20}H_{60}O_{10}Si_{10}$	741.50	Cosmetic formulations (Saribekova et al. 2021)
Octasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13,15,15-hexadecamethyl	19.05	0.75	$C_{16}H_{50}O_7Si_8$	578.20	Supporting metabolic and heart health (Venn-Watson and Butterworth 2022)
Octasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13,15,15-hexadecamethyl	19.44	1.34	$C_{16}H_{50}O_7Si_8$	578.20	Supporting metabolic and heart health (Venn-Watson and Butterworth 2022)
Octasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13,15,15-hexadecamethyl	20.60	0.89	$C_{16}H_{50}O_7Si_8$	578.20	Supporting metabolic and heart health (Venn-Watson and Butterworth 2022)
Dotriacontane, 1-iodo-	20.68	0.92	$C_{32}H_{65}I$	576.80	These complex structures not commonly found in biological systems

Octadecanoic acid, 2-(octadecyloxy) ethyl ester, and 2-propenoic acid, tridecyl ester are fatty acid esters commonly found in natural products, potentially exhibiting various biological activities. Fatty acid esters are prevalent in natural sources like marine organisms, plants, and microorganisms, contributing to their bioactivity. These compounds have been identified in marine species like *Anemonia viridis* Forsskål 1775, terrestrial plants, algae, and bacteria, showcasing diverse bioactivities such as antioxidant, cytotoxic, allelopathic, and antimicrobial properties (Chen et al. 2020; Huang et al. 2021; Quaranta et al. 2022). Pentadecafluorooctanoic acid, dodec-2-en-1-yl ester, and octasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13,15,15-hexadecamethyl are less likely to exhibit biological activities due to being primarily synthetic compounds without the functional groups associated with biological activity. In contrast, natural compounds like pentadecanoic acid (C15:0) have shown essential fatty acid properties supporting metabolic and heart health (Venn-Watson and Butterworth 2022). 1,9-Dioxa-5-thianonane, 3,7-bis (9-borabicyclo [3.3.1] non-9-yl) trideca-2,6,10-trione and dotriacontane, 1-iodo- are also less likely to have biological activities, as they are synthetic compounds with complex structures not commonly found in biological systems.

Fruits

Figure 6 shows GC-MS chromatogram analysis of compounds identified in *Ziziphus mauritiana* fruit, several compounds were detected, but two major compounds stand out due to their relative peak areas. The first major compound identified is tetracosamethyl-cyclodo-decasiloxane, which appears at a retention time of 20.52 minutes and constitutes a significant peak area of 90.18% (Blue arrow). The second major compound is 2-propenoic acid, tridecyl ester, detected at a retention time of 14.28 minutes with a peak area of 4.95% (Red arrow). While present in lower abundance compared to tetracosamethyl-cyclododecasiloxane, it still contributes significantly to the overall composition of the sample.

From the phytochemical profiles as shown in Table 3 obtained from *Z. mauritiana* fruits, three dominant compounds identified by GC-MS have biological activities that can contribute medicinally. Tetracosamethyl-cyclodo-decasiloxane has potential hepatoprotective, antispasmodic, and antirheumatic properties (Al Bratty et al. 2020). According to Ferdosi et al. (2021), tetracosamethyl-cyclododecasiloxane also possesses antibacterial and antifungal properties. 2-Propenoic acid, tridecyl ester, also present in the leaves of *Z. mauritiana* as a major compound, is categorized as an antimicrobial and pharmacological compound. Among the compounds mentioned, 2-propenoic acid, tridecyl ester is the most likely to exhibit significant biological activities due to its ester derivative nature. This compound is derived from acrylic acid, known for its potential antioxidant and antimicrobial properties.

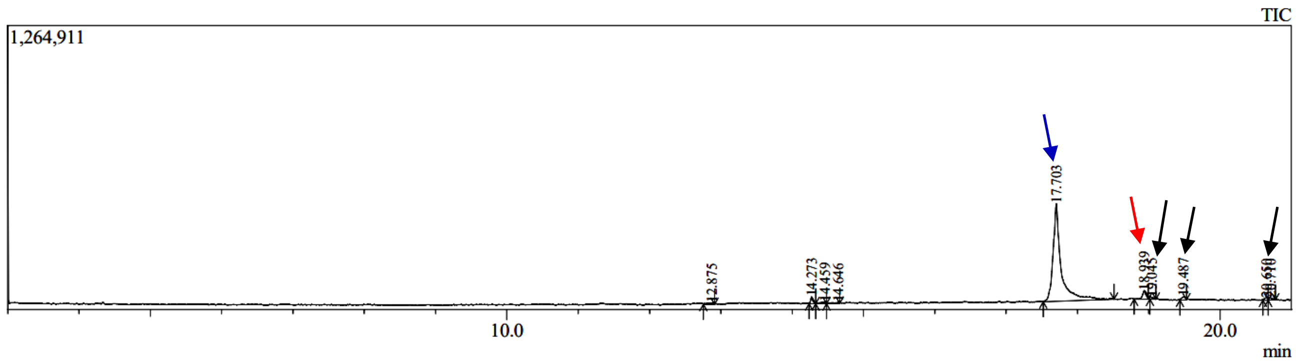

Figure 5. Gas chromatogram of chemical ingredients of ethanol extract of *Ziziphus mauritiana* leaves

