



Original article

Interspecific variations in the habitats of *Reichardia tingitana* (L.) Roth leading to changes in its bioactive constituents and allelopathic activityAhmed M. Abd-ElGawad^{a,b,*}, Yasser A. El-Amier^b, Abdulaziz M. Assaeed^a, Saud L. Al-Rowaily^a^a Plant Production Department, College of Food & Agriculture Sciences, King Saud University, P.O. Box 2455, Riyadh 11451, Saudi Arabia^b Department of Botany, Faculty of Science, Mansoura University, Mansoura 35516, Egypt

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ABSTRACT

Reichardia tingitana is an annual plant growing in different habitats of the Egyptian deserts. Little is known about variation among the habitats occupied by this species, its distribution, chemical composition, and allelopathic activity. The present study aimed to (a) assess the vegetation composition of three different habitats (Western Coast, Delta Coast, and Wadi Hagoul) of *R. tingitana* in Egypt, (b) determine their correlation to soil factors, (c) identify the changes in the bioactive constituents of *R. tingitana* in the three regions, and (d) evaluate the allelopathic activity regarding the variation in the habitat. Density and cover of all plant species associated with *R. tingitana* were estimated within 52 plots, representing three regions. Physical and chemical parameters of soil were analyzed in each plot. *R. tingitana* aboveground biomass was collected from each habitat, and the bioactive composition was analyzed using HPLC. The allelopathic effect against two weeds (*Amaranthus lividus* and *Chenopodium murale*) was assessed. The floristic composition showed the presence of 133 species belonging to 27 families. In the Delta Coast habitat of *R. tingitana*, *Zygophyllum aegyptium* and *Calligonum polygonoides* co-dominate, while *Lycium shawii* dominate the Western Coast habitat and finally the habitat of Wadi Hagoul was dominated by *Haloxylon salicornicum*. Soil analysis revealed little variations among habitats, especially salinity and organic matter. Fifteen compounds, mainly phenolics (60% of the total identified compounds) were identified from all *R. tingitana* samples. The major compounds were quercetin, naringenin, ellagic, gallic, chlorogenic, and caffeic acids. These compounds varied in diversity or quantity among different habitats. The Western Coast sample was the richest in species, followed by Delta Coast sample. Our study showed that salinity is the crucial factor that induces the production of bioactive constituents in *R. tingitana*, especially phenolics and flavonoids. The *R. tingitana* extracts significantly reduced the germination and growth of *Chenopodium* and *Amaranthus*. However, the Western Coast sample showed potent allelopathic activity, where the germination was wholly inhibited at 75 mg L⁻¹ and 50 mg L⁻¹, respectively. Thereby, this extract could be used as eco-friendly bioherbicide and may be integrated into weed control strategies.

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1. Introduction

Chemical ecology is the science addressing the role of chemical interactions between organisms and their environment. It includes signaling processes and communication between individuals (Baldwin et al., 2002). For example, after herbivores attack, the plant generates volatiles that attracts carnivorous insects that kill plant enemies (Takabayashi and Dicke, 1996). Also, infected plants can produce a signal that induces the immune system of healthy members (Baldwin et al., 2006). These chemicals that are produced by plants to either inhibit or stimulate others are called allelochemicals, and the phenomenon is known as allelopathy (Rice, 1984). The production of these compounds depends on the activa-

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tion of specialized genes and is often depends on environmental conditions, such as climatic and edaphic factors (Buchanan et al., 2015).

Allelopathy plays a crucial role in the dynamics of plant species in different environments. Understanding this biological phenomenon could help in the development of applications in both natural and agricultural systems (Wardle et al., 2011). Environmental factors of any habitat can directly or indirectly affect the allelopathic potential of a plant. The most critical ecological factors that influence allelopathy include temperature, water content, salinity, nutrient availability and competition stress (Elshamy et al. 2019; Meiners et al., 2012).

Asteraceae or Compositae is one of the largest families of the flowering plants and has worldwide distribution. Most of the family members are herbaceous although a significant number of shrubs, vines, or trees belong to the family. In the flora of Egypt, Asteraceae is represented by 98 genera and 228 species (Boulos, 2009). Plants under this family have been widely utilized in the past and are still used today for their medicinal properties. Members of Asteraceae have been reported to possess many biological activities including antibacterial, antifungal, antidiabetic, antihelminthic, immunostimulatory, and anticancer activities (Cazella et al., 2019; Salazar et al., 2018; Sharma et al., 2018).

Only two species of *Reichardia* genus were recorded in the flora of Egypt, *R. picroides* (L.) Roth and *R. tingitana* (L.) Roth. The latter is a glabrous annual herb growing wildly in the coastal and inland desert of Egypt. The stem branches from the base, the plant reaches up to 40 cm with the taproot, which gives rise to the rosette of large radical leaves first, and its flowering time extends from March to May. Preliminary phytochemical examination on above-ground biomass shows the presence of phenolics, tannins, flavonoids, coumarins, volatile oils, glycosides, flavonoids, lactones, esters, large amounts of sterols and/or triterpenes (Abdel-Mogib et al., 1993; Recio et al., 1992).

Aqueous extract of *R. tingitana* was reported to inhibit the germination and growth of *Bidens pilosa*, but the specific bioactive compounds were not determined (Abd El-Gawad et al., 2015). Moreover, little is known about the allelochemicals of *R. tingitana*, and according to our knowledge, no study had revealed the correlation between the habitats of *R. tingitana* and their bioactive composition as well as allelopathic activity. Therefore, we test the hypothesis that variations in *R. tingitana* habitats promote changes in the chemical composition of the plant and in consequence affect its allelopathic activity. The specific objectives of this study were to (i) determine the variations in the vegetational composition and soil factors among three different habitats of *R. tingitana* in Egypt, (ii) identify and compare the variation in the bioactive compounds of *R. tingitana* aboveground biomass from these three habitats, and (iii) evaluate the differences in *R. tingitana* allelopathic activity among three regions.

2. Materials and methods

2.1. Study areas

The study areas can be categorized into two sections: the first is the coastal desert which is represented by two regions; Western Coast and Delta Coast, while the second is the inland desert which is represented by Wadi Hagoul (Fig. 1). The Mediterranean coastal desert of Egypt can be classified into three sections: western, delta, and eastern sectors. The Western Coast extends eastwards from Al-Sallum to Abu Qir for about 550 km with a width of about 20 km, constituting the northern coast of the Western Desert of Egypt. The meteorological data (average of >10 years, from 2000 to 2013) of Sidi Abd El-Rahman station showed that mean annual temperature

ranges from 14.39 to 25.50 °C, while average annual rainfall was about 192.1 mm per year. The average relative humidity was up to 66.9%. The Delta Coast is characterized by the presence of three shallow lakes, receiving the main bulk of the drainage water from the Nile Delta. This sector extends from Abu Qir to Port Said with a length of about 200 km. The metrological data of Baltim station revealed that the mean annual temperature ranges from 17.3 to 24.0 °C, the average annual rainfall was about 175.2 mm per year, and the mean relative humidity was approximately 57.7%.

On the other hand, Wadi Hagoul is a drainage system occupying the valley depression between Kahaliya ridge to the south and Gebel Ataqa to the north at the Northwestern part of Gulf of Suez. The area of the wadi is 345 km³, and its main channel extends for 35 km, where it receives water through the running channels from both sides. The wadi extends in a southeast direction toward the Gulf of Suez, crossing limestone beds of the Miocene (Zahran and Willis, 2009). Wadi Hagoul exists in the Eastern Desert, which is characterized by the arid climate. According to the meteorological data of the nearest station (Suez city), the climate is arid and dry, where the mean annual air temperature ranges from 10 to 38 °C. Rainfall is scarce with 34.3 mm as yearly average, while the relative humidity is 54.4%.

2.2. Vegetation analysis

Fifty-two plots were selected to represent the three habitats (Western Coast, Delta Coast, and Wadi Hagoul) of *R. tingitana*. The area of the plot was 100 m², estimated according to the minimal area. Within each plot, the density and cover of all species associated with *R. tingitana* were determined (Canfield, 1941; Shukla and Chandel, 1989). The importance value out of 200 was calculated for each species based on the relative density and cover in each plot. The taxonomic nomenclature, identification, and chorotype of plant species were assessed according to Boulos (1999–2005) and Tackholm (1974). However, life forms were identified according to the scheme of Raunkiaer (1937).

2.3. Soil analysis

In each plot, composite soil samples (20 cm depth) were collected, packed in polyethylene bags and returned to the laboratory. The samples were dried in the air at room temperature (25 °C ± 3), sieved through 2 mm sieve to remove any contaminants, and packed in bags till further physical and chemical analyses. Soil particle size, water holding capacity (WHC), soil porosity, organic carbon, and sulphate were determined according to Piper (1947). Chlorides and calcium carbonate contents were determined according to Jackson (1962). Soil pH and electrical conductivity (EC) were measured in water suspension (1:2.5) as described by Jackson (1962). Carbonates and bicarbonates were determined by titration using 0.1 N HCl (Pierce et al., 1958). The extractable cations Na⁺ and K⁺ were determined by flame photometry (PHF 80B Biologie Spectrophotometer), while Ca⁺² and Mg⁺² were estimated using atomic absorption spectrometer (A Perkin-Elmer, Model 2380.USA) according to Allen et al. (1974).

