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Secondary Compounds Assessment in Some Street Plants Exposed to Air Pollution in Jeddah Governorate, Kingdom of Saudi Arabia

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Abstract

This research was carried out to identify the most effective plant species for air purification based on environmental factors. The existence of plants beside roadways can be considered a more efficient approach to improving air quality and minimizing pollution exposure. The samples for this research were collected from various sites across the streets of Jeddah governorate. The primary sources of air pollution in the research area are vehicle traffic and emissions from cars. Eight species were gathered from various streets in Jeddah governorate, namely, *Azadirachta indica*, *Senna sulfurea*, *Ziziphus spina-christi*, *Cordia sebestena*, *Tecoma stans*, *Bougainvillea spectabilis*, *Conocarpus lancifolius*, and *Ixora coccinea*. The leaves of the studied plants were analyzed for secondary compounds using Gas chromatography-mass spectrometry (GC-MS) techniques. Gas-chromatographic analyses revealed that bis (2-ethylhexyl) phthalate was found in every plant. Bis-(2-ethylhexyl) phthalate, a widespread environmental pollutant. Moreover, *Cordia sebestena* was the sole plant that contained Phenol, 2,2'-methylenebis [6-(1,1-dimethylethyl)-4-methyl] which is part of the phenols category. Environmental conditions can affect the production of secondary metabolites. By tracking the concentrations of these substances, researchers can evaluate the well-being of ecosystems and identify pollution.

Keywords

Secondary Compounds, Street Plants, Air Pollution, Jeddah Governorate, Gas Chromatography-Mass Spectrometry (GC-MS)

1. Introduction

In the Jeddah governorate, increased industrial activities, urban growth, and traffic

congestion may raise the levels of heavy metals in the air and soil, thereby threatening food safety and public health [1]. The primary contributors to air pollution in the study area are vehicular traffic and emissions from automobiles. Organic substances known as secondary compounds are those that plants create but do not directly contribute to their development, growth, or reproduction. They are not necessary for the basic life of plants, but they are important in how the plant interacts with its surroundings, especially when it comes to defense mechanisms. Secondary compounds are a fascinating area of plant biology with a wide range of uses and vital roles in plant survival [2]. These compounds often play crucial roles in plant defense mechanisms, such as deterring herbivores or pathogens. However, their interactions with environmental pollutants can have both positive and negative consequences. The positive roles of secondary metabolites like phenols and alkaloids can help plants tolerate and even detoxify heavy metals and other pollutants. They can bind to pollutants, making them less available for uptake by other organisms [3]. Moreover, some secondary metabolites have enzymatic properties that can break down pollutants into less harmful substances. For example, certain enzymes produced by plants can degrade organic pollutants like those that pesticides [4]. The production of secondary metabolites can be influenced by environmental conditions. By monitoring the levels of these compounds, scientists can assess the health of ecosystems and detect pollution [5]. While Allelopathic can be beneficial for plants in their natural environments, it can also have negative consequences. When Allelopathic compounds are released into the environment, they can inhibit the growth of other plants, leading to biodiversity loss [6]. In addition, some secondary metabolites can be toxic to humans and other organisms. When these compounds are released into the environment, they can pose a threat to human health and ecosystem integrity [7]. Understanding the interactions between plants and pollutants is essential for developing effective strategies to mitigate environmental pollution and protect ecosystems.

Plant secondary metabolites include a variety of phytochemicals, including alkaloids, phenolic, terpenoids, and their derivatives, which are present in the extracts of different plant components. These secondary metabolites are believed to provide an evolutionary advantage to plant species, allowing them to effectively respond to challenges from predators, diseases, and environmental pressures.

The development of these plant defense compounds has led to the discovery of bioactive substances that may possess significant applications in medicine, pharmacy, and biotechnology. An increasing number of novel compounds are being identified from multiple plant species. Furthermore, varieties of secondary compounds' uses are known. Among them are defense against herbivores: many of the secondary compounds on the plant have bitter, poisonous, or repulsive qualities that prevent herbivores from eating it. Some secondary compounds are UV protection [8]. By absorbing harmful UV radiation, certain secondary chemicals, including flavonoids, can protect plants from sun damage. In order to protect themselves from competition, plants might produce secondary substances into the soil

that impede the growth of other plants [9]. Pollinator attraction: A few secondary compounds aid in the development of flowers and the emission of scents, which draws pollinators for procreation.

Principal categories of secondary compounds consist of Terpenoids: A broad class that includes carotenoids, essential oils, waxes, and resins. Examples include rubber, menthol (found in mint), and limonene (found in citrus fruits). Phenolics: Substances having a hydroxyl group attached to the benzene ring. Examples include lignin, which is a structural element of plant cell walls, flavonoids, which are present in fruits and vegetables, and tannins, which are present in tea and wine. Alkaloids: nitrogen-containing substances that are frequently poisonous or bitter. Nicotine, morphine, caffeine, and quinine are a few examples. Polyketides are compounds made from acetyl-CoA units by a sequence of processes. Toxins (like aflatoxins), colors (like anthocyanins), and medicines (like erythromycin) are a few examples [10]. Humans have used secondary compounds for centuries for medicinal, culinary, and industrial purposes. Medicinal uses include aspirin (derived from willow bark), morphine (derived from opium poppies), and quinine (derived from cinch tree) [11].

Environmental pollution ranks among the primary contributors to numerous serious illnesses globally [12]. It is estimated that more than 80% of global wastewater does not reach the environment, leading to about 58% of health problems, including diarrhea. The primary factor contributing to premature mortality in children [13]. With population growth, swift industrialization, and fast urbanization, our planet experiences numerous forms of pollution. Different environmental factors affect the production of secondary metabolites. Environmental factors influence the production and accumulation of secondary metabolites [14] [15]. In recent years, the physiological and molecular impacts of secondary metabolites and brassinosteroids have positioned them as promising natural agents for safeguarding plants and boosting crop yields in several ways [16]. Phytoremediation is an affordable and eco-friendly approach to eliminate pollutants from soil and water by utilizing green plants [17]. To create plants appropriate for phytoremediation of polluted areas, it is crucial to comprehend plant tolerance to specific metals controlled by a complex interplay of physiological and molecular processes. Plants adjust to their surroundings by creating secondary compounds. A plant food's secondary metabolite may be a phenolic compound, alkaloid, terpene, or organosulfide. In this research, we explored if vegetation planted along streets in the Jeddah Governorate might reduce air pollution through their secondary metabolites. Air pollution comprises various contaminants, such as dust, smoke, and other forms of air pollutants [18].

