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Essential Oil of *Ipomoea carnea*: Chemical Profile, Chemometric Analysis, Free Radical Scavenging, and Antibacterial Activities

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Abstract: Essential oils (EOs) have been reported as a promising group of naturally extracted compounds due to their various reported biological activities. *Ipomoea carnea* is a widely distributed plant with many traditional uses worldwide. However, although the EOs of various *Ipomea* species have been reported, *I. carnea* remains poorly studied. Therefore, the present investigation aimed to characterize the chemical profile of the EO of *I. carnea* growing in Egypt via gas chromatography/mass spectroscopy (GC-MS) and correlate its profile with other reported species via chemometric analysis using agglomerative hierarchical clustering (AHC) and principal component analysis (PCA). In addition, the aim was to determine the antioxidant and antibacterial activities of the extracted EO. Depending on the GC-MS analysis, 31 compounds were identified, mainly terpenes (94.82), with traces of carotenoid and apocarotenoid-derived compounds. The major compounds were tau-cadinol (35.68%), α-cadinol (26.76%), spathulenol (8.11%), and caryophyllene oxide (6.56%), which were assigned as major compounds. The chemometric studies showed that the Egyptian ecospecies of *I. carnea* differs in chemical profile from those growing in Brazil, as well as those reported for other *Ipomea* species. The EO showed significant DPPH and ABTS radical scavenging abilities, with IC_{50} values of 33.69 and 40.86 mg L^{-1}, respectively. Additionally, the *I. carnea* EO displayed significant inhibition against the growth of all tested bacterial strains, where it showed an MIC range of 82–1442 mg mL^{-1}. Based on the current results, the *I. carnea* EO, particularly the major identified compounds, could be used as a potential eco-friendly green resource for antioxidant and antimicrobial activities. Therefore, further study is recommended to evaluate the biological significance of the main compounds, either individually or in combination, as well as assess their modes of action and safety.

Keywords: bush morning glory; sesquiterpenes; antioxidant; antibiotic; green chemistry

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1. Introduction

Throughout the ages, medicinal plants have been widely used in traditional medicine because of their viability, safety, low toxicity, and pharmacological potential [1]. Among the overall phytochemicals derived from plants, essential oils (EOs) are considered a promising

class that is integrated into food industries, pharmaceutics, and agriculture [2–4]. EOs possess several biological activities such as antimicrobial, antiviral, insecticide, herbicide, anti-inflammatory, antiulcerative, antipyretic, anticancer, and antiaging [5–7]. The antioxidant activity of EOs is attributed to the bioactivity of terpenoid compounds, particularly oxygenated compounds [8]. On the other hand, several bacterial strains, especially Gram-negative bacteria, have been found to construct resistance against numerous antibiotics due to their many use uses [9]; therefore, scientists are doing their best to explore the use of natural products and EOs from plants as antimicrobial agents [10].

The *Ipomoea* genus (family: Convolvulaceae) includes more than 600 plant species distributed worldwide, where they are grown as medicinal plants, weeds, and ornamental plants [11]. Plants belonging to the *Ipomoea* genus have been documented to have nutritional values; among them, *I. batatas* is well known as sweet potato worldwide [12]. The chemical analysis of *Ipomoea* plants has shown that they have several metabolites, including terpenes, flavonoids, coumarins, lignans, and alkaloids [13–15].

Ipomoea carnea Jacq. is a widely used plant in traditional medicine in several countries worldwide [16]. The different parts of this plant have been reported to be used in folk medicine for the treatment of several disorders such as venereal and skin diseases, immunodeficiency, dysentery, gout, rheumatism, and hypertension, in addition to their roles in menstruation provocation and as a laxative [16,17]. Moreover, several biological evaluations of the different extracts of *I. carnea* have been documented, including antimicrobial [18], anticancer [19], free radical scavenging [20], antidiabetic [21], immunomodulatory [22], wound healing [23], anticonvulsant, anxiolytic, anti-inflammatory, sedative, and hepatoprotective [16]. Chemically, the reported chemical characterization of the different extracts of *I. carnea* has revealed the presence of polyphenolic constituents, alkaloids, tannins, amino acids, proteins, terpenoids, carbohydrates, sterols, and saponins [24,25]. Swainsonine and calystegines have been documented as the main components of *I. carnea* [16].

The chemical profiles of the EOs of some *Ipomoea* species have been established, such as *I. pes-caprae* [13,26], *I. aquatic* [27], *I. obscura* [28], *I. asarifolia*, *I. setifera* [29], *I. batatas* [30], *I. indica*, *I. amnicola*, *I. tiliacea*, and *I. batatas* [26]. However, the EO of *I. carnea* has been reported only for Brazilian ecospecies [26], and to our knowledge, the EO of the Egyptian ecospecies of *I. carnea* has not been considered yet. Therefore, the present investigation aimed to (i) determine the chemical constituents of the EO of the aerial parts of the Egyptian ecospecies of *I. carnea*, (ii) compare the EO composition of the Egyptian ecospecies with other reported ecospecies via chemometric analysis, and (iii) evaluate the antioxidant and antimicrobial activities of the *I. carnea* EO.