2.4. Plant materials preparation and extraction

The above ground biomass of *R. tingitana* from five plants was collected from each habitat in a plastic bag and mixed as composite sample. To avoid bias, all the three habitats were sampled at the flowering stage in March and plant individuals were chosen to be of similar size. The samples were dried in room temperature (25 °C ± 3), ground and packed in paper bags. About 200 g of the prepared samples were mixed with one liter of aqueous methanol (70% v/v) and shaken well for 12 h. The suspensions were then cen-

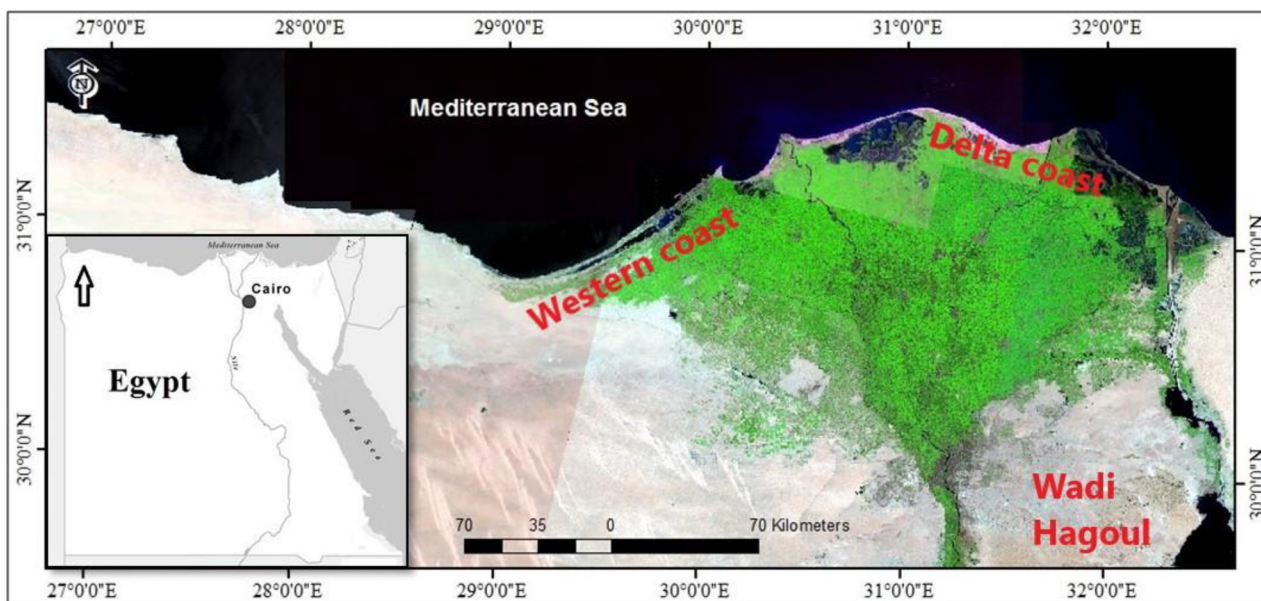


Fig. 1. Map showing the three studied regions namely: Western Coast, Delta Coast, and Wadi Hagoul.

trifuged at 2395 g for 10 min, and evaporated till dryness under rotary evaporator. The residues were collected in a glass vial till further analyses.

2.5. HPLC analysis

The extracted samples of the three *Reichardia* habitats were analyzed by HPLC. The analysis was accomplished using an Agilent 1260 series. The separation was carried out using a C18 column (4.6 mm × 250 mm i.d., five μm). The mobile phase consisted of water (A) and 0.02% trifluoroacetic acid in acetonitrile (B) at a flow rate of 1 ml min⁻¹. The mobile phase was programmed consecutively in a linear gradient as follows: 0 min (80% A); 0–5 min (80% A); 5–8 min (40% A); 8–12 min (50% A); 12–14 min (80% A) and 14–16 min (80% A). The multi-wavelength detector was scrutinized at 280 nm. The injection volume was ten μl for each of the sample solutions, and the temperature of the column was sustained at 35 °C.

2.6. Allelopathy bioassay

2.6.1. Weed seed source and preparation

To test the allelopathic activity of the three collected *Reichardia* samples, we targeted two weeds; one infesting the cultivated field in the winter season (*Chenopodium murale*, hereafter; *Chenopodium*) and the second one growing in summer season (*Amaranthus lividus*, hereafter; *Amaranthus*). The seeds were collected from several healthy plants that grow in cultivated land in Manzalla city, Al-Dakahlia Governorate, Egypt (31°07'08.4"N 31°51'56.5"E). Ripe and uniform seeds with almost of the same size and color were surface-sterilized using 0.3% NaOCl, by immersion for three minutes, then rinsed by sterile distilled water three times, dried on sterilized filter paper, and kept in sterilized vials until further use (Sampietro et al., 2009).

2.6.2. Experimental design of bioassay

For the preparation of plant extracts, different concentrations of 2.5, 5, 10, 25, 50, 75 and 100 mg L⁻¹ of the above-mentioned residues were achieved using dimethyl sulfoxide (DMSO). Also, control treatment was achieved by DMSO. Twenty seeds of each weed

were placed in 9 cm Petri dishes lined with sterilized Whatman No. 1 filter paper. The filter paper was moistened with 5 ml of each concentration and DMSO as control, in triplicates. To avoid contamination, the Petri dishes were sealed with parafilm and incubated in the growth chamber at 24 °C and 28 °C for *Chenopodium* and *Amaranthus*, respectively (Sampietro et al., 2009). A total of 144 plates [8 treatments (7 concentrations + control) × 3 samples (regions) × 2 species of weed's seeds × 3 replicates] were obtained. After eight days for *Chenopodium* and ten days for *Amaranthus*, the germinated seeds were counted, and the radicle lengths were measured per each plate. The inhibition of germination, and root growth was calculated, concerning control, as follows:

$$\text{Inhibition(\%)} = 100 \times \frac{(\text{No/Length of control} - \text{No/Length of treatment})}{\text{No/Length of control}}$$

2.7. Data analysis

The plant species diversity indexes were calculated per each habitat of *Reichardia* based on the vegetation analysis data as follows:

$$\text{Shannon-Wiener diversity index (H)} = \sum_{i=1}^s P_i \ln (P_i)$$

$$\text{Shannon - evenness index (E)} = \frac{H}{\ln s}$$

$$\text{Simpson Diversity Index (D)} = \frac{\sum_i [n_i \times (n_i - 1)]}{[N \times (N - 1)]}$$

where $P_i = n_i / N$ = proportional abundance of species, i in a habitat made up of s species, n_i = the number of plots containing species i and $N = \sum n_i$.

On the other hand, the data of both soil analysis and allelopathic bioassays were subjected to one-way ANOVA followed by Duncan's post hoc test at probability level 0.05 using CoStat software program (CoHort Software, Monterey, CA, USA). Also, the data derived from HPLC analysis of the three samples were subjected to an agglomerative hierarchical cluster (AHC) and principal component analysis (PCA) to construct a matrix of correlation and to recognize whether a significant difference exists between different treat-

ments. AHC and PCA were performed using XLSTAT statistical computer software package, version 14 (Addinsoft, New York, NY, USA).

3. Results and discussion

3.1. Vegetation composition and soil factors of the three *R. tingitana* habitats

The floristic analysis of the present study showed that the total number of the recorded plant species is 133 species (64 annuals, three biennials, and 66 perennials) belonging to 105 genera and related to 27 families. The most abundant families were Asteraceae comprising 24 species, followed by Poaceae (22 species), Chenopodiaceae (13 species), Fabaceae (12 species), and Brassicaceae (10 species). However, other families were represented by a few species (Appendix 1). These families were also reported as major families in most of the researches within the same phytogeographical region (Abd El-Gawad and Shehata, 2014; El-Amier and Abd El-Gawad, 2017; Shaltout et al., 1995, 2015; Zahran et al., 1990; Zahran and Willis, 2009). According to Raunkiaer (1937), therophytes were the most represented life form (50.38%), followed by chamaephytes (21.80%), hemicryptophytes (12.78%), geophytes (6.77%), and nanophanerophytes (6.02%). However, helophytes, parasites, and phanerophytes were represented by one species only (Appendix 1). The prevalence of therophytes over the other life forms could be attributed to the short life cycle that enables them to resist the instability of the habitat, topography variation and biotic influence. Moreover, therophytes were estimated by 50.3% for the whole Egyptian flora compared with 58.7% for the Mediterranean region and 59.4% for Egyptian Nile region (Hasib, 1950).