2. Materials and Methods

2.1. Plants Collection and Identification

The research concentrated on eight renowned medicinal plant species in the Jeddah governorate that experienced contamination during the winter period. The

samples for this study were gathered from various sites in Jeddah. The primary contributors to air pollution in the area under investigation are road traffic and emissions from vehicles. The vegetation encompassed *Azadirachta indica*, *Senna sulphurea*, *Ziziphus spina-christi*, *Cordia sebestena*, *Tecoma stans*, *Bougainvillea spectabilis*, *Conocarpus lancifolius*, *and Ixora coccinea* (including trees, shrubs, subshrubs, and vines). The plants were gathered from various sites in contaminated regions of Jeddah. The names of plant species were taken from [19] [20]. Vehicles with high emissions contribute significantly to road traffic, which is the primary source of air pollutants in the study area [19] [20]. Fresh leaf samples were obtained from each spot at each site. They were immediately preserved in an icebox, brought to the laboratory, and kept in a deep freezer. In addition, some of the leaves also, plant leaves collected and preserved in liquid nitrogen for molecular analysis. Ice was utilized to keep plant leaves fresh for the examination of secondary compounds.

2.2. Plants Preparation for GC-MS Analysis

Ten grams of each sample were dried in an oven at 30˚C for 24 hours, followed by grinding to a fine powder with an electric grinder (JANO JN0001) and then transferred into glass flasks. Every flask contained 150 mL of ethanol with sample concentrations at roughly 75% and was sealed. The samples were subsequently kept at room temperature for 48 hours, with careful observation of the ethanol levels. All needed modifications were implemented to guarantee that the specified volume of 150 mL was reliably upheld. After the designated time elapsed, the primary filtration process was carried out with a funnel and Whatman No.1 filter paper. The ethanolic extract was exclusively gathered and then kept in a cooled setting at a temperature of 3˚C until the extraction process was entirely finished. Carry out the previously mentioned steps in succession for a period of 48 hours while keeping the same plant sample. To finalize the extraction process via heating, it is essential to add a second extract to the first one. The heating procedure was carried out with the Soxhlet apparatus. Every single sample was kept at a temperature around 50˚C for a period of two hours. The samples underwent final filtration after 24 hours, after which they were kept in a cold environment until the next analysis for GC-MS and phytochemical screening [21].

Gas Chromatography-Mass Spectrometry (GC-MS) Analysis

The sample extracts were analyzed by gas chromatography-mass spectrometry (GCMS QPplus-2010, Shimadzu, Japan) and a mass spectrometer (MS, EI conditions). Prior to the identification of the compounds present in the extracts, a volume of 0.1 ml of each plant extract was combined with 1 ml of ethanol of high-performance liquid chromatography (HPLC) grade, sourced from WINLAB in the United Kingdom. The resulting mixture was subjected to filtration through a 0.22 μ Millipore filter, specifically the Millex-HV variant, in order to obtain a solution that was clear and free of impurities.

The initial temperature of the column oven was 250˚C. A HP 5 ms, 30 m

capillary column was used (30 m × 0.25 mm i.d. × 0.25 m, 5% phenylmethylsiloxane, Rtx -5MS) with a temperature program of 60˚C (2 min hold), ramp 5˚C/min to 310˚C, and 5-min hold. Helium was used as the carrier gas (2 mL/min). The ion source temperature was 220˚C and the interface temperature was 250˚C. The injection volume was 2 μL using an auto-sampler (AOC-5000, Shimadzu, Japan). Injection was performed in "splitless" mode with a spitting time of 0.98 min and a flush flow rate of 30 mL/min. Selected Ion Mode (SIM) was developed experimentally for each compound based on precursor and production ions, collision energies, and other parameters. Target compounds were positively identified by comparing their retention times and target ions to the specific reference ions [22].

2.3. Identification of the Secondary Compounds

The identification of the extract components was achieved by comparing their retention times (RT) and mass spectral data with those from the certified library of the National Institute of Standards and Technology 11. Retention time is affected by molecular weight; substances with higher molecular weights typically show longer retention times. Retention time (RT) denotes the time taken for a solute to pass through a chromatography column, measured as the period from injection to detection.

3. Results

3.1. The Existence and Nonexistence of Secondary Compounds in the Eight Plant Species

The findings presented in Table 1 indicate that bis (2-ethylhexyl) phthalate was detected in all examined plants. In contrast, terephthalic acid, ethyl 2-ethylhexyl

Table 1. The existence and nonexistence of secondary compounds in the eight plant species.

Compounds	*Azadirachta indica*	*Cassia gluca Lam.*	*Ziziphus spina-Christi (L.) Desf*	*Cordia sebestena L.*	*Tecoma stans (L.) kunth*	*Bougainvillea spectabilis willd.*	*Conocarpus lancifolius Engl.*	*Ixora coccinea L.*
1. n-Tridecan-1-ol	+	+	−	−	−	−	−	−
2. 1-Tetradecanol	+	+	−	−	−	−	−	−
3. Hexadecanoic acid, ethyl ester	+	+	−	−	−	+	−	+
4. n-Propyl 9,12-octadecadienoate	+	+	−	+	−	−	+	−
5. Octadecanoic acid, 17-methyl-, methyl ester	+	+	−	−	−	−	+	−
6. Docosanoic anhydride	+	+	−	−	−	−	−	−
7. Bicyclo[10.1.0]tridec-1-ene	+	+	−	−	−	−	−	−
8. 1,3,5-Trisilacyclohexane	+	+	−	−	−	−	−	−

Continued

9. Benzyldiethyl-(2,6-xylylcarbamoylmethyl)-ammonium benzoate	+	+	−	+	+	+	−	+
10. Bis(2-ethylhexyl) phthalate	+	+	−	+	+	+	+	+
11. Cyclohexasiloxane, dodecamethyl-	−	−	+	+	+	+	+	+
12. Cycloheptasiloxane, tetradecamethyl-	−	−	+	+	−	+	+	+
13. Lidocaine	−	−	+	+	−	+	+	+
14. Ethyl 15-methyl-hexadecanoate	−	−	+	−	−	−	−	−
15. Phytol	−	−	+	+	+	+	+	+
16. Ethyl Oleate	−	−	+	+	−	−	+	+
17. Octadecanoic acid, 2,3-dihydroxypropyl ester	−	−	+	−	−	−	−	−
18. Ethyl 13-methyl-tetradecanoate	−	−	+	+	+	−	+	−
19. Phenol, 2,2'-methylenebis[6-(1,1-dimethylethyl)] 4-methyl-	−	−	+	+	−	−	−	−
20. 5,7-Dimethyl-1,3-diazaadamantan-6-ol	−	−	−	−	+	−	−	−
21. Anisole, o-(1-ethylvinyl)-	−	−	−	−	+	+	−	−
22. Disparlure	−	−	−	−	+	+	−	−
23. 1,2,3,4,7,7a-Hexahydro-2,4,7-trimethyl-6H-2-pyrindin-6-one	−	−	−	−	+	+	−	−
24. Dichloroacetic acid, tridec-2-ynyl ester	−	−	−	−	+	−	−	−
25. 1,2-Diphenyl-1,2-di(morpholin-4-yl)ethane (threo)	−	−	−	−	−	−	+	−
26. Terephthalic acid, ethyl 2-ethylhexyl ester	−	−	−	−	−	−	−	+
27. 1,3-Benzenedicarboxylic acid, bis(2-ethylhexyl ester)	−	−	−	−	−	−	−	+

ester, and 1,3-Benzenedicarboxylic acid, bis(2-ethylhexyl) ester were exclusively identified in *Ixora coccinea* L. Additionally, *Azadirachta indica* and *Cassia glauca* Lam. contained a total of 10 compounds from the 27 compounds reported, followed by *Ziziphus spina-Christi* (L.) that contains 9 compounds. On the other hand, Benzyldiethyl-(2, 6-xylylcarbamoylmethyl)-ammonium benzoate, Cyclohexasiloxane, dodecamethyl, Cyclohexasiloxane, dodecamethyl, and Phytol, were reported in six plants out of eight (Table 1).