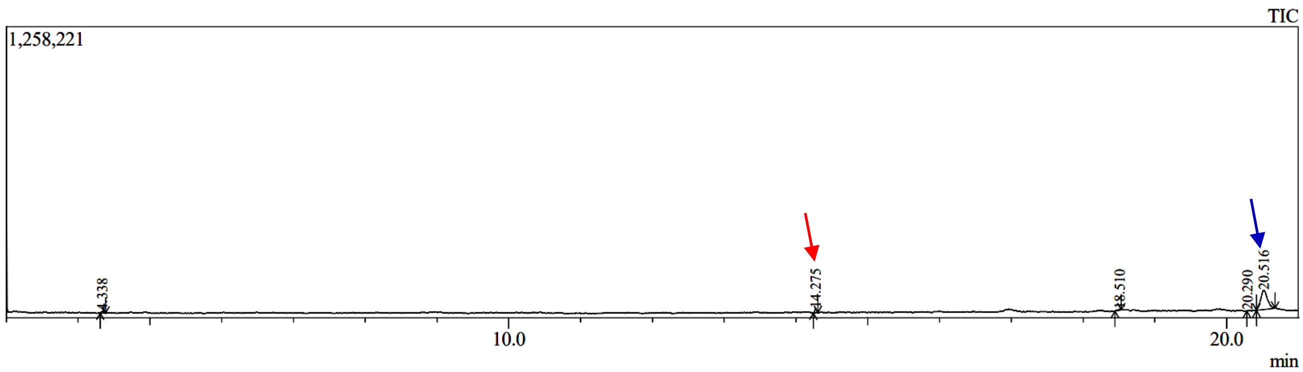

Figure 6. Gas chromatogram of chemical ingredients of ethanol extract of *Ziziphus mauritiana* fruit

Decane, 2,2-dimethyl-, is a hydrocarbon commonly utilized as a solvent in industrial applications, known for its simple organic composition of carbon and hydrogen atoms. Octasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13,15,15-hexadecamethyl, belongs to the siloxane group of silicon-based compounds. Siloxanes like octasiloxane find extensive use in industries for producing silicone polymers, lubricants, and sealants (Winchester and Seymour 2020; Nikonov 2021). While decane, 2,2-dimethyl-, and octasiloxane are valuable in industrial processes due to their chemical properties, they are not typically associated with significant biological activities (Sahin 2023; Sonawane and Agarwal 2023). These compounds play crucial roles in industrial applications but are not commonly linked to notable biological effects.

Barks

Figure 7 shows the GC-MS chromatogram analysis of compounds identified in *Z. mauritiana* bark, several compounds were detected, but three major compounds stand out due to their relatively high peak areas. The first major compound identified is 2-propenoic acid, tridecyl ester, which appears at retention times of 14.222 and 14.274 minutes, with peak areas of 28.97% and 8.49% (Blue arrow), respectively. The second major compound is cyclononasiloxane, octadecamethyl-, which appears at a retention time of 19.07 minutes, with a peak area of 25.61% (Red arrow). Lastly, cyclooctasiloxane, hexadecamethyl- appears at retention times ranging from 15.98 to 19.30 minutes, with peak areas ranging from 1.22% to 20.89% (Black arrow).

From the phytochemical profiles obtained from *Z. mauritiana* bark as shown in Table 4, two dominant compounds identified by GC-MS have biological activities that can contribute medicinally. The first compound, 2-propenoic acid, tridecyl ester (also known as tridecyl acrylate), is an ester of acrylic acid. Its derivatives have been extensively researched for their diverse biological activities, such as antimicrobial and antioxidant properties. The biological activities of tridecyl acrylate are likely influenced by its chemical structure and functional groups (Shen 2023). Acrylic acid, a precursor to tridecyl acrylate, is a valuable chemical used in various industrial applications, including the production of diapers, paints, and adhesives (Ahmed et al. 2023). Additionally, the toxicity of acrylic acid and related monomers, such as acrylamide, has been studied, highlighting potential cytotoxic effects and DNA damage in certain cell lines (Rodrigues 2022). These insights underscore the importance of understanding the specific properties and potential biological effects of tridecyl acrylate for various applications.

Table 3. Detail of compounds identified in *Ziziphus mauritiana* fruit

Compounds	RT (min.)	Area (%)	MF	MW (g/mol)	Biological activity
Decane, 2,2-dimethyl-	4.34	2.63	$C_{12}H_{26}$	170.33	Industrial applications (Sahin 2023; Sonawane and Agarwal 2023)
2-Propenoic acid, tridecyl ester	14.28	4.95	$C_{16}H_{30}O_2$	254.41	Anticancer (Sahu et al. 2023)
Octasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13,15,15-hexadecamethyl	18.51	1.97	$C16H_{50}O_7Si_8$	578.20	Supporting metabolic and heart health (Venn-Watson and Butterworth 2022)
1,3,7,9,2,8-Parazabol, 2,2,8,8-tetraethyl-4,6,10,12-tetraphenyl-	20.29	0.27	-	-	-
Tetracosamethyl-cyclododecasiloxane	20.52	90.18	$C_{24}H_{72}O_{12}Si_{12}$	889.80	Hepatoprotective, antispasmodic, and antirheumatic properties (Al Bratty et al. 2020)

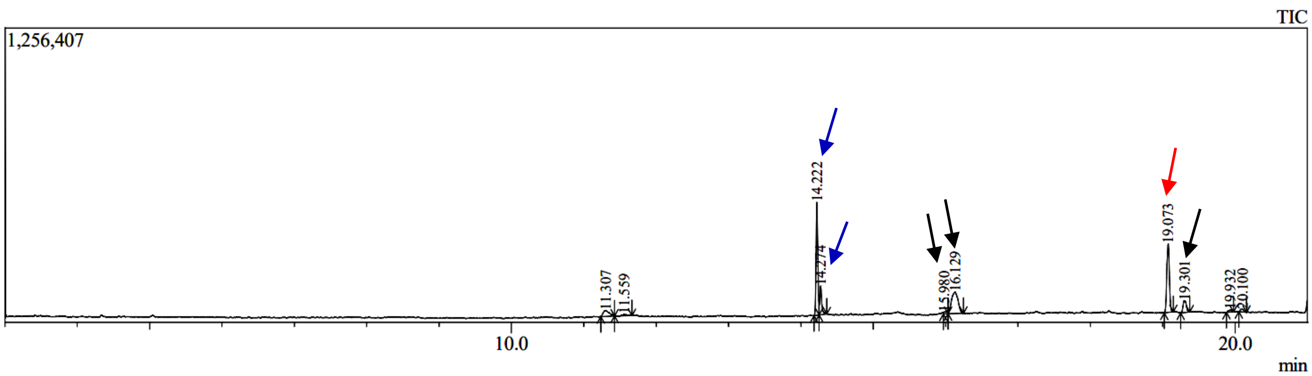

Figure 7. Gas chromatogram of chemical ingredients of ethanol extract of *Ziziphus mauritiana* bark