3.1.1. The habitat of *R. tingitana* in the Delta Coast

Within the habitat of *R. tingitana* in the Delta Coast, 66 plant species were recorded (35 annuals, two biennials, and 29 perennials) inhabiting 17 plots that were co-dominated by the halophytic plants; *Zygophyllum aegyptium* and *Calligonum polygonoides*. This habitat has average Shannon-evenness value of 0.80 and Simpson diversity value of 0.95 (Table 1). The most important associated annual species (have relatively high importance values) linked to this habitat were *Hordeum murinum*, *Senecio glaucus*, *Cakile maritima*, *Mesembryanthemum crystallinum*, and *M. nodiflorum*. The soil analyses of this region showed that it was characterized by significant high levels of sand, salinity, soil pore spaces, pH, SO_4^{2-} , and HCO_3^- , while cations except Ca^{2+} were detected in low concentration (Table 2). No bicarbonates were detected. The northern coast of the Nile Delta of Egypt is mainly characterized with halophytic vegetation as it is affected with the Mediterranean Sea as well as the three shallow lakes of this coastal area that receive the main bulk of the drainage water from the Nile Delta (El-Amier and Abd El-Gawad, 2017; Zahran and Willis, 2009). Therefore, the perennial halophytes are common in this site of study, however, there were also a significant number of annuals which corroborated to the presence of sand dunes that distributed along the shoreline of the delta (El Banna, 2004). The sand dune habitat is characterized by its rich seed bank (Yu et al., 2007). It is worth mentioning here that many studies recorded the *C. maritima* as a common plant in this area (Abd El-Gawad and Shehata, 2014; El-Amier and Abd El-Gawad, 2017; Zahran et al., 1990). Plants of Fabaceae family tended to persist in soil rather than those of other plant functional groups, where their seeds have strong testa (Yu et al., 2007).

Moreover, Abd El-Gawad and Shehata (2014) reported that *M. crystallinum* (important species in the present study) survives well in sandy dune habitats and tolerates the high content of salinity

along the Nile Delta Coast. Also, *H. murinum*, *S. glaucus*, and *M. nodiflorum* were reported as predominant species in similar habitats.

3.1.2. The habitat of *R. tingitana* in the Western Coast

The floristic analysis of *R. tingitana* habitat at the Western Coast revealed the dominance of *Lycium shawii* within 19 plots. Also, this habitat attained the highest number of species (69 species; 38 annuals, two biennials, and 29 perennials) as well as the highest diversity, where it has average Shannon-evenness value of 0.87 and Simpson diversity value of 0.96 (Table 1). The other important associated species were *S. glaucus*, *Bromus diandrus*, *Suaeda pruinosa*, *M. nodiflorum*, *Cyndon dactylon*, *Emex spinosa*, and *Malva parvifolra*. The community structure of this site has some important halophytes such as *S. pruinosa* and *M. nodiflorum* as well as some common associates with halophytic vegetation such as *S. glaucus*, *B. diandrus*, *C. dactylon*, *E. spinosa*, and *M. parvifolra* (Table 1). This reflects the salt-affected habitat in this site where the soil composition is characterized by high EC (1.84 mS cm^{-1}) as well as high content of WHC, organic carbon, EC, Cl, Na^+ , K^+ , Mg^{2+} , and lowest content of SO_4^{2-} and HCO_3^- (Table 2). This result is in consistency with other studies related to the vegetation structure of this area (Shaltout et al., 1995, 2015).

The Western Coastal belt of the Mediterranean Sea is the wealthiest part of Egypt in its floristic composition due to its relatively high rainfall (Tackholm, 1974). However, most of these species are therophytes (annuals) that flourish during the rainy season.

3.1.3. The habitat of *R. tingitana* in Wadi Hagoul

The vegetation analysis of the inland desert region (Wadi Hagoul) revealed the dominance of perennials (63 species; 28 annuals, one biennial, and 34 perennials), where the woody bush plant, *Haloxylon salicornicum* dominate this habitat. In this context, the dominance of perennials is typical in the desert habitat, where these plants have well-adapted strategies against drought, while the other small plants cannot compete with them (Zahran and Willis, 2009). In addition, this habitat has an average Shannon-evenness value of 0.86 and Simpson diversity value of 0.96 (Table 1). The other important associated species were desert plants including; both perennials (*Launaea nudicaulis* and *C. dactylon*) and annuals (*Bassia muricata*, *Diploaxis harra*, *Erodium laciniatum*, *Z. simplex*, and *S. glaucus*) that flourish during the rainy season. The soil of the plots representing this region is characterized by high content of CaCO_3 , HCO_3^- and Ca^{2+} and moderate levels of pH, EC, Na^+ , and K^+ (Table 2). These results are in congruence with previous studies of the vegetation of different wadis in the Egyptian deserts (El-Sharkawi et al., 1982; Mashaly, 1996; Zahran and Willis, 2009).

3.2. Bioactive composition of the three *R. tingitana* samples and their correlations to soil variables

Fifteen compounds were separated and identified from above-ground biomass of *R. tingitana* collected from the three regions through HPLC analysis (Table 3). These compounds are mainly phenolics (60.0%), while flavonoid compounds come as second rank (26.7%). The identified compounds varied either in the diversity or quantity between the three samples of the *R. tingitana*. Western Coast sample was the richest sample, followed by Delta Coast sample and finally Wadi Hagoul sample.

Caffeic acid, cinnamic acid, coumaric acid, ellagic acid, gallic acid, propyl gallate, and quercetin were identified in the samples of *R. tingitana* in the three regions with significant variation in the quantity. However, chlorogenic acid, daidzein, ferulic acid, naringenin, and syringic acid were identified in two regions, while

Table 1
Plant diversity, dominant and important plant species of the three studied habitats of *Reichardia tingitana*.

Regions	No. of plots	Total species	Shannon-evenness	Simpson diversity	Dominant species	Other important species
Delta Coast	17	66	0.80	0.95	<i>Zygophyllum aegyptium</i> (11.51 ± 2.47)* <i>Calligonum polygonoides</i> (10.89 ± 3.14)	<i>Hordeum murinum</i> (9.99 ± 1.65) <i>Senecio glaucus</i> (9.51 ± 1.00) <i>Cakile maritima</i> (9.17 ± 1.22) <i>Mesembryanthemum crystallinum</i> (8.71 ± 1.2) <i>Mesembryanthemum nodiflorum</i> (8.53 ± 1.00) <i>Reichardia tingitana</i> (7.73 ± 0.58)
Western Coast	19	69	0.87	0.96	<i>Lycium shawii</i> (20.62 ± 2.58)	<i>Reichardia tingitana</i> (15.40 ± 0.38) <i>Senecio glaucus</i> (8.95 ± 0.56) <i>Bromus diandrus</i> (8.24 ± 0.73) <i>Suaeda pruinosa</i> (8.05 ± 0.81) <i>Mesembryanthemum nodiflorum</i> (5.37 ± 0.43) <i>Cyndon dactylon</i> (5.23 ± 0.49) <i>Emex spinosa</i> (5.21 ± 0.36) <i>Malva parvifolia</i> (5.12 ± 0.47)
Wadi Hagoul	16	63	0.86	0.96	<i>Haloxylon salicornicum</i> (14.17 ± 1.11)	<i>Launaea nudicaulis</i> (12.44 ± 1.08) <i>Cyndon dactylon</i> (9.49 ± 0.81) <i>Bassia muricata</i> (9.34 ± 0.96) <i>Diploaxis harra</i> (9.23 ± 0.82) <i>Erodium laciniatum</i> (7.45 ± 0.47) <i>Zygophyllum simplex</i> (7.45 ± 0.64) <i>Senecio glaucus</i> (7.28 ± 0.53) <i>Reichardia tingitana</i> (6.77 ± 0.18)

* Values are means ± standard variation.

Table 2
Soil variables (Mean values ± standard error) of the three studied habitats of *Reichardia tingitana*. WHC: water holding capacity, and EC: electrical conductivity.

Soil variables	Delta coast (n = 17)	Western coast (n = 19)	Wadi Hagoul (n = 16)	F-value
Sand (%)	93.91 ± 1.21a	92.33 ± 0.93a	93.26 ± 1.08a	0.54
Silt (%)	0.90 ± 0.24b	4.81 ± 0.51a	1.87 ± 0.31b	29.71
Clay (%)	5.19 ± 1.01a	2.86 ± 0.61a	4.87 ± 1.18a	1.71
Porosity (%)	39.66 ± 0.75a	25.44 ± 1.01c	33.88 ± 1.31b	46.32
WHC (%)	28.64 ± 1.04a	29.18 ± 0.78a	27.69 ± 1.07a	0.60
CaCO ₃ (%)	2.43 ± 0.38b	2.65 ± 0.19b	15.25 ± 1.90a	42.83
Organic carbon (%)	0.52 ± 0.09b	1.11 ± 0.13a	0.35 ± 0.06b	17.85
pH	8.22 ± 0.11a	7.84 ± 0.09b	8.09 ± 0.11ab	3.47
EC (mS cm ⁻¹)	1.26 ± 0.01b	1.85 ± 0.09a	0.67 ± 0.05c	199.44
Cl ⁻ (%)	0.06 ± 0.01b	0.17 ± 0.02a	0.04 ± 0.01b	43.15
SO ₄ ²⁻ (%)	0.47 ± 0.08a	0.04 ± 0.01b	0.40 ± 0.04a	20.80
HCO ₃ ⁻ (%)	0.14 ± 0.01b	0.05 ± 0.01c	0.23 ± 0.02a	37.15
Na ⁺ (mg g ⁻¹)	5.05 ± 0.14b	69.17 ± 5.48a	11.29 ± 0.41b	124.09
K ⁺ (mg g ⁻¹)	2.25 ± 0.06c	8.54 ± 0.53a	5.35 ± 0.32b	76.30
Ca ²⁺ (mg g ⁻¹)	16.71 ± 0.18b	14.36 ± 0.92b	36.44 ± 2.12a	82.21
Mg ²⁺ (mg g ⁻¹)	4.73 ± 0.09b	7.02 ± 0.31a	4.70 ± 0.32b	25.49

The different letter within each row means values with a significant difference after Duncan's post hoc test ($P \leq 0.05$). LSD_{0.05}: least significant difference at a probability level of 0.05.

catechin, vanillin, and rutin were only detected in the Western Coast sample (Table 3).