Nonetheless, many secondary compounds were reported in only two plants. These are, n-Tridecan-1-ol, Tetradecanol, Docosanoic anhydride, Bicyclo[10.1.0]tridec-1-ene, 1,3,5-Trisilacyclohexane, Phenol, 2,2'-methylenebis[6-(1,1-dimethylethyl)-4-methyl, Anisole, o-(1-ethylvinyl), Disparlure, 1,2,3,4,7,7a-Hexahydro-2,4,7-trimethyl-6H-2-pyrindin-6-one. These compounds were located mainly in *Azadirachta indica* and *Cassia gluca* Lam (Table 1).

3.2. Chemical Constituents, Retention Time (RT), Percentage of Peak Area (PIC % Area), of the Secondary Compounds of *Azadirachta indica*

The data presented in Table 2 indicates that the secondary compounds identified

Table 2. Chemical constituents, retention time/minutes (RT), percentage of peak area (PIC percentage area), height, and chemical class of the secondary compounds of *Azadirachta indica*.

Peaks	RT (min)	Compounds	Area (%)	Height	Chemical class	Molecular Formula
1.	12.349	n-Tridecan-1-ol	5.5	2,835,791	Alcohol	$C_{13}H_{28}O$
2.	15.061	1-Tetradecanol	31.31	17,331,151	Alcohol	$C_{14}H_{28}$
3.	18.325	Hexadecanoic acid, ethyl ester	11.12	6,934,401	Fatty acid esters	$C_{18}H_{36}O_2$
4.	19.98	n-Propyl 9,12-octadecadienoate	4.92	2,862,323	Fatty acid	$C_{19}H_{34}O_2$
5.	20.264	Octadecanoic acid, 17-methyl-, methyl ester	7.41	4,663,947	Fatty acid esters	$C_{20}H_{40}O_2$
6.	21.202	Docosanoic anhydride	5.12	3,181,368	Fatty acid	$C_{44}H_{86}O_3$
7.	22.717	Bicyclo[10.1.0]tridec-1-ene	7.6	3,797,623	Terpenoids	$C_{13}H_{20}O$
8.	22.758	1,3,5-Trisilacyclohexane	7.22	4,390,495	Sulfur Compounds	$C_3H_6Si_3$
9.	23.308	Benzyl diethyl-(2,6-xylylcar-bamoylmethyl)-ammonium benzoate Lidocaine benzyl benzoate1	4.06	2,247,925	amino acid amide	$C_{28}H_{34}N_2O_3$
10.	23.365	Bis(2-ethylhexyl) phthalate, (23.356)	15.74	9,332,298	Ester	$C_{24}H_{38}O_4$
Total			100			

Table 3. Chemical constituents, retention time (RT), percentage of peak area (PIC % area), of the secondary compounds of *Senna sulfurea*.

Peaks	RT	compounds	PIC % Area	Height	Chemical class
1.	10.317	n-Tridecan-1-ol	8.36	1,264,566	Alcohol
2.	12.67	1-Tetradecanol	8.29	1,536,677	Alcohol
3.	15.055	Hexadecanoic acid, ethyl ester	9.18	1,220,147	Fatty acid esters
4.	17.472	n-Propyl 9,12-octadecadienoate	4.88	8,112,183	Fatty acid
5.	18.323	Octadecanoic acid, 17-methyl-, methyl ester	8.98	2,310,627	Fatty acid esters
6.	20.025	Docosanoic anhydride	5.34	6,008,293	Fatty acid
7.	21.201	Bicyclo[10.1.0]tridec-1-ene	4.69	2,648,138	Terpenoids
8.	22.756	1,3,5-Trisilacyclohexane	12.19	16,136,620	Sulfur Compounds
9.	23.308	Benzyldiethyl-(2,6-xylylcarbamoylmethyl)-ammonium benzoate Lidocaine benzyl benzoate	5.37		amino acid amide
10.	23.363	Bis(2-ethylhexyl) phthalate	32.72	9,332,298	Ester
Total			100		

in *A. indica* are primarily categorized into specific groups. These groups include Alcohols, Fatty Acid Esters, Fatty Acids, Terpenoids, Sulfur Compounds, Amino Acid Amides, and Esters. Results in Table 3 indicate that n-Tridecan-1-ol was present in the sample and that it made up 5.5% of the total peak area in the chromatogram. Concerning 1-Tetradecanol: This refers to a specific chemical compound, in this case, an alcohol with 14 carbon atoms. Retention time 15.061: This

means that it took 15.061 minutes for this compound to travel through a chromatography column and be detected. In chromatography, various compounds traverse the column at distinct velocities, influenced by their individual characteristics, which facilitates their separation and identification. The area percentage of 31.31 indicates the relative concentration of 1-tetradecanol within the analyzed sample, signifying that 31.31% of the total signal recorded during the chromatography process was attributable to 1-tetradecane. This compound was identified as the predominant secondary compound in *A. indica* (refer to Table 3, Figure 1). A significant retention time was observed for Bis (2-ethylhexyl) phthalate; measuring 23.356 (see Table 2, Figure 1). However, the area percentage for this compound is nearly half that of 1-tetradecanol, at 15.74%. It is noteworthy that 1-tetradecanol exhibited a prolonged peak, whereas Bis (2-ethylhexyl) phthalate displayed a shorter peak. Generally, elongated peaks suggest inadequate separation, while shorter peaks are indicative of effective separation.