Cyclononasiloxane, octadecamethyl-, and cyclooctasiloxane, hexadecamethyl- possess antibacterial and antifungal properties (Wohlgemuth 2023). Cyclonona-siloxane and cyclooctasiloxane, along with other siloxanes, exhibit significant antibacterial and antifungal properties, making them valuable in various applications, including personal care and pharmaceuticals. This finding indicates that siloxane-silver nanofluids demonstrate promising antimicrobial activity against drug-resistant bacteria and fungi, such as *Acinetobacter baumannii* and *Candida albicans*, highlighting their potential as alternatives to conventional antibiotics (Tiwari et al. 2023). Additionally, studies on organosilicon nitriles and siloxanes reveal their effective fungicidal activity, which can last for weeks, suggesting their utility in industrial applications to combat microbiological corrosion. Despite regulatory concerns regarding the environmental impact of certain siloxanes, their unique properties and effectiveness in combating microbial resistance underscore their importance in developing new antimicrobial agents (Hogue 2018). Another compound from *Z. mauritiana* bark that exhibits biological activities is hexadecanoic acid, as identified through GC-MS analysis (Soraya et al. 2022). This compound is known for its potential medicinal activity and contributes to the plant's pharmacological advantages. Moreover, the stem bark extract of *Z. mauritiana* demonstrated significant antioxidant, thrombolytic, anti-inflammatory, anti-diarrheal, analgesic, and hypoglycemic activities, indicating the medicinal value of this plant part (Akanda and Hasan 2021). These findings collectively highlight the diverse bioactive compounds present in *Z. mauritiana*, emphasizing its potential for functional food and pharmaceutical applications.

Stems

The GC-MS chromatogram analysis of compounds identified in *Z. mauritiana* stem (Figure 8), several compounds were detected, but one major compound stands out due to its exceptionally high relative peak area. The major compound identified is dimyristyl thiodipropionate (DMDTP), which appears at a retention time of 27.81 minutes and constitutes a significant peak area of 96.21% (Blue arrow). This compound is overwhelmingly dominant in the stem extract, indicating its prevalence and abundance in this part of the plant. In addition to dimyristyl thiodipropionate, several other compounds were also identified in the stem extract, but they contribute minimally to the overall composition based on their low peak areas. These compounds include 2-propenoic acid, pentadecyl ester, octadecane, mannonic acid, octadecane, 9-octadecene, and various other compounds detected in trace amounts.

Table 5 shows the phytochemical profiles obtained from the stem of *Z. mauritiana*, two dominant compounds identified by GC-MS exhibit significant biological activities with potential medicinal applications. Dimyristyl thiodipropionate (DMDTP), also a major compound in the root of *Z. mauritiana*, acts as a secondary stabilizer and antioxidant in combination with phenolic antioxidants for polymers. DMDTP is a dialkyl ester of thiodipropionic acid used as an antioxidant in various applications. Studies have shown that related compounds, such as dilauryl thiodipropionate (DLTDP), exhibit antioxidant properties and are considered safe for use in cosmetic products (Gregory et al. 2021). Additionally, dimethylsulfoniopropionate (DMSP), a marine metabolite, has been found to possess antioxidant defense capabilities in mammalian neural cells, protecting against cytotoxic effects induced by tropodithietic acid (TDA) (Diamante et al. 2010). This suggests that DMDTP, being structurally similar to DLTDP and part of the thiodipropionate family, may also exhibit antioxidant properties.

The compound from the *Z. mauritiana* stem that exhibits notable biological activities is octadecane, 1,1'-[1,3-propanediylbis(oxy)] bis. This compound was identified in the stem extracts of *Z. mauritiana* and is associated with pharmacological significance (Prakash et al. 2021; Egbe et al. 2022). The plant's stem contains a plethora of active phytochemical constituents, including compounds like octadecane, which contribute to its medicinal properties such as antioxidant, cytotoxic, and immunomodulatory activities. Additionally, the phytochemical analysis of the *Z. mauritiana* stem revealed the presence of various bioactive compounds, indicating its potential for the pharmaceutical and food industries (Keita et al. 2020). Therefore, octadecane, 1,1'-[1,3-propanediylbis(oxy)] bis from the *Z. mauritiana* stem holds promise for further exploration in drug development and health applications.

Table 4. Detail of compounds identified in *Ziziphus mauritiana* bark

Compounds	RT (min.)	Area (%)	MF	MW (g/mol)	Biological activity
n-Tridecan-1-ol	11.31	5.42	$C_{13}H_{28}O$	200.36	Reduces serum markers of liver damage (Babu et al. 2023)
1-Dodecanol	11.56	1.28	$C_{12}H_{26}O$	186.33	Pheromone Synergy (Tian et al. 2020)
2-Propenoic acid, tridecyl ester	14.22	28.97	$C_{16}H_{30}O_2$	254.41	Anticancer (Sahu et al. 2023)
2-Propenoic acid, tridecyl ester	14.27	8.49	$C_{16}H_{30}O_2$	254.41	
Cyclooctasiloxane, hexadecamethyl-	15.98	1.22	$C_{16}H_{48}O_8Si_8$	593.20	
Cyclooctasiloxane, hexadecamethyl-	16.13	20.89	$C_{16}H_{48}O_8Si_8$	593.20	Antibacterial and antifungal
Cyclononasiloxane, octadecamethyl-	19.07	25.61	$C_{18}H_{54}O_9Si_9$	667.40	properties (Wohlgemuth 2023)
Cyclooctasiloxane, hexadecamethyl-	19.30	5.73	$C_{16}H_{48}O_8Si_8$	593.20	
Octasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13,15,15-hexadecamethyl	19.93	1.00	$C_{16}H_{50}O_7Si_8$	578.20	Supporting metabolic and heart health (Venn-Watson and
Octasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13,15,15-hexadecamethyl	20.10	1.39	$C_{16}H_{50}O_7Si_8$	578.20	Butterworth 2022)