2. Materials and Methods

2.1. Plant Materials

Aerial parts of *Ipomoea carnea* were collected in April 2021 from three populations growing in the wild on a canal bank habitat in cultivated fields around Mansoura City, Egypt (31°04′29.4″ N 31°25′05.3″ E). The collected samples consisted of leaves, stems, and flowers (Figure 1). The samples were air-dried until complete dryness at room temperature, crushed, and stored in a paper bag until further analyses. The plant specimen was identified and authenticated according to the books of the flora of Egypt following Tackholm [31] and Boulos [32]. Additionally, the voucher sample was prepared and dropped into the Mansoura University Herbarium with Voucher Code Mans.0030903009.

2.2. EO Extraction Analysis and Characterization

From each sample of *I. carnea*, 250 g of EO was extracted by hydrodistillation over a Clevenger device for 3 h, separated by *n*-hexane, and dried with about 0.5 g of anhydrous Na_2SO_4. The three EO samples were stored in glass vials at 4 °C in a refrigerator for analysis. Chemical profiling of the EOs was established separately using gas chromatography/mass spectrometry (GC/MS) at the National Research Center of Egypt under the same protocols described previously [33]. In detail, the analysis of the extracted EO samples was performed

using a GC-MS apparatus combined with the TRACE GC ultra gas chromatograph and Thermo Scientific™ EC quadrupole mass spectrometer unit (Waltham, MA, USA). The dimension and film thickness of the GC-MS column was 30 m × 0.32 mm × 0.25 µm. Helium as a transporter gas was used with a split ratio of 1 to 10 and a flow rate of 1.0 mL per min. The temperature was justified as usual according to the following: 60 °C (1 min), then increased to 240 °C within 4 °C/min. The EO samples were diluted in 1 µL of *n*-hexane with a ratio of 1:10 (*v*/*v*) and then injected in an injector and detector modified at 210 °C. The mass spectral data of components were obtained via electron ionization (EI) with *m*/*z* 40–450 as the spectral range at 70 eV. The chemical components were authenticated and identified using Automated Mass Spectral Deconvolution and Identification System (AMDIS) software, NIST library database, the Wiley Spectral Library Collection, and the retention indices closed to *n*-alkanes (C_8–C_{22}).

Figure 1. *Ipomoea carnea* Jacq. Plant: (**a**) overview of the growing shrub; (**b**) and (**c**) close view of the flowering branches.

2.3. Antioxidant Activity

The EO extracted from *I. carnea* was assayed for its antioxidant activity via the scavenging ability of the free radicals 2,2-diphenyl-1-picrylhydrazyl (DPPH) and 2,2′-azinobis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) (Sigma-Aldrich, Darmstadt, Germany). According to Miguel [34], serial concentrations of the EO (5–50 mg L^{-1}) were prepared using 95% methanol as a solvent. In glass tubes, each concentration (2 mL) and freshly prepared DPPH (2 mL of 0.3 mM) were vigorously shaken and left for 30 min in dark conditions at room temperature. At 517 nm, the measurement of the absorbance was performed using a Spectronic 21D model spectrophotometer. For additional confirmation of the antioxidant activity, ABTS scavenging was tested according to Re et al. [35]. In brief, 0.2 mL of each concentration was mixed with 2 mL of 7 mM of freshly prepared ABTS. The mixtures were incubated for 6 min at room temperature, and the absorbance was immediately measured with a spectrophotometer at 734 nm. The positive control was prepared using ascorbic acid

(standard antioxidant) with a range of 1–20 mg L^{-1}, while the negative control was treated using methanol similarly to the samples. The calculation of the scavenging potential was established by the following equation:

$$\text{Scavenging } \% \ = 100 \times \left[1 - \frac{\text{Absorbance}_{\text{EO}}}{\text{Absorbance}_{\text{control}}}\right]$$

The IC_{50} (required EO concentration for 50% scavenging) was calculated based on the exponential curve of the absorbance and concentrations using Microsoft Excel 2019.