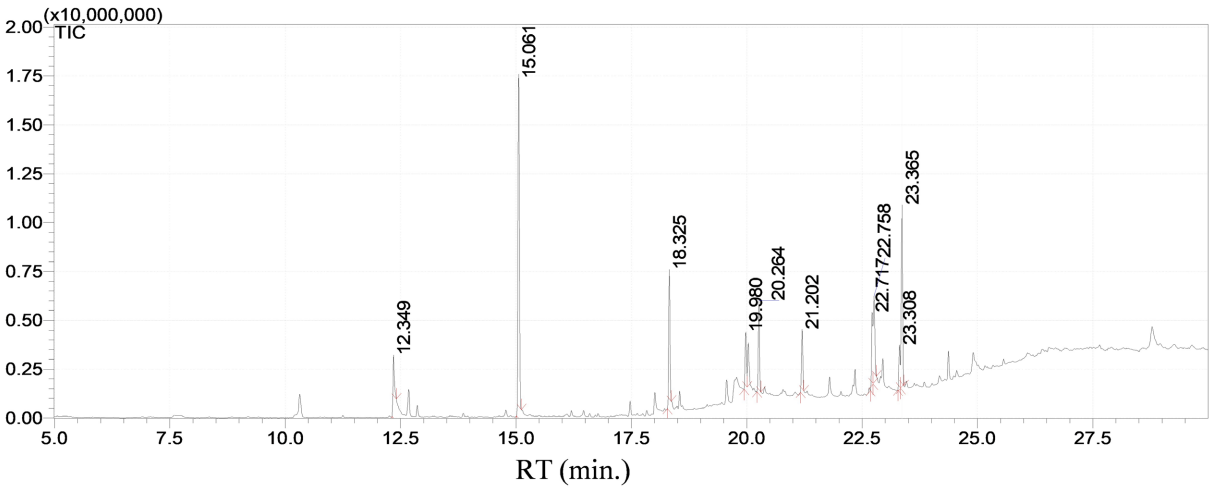

Figure 1. Gas chromatography-mass spectrometry chromatogram of ethanol extract of *Azadirachta indica*.

3.3. Chemical Constituents, Retention Time (RT), Percentage of Peak Area (PIC % Area), of the Secondary Compounds of *Senna sulfurea*

The results of the analysis of *S. sulfurea* are presented in Table 3 and Figure 2. The secondary compounds identified in this plant encompass various groups, including Alcohols, Fatty Acid Esters, Fatty Acids, Terpenoids, Sulfur Compounds, Amino Acid Amides, and Esters. All secondary compounds exhibited significantly higher retention times in comparison to those found in *A. indica*. Notably, bis (2-ethylhexyl) phthalate demonstrated a high retention time of 23.363 and a substantial percentage area of 32.72. Conversely, n-Tridecan-1-ol recorded the lowest retention time at 10.317.

In addition, Bicyclo [10.1.0] tridec-1-ene, a terpenoid found in *S. sulphurea*, exhibited the lowest percentage area at 4.69%. Figure 2 demonstrates effective separation of secondary compounds in *S. sulphurea*. Most secondary compounds

in *S. sulphurea* presented short peaks, with the exception of bis (2-ethylhexyl) phthalate, which displayed a prolonged peak.

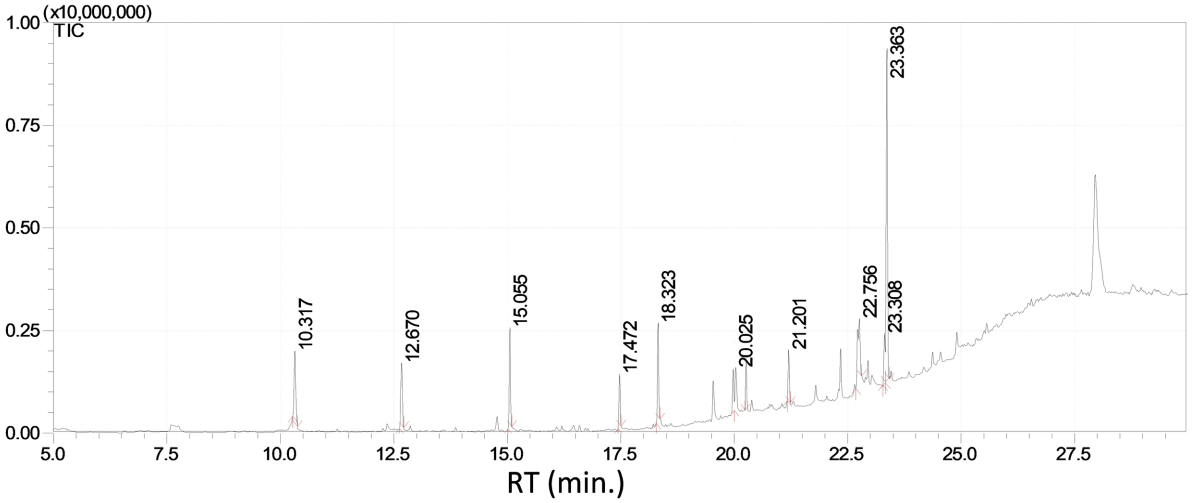

Figure 2. Gas chromatography-mass spectrometry chromatogram of the extract of *Senna sulfurea*.

3.4. Chemical Constituents, Retention Time (RT), Percentage of peak Area (PIC % Area), of the Secondary Compounds of *Ziziphus spina-christi*

Results presented in **Table 4** and **Figure 3**, showed that *Ziziphus spina-christi* secondary compounds were mainly, cyclic methyl siloxane, organosilicon compound, Amines Alkaloids, Fatty acid, Terpenes, Fatty acid esters, Alkane, amino acid amide, alkaloids and ester. As in the above species, Bis(2-ethylhexyl) phthalate showed the highest RT (23.363) and the highest % area (34.96%). On the other hand, Cyclohexasiloxane, dodecamethyl showed low RT (10.317). Octadecanoic acid, 2,3-dihydroxypropyl ester had a percentage area of 3.25 as the smallest % area among all compounds.

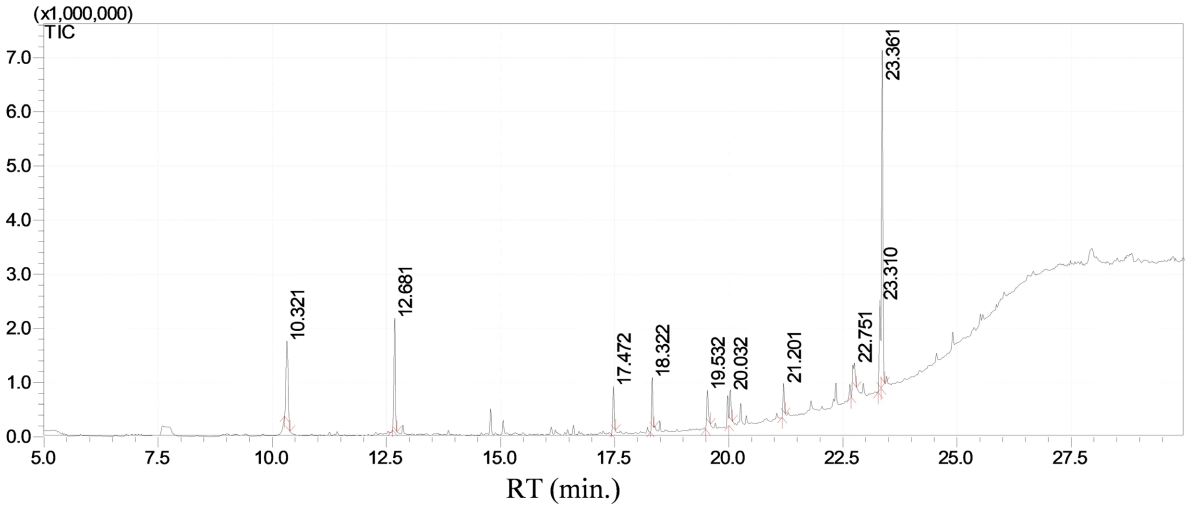

Figure 3. Gas chromatography-mass spectrometry chromatogram of ethanol extract of *Ziziphus spina-christi*.