The *R. tingitana* sample collected from Western Coast attained the highest significant values of constituents compared to the others two samples (Delta Coast and Wadi Hagoul), where quercetin, ellagic acid, gallic acid, chlorogenic acid, naringenin, and caffeic acid are the major compound in this sample. On the other hand, quercetin was detected as major compound in deltaic coast *R. tingitana* sample, while quercetin and ellagic acid attained the highest concentration in the sample of the Wadi Hagoul. The accumulation of active secondary metabolites could be ascribed to the influences of multiple environmental factors on the wild plant during developmental and growth periods in addition to genetic factors. Certain compounds are synthesized, and their concentration significantly increase under specific environments (Liu et al., 2015).

The environmental stress factors (light, temperature, soil water, soil fertility, and salinity) eventually lead to changes in overall phy-

tochemical composition which thereby play a strategic role in the generation of bioactive compounds (Yang et al., 2018). This is considered as plant behavior that improves the adaptation and survival in response to the harsh environment as well as enhances the immune system of the plant against herbivores and pathogens (Pellissier et al., 2016).

To evaluate the correlation between the different studied habitats and their content of bioactive compounds derived from HPLC analysis, we subjected the data to PCA and AHC. The sample of *R. tingitana* collected from the Western Coast region was not correlated to the other two samples, which reflect the variation of the chemical composition (Fig. 2a). However, the samples of Delta Coast and Wadi Hagoul were correlated to each other. On the other hand, the application of AHC reflected the same conclusion, where we can classify the samples into two groups; one comprising the Western Coast sample and the other group contained the samples of Delta Coast and Wadi Hagoul (Fig. 2b).

Table 3
Concentration of fifteen identified compounds derived from HPLC analysis of the collected *Reichardia tingitana* samples from the three habitats.

Compound name	Chemical formula	Class	Concentration ($\mu\text{g g}^{-1}$ dry weight)		
			Delta coast	Western coast	Wadi Hagoul
Caffeic acid	$\text{C}_9\text{H}_8\text{O}_4$	Phenolic	13.86	89.72	5.05
Catechin	$\text{C}_{15}\text{H}_{14}\text{O}_6$	Phenolic	tr*	4.56	tr
Chlorogenic acid	$\text{C}_{16}\text{H}_{18}\text{O}_9$	Phenolic	20.15	101.12	tr
Cinnamic Acid	$\text{C}_9\text{H}_8\text{O}_2$	Carboxylic acid	8.01	1.88	1.23
Coumaric Acid	$\text{C}_9\text{H}_8\text{O}_3$	Carboxylic acid	3.51	1.48	9.97
Daidzein	$\text{C}_{15}\text{H}_{10}$	Isoflavone	1.63	51.67	tr
Ellagic acid	$\text{C}_{14}\text{H}_6\text{O}_8$	Phenolic	9.62	174.45	42.53
Ferulic Acid	$\text{C}_{10}\text{H}_{10}\text{O}_4$	Phenolic	tr	0.71	1.67
Gallic Acid	$\text{C}_7\text{H}_6\text{O}_5$	Phenolic	6.23	116.16	tr
Naringenin	$\text{C}_{15}\text{H}_{12}\text{O}_5$	Flavanone	21.14	93.72	tr
Propyl Gallate	$\text{C}_{10}\text{H}_{12}\text{O}_5$	Phenolic	1.84	11.77	0.95
Quercetin	$\text{C}_{15}\text{H}_{10}\text{O}_7$	Flavonol	291.60	349.66	40.35
Rutin	$\text{C}_{27}\text{H}_{30}\text{O}_{16}$	Flavonol	tr	14.59	tr
Syringic Acid	$\text{C}_9\text{H}_{10}\text{O}_5$	Phenolic	tr	29.24	3.01
Vanillin	$\text{C}_8\text{H}_8\text{O}_3$	Phenolic	tr	8.33	tr
% respect to all			66.67	100	53.33

* tr: detected in trace amount.

From the PCA analysis, it was clear that quercetin was the main compounds that showed a close correlation to the Delta Coast sample, while it showed a little bit correlation to Wadi Hagoul sample.

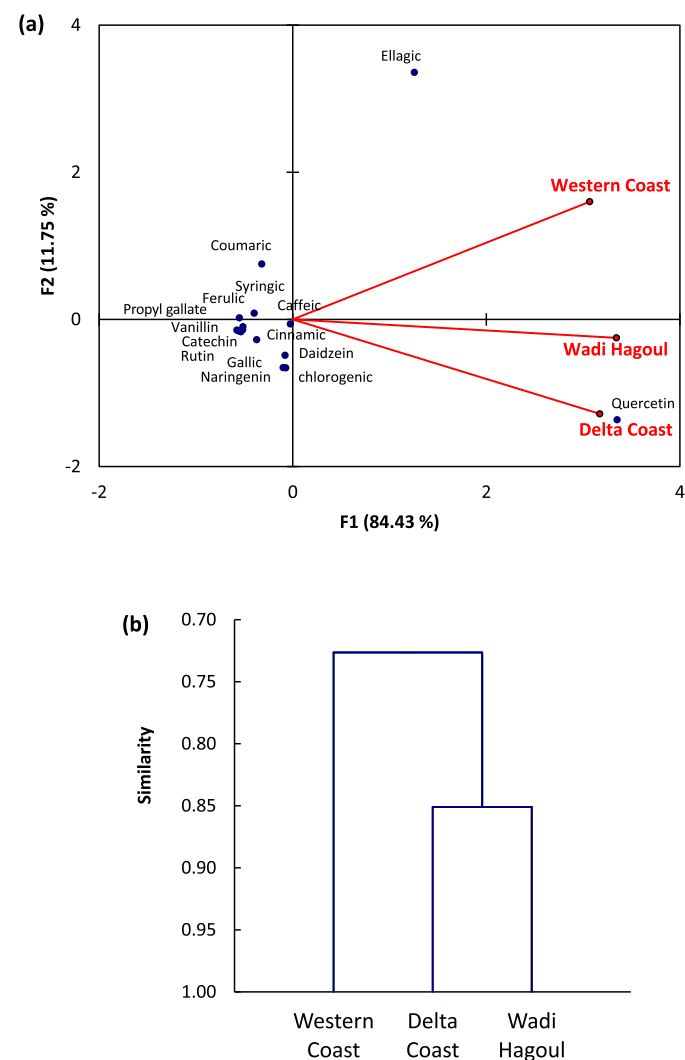


Fig. 2. (a) Principal component analysis (PCA) and (b) agglomerative hierarchical clustering (AHC) based on the chemical composition derived from HPLC analysis of the three collected samples of *Reichardia tingitana*.

This mean that it is considered as an indicator compound in the studied *R. tingitana* samples. On the other hand, ellagic acid showed a low correlation to the Western Coast sample and did not show any relationship to either Wadi Hagoul or Delta Coast samples. The other compounds showed the same correlation to all samples.

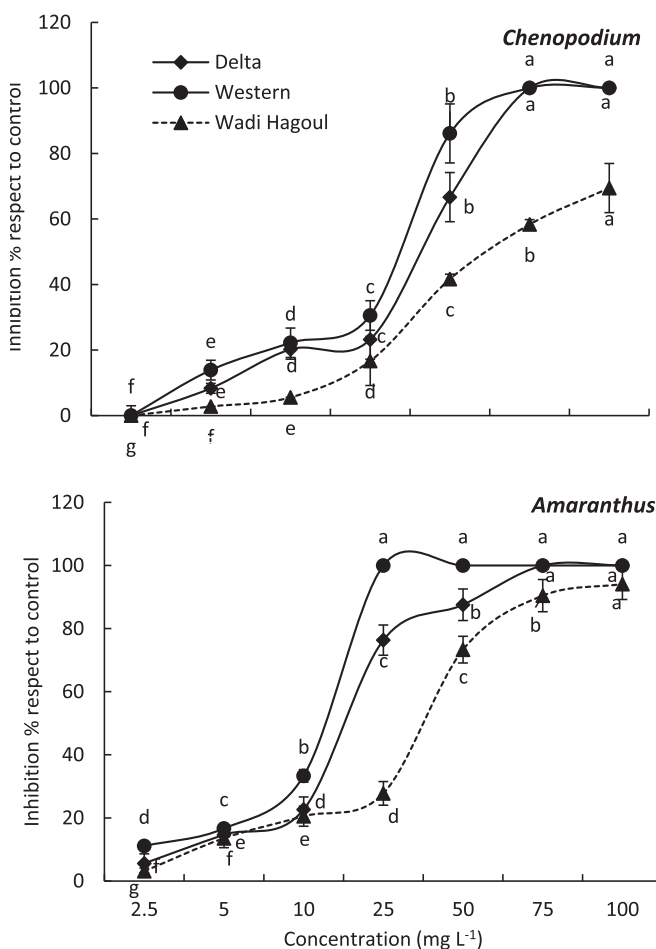


Fig. 3. Allelopathic effect of *Reichardia tingitana* aboveground biomass collected from three habitats on the germination of *Chenopodium murale* (above) and *Amaranthus lividus* (below). The different letters within each line means significant difference at $p \leq 0.05$.