2.4. Antibacterial Activity

The EO extracted from the aerial parts of *I. carnea* was evaluated for its bacterial inhibitory potential via the agar diffusion method [36]. The activity was tested against four Gram-negative bacterial isolates (*Escherichia coli* ATCC 10536, *Klebsiella pneumoniae* ATCC 10031, *Pseudomonas aeruginosa* ATCC 9027, and *Salmonella typhimurium* ATCC 25566) and four Gram-positive bacterial isolates (*Bacillus cereus* EMCC 1080, *Staphylococcus epidermidis* ATCC 12228, *Staphylococcus haemolyticus* ATCC 29970, and *Staphylococcus xylosus* NCCP 10937). These bacterial isolates were purchased from the Cairo Microbiological Resources Centre (Cairo MIRCEN), Agriculture College, Ain Shams University, Egypt. To test the antibacterial activity of the EO, 10 mg mL^{-1} EO was prepared using 1% $(CH_3)_2SO$ (DMSO), and filter paper discs (0.5 cm) were impregnated with 50 µL of EO. Petri plates with the medium of nutrient agar were incubated with 1×10^8 colony forming units (CFU)/mL of each bacterial isolate, and the discs saturated with EO were placed over the medium within the plates. The plates were immediately sealed with Parafilm® tape (Sigma, St. Louis, MO, USA) and incubated in an incubator modified at 37 °C. After 24 h, the diameter of the clear (inhibition) zone around the disc was measured in millimeters from three points. In addition, DMSO was used as a negative control, where it was prepared and treated as previously mentioned for the EO, as it did not show any antibacterial activity. Cephalexin, tetracycline, ofloxacin, and ampicillin were tested as the positive control (standard antibiotic). The minimum inhibitory concentration (MIC) was calculated for each bacterial isolate based on the exponential curve of the inhibition zone diameter and various concentrations of the EO.

2.5. Data Analysis

The antioxidant and antibacterial activity experiments were repeated with 3 replicas, and the data were expressed as average ± standard error. To test the significance among treatments, the data of either antioxidant or antibacterial activities, with replications, were subjected to a one-way ANOVA, followed by Duncan's post-hoc test at a 0.05 probability level using CoStat software (version 6.311, CoHort Software, Monterey, CA, USA). To correlate the ecospecies studied in this paper with other reported species, we used two chemometric analyses: agglomerative hierarchical clustering (AHC) and principal component analysis (PCA). A dataset of 22 *Ipomea* ecospecies was constructed, consisting of (1) *I. carnea* (leaf) collected from Egypt, (2) *I. pes-caprae* (fresh leaf) collected from Mauritius, (3) *I. pes-caprae* (dry leaf) collected from Mauritius [13], (4) *I. obscura* (dry leaf) collected from India [28], (5) *I. aquatica* (aerial parts) collected from Japan [27], (6) *I. asarifolia* (leaf) collected from Brazil, (7) *I. setifera* (leaf) collected from Brazil [29], (8) *I. batatas* (leaf) collected from Nigeria [30], (9) *I. batatas* (leaf) collected from Brazil, (10) *I. batatas* (flower) collected from Brazil, (11) *I. carnea* (leaf) collected from Brazil, (12) *I. carnea* (flower) collected from Brazil, (13) *I. pes-caprae* (leaf) collected from Brazil, (14) *I. pes-caprae* (flower) collected from Brazil, (15) *I. alba* (leaf) collected from Brazil, (16) *I. alba* (flower) collected from Brazil, (17) *I. indica* (leaf) collected from Brazil, (18) *I. indica* (flower) collected from Brazil, (17) *I. indica* (leaf) collected from Brazil, (18) *I. indica* (flower) collected from Brazil, (19) *I. tiliacea* (leaf) collected from Brazil, (20) *I. tiliacea* (flower) collected from Brazil, (21) *I. amnicola* (leaf) collected from Brazil, and (22) *I. amnicola* (flower) collected from Brazil [26]. The dataset contains 46 major

compounds (>3%) from 22 *Ipomea* ecospecies (see Supplementary Materials Table S1). The dataset matrix was subjected to AHC and PCA.

3. Results and Discussion

3.1. Chemical Profile of I. carnea EO

The hydrodistillation of the *I. carnea* aerial parts provided 0.034% (*v*/*w*) golden-yellow EO. The yield of EOs from other reported Ipomea species such as *I. carnea*, *I. pes-caprae*, *I. alba*, *I. batatas*, and *I. indica* was 0.01–0.13% for fresh leaves and 0.01–0.03 for fresh flowers [26]. The extracted oil was subjected to GC-MS analysis (Figure 2), where 31 compounds were identified with a relative concentration of 97.58%. The compound names, molecular formulas, retention times, relative concentrations (%), and Kovats indices (KIs) of all identified compounds are presented in Table 1.

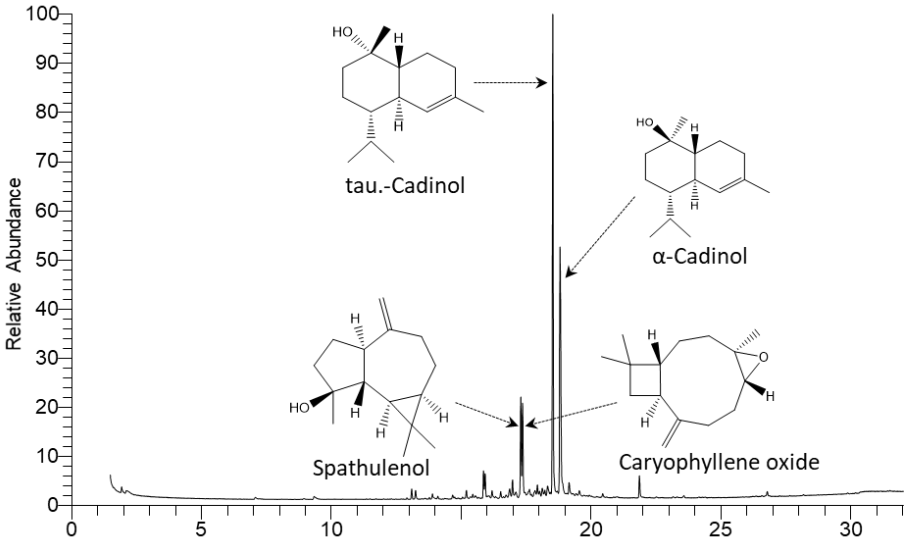

Figure 2. GC-MS of the EO extracted from *Ipomoea carnea* aerial parts.