Table 4. Chemical constituents, retention time (RT), percentage of peak area (PIC % area), of the secondary compounds of *Ziziphus spina-christi*.

Peaks	RT	compounds	PIC % Area	Height	Chemical class
1.	10.317	Cyclohexasiloxane, dodecamethyl-	13.73	1,506,150	Cyclic methyl siloxane
2.	12.67	Cycloheptasiloxane, tetradecamethyl-	12.91	2,083,958	organosilicon compound
3.	15.055	Lidocaine	4.86	853,573	Amines Alkaloids
4.	17.472	Ethyl 15-methyl-hexadecanoate	5.06	964,005	Fatty acid
5.	18.323	Phytol	4.89	689,413	Terpenes
6.	20.025	Ethyl Oleate	4.16	620,621	Fatty acid esters
7.	21.201	Octadecanoic acid, 2,3-dihydroxypropyl ester	3.25	595,355	Ester
8.	22.756	Tridecanedial	6.14	522,306	Alkane
9.	23.308	Benzyldiethyl-(2,6-xylylcarbamoylmethyl)-ammonium benzoate Lidocaine benzyl benzoate	10.04	1,650,687	amino acid amide Alkaloids
10.	23.363	Bis(2-ethylhexyl) phthalate	34.96	6,219,722	Ester
Total			100		

3.5. Chemical Constituents, Retention Time (RT), Percentage of Peak Area (PIC % Area), of the Secondary Compounds of *Cordia sebestena*

The findings presented in Table 5 and Figure 4 indicate that the secondary compounds identified in *C. sebestena* include cyclic methyl siloxane, organosilicon compounds, amine alkaloids, fatty acids, terpenes, fatty acid esters, phenols, amino acid amides, and esters. Among these, bis (2-ethylhexyl) phthalate exhibited the highest percentage area at 40.3%, whereas n-propyl 9,12-octadecadienoate recorded the lowest percentage area at 3.01%

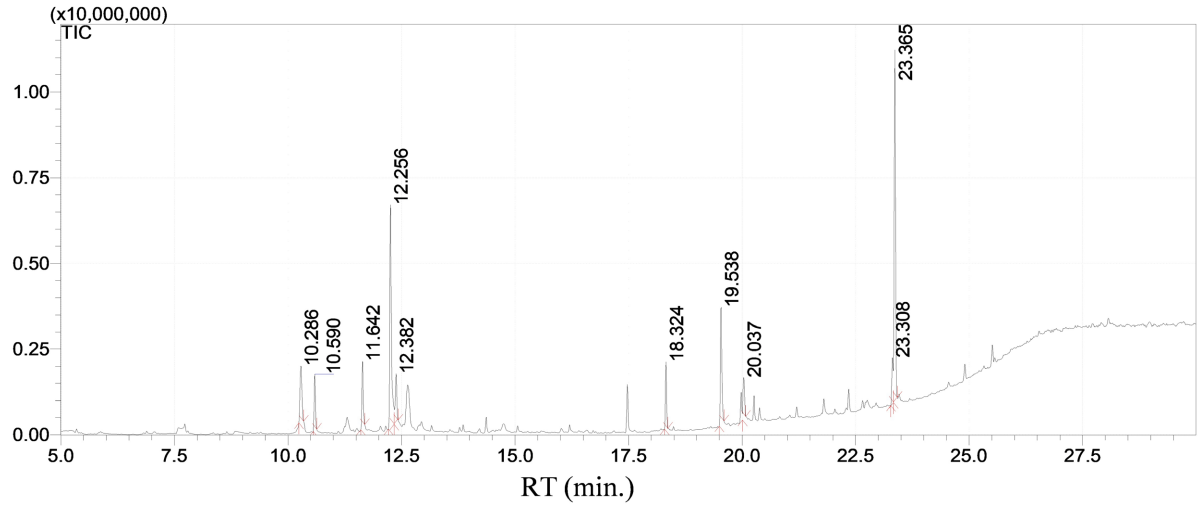

Figure 4. Gas chromatography-mass spectrometry chromatogram of ethanol extract of *Cordia sebestena*.

Table 5. Chemical constituents, retention time (RT), percentage of peak area (PIC % area), of the secondary compounds of *Cordia sebestena*.

Peaks	RT	Compunds	PIC % Area	Height	Chemical class
1.	10.282	Cyclohexasiloxane, dodecamethyl-	13.89	1,577,451	Cyclic methyl siloxane
2.	12.625	Cycloheptasiloxane, tetradecamethyl-	15.34	1,055,324	organosilicon compound
3.	17.474	Lidocaine	6.92	1,202,099	Amines Alkaloids
4.	18.324	Ethyl 13-methyl-tetradecanoate	5.94	1,113,366	Fatty Acids
5.	19.533	Phytol	4.03	653,111	Terpenes
6.	19.979	n-Propyl 9,12-octadecadienoate	3.01	547,830	Fatty acid
7.	20.033	Ethyl Oleate	4.36	634,207	Fatty acid esters
8.	22.347	Phenol, 2,2'-methylenebis[6-(1,1-dimethylethyl)-4-methyl]	2.75	509,260	Phenols
9.	23.308	Benzyldiethyl-(2,6-xylylcarbamoylmethyl)-ammonium benzoate Lidocaine benzyl benzoate	3.46	620,301	amino acid amide
10.	23.362	Bis(2-ethylhexyl) phthalate	40.3	6,443,726	Ester
Total			100		

3.6. Chemical Constituents, Retention Time (RT), Percentage of Peak Area (PIC % Area), of the Secondary Compounds of *Tecoma stans*

The findings presented in Table 6 and Figure 5, indicate that the chemical class group in *Tecoma stans* comprises Cyclic methyl siloxane, Alkaloids, Terpenes, Alkanes, Fatty Acids, Terrenes, Fatty acid esters, amino acid amide, and esters. It is noteworthy that several compounds exhibited a low percentage area, with the exceptions of bis (2-ethylhexyl) phthalate (29.74%) and Disparlure (23.61%). Conversely, Dichloroacetic acid, tridec-2-ynyl ester recorded the lowest percentage area at 4.07%. Overall, the majority of compounds displayed low peak intensities.