Table 5. Detail of compounds identified in *Ziziphus mauritiana* stem

Compounds	RT (min.)	Area (%)	MF	MW (g/mol)	Biological activity
Silane, methyl-	3.04	1.46	CH_6Si	46.14	Cytotoxicity and antibacterial action (Zablotskaya et al. 2013)
Phosphinous bromide, methylenebis[[2,4,6-tris(1-methyl ethyl) phenyl] methylene]]	8.57	0.09	H_2PBr	112.88	Synthesis and antimicrobial activity (Uygun et al. 2013; Strobykina et al. 2019)
Nn-Heptyl-N'-(12-[2-(heptyl-methyl-carbamoyl)-acetylamino]-dodecyl)-N-methyl-malonamide	11.14	0.04	$C_{34}H_{66}N_4O_4$	594.90	Antiviral and anticancer properties (Mohamed et al. 2019)
2-Propenoic acid, -pentadecyl ester	11.28	0.44	$C_{16}H_{30}O_2$	254.41	Anticancer (Sahu et al. 2023)
Octadecane, 1,1'-[1,3-propanediylbis(oxy)] bis	27.34	0.02	$C_{39}H_{80}O_2$	581.10	Antimicrobial (Terent′eva et al. 2017)
Mannonic acid (Et-TFA)	27.37	0.05	$C_6H_{12}O_7$	196.16	Antibacterial and Antifungal activities (Roman 2015; Liaqat et al. 2018)
Dimyristyl thiodipropionate (DMDTP)	27.81	96.21	$C_{34}H_{66}O_4S$	571.00	Antioxidant and cosmetic products (Gregory et al. 2021)
Octadecane, 1,1'-[1,3-propanediylbis(oxy)] bis	28.24	1.16	$C_{39}H_{80}O_2$	581.10	Anti-fatigue, antioxidant, and anti-inflammatory properties (Zhou et al. 2022)
9-Octadecene, 1-[3-(octadecyloxy)propoxy]-, (Z)-	28.34	0.44	$C_{39}H_{78}O_2$	579.00	This complex structures not commonly found in biological systems
Octadecane, 1,1'-[1,3-propanediylbis(oxy)] bis-	28.38	0.08	$C_{39}H_{80}O_2$	581.10	Anti-fatigue, antioxidant, and anti-inflammatory properties (Zhou et al. 2022)

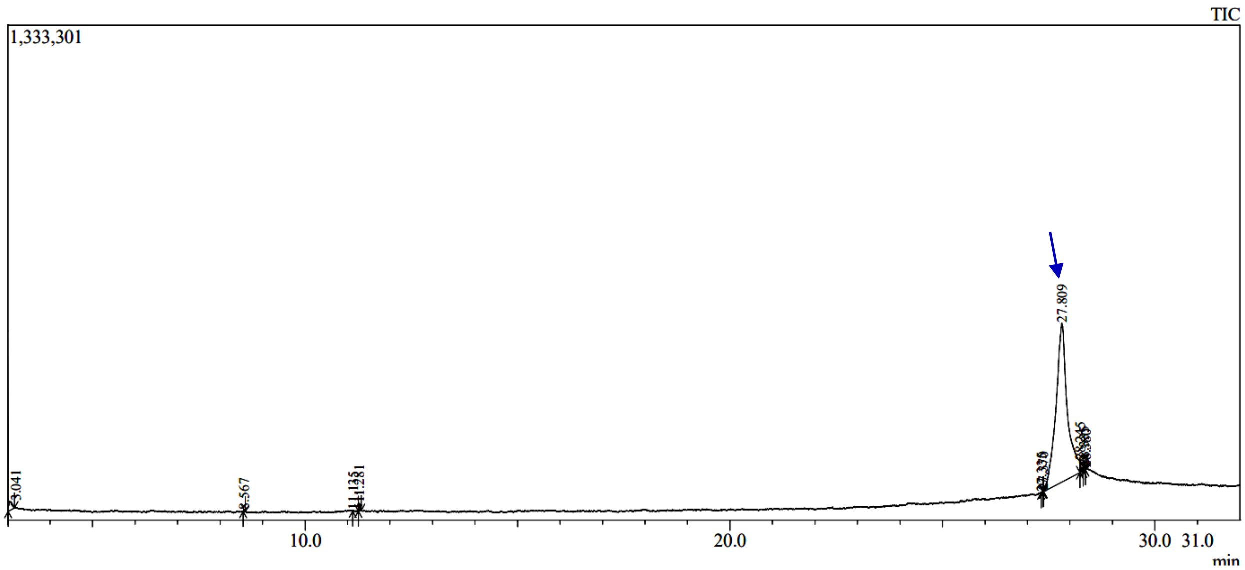

Figure 8. Gas chromatogram of chemical ingredients of ethanol extract of *Z. mauritiana* stem

In conclusion, the GC-MS analysis revealed that certain compounds were common across multiple parts of *Z. mauritiana*. These shared compounds indicate a similarity in the chemical profile of different plant parts. Several compounds identified in the GC-MS analysis have known or potential biological activities, which may include anti-microbial, antioxidant, anti-inflammatory, or other pharmacological properties. Compounds such as 2-propenoic acid derivatives, silanes, thiodipropionates, and various organic acids may contribute to these activities. The presence of bioactive compounds suggests that *Z. mauritiana* may have potential health benefits. These compounds could be explored further for their therapeutic potential in traditional medicine or pharmaceutical applications. While the GC-MS analysis provides valuable insights into the chemical composition of *Z. mauritiana*, further research is needed to fully understand the biological activities and health benefits associated with these compounds. Additionally, studying the synergistic effects of these compounds and their interactions could provide deeper insights into the medicinal properties of *Z. mauritiana*.