The identified compounds can be grouped into six classes: oxygenated monoterpenes, sesquiterpene hydrocarbons, oxygenated sesquiterpenes, diterpene hydrocarbons, carotenoid, and apocarotenoid-derived compounds (Table 1). Sesquiterpene represented the abundant EO components with a relative concentration of 92.71% comprising mainly oxygenated sesquiterpene (82.88%) and a low relative concentration of sesquiterpene hydrocarbons (9.83%). The abundance of the sesquiterpenoids was common in the EOs of several *Ipomoea* plants such as *I. batatas* (46.5%) [30], *I. pes-caprae* (70.4%) [13], and *I. obscura* (84.9%) [28].

Tau-cadinol (35.68%), α-cadinol (26.76%), spathulenol (8.11%), and caryophyllene oxide (6.56%) (Figure 2) represented the major constituents of oxygenated sesquiterpene compounds, while 6-epishyobunone (0.35%) was determined as a minor compound. On the other hand, ar-curcumene (1.83%), γ-muurolene (1.76%), and α-calacorene (1.04%) were identified as the main components of sesquiterpene hydrocarbons. The preponderance of the cadinene and cadinol isomers was documented in numerous *Ipomoea* plants such as *I. carnea* collected from Brazil [26] and *I. pes-caprae* collected from Belgium [13]. In addition, spathulenol and caryophyllene oxide were documented as major sesquiterpenoids in the EOs of Brazilian *I. pes-caprae* [13] and Nigerian *I. batatas* [30].

On the other hand, monoterpenes were assigned as trace components and represented only by oxygenated compounds (1.75%) and no monoterpene hydrocarbons were detected (Table 1). Three oxygenated monoterpenes, 4-terpineol (0.69%), α-fenchyl alcohol (0.57%), and linalool (0.49%), were only assigned. The scarcity of the monoterpenes is common in the reported EO profiles of many studied *Ipomoea* species [13,27,28,30].

Table 1. Identified components of essential oil of *Ipomoea carnea* assigned by GC-MS.

No	Compound name	KI_p [1]	KI_c [2]	Conc. (%)	Identification [3]
		Oxygenated Monoterpenes			
1	Linalool	1095	1095	0.49 ± 0.01	MS, KI
2	α-Fenchyl alcohol	1114	1115	0.57 ± 0.02	MS, KI
3	4-Terpineol	1177	1175	0.69 ± 0.01	MS, KI
		Sesquiterpene Hydrocarbons			
4	β-Patchoulene	1381	1379	0.77 ± 0.03	MS, KI
5	α-Gurjunene	1409	1411	0.53 ± 0.01	MS, KI
6	E-Caryophyllene	1417	1417	0.67 ± 0.02	MS, KI
7	trans-α-Bergamotene	1432	1435	0.33 ± 0.01	MS, KI
8	Aromandendrene	1439	1441	0.69 ± 0.02	MS, KI
9	α-Humulene	1452	1449	0.31 ± 0.01	MS, KI
10	ar-Curcumene	1479	1476	1.83 ± 0.04	MS, KI
11	γ-Muurolene	1480	1483	1.76 ± 0.03	MS, KI
12	α-Muurolene	1500	1502	0.56 ± 0.01	MS, KI
13	δ-Cadinene	1522	1520	0.97 ± 0.03	MS, KI
14	α-Calacorene	1544	1541	1.04 ± 0.03	MS, KI
15	Guaiazulene	1780	1784	0.37 ± 0.01	MS, KI
		Oxygenated Sesquiterpenes			
17	Citronellyl 3-methylbutanoate	1531	1529	1.55 ± 0.04	MS, KI
18	Spathulenol	1578	1581	8.11 ± 0.08	MS, KI
19	Caryophyllene oxide	1583	1585	6.56 ± 0.06	MS, KI
20	Geranyl isovalerate	1607	1604	0.81 ± 0.02	MS, KI
21	Humulene epoxide II	1608	1612	0.97 ± 0.03	MS, KI
22	tau-Cadinol	1640	1643	35.68 ± 0.16	MS, KI
23	α-Cadinol	1654	1650	26.76 ± 0.12	MS, KI
24	α-Santalol	1674	1677	0.63 ± 0.02	MS, KI
25	6-Epishyobunone	1680	1680	0.35 ± 0.01	MS, KI
26	Ledene oxide-(II)	1682	1683	0.69 ± 0.02	MS, KI
27	Bisabolone	1742	1746	0.77 ± 0.02	MS, KI
		Diterpene Hydrocarbons			
28	Beyerene	1931	1936	0.36 ± 0.01	MS, KI
		Carotenoid-Derived Compounds			
29	E-β-Damascenone	1383	1382	0.77 ± 0.02	MS, KI
30	E-α-Ionone	1428	1430	0.18 ± 0.01	MS, KI
		Apocarotenoid-Derived Compounds			
31	Hexahydrofarnesyl acetone	1845	1849	1.81 ± 0.03	MS, KI
	Oxygenated monoterpenes			1.75	
	Sesquiterpene hydrocarbons			9.83	
	Oxygenated sesquiterpenes			82.88	
	Diterpene hydrocarbons			0.36	
	Carotenoid-derived compounds			0.95	
	Apocarotenoid-derived compounds			1.81	