Flavonoids play an essential role in several arrays of plant life such protection against pathogens, insect attraction, pollination, and allelopathy (Winkel-Shirley, 2001). Moreover, under biotic and abiotic stresses, reactive oxygen species (ROS) are generated in the plant cells, and in consequence, flavonoids induced in the plant to scavenge ROS (Baskar et al., 2018; El-Shora and Abd El-Gawad, 2015a, b). Therefore, the higher concentration of quercetin in the *R. tingitana* sample from Western Coast region could be ascribed to the high salinity, where quercetin produced as a protecting agent in plants against oxidative stress.

From the other side, caffeic acid, cinnamic acid, coumaric acid, ellagic acid, gallic acid, and propyl gallate were also reported to be induced under salinity stress (Colla et al., 2013), therefore we can say that the higher the content of phenolics in the samples from the Western Coast could be attributed to the salinity level. A compound like ellagic acid has the ability to alleviate the osmotic stress (Abu El-Soud et al., 2013), therefore the higher content of ellagic acid in the samples of *R. tingitana* from the Western Coast habitat could be considered as a strategy of the plant to cope with salt stress, while for the sample of Wadi Hagoul it could be like a defense against the drought. Our study showed that the salinity, organic matter, and macro-elements (Na^+ , K^+ , and Mg^{2+}) may be the crucial factors that induce the production of bioactive constituents in *R. tingitana*, especially the phenolic acids and flavonoids.

3.3. Allelopathic activity of the three *R. tingitana* samples

The allelopathic effect of various extracts of *R. tingitana* above-ground biomass collected from three different regions (Delta Coast, Western Coast, and Wadi Hagoul) on germination of *Chenopodium* and *Amaranthus* was illustrated in Fig. 3. In general, *R. tingitana* extracts from all regions significantly ($p \leq 0.05$) reduced the germination of *Amaranthus* more than *Chenopodium* (Fig. 3). The seed germination of *Chenopodium* was completely inhibited at a concentration of 75 mg L^{-1} under the effect of Delta Coast and Western Coast *R. tingitana* extracts, while it was inhibited by 58.33% for the Wadi Hagoul *R. tingitana* extract at the same concentration. The IC_{50} values (the concentration of a substance that is required for 50% inhibition of a specific biological function) of the germination of *Chenopodium* were 37.85 mg L^{-1} , 42.33 mg L^{-1} and 66.06 mg L^{-1} for Western Coast, Delta Coast, and Wadi Hagoul *R. tingitana* extracts, respectively. On the other hand, the germination of *Amaranthus* was completely inhibited at a concentration of 25 mg L^{-1} under the effect of Western Coast. While it was inhibited by 76.35% and 27.78% under treatments of Delta Coast and Wadi Hagoul *R. tingitana* extracts, respectively. The IC_{50} values of the germination of *Amaranthus* were 20.65 mg L^{-1} , 29.99 mg L^{-1} and 42.16 mg L^{-1} for Western Coast, Delta Coast, and Wadi Hagoul *R. tingitana* extracts, respectively.

Various extracts from *R. tingitana* showed significant ($p \leq 0.05$) inhibition of root growth of *Chenopodium* and *Amaranthus* after

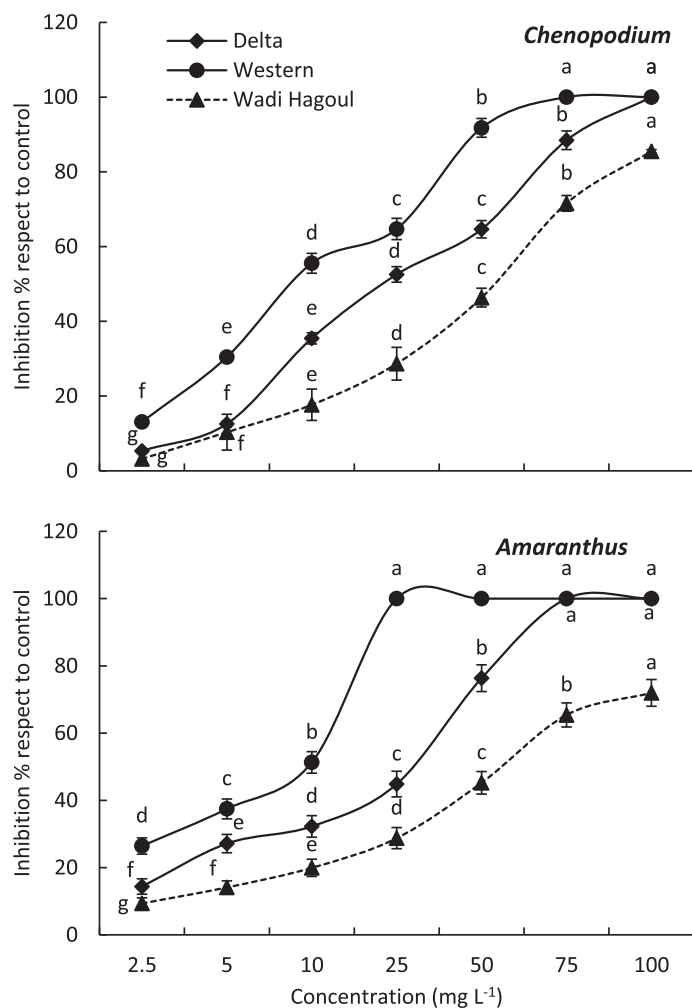


Fig. 4. Allelopathic effect of *Reichardia tingitana* aboveground biomass collected from the three habitats on the root growth of *Chenopodium murale* (above) and *Amaranthus lividius* (below). The different letters within each line means significant difference at $p \leq 0.05$.

treatment, and the degree of inhibition of plant extracts increased with increasing concentration (Fig. 4). The *R. tingitana* extracts from the Western Coast and Delta Coast samples expressed total inhibition of *Chenopodium* root growth at concentration of 75 mg L⁻¹, while it was inhibited by 88.45% and 71.57% for the Delta Coast and Wadi Hagoul *R. tingitana* extracts, respectively. The IC₅₀ values of the root growth of *Chenopodium* were 19.66 mg L⁻¹, 36.80 mg ml⁻¹ and 53.27 mg L⁻¹ for Western Coast, Delta Coast, and Wadi Hagoul *R. tingitana* extracts, respectively.

On the other hand, the root growth of *Amaranthus* was entirely inhibited at a concentration of 25 mg L⁻¹ under the effect of Western Coast. However, the extracts of Delta Coast and Wadi Hagoul *R. tingitana* samples inhibited it by 76.34% and 45.23%, respectively at the same concentration. The IC₅₀ values of the germination of *Amaranthus* were 4.60 mg L⁻¹, 31.12 mg L⁻¹ and 59.11 mg L⁻¹ for Western Coast, Delta Coast, and Wadi Hagoul *R. tingitana* extracts, respectively.

Generally, the extracts from the *R. tingitana* collected from the Western Coast revealed more allelopathic effect against the tested plants than the samples from Delta Coast or Wadi Hagoul regions. This activity might be attributed to the higher concentrations of phenolics and flavonoids reported in this sample. Phenolic compounds, especially quercetin, ellagic acid, gallic acid, chlorogenic acid, caffeic acid, and naringenin have been reported to possess various biological activities. Moreover, the bioactive ingredients enable the plant to face or survive in the variable stressful conditions, and they are considered as an important part of the plant defense system against pathogenic attacks and environmental stresses (Yang et al., 2018). In addition, most of the identified compounds in this sample were reported as allelochemicals (Inderjit, 1996; Li et al., 2010). Phenolics and flavonoids were reported as defense compounds against herbivores and pathogens such as bacteria and fungi (Agrawal, 2007). Quercetin and naringenin were reported as the most often cited allelopathic flavonoids (Berhow and Vaughn (1999)). Naringenin was reported to inhibit the growth of soybean (Bido et al 2010). These bioactive compounds might play a role in the allelopathic activity of *R. tingitana* either singular or in a synergetic manner.