ACKNOWLEDGEMENTS

The author thanks the Faculty of Tropical Forestry at Universiti Malaysia Sabah for graciously providing all the research equipment required for the effective completion of this study. Additionally, deep gratitude is extended to Dr. Rafidah Md. Salim for her significant scientific guidance during the research process. We also thank Assoc. Dr. Liew Kang Chiang, Dr. Mandy Maid, and Dr. Shirley Marylinda Bakansing for their assistance and contributions. The anonymous referees' efforts, including diligent reading and helpful rewriting of the text, are also greatly appreciated. This work was supported by the Research Priority Area Scheme of Universiti Malaysia Sabah (Grant no-SBK0495-2021). The authors declare that they have no conflicts of interest to report regarding the present study.

REFERENCES

Abdallah EM. 2017. Antibacterial activity of fruit methanol extract of *Ziziphus spina-christi* from Sudan. Intl J Curr Microbiol Appl Sci 6 (5): 38-44. DOI: 10.20546/ijcmas.2017.605.005.

Abubakar YS. 2021. Proximate and selected mineral elements analysis of Nigerian *Ziziphus spina-christi* (L.) wild edible fruit pulp. Earthline J Chem Sci 5 (1): 231-240. DOI: 10.34198/ejcs.5121.231240.

Adilah HN, Saleh MI, Az-Zahra NDA, Cho E, Sinaga E. 2023. Total phenolic and total flavonoid content, antioxidant activity, and nutritional profile of *Ziziphus mauritiana* fruit juice. Intl J Biol Phys Chem Stud 5 (1): 01-08. DOI: 10.32996/ijbpcs.2023.5.1.1.

Ahmed WA, Salih N, Salimon J. 2023. Synthesis, characterization, tribological and rheological properties of di (2-butyl octyl) dicarboxylate esters for environmentally friendly biolubricant applications. Biointerface Res Appl Chem 1: 2783. DOI: 10.33263/BRIAC133.278.

Akanda MKM, Hasan AN. 2021. Characterization of pharmacological properties of methanolic seed and stem bark extracts of *Ziziphus mauritiana* (BAU Kul) using in-vitro and in-vivo animal (Swiss albino male mice) model. Clin Phytosci 7: 8. DOI: 10.1186/s40816-020-00246-0.

Akassh M, Fathima T, Mruthunjaya K. 2020. Health promoting effects of *Ziziphus mauritiana*: An overview. Intl J Res Pharm Sci 11: 1067-1072. DOI: 10.26452/ijrps.v11i1.1937.

Al Bratty M, Makeen HA, Alhazmi HA, Syame SM, Abdalla AN, Homeida HE, Sultana S, Ahsan W, Khalid A. 2020. Phytochemical, cytotoxic, and antimicrobial evaluation of the fruits of miswak plant, *Salvadora persica* L. J Chem 1: 4521951. DOI: 10.1155/2020/4521951.

Babu PS, Krishna V, Bhavya DC. 2023. Hepatoprotective activity of Tridecan-1-ol isolatedfrom *Flaveria trinervia* (Speng). C. Mohr. GSC Biol Pharm Sci 22: 271-279. DOI: 10.30574/gscbps.2023.22.3.0093.

Benidir M, El Massoudi S, El Ghadraoui L, Lazraq A, Benjelloun M, Errachidi F. 2020. Study of nutritional and organoleptic quality of formulated juices from jujube (*Ziziphus lotus* L.) and dates (*Phoenix dactylifera* L.) fruits. Sci World J 1: 9872185. DOI: 10.1155/2020/9872185

Byalt VV, Korshunov MV. 2021. *Ziziphus mauritiana* Lam. f. pendula VV Byalt & Korshunov (Rhamnaceae), a new form of an alien species newly recorded for the United Arab Emirates. Skvortsovia: Intl J Salicol Plant Biol 7 (2): 30-40. DOI: 10.51776/2309-6500.

Campana R, Mangiaterra G, Tiboni M, Frangipani E, Biavasco F, Lucarini S, Citterio B. 2020. A fluorinated analogue of marine bisindole alkaloid 2, 2-Bis (6-bromo-1 H-indol-3-yl) ethanamine as potential anti-biofilm agent and antibiotic adjuvant against *Staphylococcus aureus*. Pharmaceuticals 13 (9): 210. DOI: 10.3390/ph13090210.

Chen YH, Chang YC, Chen YH, Zheng LG, Huang PC, Huynh TH, Peng BR, Chen YY, Wu YJ, Fang LS, Su JH. 2020. Natural products from octocorals of the genus *Dendronephthya* (Family Nephtheidae). Molecules 24: 5957. DOI: 10.3390/molecules25245957.

Diamante C, Zondlo Fiume M, Bergfeld WF, Belsito DV, Hill RA, Klaassen CD, Liebler DC, Marks JG, Shank RC, Slaga TJ, Snyder PW. 2010. Final safety assessment of thiodipropionic acid and its dialkyl esters as used in cosmetics. Intl J Toxicol 29: 137S-50S. DOI: 10.1177/109158181037315.

Egbe NE, Garba S, Adamu A, Aliyu F. 2022. Phytochemical screening, in vitro antioxidant and gc-ms analysis of *Ziziphus mauritiana* leaves extract. Bima J Sci Technol 6: 80-90. DOI: 10.56892/bima.v6i03.48.

Ekiert HM, Szopa A. 2023. Biological activities of natural products III. Molecules 28 (12): 4854. DOI: 10.3390/molecules28124854.