[1] Calculated Kovats indices (KIc), [2] published Kovats indices (KI_p), [3] components of EO were identified via mass spectra (MS) and Kovats retention indices (KI) along with the Wiley spectral and NIST databases.

In the extracted EO of *I. carnea* in the present study, only one diterpene compound, beyerene, was identified with a very low relative concentration (0.36%). The scarcity of the diterpenes in the EOs derived from medicinal and aromatic plants is common, with a few exceptions [8]. In addition, the EOs of *Ipomoea* plants have been reported to contain a low relative concentration of diterpenoid compounds [13,27,28,30]. In addition, three non-terpenoid compounds were characterized that can be categorized into carotenoid (0.95%), including *E*-β-damascenone (0.77%), *E*-α-ionone (0.18%), and apocarotenoid (1.81%), comprising compounds derived from hexahydrofarnesyl acetone (1.81%). These three compounds were identified as trace components in the EOs of some *I. pes-caprae* [13].

The present chemical characterization of *I. carnea* EO deduced some similarities with the other *Ipomoea* species, which may be ascribed to the climatic, genetic, and environmental conditions [4,37,38].

3.2. Chemometric Analysis of the EOs of Ipomea Specie

The chemometric analysis of the EO profile of the Egyptian *I. carnea* ecospecies and the other reported *Ipomea* species revealed considerable variation (Figure 3).

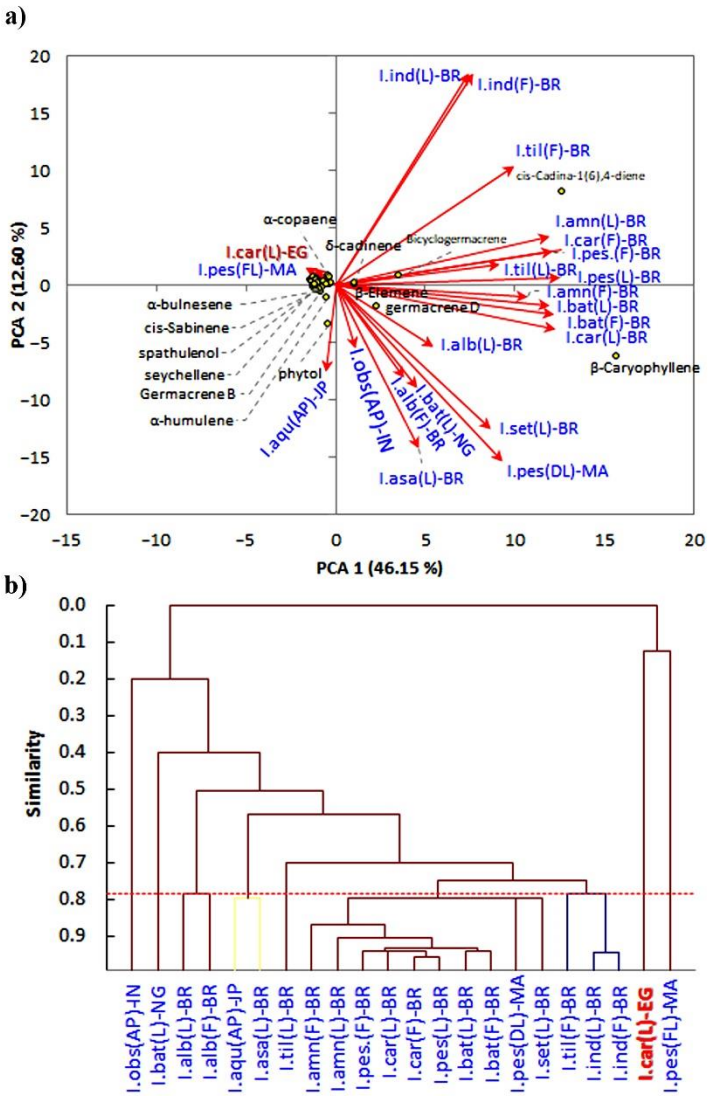

Figure 3. Chemometric analysis of the EOs of various *Ipomoea carnea* and various reported *Ipomoea* species: (**a**) principal component analysis (PCA); (**b**) agglomerative hierarchical clustering (AHC). I.car: *I. carnea*, I.pes: *I. pes-caprae*, I.obs: *I. obscura*, I.Aqu: *I. aquatica*, I. asa: *I. asarifolia*, I.set: *I. setifera*, I.bat: *I. batatas*, I.alb: *I. alba*, I.ind: *I. indica*, I.til: *I. tiliacea*, I.amn: *I. amnicola*, AP: aerial parts, L: leaf, F: flower, DL: dry leaf, FL: fresh leaf, IN: India, NG: Nigeria, BR: Brazil, JP: Japan, MA: Mauritius, EG: Egypt.