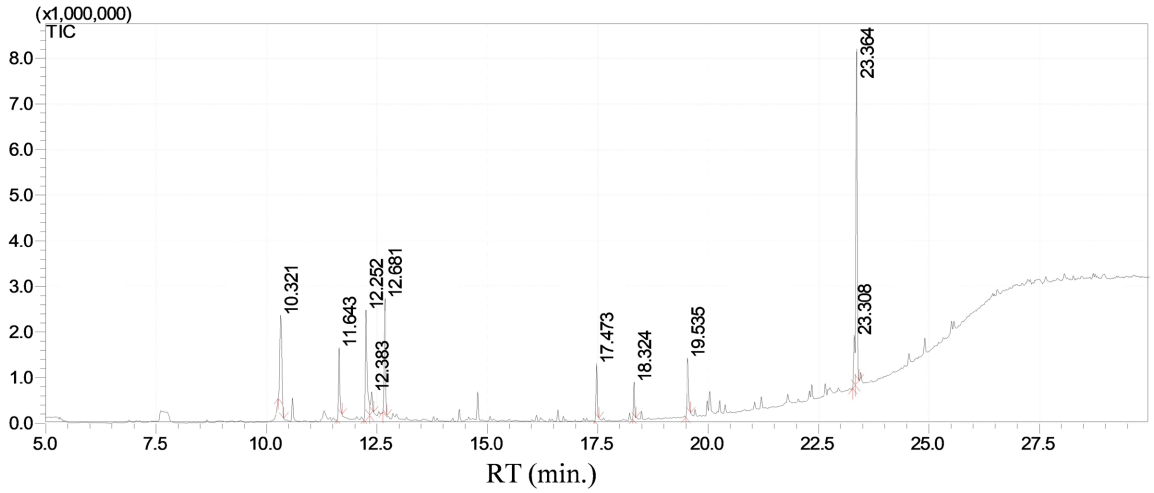

Figure 5. Gas chromatography-mass spectrometry chromatogram of ethanol extract of *Tecoma stans*.

Table 6. Chemical constituents, retention time (RT), percentage of peak area (PIC % area), of the secondary compounds of *Tecoma stans*.

Peaks	RT	compounds	PIC % Area	Height	Chemical class
1.	10.286	Cyclohexasiloxane, dodecamethyl-	6.91	1,643,041	Cyclic methyl siloxane
2.	10.59	5,7-Dimethyl-1,3-diazaadamantan-6-ol	4.44	1,636,028	Alkaloid
3.	11.642	Anisole, o-(1-ethylvinyl)-	5.50	1,937,203	Terpenes
4.	12.256	Disparlure	23.61	6,488,950	Alkanes
5.	12.382	1,2,3,4,7,7a-Hexahydro-2,4,7-trimethyl-6H-2-pyrindin-6-one	4.95	1,407,936	Alkaloids
6.	18.324	Ethyl 13-methyl-tetradecanoate	4.95	1,950,616	Fatty Acids
7.	19.538	Phytol	11.58	3,400,792	Terpenes
8.	20.037	Dichloroacetic acid, tridec-2-ynyl ester	4.07	1,199,793	Fatty acid esters
9.	23.308	Benzyldiethyl-(2,6-xylylcarbamoylmethyl)-ammonium benzoate Lidocaine benzyl benzoate	4.25	1,332,812	amino acid amide
10.	23.365	Bis(2-ethylhexyl) phthalate	29.74	10,216,834	Ester
Total			100		

3.7. Chemical Constituents, Retention Time (RT), Percentage of Peak Area (PIC % Area), of the Secondary Compounds of *Bougainvillea spectabilis*

The secondary compounds of *Bougainvillea spectabilis* are detailed in Table 7 and illustrated in Figure 6. These compounds encompass a variety of chemical classes, including cyclic methyl siloxane, terpenes, alkanes, alkaloids, amines, fatty acids, amino acid amides, and esters. Among these, bis (2-ethylhexyl) phthalate exhibited the highest percentage area at 30.86%, whereas hexadecanoic acid, ethyl ester recorded the lowest at 3.03%. Additionally, bis (2-ethylhexyl) phthalate demonstrated a significant retention time of 23.364 and a substantial percentage area of 30.86%. In contrast, dichloroacetic acid, tridec-2-ynyl ester accounted for 4.07%.

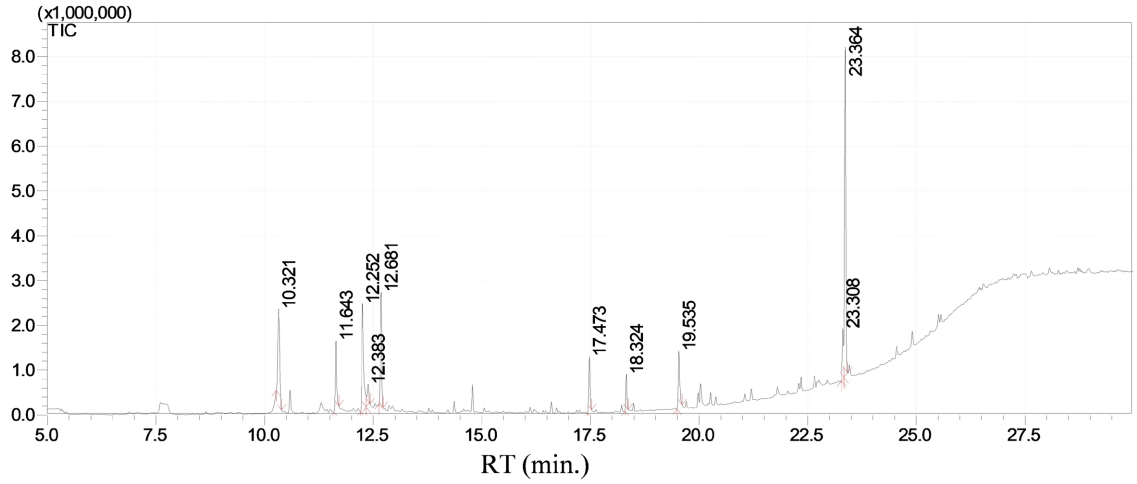

Figure 6. Gas chromatography-mass spectrometry chromatogram of ethanol extract of *Bougainvillea spectabilis*.

Table 7. Chemical constituents, retention time (RT), percentage of peak area (PIC % area), of the secondary compounds of *Bougainvillea spectabilis*.