4. Conclusion

The vegetation analysis of the three habitats of *R. tingitana* within three different regions (Western Coast, Delta Coast, Wadi

Hagoul) revealed a significant variation in the vegetation composition as well as soil variables, while salinity, organic matter, and macro-elements (Na⁺, K⁺, and Mg²⁺) were the most controlling factor. Fifteen identified secondary compounds were determined using HPLC, where they are varied in the diversity and quantity between the three samples of the *R. tingitana*. Western Coast sample had the highest number of the bioactive compounds, followed by Delta Coast sample and finally Wadi Hagoul sample. Therefore, we can say that *R. tingitana* extract from the same species but from different conditions caused different allelopathic (inhibitory) effect, and this supposed to be related to the variation in the bioactive constituents. Our study showed that the salinity is the key factor that induce the production of bioactive constituents in *R. tingitana*, especially the phenolic acids and flavonoids as well. The *R. tingitana* methanol extract, especially Western Delta sample, showed potent allelopathic activity against *Chenopodium* and *Amaranthus*, where the germination was utterly inhibited at a concentration of 75 mg L⁻¹ and 50 mg L⁻¹, respectively. Therefore, these extracts could be used as a green source, eco-friendly bioherbicide and to be integrated into the weed control program of weeds. However, further study is needed for characterization of the specific allelochemical(s), evaluation the modes of action, and the biosafety. Also, further study is needed to confirm the mechanism(s) of salinity to induce the bioactive compounds.

Acknowledgments

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Appendix 1

Vegetation composition of the three habitats of *Reichardia tin-gitana* representing both coastal and inland desert of Egypt, and the life forms of different associated plants. Values are mean of the importance values (based on density and cover of the plant species) ± standard error. Th: therophytes, Ch: chamaephytes, H: hemicryptophytes, G: geophytes, Nph: nanophanerophytes, He: helophytes, P: parasites, and Ph: phanerophytes.

Plant species	Life form	Coastal desert		Inland desert
		Delta Coast	Western Coast	Wadi Hagoul
Perennials				
1 <i>Achillea santolina</i> L.	Ch		0.83 ± 0.19	
2 <i>Alhagi graecorum</i> Boiss.	H	0.32 ± 0.19		
3 <i>Anabasis articulata</i> (Forssk.) Moq.	Ch			2.18 ± 0.54
4 <i>Artemisia judiaca</i> L.	Ch		3.27 ± 0.40	1.05 ± 0.26
5 <i>Astragalus spinosus</i> (Forssk.) Muschl.	Ch		1.53 ± 0.27	
6 <i>Atractylis carduus</i> (Forssk.) C.Chr.	H	0.30 ± 0.12	2.13 ± 0.23	
7 <i>Atriplex halimus</i> L.	Nph	2.28 ± 1.34	4.87 ± 0.47	
8 <i>Atriplex semibaccata</i> R.Br.	H	6.76 ± 1.96	1.10 ± 0.20	
9 <i>Calotropis procera</i> (Willd.) R.Br.	Ph			3.38 ± 0.58
10 <i>Calligonum polygonoides</i> L. subsp. <i>comosum</i> (L' Her.) Soskov	Nph	10.89 ± 3.14	0.16 ± 0.04	
11 <i>Lepidium draba</i> L.	H			0.25 ± 0.06
12 <i>Cenchrus ciliaris</i> L.	He		3.91 ± 0.66	

Appendix 1 (continued)

	Plant species	Life form	Coastal desert		Inland desert
			Delta Coast	Western Coast	Wadi Hagoul
13	<i>Cistanche phelypaea</i> (L.) Cout.	P, G	0.76 ± 0.23		
14	<i>Cleome droserifolia</i> (Forssk.) Delile	Ch			1.24 ± 0.31
15	<i>Convolvulus arvensis</i> L.	H		3.54 ± 0.41	
16	<i>Convolvulus lanatus</i> Vahl	Ch			1.26 ± 0.31
17	<i>Cynanchum acutum</i> L.	H	0.79 ± 0.64		5.16 ± 0.58
18	<i>Cyondon dactylon</i> (L.) Pers.	G	4.63 ± 1.25	5.23 ± 0.49	9.49 ± 0.81
19	<i>Deverra tortuosa</i> (Desf.) DC.	Ch			1.25 ± 0.23
20	<i>Diploaxis harra</i> (Forssk.) Boiss.	Ch			9.23 ± 0.82
21	<i>Echinops spinosus</i> L.	H	5.20 ± 1.49	0.64 ± 0.14	1.33 ± 0.33
22	<i>Elymus farctus</i> (Viv.) Runem. ex Melderis	G	0.20 ± 0.12		
23	<i>Euphorbia terracina</i> L.	H		1.31 ± 0.22	
24	<i>Euphorbia retusa</i> Forssk.	H			1.48 ± 0.16
25	<i>Fagonia arabica</i> L.	Ch		4.40 ± 0.75	1.33 ± 0.33
26	<i>Fagonia cretica</i> L.	Ch		4.59 ± 0.47	
27	<i>Farsetia aegyptia</i> Turra	Ch			2.20 ± 0.30
28	<i>Gypsopila capillaris</i> (Forssk.) C.Chr	H			0.58 ± 0.14
29	<i>Halocnemum strobilaceum</i> (Pall.) M. Bieb.	Ch	4.74 ± 2.08	1.15 ± 0.14	
30	<i>Haloxylon salicornicum</i> (Moq.) Bunge ex Boiss.	Ch			14.17 ± 1.11
31	<i>Heliotropium curassavicum</i> L.	Ch	1.47 ± 0.60		
32	<i>Hyoscyamus muticus</i> L.	Ch			1.28 ± 0.22
33	<i>Imperata cylindrical</i> (L.) Raeusch.	H		1.30 ± 0.22	
34	<i>Iphiaea mucronata</i> (Forssk.) Asch. & Schweinf.	Ch	0.23 ± 0.13		
35	<i>Kickxia aegyptiaca</i> (L.) Nabelek.	Ch			0.19 ± 0.05
36	<i>Lasiurus scindicus</i> Henrard	G			3.01 ± 0.44
37	<i>Launaea mucronata</i> (Forssk.) Muschl.	H	5.04 ± 0.89		1.74 ± 0.21
38	<i>Launaea nudicaulis</i> (L.) Hook.f.	H	4.36 ± 0.92	2.24 ± 0.24	12.44 ± 1.08
39	<i>Launaea spinosa</i> (Forssk.) Sch. Bip. ex Kuntze	Ch			1.85 ± 0.37
40	<i>Limbarda crithmoides</i> (L.) Dumort.	Ch	2.26 ± 1.08		
41	<i>Limonium pruinum</i> (L.) Chaz.	G, He		1.23 ± 0.19	
42	<i>Lotus creticus</i> L.	H	1.65 ± 0.97		
43	<i>Lycium shawii</i> Roem & Schult.	Nph	9.92 ± 0.24	20.62 ± 2.58	
44	<i>Moltkiopsis ciliata</i> (Forssk.) I. M. Johnst.	Ch	3.51 ± 2.07	2.82 ± 0.35	
45	<i>Ochradenus baccatus</i> Delile	Nph			4.54 ± 0.78
46	<i>Pancratium maritimum</i> L.	G	0.25 ± 0.15		
47	<i>Panicum coloratum</i> L.	G			2.59 ± 0.30
48	<i>Panicum turgidum</i> Forssk.	H	4.73 ± 1.93		3.59 ± 0.53
49	<i>Phragmites australis</i> (Cav.) Trin. ex Steud.	G, He	2.23 ± 0.74	3.69 ± 0.47	2.92 ± 0.39
50	<i>Pluchea dioscoridis</i> (L.) DC.	Nph		1.09 ± 0.24	1.56 ± 0.39
51	<i>Polycarpaea repens</i> (Forssk.) Asch. & Schweinf.	Ch			0.49 ± 0.12
52	<i>Polygonum equisetiforme</i> Sm.	G	4.23 ± 2.49	1.01 ± 0.16	
53	<i>Retama raetam</i> (Forssk.) Webb & Berthel.	Nph	0.47 ± 0.28	1.14 ± 0.25	2.27 ± 0.42
54	<i>Silene succulenta</i> Forssk.	H	0.91 ± 0.53		
55	<i>Silybum marianum</i> (L.) Gaertn.	H		0.92 ± 0.14	
56	<i>Stipagrostis lanata</i> (Forssk.) De Winter	G	0.33 ± 0.19		
57	<i>Suaeda monoica</i> Forssk.	Ch			0.15 ± 0.04
58	<i>Suaeda pruinosa</i> Lange	Ch		8.05 ± 0.81	
59	<i>Symphyotrichum squamatum</i> (Spreng.) Nesom	Ch		0.43 ± 0.10	
60	<i>Tamarix nilotica</i> (Ehrenb.) Bunge	Nph		1.30 ± 0.22	2.22 ± 0.38
61	<i>Thymelaea hirsuta</i> (L.) Endl.	Nph	3.25 ± 1.92		
62	<i>Zilla spinosa</i> (L.) Prantl	Ch			5.25 ± 0.56
63	<i>Zygophyllum aegyptium</i> Hosny	Ch	11.51 ± 2.47	0.76 ± 0.14	
64	<i>Zygophyllum album</i> L.	Ch	7.45 ± 2.15		
65	<i>Zygophyllum coccineum</i> L.	Ch			4.97 ± 0.47
66	<i>Zygophyllum decumbens</i> Delile	Ch			1.19 ± 0.24
Biennials					
67	<i>Beta vulgaris</i> L.	Th	1.79 ± 1.05		
68	<i>Centaurea aegyptiaca</i> L.	Th		3.93 ± 0.69	2.17 ± 0.23
69	<i>Spergularia marina</i> (L.) Griseb.	Th	0.37 ± 0.22	1.40 ± 0.19	