However, the present results showed a positive correlation with the profile of the EO of the *I. pes-caprae* collected from Mauritius [13]. The cluster analysis showed that each *Ipomea* ecospecies has its own specific chemical profile signature of the EO compounds. These data could be ascribed to the genetic characteristics of each species [38,39]. In addition, the only studied *I. carnea* from Brazil did not correlate with those reported in the Egyptian ecospecies of the present study. This could be attributed to the variation in the environmental and climatic conditions [40]. The extraction techniques have been reported to have a great

effect on the composition of the extracted EO [41–43]; therefore, this variation could be a reasonable factor for the determined variation between the Egyptian and Brazilian ecospecies of *I. carnea*, where, for the Brazilian ecospecies, the EO was extracted with steam distillation, while for the Egyptian ecospecies, the EO was extracted upon hydrodistillation.

The application of PCA on the dataset of the 22 *Ipomea* ecospecies showed that present Egyptian *I. carnea* and *I. pes-caprae* collected from Mauritius are correlated with each other, where they did not show specific correlation with specific compounds. On the other side of the PCA, the Brazilian ecospecies of *Ipomoea amnicola*, *I. indica*, *I.alba*, *I. pes-caprae*, *I. carnea*, *I. tiliacea*, and *I. batatas* were separated at the right side of the PCA and showed a correlation with β-caryophyllene, cis-cadina-1(6),4-diene, germacrene, β-elemene, bicyclogermacren, and δ-cadinene. On the other hand, the Japanese ecospecies of *I. aquatica* were separated alone and revealed a correlation with the phytol compound.

3.3. Free Radical Scavenging Activity of I. carnea EO

The free radical scavenging potentiality of *I. carnea* EO was evaluated using DPPH and ABTS assays with respect to ascorbic acid as a reference antioxidant agent. The present data showed that the EO of *I. carnea* has strong antioxidant capability in comparison to the standard antioxidant (ascorbic acid) (Table 2). The activity of scavenging increased with the increment of the concentration. At a concentration of 20 mg L^{-1}, the EO showed 31.05% and 24.15% DPPH and ABTS scavenging, respectively, while ascorbic acid showed 73.17% and 69.06% scavenging, respectively. According to the IC_{50} values, the EO of *I. carnea* displayed IC_{50} of 33.69 mg L^{-1} for DPPH and 40.86 mg L^{-1} for ABTS, whereas ascorbic acid showed an IC_{50} of 11.51 and 12.94 mg L^{-1}.

Table 2. DPPH and ABTS radicals scavenging activity percentage and IC_{50} values by the EO of the *Ipomoea carnea* and ascorbic acid as standard.

Treatment	Conc. (mg L^{-1})	Scavenging Activity (%)			
		DPPH	IC_{50} (mg L^{-1})	ABTS	IC_{50} (mg L^{-1})
Ipomoea carnea EO	5	11.37 ± 0.32 ^{I} *	33.69	6.52 ± 0.19 ^{J}	40.86
	10	17.21 ± 0.49 ^{H}		12.66 ± 0.46 ^{I}	
	20	31.07 ± 0.89 ^{F}		24.15 ± 0.69 ^{G}	
	30	52.54 ± 1.64 ^{D}		38.41 ± 1.10 ^{E}	
	40	63.29 ± 1.81 ^{B}		50.6 ± 1.88 ^{D}	
	50	74.31 ± 2.12 ^{A}		59.69 ± 1.97 ^{C}	
	$LSD_{0.05}$	3.21 ***			
	F-value	436.40			
Ascorbic acid	1	5.25 ± 0.12 ^{K}	11.51	2.14 ± 0.08 ^{L}	12.94
	2.5	14.47 ± 0.42 ^{I}		10.36 ± 0.35 ^{J}	
	5	41.19 ± 1.28 ^{G}		37.08 ± 1.26 ^{H}	
	10	53.73 ± 1.67 ^{E}		45.62 ± 1.58 ^{F}	
	15	60.02 ± 1.79 ^{C}		55.91 ± 2.11 ^{D}	
	20	73.17 ± 2.17 ^{A}		69.06 ± 2.63 ^{B}	
	$LSD_{0.05}$	2.03 ***			
	F-value	1307.67			

* Values are means of 3 replicas ± standard error. Within each column, the different superscript letters show significant variation at $p \leq 0.05$. *** $p < 0.001$.