Peaks	RT	Compounds	Area	Height	Chemical class
1.	10.321	Cyclohexasiloxane, dodecamethyl-	13.79	2,016,181	Cyclic methyl siloxane
2.	11.643	Anisole, o-(1-ethylvinyl)-	6.97	1,538,611	Terpenes
3.	12.252	Disparlure	13.82	2,370,317	Alkanes
4.	12.383	1,2,3,4,7,7a-Hexahydro-2,4,7-trimethyl-6H-2-pyrindin-6-one	2.86	475,975	Alkaloids
5.	12.681	Cycloheptasiloxane, tetradecamethyl-	11.94	2,529,438	Cyclic methyl siloxane
6.	17.473	Lidocaine	5.11	1,236,535	Amines Alkaloids
7.	18.324	Hexadecanoic acid, ethyl ester	3.03	808,898	Fatty Acids
8.	19.536	Phytol	6.45	1,261,779	Terpenes
9.	23.308	Benzyldiethyl-(2,6-xylylcarbamoylmethyl)-ammonium benzoate Lidocaine benzyl benzoate	5.17	1,126,824	amino acid amide
10.	23.364	Bis(2-ethylhexyl) phthalate	30.86	7,335,587	Ester
Total			100		

3.8. Chemical Constituents, Retention Time (RT), Percentage of Peak Area (PIC % Area), of the Secondary Compounds of *Conocarpus lancifolius*

Table 8 and Figure 7, illustrate the chemical components present in *Conocarpus lancifolius*. A variety of compounds belonging to multiple chemical classes was identified in this plant. These classes encompass cyclic methyl siloxane, organ silicon compounds, amine alkaloids, fatty acids, terpenes, as well as fatty acids and esters. Notably, bis (2-ethylhexyl) phthalate exhibited the highest percentage area at 42.93%, whereas Octadecanoic acid, 17-methyl-, methyl ester recorded the lowest percentage area at 2.02%.

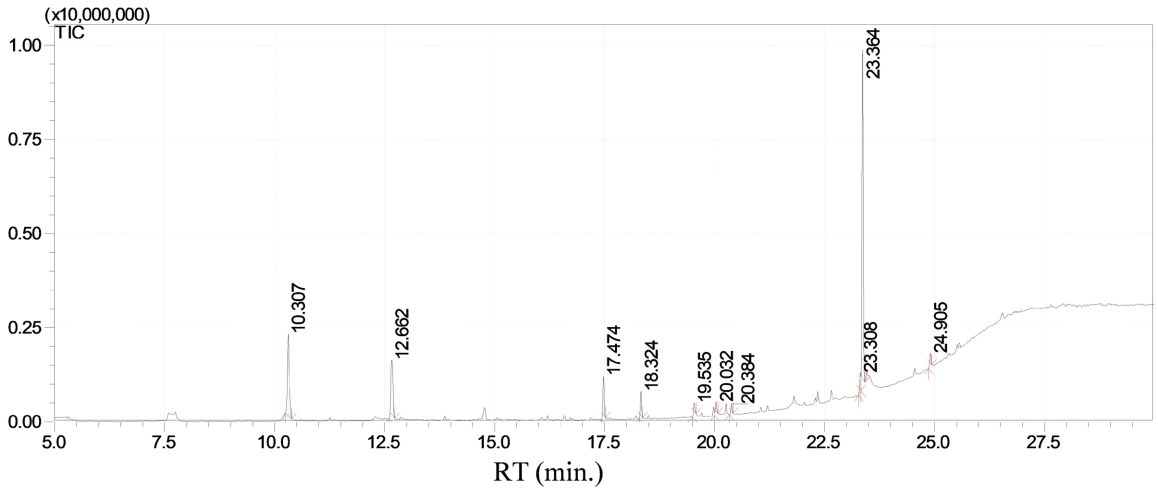

Figure 7. Gas chromatography-mass spectrometry chromatogram of ethanol extract of ethanol extract of *Conocarpus lancifolius*.

Table 8. Chemical constituents, retention time (RT), percentage of peak area (PIC % area), of the secondary compounds of *Conocarpus lancifolius*.

Peaks	RT	compounds	PIC % Area	Height	Chemical class
1.	10.287	Cyclohexasiloxane, dodecamethyl-	14.51	1,783,160	Cyclic methyl siloxane
2.	12.651	Cycloheptasiloxane, tetradecamethyl-	11.56	1,636,867	organosilicon compound
3.	17.474	Lidocaine	4.65	1,262,511	Amines Alkaloids
4.	18.325	Ethyl 13-methyl-tetradecanoate	6.36	1,788,090	Fatty Acids
5.	19.54	Phytol	6.93	1,468,925	Terpenes
6.	19.979	n-Propyl 9,12-octadecadienoate	2.13	600,739	Fatty acid
7.	20.034	Ethyl Oleate	3.85	893,047	Fatty acid esters
8.	20.264	Octadecanoic acid, 17-methyl-, methyl ester	2.02	569,990	Fatty acid ester
9.	23.308	1,2-Diphenyl-1,2-di(morpholin-4-yl)ethane (threo)	5.06	1,129,237	Alkaloids
10.	23.366	Bis(2-ethylhexyl) phthalate	42.93	10,696,163	Ester
Total			100		

3.9. Chemical Constituents, Retention Time (RT), Percentage of Peak Area (PIC % Area), of the Secondary Compounds of *Ixora Coccinea*

The findings presented in Table 9 and Figure 8 illustrate the chemical constituents of *Ixora coccinea*. The chemical classes identified in this plant encompass cyclic methyl siloxane, Amines Alkaloids, Fatty Acids, Terpenes, Fatty alcohols, Amino acid amides, and Esters. Notably, 1,3-Benzenedicarboxylic acid, bis (2-ethylhexyl) ester exhibited a longer retention time of 24.905, whereas Cyclohexasiloxane, dodecamethyl demonstrated a shorter retention time of 10.307. Furthermore, bis (2-ethylhexyl) phthalate accounted for the largest percentage area among all examined plants, measuring 49.11%, while Terephthalic acid, ethyl 2-ethylhexyl ester represented the smallest percentage area at 1.41%.

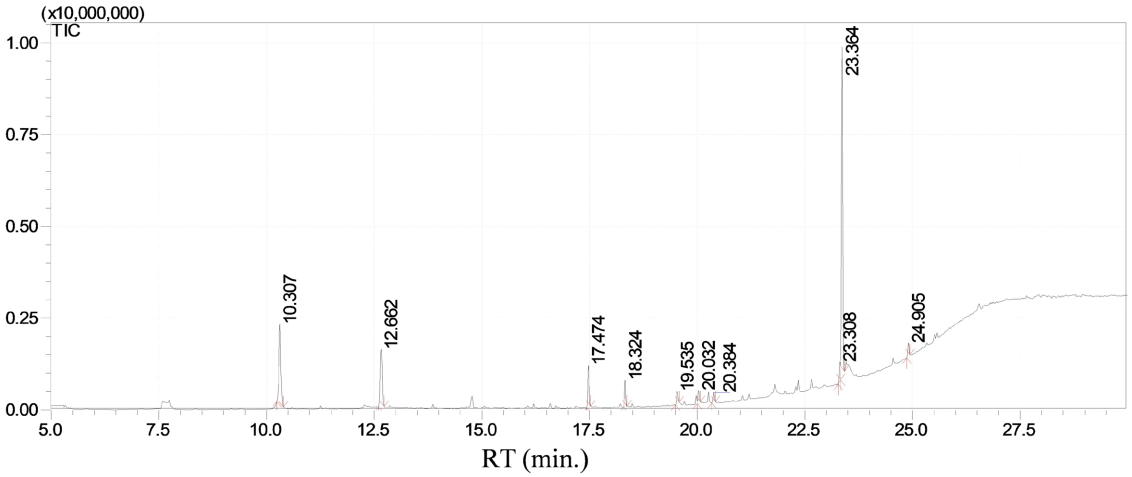

Figure 8. Gas chromatography-mass spectrometry chromatogram of ethanol extract of *Ixora coccinea*.