(continued on next page)

Appendix 1 (continued)

Plant species	Life form	Coastal desert		Inland desert	
		Delta Coast	Western Coast	Wadi Hagoul	
Annuals					
70	<i>Aegilops bicornis</i> (Forssk.) Jaub. & Spach	Th	2.71 ± 1.13	2.30 ± 0.32	
71	<i>Aegilops crassa</i> Boiss	Th		4.01 ± 0.50	
72	<i>Aegilops kotschy</i> Boiss.	Th	2.30 ± 1.03		
73	<i>Anchusa humilis</i> (Desf.) I.M. Johnst.	Th		1.43 ± 0.32	
74	<i>Anthemis cotula</i> L.	Th			0.83 ± 0.14
75	<i>Astragalus bombycinus</i> Boiss.	Th		1.32 ± 0.20	2.22 ± 0.22
76	<i>Astragalus peregrinus</i> Vahl	Th		1.47 ± 0.26	
77	<i>Atriplex lindleyi</i> Moq. subsp. <i>inflata</i> (Muell.) Willson.	Th	0.28 ± 0.17	1.29 ± 0.17	
78	<i>Avena fatua</i> L.	Th	0.13 ± 0.08	5.79 ± 0.34	
79	<i>Bassia indica</i> (Wight) Scott.	Th	6.63 ± 0.99	1.44 ± 0.24	1.17 ± 0.16
80	<i>Bassia muricata</i> (L.) Asch.	Th	0.58 ± 0.34		9.34 ± 0.96
81	<i>Brassica tournefortii</i> Gouan.	Th	0.54 ± 0.32	2.77 ± 0.40	4.45 ± 0.76
82	<i>Bromus diandrus</i> Roth	Th	3.37 ± 1.12	8.24 ± 0.73	
83	<i>Cakile maritima</i> Scop. subsp. <i>aegyptiaca</i> (Willd.) Nyman	Th	9.17 ± 1.22	3.13 ± 0.37	
84	<i>Carduus getulus</i> Pomel	Th	0.15 ± 0.09	0.33 ± 0.07	
85	<i>Carthamus tenuis</i> (Boiss & Blanche) Bornm.	Th	2.73 ± 0.70	4.26 ± 0.61	
86	<i>Chenopodium murale</i> L.	Th	4.11 ± 0.70	4.68 ± 0.35	1.25 ± 0.15
87	<i>Cutandia memphitica</i> (Spreng.) Benth.	Th	0.54±		
88	<i>Emex spinosa</i> (L.) Campd.	Th	1.22 ± 0.49	5.21 ± 0.36	0.52 ± 0.13
89	<i>Enarthrocarpus lyratus</i> (Forssk.) DC.	Th		0.48 ± 0.11	
90	<i>Erodium laciniatum</i> (Cav.) Wild.	Th	0.27 ± 0.16	1.47 ± 0.25	7.45 ± 0.47
91	<i>Euphorbia heliscopia</i> L.	Th		2.37 ± 0.39	
92	<i>Euphorbia peplus</i> L.	Th		3.45 ± 0.47	
93	<i>Herniaria hemistemon</i> J. Gay	Th			0.36 ± 0.09
94	<i>Hordeum murinum</i> L.	Th	10.02 ± 1.65		2.42 ± 0.36
95	<i>Hordeum spontaneum</i> K. Koch	Th			1.18 ± 0.22
96	<i>Ifloga spicata</i> (Forssk.) Sch. Bip.	Th	2.57 ± 1.09		4.89 ± 0.68
97	<i>Lactuca serriola</i> L.	Th	0.25 ± 0.15	4.70 ± 0.59	
98	<i>Lavatera cretica</i> L.	Th		2.90 ± 0.31	
99	<i>Legousia speculum-veneris</i> (L.) Chaix	Th		1.43 ± 0.32	
100	<i>Lobularia arabica</i> (Boiss.) Muschl.	Th		1.31 ± 0.29	
101	<i>Lolium multiflorum</i> Lam.	Th	4.30 ± 1.25		0.96 ± 0.17
102	<i>Lolium perenne</i> L.	Th		3.66 ± 0.55	
103	<i>Lotus glinoides</i> Delile	Th			1.29 ± 0.15
104	<i>Lotus halophilus</i> Boiss.	Th	0.70 ± 0.29		
105	<i>Lotus polyphyllus</i> E. D. Clarke	Th		2.57 ± 0.35	
106	<i>Malva parviflora</i> L.	Th	4.27 ± 0.74	5.12 ± 0.47	6.51 ± 0.61
107	<i>Matthiola longipetala</i> (Vent.) DC. subsp. <i>livida</i> (Delile) Maire	Th			6.99 ± 0.61
108	<i>Medicago polymorpha</i> L.	Th	0.46 ± 0.27		
109	<i>Melilotus indicus</i> (L.) All.	Th		2.17 ± 0.29	
110	<i>Mesembryanthemum crystallinum</i> L.	Th	8.71 ± 1.22	3.89 ± 0.41	
111	<i>Mesembryanthemum forsskaolii</i> Hochst. ex Boiss.	Th			4.57 ± 0.49
112	<i>Mesembryanthemum nodiflorum</i> L.	Th	8.53 ± 1.00	5.37 ± 0.43	
113	<i>Orobanche crenata</i> Forssk.	Th			0.24 ± 0.06
114	<i>Parapholis incurva</i> (L.) C.E. Hubb	Th	1.20 ± 0.71	0.12 ± 0.03	
115	<i>Paronychia arabica</i> (L.) DC.	Th	0.09 ± 0.05		
116	<i>Phalaris minor</i> Retz.	Th	1.05 ± 0.47		
117	<i>Plantago lagopus</i> L.	Th		4.24 ± 0.58	1.45 ± 0.36
118	<i>Poa annua</i> L.	Th	1.43 ± 0.84	0.22 ± 0.05	1.14 ± 0.21
119	<i>Reichardia tingitana</i> (L.) Roth	Th	7.73 ± 0.58	15.40 ± 0.38	6.77 ± 0.18
120	<i>Reseda decursiva</i> Forssk.	Th		0.65 ± 0.10	
121	<i>Rumex pictus</i> Forssk.	Th	6.71 ± 0.73		
122	<i>Rumex vesicarius</i> L.	Th			4.86 ± 0.52
123	<i>Salsola kali</i> L.	Th	2.81 ± 0.58		0.49 ± 0.12
124	<i>Senecio glaucus</i> L.	Th	9.51 ± 1.00	8.95 ± 0.56	7.28 ± 0.53
125	<i>Silene vivianii</i> Steud.	Th	0.94 ± 0.42		
126	<i>Sisymbrium irio</i> L.	Th		4.50 ± 0.32	
127	<i>Sonchus oleraceus</i> L.	Th	0.07 ± 0.04		
128	<i>Spergularia rubra</i> (L.) J. & C.Presl	Th			0.11 ± 0.03

Appendix 1 (continued)

	Plant species	Life form	Coastal desert		Inland desert
			Delta Coast	Western Coast	Wadi Hagoul
129	<i>Trigonella stellata</i> Forssk.	Th			1.93 ± 0.25
130	<i>Urospermum picroides</i> (L.) F.W. Schmidt	Th	1.04 ± 0.41	4.64 ± 0.44	
131	<i>Urtica urens</i> L.	Th		0.19 ± 0.04	
132	<i>Volutaria lippii</i> (L.) Cass. Ex Maire	Th			1.29 ± 0.25
133	<i>Zygophyllum simplex</i> L.	Th			7.45 ± 0.64