The current findings were in total agreement with the fact of the significant antioxidant activities of the different extracts of the *Ipomoea* species. The alcoholic extract of the Indian *I. carnea* was reported to exhibit significant in vitro antioxidant activity using DPPH and ABTS assays [20]. In addition, the different extracts of the leaves of *I. batatas*, including EOs, were described to have strong antioxidant potential [13–15]. Alam and coworkers described that the methanolic extract of *I. mauritiana* has potent DPPH scavenging activity

compared with ascorbic acid [44]. Moreover, the phenolic-enriched alcoholic extract of the halophyte, *I. pes-caprae*, was reported to have strong reducing power on DPPH radicals, better than butylated hydroxyanisole and butylated hydroxytoluene [45].

The antioxidant activity of *I. carnea* EO might be ascribed to the chemical constituents characterized mainly as terpenes. The reproducible free radical scavenging potential of the EOs was documented to be strongly correlated with the overbalance of the terpenoid compounds [6,8,46]. In addition, the oxygenated compounds are responsible for more antioxidant activity due to their functions in the oxygenation of the components and scavenging the free radicals [8,47,48]. The chemical profiling of the *I. carnea* EO showed that 83.63% of overall oil mass are oxygenated compounds that could cause significant observed antioxidant activity.

Among the oxygenated compounds, the oxygenated sesquiterpene compounds, tau-cadinol, α-cadinol, spathulenol, and caryophyllene oxide, represented the main compounds in the *I. carnea* EO. These compounds might have played an effective role as antioxidant agents either individually or synergistic with others. The EO derived from *Cullen plicata* has been reported to possess a strong antioxidant ability due to the abundance of tau-cadinol, α-cadinol, and caryophyllene oxide [49]. In addition, the EO of Algerian *Teucrium polium* was reported to have significant antioxidant activity due to its high content of spathulenol and tau-cadinol [50]. Caryophyllene oxide represented one of the most common compounds in the plants' EOs with important biological actions, especially antioxidant activity, due to the presence of lone pairs of electrons that increase the free radicals trapping [51]. This compound was reported to be of the main contributors to the increase in the antioxidant activity of the EOs of *Cannabis sativa* [51], *Salvia palaestina*, *S. ceratophylla* [52], and *Heliotropium curassavicum* [53]. Additionally, α-cadinol was promoted to act as a significant antioxidant mediator in the EO of several herbs such as *Tabernaemontana catharinensis* [54] and *Xenophyllum poposum* [55]. Furthermore, the minor constituents could be contributed to the antioxidant activity via the synergetic effect [56].

3.4. Antibacterial Activity of I. carnea EO

The inhibitory effects of the EO derived from *I. carnea* were estimated against eight bacterial strains (four Gram-negative and four Gram-positive strains). The results showed that the EO displayed significant inhibitory effects against all strains. For Gram-negative bacteria, the activity can be ordered as follows: *K. pneumoniae* > *E. coli* > *P. aeruginosa* > *S. typhimurium*, where they showed MIC values of 84, 94, 124, and 158 mg mL^{-1}, respectively (Table 3). However, the EO exhibited inhibition against the four Gram-positive bacteria strains in the following order: *S. xylosus* > *B. cereus* > *S. epidermidis* > *S. haemolyticus*, with MIC values of 82, 84, 1442, and 82 mg mL^{-1}, respectively. Previously, different extracts and EOs of several *Ipomoea* plants were stated to have inhibitory effects against different bacterial strains. The crude alcoholic extract of *I. mauritiana* was described to significantly inhibit the growth of several bacteria strains [44]. Moreover, the whole plant extracts of *I. pes-caprae* have been reported to inhibit a set of Gram-positive and Gram-negative bacterial strains [57]. In addition, some compounds isolated from different extracts and oils of *I. pes-caprae*, such as (-) mullein [58] and *E*-phytol [59], have been described to have the potential for inhibiting some bacterial strains such as *Escherichia coli* and *Staphylococcus* sp. In agreement with our data, Yuan et al. [60] described that the EO derived from the waste materials of *I. batatas* can strongly stop the growth of *Pseudomonas aeruginosa*, *Escherichia coli*, and *Bacillus cereus*.

The bacterial inhibition capability of the *I. carnea* EO was stronger than that described for other plants' EOs as *Kickxia aegyptiaca* [46], *Teucrium polium* [41], and *Deverra tortuosa* [6]. The observed antibacterial activity of the *I. carnea* EO in the present study could be attributed to the major compounds such as caryophyllene oxide, tau-cadinol, α-cadinol, and spathulenol. The two main compounds, tau-cadinol and α-cadinol, in the current study were also reported in high concentrations of the EO of various plants that showed strong bacterial growth inhibition such as *Eugenia chlorophylla* [61], *Litsea acutivena* [62],