Ferdosi MF, Javaid A, Khan IH, Khan S, Shad N. 2021. Analysis of n-butanol flower extract of *Cassia fistula* through GC-MS and identification of antimicrobial compounds. Pak J Pyhtopathol 33 (1): 103-107. DOI: 10.33866/phytopathol.033.01.0661.

Gregory GJ, Boas KE, Boyd EF. 2021. The organosulfur compound dimethylsulfoniopropionate (DMSP) is utilized as an osmoprotectant by *Vibrio* species. Appl Environ Microbiol 87 (5): e02235-20. DOI: 10.1128/AEM.02235-20.

Hassan AA, Abd-Elaziz GO. 2020. Genotoxicity and antimicrobial activity of *Myrtus communis* L., *Ziziphus spina-christi* (L.) Willd and *Cassia angustifolia* Vahl extracts. Bangladesh J Bot 49 (3): 557-566. DOI: 10.3329/bjb.v49i3.49640.

Hogue C. 2018. Siloxanes are candidates for tight control in EU. Chem Eng News 96 (27): 15-15. DOI: 10.1021/cen-09627-polcon4.

Huang L, Zhu X, Zhou S, Cheng Z, Shi K, Zhang C, Shao H. 2021. Phthalic acid esters: Natural sources and biological activities. Toxins 13 (7): 495. DOI: 10.3390/toxins13070495.

Jasim H, Hussein AO, Hameed IH, Kareem MA. 2015. Characterization of alkaloid constitution and evaluation of antimicrobial activity of *Solanum nigrum* using gas chromatography mass spectrometry (GC-MS). J Pharmacognosy Phytother 7: 56-72. DOI: 10.5897/JPP2015.0346.

Katz DH, Marcelletti JF, Khalil MH, Pope LE, Katz LR. 1991. Antiviral activity of 1-docosanol, an inhibitor of lipid-enveloped viruses including herpes simplex. Proc Nat Acad Sci U S A 88 (23): 10825-10829. DOI: 10.1073/PNAS.88.23.10825.

Keita S, Wele M, Cisse C, Togola I, Diarra N, Baba-Moussa L. 2020. Phytochemistry and biological activities of leaves and pulp extracts from *Ziziphus mauritiana* (Lam.) collected in Mali. J Adv Biol Biotechnol 23: 1-10. DOI: 10.9734/JABB/2020/v23i130133.

Khan MP, Ahmad M, Zafar M, Sultana S, Ali MI, Sun H. 2015. Ethnomedicinal uses of edible wild fruits (EWFs) in Swat Valley, Northern Pakistan. J Ethnopharmacol 173: 191-203. DOI: 10.1016/j.jep.2015.07.029.

Khromykh NO, Lykholat YV, Didur OO, Sklyar TV, Davydov VR, Lavrentieva KV, Lykholat TY. 2022. Phytochemical profiles, antioxidant and antimicrobial activity of *Actinidia polygama* and *A. arguta* fruits and leaves. Biosyst Divers 30: 39-45. DOI: 10.15421/012205.

Kirby SA, Dowd CS. 2021. Phosphoryl prodrugs: Characteristics to improve drug development. Med Chem Res 31 (2): 207-216. DOI: 10.1007/s00044-021-02766-x.

Kishor R, Bharagava RN, Ferreira LF, Bilal M, Purchase D. 2021. Molecular techniques used to identify perfluorooctanoic acid degrading microbes and their application in a wastewater treatment reactor/plant. In: Shah MP, Rodriguez-Couto S (eds). Wastewater Treatment Reactors. Elsevier, Amstredam. DOI: 10.1016/B978-0-12-823991-9.00009-5.

Kushwaha P, Yadav SS, Singh V, Dwivedi LK. 2020. GC-MS analysis of bio-active compounds in methanolic extract of Ziziphus mauritiana fruit. Intl J Pharm Sci Res 10 (6): 2911-2916. DOI: 10.13040/IJPSR.0975-8232.10(6).2911-16.

Liaqat M, Mahmud TA, Ashraf MU, Muddassar MU, Imran M, Ahmad T, Mitu LI. 2017. Synthesis, characterization and biological activities of a novel mannich base 2- [(3, 4-dimethoxyphenyl) (pyrrolidinyl) methyl] cyclohexanone and its complexes with Cu (II), Ni (II), Co (II) and Fe (II) ions. Revista De Chimie 68 (12): 2845-2849. DOI: 10.37358/RC.17.12.5991.

Maruza IM, Musemwa L, Mapurazi S, Matsika P, Munyati VT, Ndhleve S. 2017. Future prospects of *Ziziphus mauritiana* in alleviating household food insecurity and illnesses in arid and semi-arid areas: A review. World Dev Perspect 5: 1-6. DOI: 10.1016/j.wdp.2017.01.001.

Mohamed KK, Banu RF, Kumar VA, Sundaram L, Thyagarajan SP. 2022. GC-MS and surface characteristics of polyvinyl siloxane-an in vitro analysis. J Chromatogr Sci 60 (2): 111-116. DOI: 10.1093/chromsci/bmab054.

Mohamed MF, Hassaneen HM, Elzayat EM, El-Hallouty SM, El-Manawaty M, Saleh FM, Mohamed Y, El-Zohiry D, Fahmy G, Abdelaal N, Hassanin N. 2019. Biological activity, apoptotic induction and cell cycle arrest of new hydrazonoyl halides derivatives. Anti-