References

- Abd El-Gawad, A., Mashaly, I.A., Al-Nafie, R.I., 2015. Antioxidant activity and allelopathic potential of five wild plants on germination and growth *Bidens pilosa* L. Int. J. Curr. Res. 7, 21019–21024.
- Abd El-Gawad, A.M., Shehata, H.S., 2014. Ecology and development of *Mesembryanthemum crystallinum* L. in the Deltaic Mediterranean coast of Egypt. Egyptian J. Basic Appl. Sci. 1, 29–37.
- Abdel-Mogib, M., Abou-Elzahab, M., Dawidar, A., Ayyad, S., 1993. A sesquiterpene glucoside from *Reichardia tingitana*. Phytochemistry 34, 1434–1435.
- Abu El-Soud, W., Hegab, M.M., AbdElGawad, H., Zinta, G., Asard, H.J.P.P., 2013. Ability of ellagic acid to alleviate osmotic stress on chickpea seedlings. Plant Physiol. Biochem. 71, 173–183.
- Agrawal, A.A., 2007. Macroevolution of plant defense strategies. Trends Ecol. Evol. 22, 103–109.
- Allen, S.E., Grimshaw, H., Parkinson, J.A., Quarmby, C., 1974. Chemical Analysis of Ecological Materials. Blackwell Scientific Publications.
- Baldwin, I.T., Halitschke, R., Paschold, A., Von Dahl, C.C., Preston, C.A., 2006. Volatile signaling in plant-plant interactions: "talking trees" in the genomics era. Science 311, 812–815.
- Baldwin, I.T., Kessler, A., Halitschke, R., 2002. Volatile signaling in plant-plant-herbivore interactions: what is real? Curr. Opin. Plant Biol. 5, 351–354.
- Baskar, V., Venkatesh, R., Ramalingam, S., 2018. Flavonoids (antioxidants systems) in higher plants and their response to stresses. In: Gupta, D.K., Palma, J.M., Corpas, F.J. (Eds.), Antioxidants and Antioxidant Enzymes in Higher Plants. Springer International Publishing, Cham, pp. 253–268.
- Bido, G.D.S., Ferrarese, M.D.L.L., Marchiosi, R., Ferrarese-Filho, O., 2010. Naringenin inhibits the growth and stimulates the lignification of soybean root. Brazilian Arch. Biol. Technol. 53, 533–542.
- Berhow, M., Vaughn, S., 1999. Higher plant flavonoids: biosynthesis and chemical ecology. In: Inderjit, K.M.M.D., Foy, C.L. (Eds.), Principles Practices in Plant Ecology: Allelochemical Interactions. CRC Press, Boca Raton.
- Boulos, L., 1999–2005. Flora of Egypt. Al Hadara Publishing, Cairo, Egypt, pp. 1–4.
- Boulos, L., 2009. Flora of Egypt Checklist. Al Hadara Publishing, Cairo, Egypt.
- Buchanan, B.B., Gruijssem, W., Jones, R.L., 2015. Biochemistry and Molecular Biology of Plants. John Wiley & Sons, UK.
- Canfield, R., 1941. Application of the line interception method in sampling range vegetation. J. Forest. 39, 288–394.
- Cazella, L.N., Glamočlija, J., Sokovic, M., Gonçalves, J.E., Linde, G.A., Colauto, N.B., Gazim, Z.C., 2019. Antimicrobial activity of essential oil of *Baccharis dracunculifolia* DC (Asteraceae) aerial parts at flowering period. Front. Plant Sci. 10, 27.
- Colla, G., Roupheal, Y., Cardarelli, M., Svecova, E., Rea, E., Lucini, L., 2013. Effects of saline stress on mineral composition, phenolic acids and flavonoids in leaves of artichoke and cardoon genotypes grown in floating system. J. Sci. Food Agric. 93, 1119–1127.
- El-Amier, Y.A., Abd El-Gawad, A.M., 2017. Plant communities along the international coastal highway of Nile delta. Egypt. J. Sci. Agric. 1, 117–131.
- Elshamy, A.I., Abd-ElGawad, A.M., El-Amier, Y.A., El Gendy, A.E., Al-Rowaily, S.L., 2019. Interspecific variation, antioxidant and allelopathic activity of the essential oil from three *Launaea* species growing naturally in heterogeneous habitats in Egypt. Flavour Fragrance J. 34, 1–13.
- El-Shora, H.M., Abd El-Gawad, A.M., 2015a. Physiological and biochemical responses of *Cucurbita pepo* L. mediated by *Portulaca oleracea* L. allelopathy. Fresenius Environ. Bull. 24, 386–393.
- El-Shora, H.M., Abd El-Gawad, A.M., 2015b. Response of *Cicer arietinum* L. to allelopathic effect of *Portulaca oleracea* L. root extract. Phytol. Annuaire Rei Botanicae 55, 215–232.
- El-Sharkawi, H., Salama, F., Fayed, A., 1982. Vegetation of inland desert wadies in Egypt III. Wadi Gimal and Wadi El-Miyah. Feddes Repertorium 93, 135–145.
- El Banna, M.M., 2004. Nature and human impact on Nile Delta coastal sand dunes, Egypt. J. Environ. Geol. 45, 690–695.
- Hasib, M., 1950. Distribution of Plant Communities in Egypt. Fouad I University Press, Egypt.
- Inderjit, 1996. Plant phenolics in allelopathy. Bot. Rev. 62, 186–202.
- Jackson, M.L., 1962. Soil Chemical Analysis. Constable and Co, LTD, London.
- Li, Z.-H., Wang, Q., Ruan, X., Pan, C.-D., Jiang, D.-A., 2010. Phenolics and plant allelopathy. Molecules 15, 8933–8952.
- Liu, W., Liu, J., Yin, D., Zhao, X., 2015. Influence of ecological factors on the production of active substances in the anti-cancer plant *Sinopodophyllum hexandrum* (Royle) TS Ying. PLoS ONE 10, e0122981.
- Mashaly, I., 1996. On the phytosociology of Wadi Hagul, Red Sea Coast. Egyptian J. Environ. Sci. 12, 31–54.
- Meiners, S.J., Kong, C.-H., Ladwig, L.M., Pisula, N.L., Lang, K.A., 2012. Developing an ecological context for allelopathy. Plant Ecol. 213, 1221–1227.
- Pellissier, L., Moreira, X., Danner, H., Serrano, M., Salamin, N., Dam, N.M., Rasmann, S., 2016. The simultaneous inducibility of phytochemicals related to plant direct and indirect defences against herbivores is stronger at low elevation. J. Ecol. 104, 1116–1125.
- Pierce, W.C., Haenisch, E.L., Sawyer, D.T., 1958. Quantitative Analysis. Wiley Toppen, Tokyo.
- Piper, C.S., 1947. Soil and Plant Analysis. Interscience Publishers Inc, New York.
- Raunkiaer, C., 1937. The Life Forms of Plant and Statistical Plant Geography. Clarendon Press, Oxford.
- Recio, M.C., Giner, R.M., Hermenegildo, M., Peris, J.B., Mañez, S., Rios, J.-L., 1992. Phenolics of *Reichardia* and their taxonomic implications. Biochem. Syst. Ecol. 20, 449–452.
- Rice, E., 1984. Allelopathy. Academic Press, New York, USA.
- Salazar, G.J.T., de Sousa, J.P., Lima, C.N.F., Lemos, I.C.S., da Silva, A.R.P., de Freitas, T.S., Coutinho, H.D.M., da Silva, L.E., do Amaral, W., Deschamps, C.J.I.C., 2018. Phytochemical characterization of the *Baccharis dracunculifolia* DC (Asteraceae) essential oil and antibacterial activity evaluation. Ind. Crops Products 122, 591–595.
- Sampietro, D.A., Catalan, C.A., Vattuone, M.A., 2009. Isolation Identification and Characterization of Allelochemicals/Natural Products. Science Publishers, Enfield, NH, USA.
- Shaltout, K., El-Kady, H., Al-Sodany, Y., 1995. Vegetation analysis of the Mediterranean region of Nile Delta. Vegetatio 116, 73–83.
- Shaltout, K.H., Hosni, H.A., El-Fahar, R., Ahmed, D.A., 2015. Flora and vegetation of the different habitats of the western Mediterranean region of Egypt. Taekholmia 35, 45–76.
- Sharma, P., Prasad, G., Archana, S., 2018. A comprehensive review: Medicinal plants with potential antidiabetic activity. J. Herbal Sci. 4, 29–57.
- Shukla, R.S., Chandel, P.S., 1989. Plant Ecology and Soil Science. S. Chand & Company LTD, Ram Nagar, New Delhi, India.
- Tackholm, V., 1974. Students' Flora of Egypt. Cairo University Press, Cairo, Egypt.
- Takabayashi, J., Dicke, M., 1996. Plant-carnivore mutualism through herbivore-induced carnivore attractants. Trends Plant Sci. 1, 109–113.
- Wardle, D.A., Karban, R., Callaway, R.M., 2011. The ecosystem and evolutionary contexts of allelopathy. Trends Ecol. Evol. 26, 655–662.
- Winkel-Shirley, B., 2001. It takes a garden. How work on diverse plant species has contributed to an understanding of flavonoid metabolism. J. Plant Physiol. 127, 1399–1404.
- Yang, L., Wen, K.-S., Ruan, X., Zhao, Y.-X., Wei, F., Wang, Q., 2018. Response of plant secondary metabolites to environmental factors. Molecules 23, 762.
- Yu, S., Sternberg, M., Kutiel, P., Chen, H., 2007. Seed mass, shape, and persistence in the soil seed bank of Israeli coastal sand dune flora. Evol. Ecol. Res. 9, 325–340.
- Zahrán, M., El-Demerdash, M., Mashaly, I., 1990. Vegetation types of the deltaic Mediterranean coast of Egypt and their environment. J. Veg. Sci. 1, 305–310.
- Zahrán, M.A., Willis, A.J., 2009. The Vegetation of Egypt. Springer Science & Business Media, Netherlands.