Table 9. Chemical constituents, retention time (RT), percentage of peak area (PIC % area), of the secondary compounds of *Ixora coccinea*.

Peaks	RT	compounds	PIC % Area	Height	Chemical class
1.	10.307	Cyclohexasiloxane, dodecamethyl-	17.35	2,165,363	Cyclic methyl siloxane
2.	12.662	Cycloheptasiloxane, tetradecamethyl-	14.11	1,559,491	Cyclic methyl siloxane
3.	17.474	Lidocaine	6.1	1,145,446	Amines Alkaloids
4.	18.324	Hexadecanoic acid, ethyl ester	3.39	710,843	Fatty Acids
5.	19.535	Phytol	2.05	327,233	Terpenes
6.	20.032	Ethyl Oleate	1.91	337,032	Fatty acid esters
7.	20.384	Terephthalic acid, ethyl 2-ethylhexyl ester	1.41	264,051	Fatty alcohols
8.	23.308	Benzyldiethyl-(2,6-xylylcar-bamoylmethyl)-ammonium benzoate Lidocaine benzyl benzoate	2.66	519,994	amino acid amide
9.	23.364	Bis(2-ethylhexyl) phthalate	49.11	8,962,493	Ester
10.	24.905	1,3-Benzenedicarboxylic acid, bis(2-ethylhexyl) ester	1.91	17,993,349	Ester
Total			100		

4. Discussion

Plants generate a variety of low-molecular-weight natural compounds that are crucial for their adaptation to different environmental conditions [11]. Secondary metabolites in plants are vital for the formation of numerous enzymes in nature that break down organic pollutants [23]. In this study, bis (2-ethylhexyl) phthalate was detected in eight different plants. However, [24] noted that in plants, the uptake of bis (2-ethylhexyl) phthalate through the roots is minimal, resulting in a negligible level of bio concentration. Those researchers pointed out that bis-(2-ethylhexyl)phthalate (BEHP) easily leaches into the environment from plastic products due to its unbound characteristics, liquidity, and volatility, as DEHP is not chemically linked to the polymer framework of plastics. As a result, DEHP might act as an organic pollutant in vegetables cultivated in greenhouses that employ such films. In chromatography, both the height of the peak and its width are essential factors for evaluating the quality of separation, with elongated peaks often indicating poor separation or peak broadening. In recent years, the worldwide increase in urbanization and industrial activities has led to the release of various complex and hazardous organic substances into the environment. Di(ethylhexyl) phthalate (DEHP) is a widely recognized environmental contaminant. Di(2-ethylhexyl) phthalate (DEHP) is a prevalent phthalate commonly used in industrial processes for producing polymeric materials, with 97% of DEHP being utilized for this purpose, especially in the manufacture of polyvinyl chloride (PVC) [25] [26]. The synthesis of plant secondary metabolites (PSMs) is vital for defense mechanisms and the management of defense-signaling pathways, which help

protect plants from herbivores. Plants generate a wide variety of secondary metabolites through numerous metabolic pathways that derive from primary metabolites. In this research, these secondary metabolites include terpenoids, fatty acids, flavonoids, phenolic, alkaloids, esters, among others, all of which exhibit a broad range of biological effects.

There is a growing concern about environmental pollution around the world. A variety of pollutants accumulate in the environment because of rapid industrialization and other anthropogenic activities. Numerous environmental pollutants can influence primary metabolism, subsequently influencing the production of a variety of secondary metabolites [27]. Elucidation of the physiological and molecular effects of secondary metabolites and brassinosteroids have catapulted them as highly promising and environment-friendly natural substances, suitable for wider application in plant protection and crop yield promotion [28]. It was noticeable that all street plants had large area of bis (2-ethylhexyl) phthalate, which belongs to the Ester group. Many authors have reported the beneficial roles of esters. Plant esters are a class of organic compounds formed by the reaction of an alcohol and an acid. They are widely found in plants, where they serve various functions, including attracting pollinators, repelling herbivores, and protecting against pathogens. While plant esters generally have low toxicity to humans and other organisms, they can still contribute to environmental pollution in certain circumstances [29]-[31]. Biodegradable components: Plant esters are often biodegradable, meaning microorganisms into less harmful substances can break them down [32]. This makes them a more environmentally friendly alternative to synthetic chemicals. Plant esters can play both positive and negative roles in environmental pollution. While they can be beneficial as natural repellents and biodegradable components, they can also contribute to air, water, and soil pollution [33]. Understanding the properties and impacts of plant esters is essential for developing sustainable and environmentally friendly practices.

It is important to note that all plants contain cyclic methyl siloxane, with the exception of *Azadirachta indica* and *Senna sulfurea*. [34] indicated that the levels of cyclic methyl siloxane were greater in indoor air and biosolids; however, no notable concentrations were found in water, soil, or sediments, apart from wastewater. [35] indicated that cyclic methyl siloxane possesses high vapor pressures and low solubility in Henry's law, resulting in a tendency to partition into the atmosphere. The environmental effects of these substances are further complicated by the breakdown of these compounds in the atmosphere, as noted by [36]. A phenolic compound, 2,2'-methylene bis [6-(1,1-dimethyl ethyl)-4-methyl], was found exclusively in *Cordia sebestena* plant.

Phenolic compounds typically shield plants from UV radiation and threats posed by pathogens, parasites, and predators, while also playing a role in their coloration [37]-[39]. All the plants examined in this research contain terpenoids in their tissues. The main roles of terpenoids within plant tissues are to prepare for abiotic stresses and combat biotic threats, such as herbivores and pathogens.

Furthermore, the high volatility and reactivity of certain terpenoids can significantly influence atmospheric composition. A study by [40] demonstrated that terpenoids constitute the most extensive and diverse group of organic compounds regarding their structure. These compounds fulfill numerous ecological functions, which may be influenced by changes in environmental conditions.

5. Conclusion

This study offers valuable insights into the ecological impacts of air pollution in the densely populated streets of Jeddah. The eight species of street plants examined exhibit notable secondary compounds that may play a role in maintaining ecosystem health and biodiversity. Understanding how air pollution stress influences the production of these secondary compounds is crucial for comprehending plant responses to adverse conditions. The findings of this research could pave the way for innovative strategies to address environmental challenges and promote sustainable resource management in areas affected by air pollution, thereby deepening our understanding of plant behavior in such contexts. Further investigations are necessary regarding street plants exposed to vehicular emissions in the Jeddah Governorate. Comprehensive research on air quality and secondary compounds is essential to identify the most suitable plants for cultivation in urban settings.

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Data Availability Statement

This manuscript's author agrees to share all data.

Conflicts of Interest

The author declares no conflicts of interest.

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