Diospyros discolor [63], and *Teucrium polium* [41]. Spathulenol and caryophyllene oxide represented common compounds in EOs derived from the plant kingdom [4]. Many EOs were documented to have strong antibacterial activity due to the preponderance of spathulenol and caryophyllene oxide such as *Baccharis dracunculifolia* [64], *Salvia hydrangea* [65], *Satureja coerulea* [66], and *Kickxia aegyptiaca* [46]. Schmidt and coworkers described that caryophyllene oxide is one of the most active antibacterial agents as a single compound against *Escherichia*, *Klebsiella*, and *Salmonella* strains [67]. The major compound, tau-cadinol, in the present study was described as a potent antibacterial agent against *S. aureus* [68]. In addition, caryophyllene and its oxygenated derivatives were documented to have bactericidal effects against several bacterial strains, including *B. cereus*, *B. subtilis*, *E. coli*, *S. aureus*, and *P. aeruginosa* [69]. Spathulenol has been reported in high concentrations (36.6%) of *Helichrysum amorginum* EO, where it showed strong inhibitory effects against *S. aureus* and *S. epidermidis* [70]. Moreover, the other minor components might act in synergetic interaction with other compounds as antibacterial agents [4].

Table 3. Antibacterial activity of the *Ipomoea carnea* essential oil and some selected reference antibiotics (10 mg mL^{-1}).

Bacterial Strain	EO (10 mg mL^{-1})		Reference Antibiotics IZ mm			
	IZ mm	MIC (mg mL^{-1})	Cephalexin	Tetracycline	Ofloxacin	Ampicillin
			Gram-negative bacteria			
Escherichia coli	19.62 ± 0.59 $^{C\#}$	84.0	10.29 ± 0.31 ^{D}	21.08 ± 0.64 ^{A}	24.91 ± 0.75 ^{A}	20.06 ± 0.63 ^{D}
Klebsiella pneumoniae	23.56 ± 0.71 ^{A}	94.0	10.05 ± 0.30 ^{D}	20.62 ± 0.62 ^{A}	20.11 ± 0.61 ^{C}	6.71 ± 0.21 ^{E}
Pseudomonas aeruginosa	16.41 ± 0.50 ^{D}	124	0.00 ^{E}	0.00 ^{E}	10.36 ± 0.31 ^{E}	0.00 ^{F}
Salmonella typhimurium	12.39 ± 0.38 ^{E}	158	0.00 ^{E}	9.88 ± 0.30 ^{D}	0.00 ^{F}	0.00 ^{F}
			Gram-positive bacteria			
Bacillus cereus	21.36 ± 0.65 ^{B}	82	19.13 ± 0.58 ^{B}	10.34 ± 0.31 ^{D}	19.66 ± 0.60 ^{CD}	7.53 ± 0.21 ^{E}
Staphylococcus epidermidis	19.05 ± 0.58 ^{C}	84	14.07 ± 0.43 ^{C}	17.65 ± 0.53 ^{C}	23.05 ± 0.70 ^{B}	27.96 ± 0.74 ^{A}
Staphylococcus haemolyticus	8.47 ± 0.26 ^{F}	1442	23.74 ± 0.72 ^{A}	19.51 ± 0.59 ^{B}	23.48 ± 0.61 ^{B}	21.07 ± 0.61 ^{C}
Staphylococcus xylosus	22.69 ± 0.69 ^{A}	82	18.39 ± 0.56 ^{B}	17.04 ± 0.52 ^{C}	19.03 ± 0.58 ^{D}	23.64 ± 0.81 ^{B}
$LSD_{0.05}$	0.94 ***		0.89 ***	0.92 ***	0.90 ***	0.82 ***
F-value	279.11		867.02	565.54	765.49	1408.00

$^{\#}$ Value is an average of three replicas of the inhibition zone (IZ) diameter expressed as mm ± standard error. Within each column, different superscript letters mean significant variation. LSD: least significant difference. *** $p < 0.001$.

The Gram-negative bacteria were well-known bacteria with strong resistance to antibiotics due to their outer rigid membrane with a high content of lipopolysaccharide [9]. Several documented data have revealed that the EOs and their bioactive constituents could attach to the bacterial cell surface and therefore perforate the cell membrane phospholipid bilayer, then accumulate with mischievous effects on the cell metabolism, causing bacterial cell death [71].

4. Conclusions

The present study showed for the first time the chemical profile of the EO extracted from the Egyptian ecospecies of *I. carnea*. The identified compounds were mainly sesquiterpenes with caryophyllene oxide, tau-cadinol, α-cadinol, and spathulenol as major compounds. The chemometric analysis revealed that the EO of the presently studied *I. carnea* is different from that reported from other species of *Ipomoea*. The extracted EO exhibited substantial antioxidant activity and strong inhibition against the tested Gram-negative and Gram-positive bacteria. The observed activities of this oil in the current study might be ascribed to the major identified constituents, which could be integrated as eco-friendly natural resources with antioxidant and antibacterial potential. Further study is recommended to evaluate the various activities of the major identified compounds, either individually or in combination, and determine their potential, modes of action, and safety.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14159504/s1, Table S1: A dataset of the major compounds (>3%) of the present studied *Ipomea carnea* and 21 other reported *Ipomea* ecospecies.

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