Cancer Agents Med Chem 19 (9): 1141-1149. DOI: 10.2174/1871520619666190306123658.
Mohd Jailani FNAM, Zaidan UH, Hanizam Abdul Rahim MB, Abd Gani SS, Halmi MI. 2020. Evaluation of constituents and physicochemical properties of Malaysian underutilized *Ziziphus mauritiana* (Bidara) for nutraceutical potential. Intl J Fruit Sci 20 (3): 394-402. DOI: 10.1080/15538362.2019.1641458.
Montiel MC, Máximo MF, Serrano-Arnaldos M, Ortega-Requena S, Murcia MD, Bastida J. 2019. Biocatalytic solutions to cyclomethicones problem in cosmetics. Eng Life Sci 19 (5): 370-388. DOI: 10.1002/ELSC.201800194.
Mukovoz PP, Slepukhin PA, Danilova EA, Aysuvakova OP, Glinushkin AP. 2008. Synthesis, structure, and biological activity of products of reactions of 3, 4-dioxohexane-1, 6-dioic acid esters with 2-aminophenol. Russian J General Chem 88: 1363-1368. DOI: 10.1134/S1070363218070022.
Nikonov AY, Sterkhova IV, Lazareva NF. 2021. 2, 2-Dimethyl-3-[(4-methylphenyl) sulfonyl]-2, 3-dihydro-1, 3, 2-benzoxazasilole: synthesis, properties, and structure. Russian Chem Bull 70 (2): 386-90. DOI: 10.1007/s11172-021-3097-3.
Paprocka R, Wiese-Szadkowska M, Kołodziej P, Kutkowska J, Balcerowska S, Bogucka-Kocka A. 2023. Evaluation of biological activity of new 1, 2, 4-triazole derivatives containing propionic acid moiety. Molecules 28 (9): 3808. DOI: 10.3390/molecules28093808.
Prakash O, Usmani S, Singh R, Singh N, Gupta A, Ved A. 2021. A panoramic view on phytochemical, nutritional, and therapeutic attributes of *Ziziphus mauritiana* Lam.: A comprehensive review. Phytother Res 35 (1): 63-77. DOI: 10.1002/ptr.6769.
Quaranta A, Revol-Cavalier J, Wheelock CE. 2022. The octadecanoids: An emerging class of lipid mediators. Biochem Soc Transac 50 (6): 1569-1582. DOI: 10.1042/BST20210644.
Rashwan AK, Karim N, Shishir MR, Bao T, Lu Y, Chen W. 2020. Jujube fruit: A potential nutritious fruit for the development of functional food products. J Funct Foods 75: 104205. DOI: 10.1016/j.jff.2020.104205.
Ratto A, Honek JF. 2024. Oxocarbon acids and their derivatives in biological and medicinal chemistry. Curr Med Chem 31 (10): 1172-1213. DOI: 10.2174/0929867330666230313141452.
Rodrigues JL. 2022. Heterologous production of acrylic acid: Current challenges and perspectives. Synbio 1: 3-32. DOI: 10.3390/synbio1010002.
Roman G. 2015. Mannich bases in medicinal chemistry and drug design. Eur J Med Chem 89: 743-816. DOI: 10.1002/CHIN.201506309.
Sahu MK, Suthakaran S, Ghosh SC, Singh D, Das A, Jha H. 2023. Anticancer activity of secondary metabolite isolated from the rhizospheric fungus *Fusarium oxysporum* isolate-ABRF1, 2-propenoic acid, pentadecyl ester. Asian J Nat Prod Biochem 21 (2): 88-100. DOI: 10.13057/biofar/f210205.
Sangeetha C, Krishnamoorthy AS, Amirtham D. 2015. Antifungal bioactive compounds from Chinese caterpillar fungus (*Ophiocordyceps sinensis* (Berk.) GH Sung et al.) against plant pathogens. Madras Agric J 102: 1. DOI: 10.29321/MAJ.10.001133.
Sapijanskaitė-Banevič B, Grybaitė B, Vaickelionienė R, Bružaitė I. 2023. Synthesis, transformation and preliminary bioassay of 3-(thiazol-2-yl (p-tolyl) amino) propanoic acid derivatives. Chemija 34 (1): 57-69. DOI: 10.6001/chemija.2023.34.1.7.
Saribekova D, Kunik O, Harhaun R, Saleba L, Cavallaro G. 2021. The use of silicones as extractants of biologically active substances from vegetable raw materials. Appl Sci 11 (22): 10625. DOI: 10.3390/app112210625.
Seenivasan N. 2018. Phytochemical profiling of burrowing nematode (*Radopholus similis*) resistant and susceptible banana (*Musa* spp.) genotypes for detection of marker compounds. Fruits 73 (1): 48-59. DOI: 10.17660/th2018/73.1.6.
Shaaban MT, Ghaly MF, Fahmi SM. 2021. Antibacterial activities of hexadecanoic acid methyl ester and green-synthesized silver nanoparticles against multidrug-resistant bacteria. J Basic Microbiol 61 (6): 557-568. DOI: 10.1002/JOBM.202100061.
Shen C, Wang C, Zhao S, Guo Q. 2023. Acrylamide, acrylic acid, or 2-acrylamido-2-methyl-1-propanesulfonic acid induced cytotoxic in *Photobacterium phosphoreum*, PC12, and SK-N-SH cells. Environ Toxicol 38 (3): 489-499. DOI: 10.1002/tox.23673.
Sonawane U, Agarwal AK. 2023. Comparative spray atomization and evaporation characteristics of dimethyl ether and mineral diesel. J Energy Resour Technol 145 (12): 121201. DOI: 10.1115/1.4062619.
Soraya S, Sukara E, Sinaga E. 2022. Identification of chemical compounds in *Ziziphus mauritiana* Fruit juice by GC-MS and LC-MS/MS analysis. Intl J Biol Phys Chem Stud 4 (2): 11-19. DOI: 10.32996/ijbpcs.2022.4.2.2.
Srinivasulu K, Babu BH, Kumar KS, Reddy CB, Raju CN, Rooba D. 2008. Synthesis and bioactivity of 6-bromo-2-(substituted) -3-(1-phenyl-ethyl) -3, 4-dihydro-1H-isophosphinoline 2-chalcogenides. J Heterocycl Chem 45 (3): 751-757. DOI: 10.1002/CHIN.200839173.
Strobykina IY, Nemtarev AV, Garifullin BF, Voloshina AD, Sapunova AS, Kataev VE. 2019. Synthesis and biological activity of alkane-1, 1-diylbis (phosphonates) of diterpenoid isosteviol. Russian J Organic Chem 55: 17-24. DOI: 10.1134/S1070428019010044.
Sucheta, Tahlan S, Verma PK. 2007. Biological potential of thiazolidinedione derivatives of synthetic origin. Chem Central J 11: 130. DOI: 10.1186/S13065-017-0357-2.
Sudharsan S, Saravanan R, Shanmugam A, Vairamani S, Kumar RM, Menaga S, Ramesh N. 2011. Isolation and characterization of octadecanoic acid from the ethyl acetate root extract of *Trigonella foneum graecum* L. by using hydroponics method. Bioterrorism Biodefense 2 (1): 1-4. DOI: 10.4172/2157-2526.1000105.
Suriani NL. 2016. Identification of the substance bioactive leaf extract *Piper caninum* potential as botanical pesticides. Intl J Pure App Biosci 4 (4): 26-32. DOI: 10.18782/2320-7051.2337.
Terent′ eva EO, Saidov AS, Khashimova ZS, Tseomashko NE, Sasmakov SA, Abdurakhmanov DM, Vinogradova VI, Azimova SS. 2017. Synthesis and biological activity of 1, 11-bis (6, 7-methylenedioxy- and 6, 7-dimethoxy-1, 2, 3, 4-tetrahydroisoquinolin-1-yl) undecanes. Chem Nat Compounds 53: 328-332. DOI: 10.1007/S10600-017-1981-8.
Tewari H, Jyothi KN, Kasana VK, Prasad AR, Prasuna AL. 2015. Insect attractant and oviposition enhancing activity of hexadecanoic acid ester derivatives for monitoring and trapping *Caryedon serratus*. J Stored Prod Res 61: 32-38. DOI: 10.1016/J.JSPR.2015.02.003.
Tian Z, Li Y, Zhou T, Ye X, Li R, Liu J. 2020. Structure dynamics reveal key residues essential for the sense of 1-dodecanol by *Cydia pomonella* pheromone binding protein 2 (CpomPBP2). Pest Manag Sci 76 (11): 3667-3675. DOI: 10.1002/PS.5915.
Tiwari AK, Gupta MK, Pandey G, Pandey PC. 2023. Siloxane-silver nanofluid as potential self-assembling disinfectant: A preliminary study on the role of functional alkoxysilanes. Nanoarchitectonics 1-15. DOI: 10.37256/nat.4120231576.
Tumosienė I, Jonuškienė I, Kantminienė K, Šiugždaitė J, Mickevičius V, Beresnevičius ZJ. 2016. Synthesis and biological activity of 1, 3, 4-oxa (thia) diazole, 1, 2, 4-triazole-5-(thio) one and S-substituted derivatives of 3-((2-carboxyethyl) phenylamino) propanoic acid. Res Chem Intermediates 42: 4459-4477. DOI: 10.1007/S11164-015-2290-0.
Uygun Y, Bayrak H, Özkan H. 2013. Synthesis and biological activities of methylenebis-4H-1, 2, 4-triazole derivatives. Turk J Chem 37 (5): 812-823. DOI: 10.3906/KIM-1212-66.
Venn-Watson SK, Butterworth CN. 2022. Broader and safer clinically-relevant activities of pentadecanoic acid compared to omega-3: Evaluation of an emerging essential fatty acid across twelve primary human cell-based disease systems. PLoS One 17 (5): e0268778. DOI: 10.1371/journal.pone.0268778.
Wang H, Tian N, Chu D, Yan H. 2024. Synthesis and biological evaluation of 3, 9-Dioxatetraasteranes as potential inhibitors of epidermal growth factor receptor. Letters Drug Design Discover 21 (3): 552-558. DOI: 10.2174/1570180819666220928151144.
Winchester WR, Seymour J. 2022. Computational and dynamic NMR investigation of 2, 2-dimesityl-1, 1, 1, 3, 3, 3-hexamethyltrisilane. Magn Reson Chem 58 (4): 312-318. DOI: 10.1002/mrc.4991.
Wohlgemuth R. 2023. Advances in the synthesis and analysis of biologically active phosphometabolites. Intl J Mol Sci 24 (4): 3150. DOI: 10.3390/ijms24043150.
Yadav SM, Sharma VK, Sharma PK, Sharma J. 2022. Pharmacognostical, phytochemical, antimicrobial and hepatoprotective screening of some plants of family rhamnaceae. Intl J Health Sci 6: 4890-4911. DOI: 10.53730/ijhs.v6nS3.6985.
Yamini DP, Singh AK, Panigrahi HK. Morphological evaluation of tree, leaf and branch characteristics in indigenous ber (*Ziziphus mauritiana* Lamk.) at Bemetara district of Chhattisgarh. Intl J Adv Biochem Res 8 (8): 376-379. DOI: 10.33545/26174693.2024.v8.i8e.1760.
Yusof MY, Ramli MA. 2021. Local wisdom of Tahlil and Tunggu Kubur practices in death custom among The Malays in Malaysia. UMRAN-J Islamic Civilizational Stud 8: 39-48. DOI: 10.11113/umran2021.8n2.396.

Zablotskaya A, Segal I, Popelis Y, Grinberga S, Shestakova I, Nikolajeva V, Eze D. 2013. Silyl modification of biologically active compounds. 13. Synthesis, cytotoxicity and antibacterial action of N-methyl-N-(2-triorganylsiloxyethyl) -1, 2, 3, 4-tetrahydro (Iso) Quinolinium Iodides. Appl Organometal Chem 27 (2): 114-124. DOI: 10.1002/AOC.2952.

Zhou Y, Cao F, Luo F, Lin Q. 2022. Octacosanol and health benefits: Biological functions and mechanisms of action. Food Biosci 47: 101632. DOI: 10.1016/j.fbio.2022.101632.