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Ecology and allelopathic control of *Brassica tournefortii* in reclaimed areas of the Nile Delta, Egypt

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Abstract: Land reclamation causes weedy species to replace wild plant species. The present study characterizes the community of *Brassica tournefortii* Gouan in reclaimed areas of the Nile Delta of Egypt to determine its ecological amplitude, soil factors controlling its distribution, and its allelopathic control. The plant communities dominated by *B. tournefortii* were investigated in 60 sites. The importance value of each species based on cover and density was determined. Data were treated by multivariate analyses. Soils representing each community were analyzed. The allelopathic effects of *Conyza bonariensis* (L.) Cronquist, *Trianthema portulacastrum* L., and *Pulicaria undulata* (L.) C.A.Mey. and their mixtures on germination and seedling growth of *B. tournefortii* were investigated. Total phenolics, tannins, alkaloids, flavonoids, and saponins were estimated. The applications of TWINSPAN classification based on 140 species led to recognition of 4 vegetation clusters; 3 were dominated by *B. tournefortii* and 1 was codominated by *Malva parviflora* L. and *Senecio glaucus* L. Canonical correspondence analysis demonstrated that $CaCO_3$, soil texture, and water holding capacity contributed significantly to the distribution of species. The water extracts of *T. portulacastrum*, *C. bonariensis*, and *P. undulata* could be applied at a concentration of 10 g/L for the management of this weed.

Key words: Allelopathy, weed control, ecology, *Brassica tournefortii*, Nile Delta, reclaimed areas

1. Introduction

The increase in human population of Egypt necessitates the expansion of the cultivated lands by reclamation of desert areas (Hegazy et al., 2004). This human interference causes weedy species to replace wild plant species in the reclaimed areas (Baessler and Klotz, 2006). *Brassica tournefortii* Gouan (Sahara mustard) is a winter annual to spring ephemeral, herbaceous, erect, usually branched from the base, and widely branched above; up to nearly 1 m tall or more, its seeds are globose, finely reticulate, brown to brown-purple, and approximately 1 mm in diameter. It produces between 750 and 9000 seeds per plant, which stay viable for several years in soil. It is characterized by high competition and a strategy of early and quick growth (Minnich and Sanders, 2000). It is also drought-tolerant (West and Nabhan, 2002) and it possesses allelopathic activity (Patterson, 1983). It is native to arid deserts of North Africa and the Middle East (Minnich and Sanders, 2000), as well as to the southern and eastern part of the Mediterranean rim, where it thrives on marine beaches and sand dunes (Thanos et al., 1991). It is considered an aggressively invasive weed in many countries like Australia (Chauhan et al., 2006) and the United States (Abella et al., 2009).

Brassica tournefortii has been managed by prevention (Trader et al., 2006) and by physical and chemical control (Rice, 1992), but by little to no biological control (Minnich and Sanders, 2000). Modern agriculture is productivity-oriented and relies primarily on synthetic inputs to tackle weeds and other pest problems (Sadeghi et al., 2010). The use of intensive herbicides to control weeds over the last few decades is presenting serious ecological and environmental threats to the planet and its inhabitants, which diverts the attention of researchers to discover and establish alternative weed management strategies (Jamil et al., 2009). It has been shown that allelopathy offers great potential to increase agricultural production, decrease the harmful effects of modern agricultural practices, and maintain soil productivity and a pollution-free environment for future generations. Allelopathic interactions are mediated by secondary metabolites, released through leaching, root exudation, volatilization, and residue decomposition into the environment, and they affect growth and development in natural environments and agroecosystems (Cheema et al., 2013).

The goal of the present study was to characterize the community of *B. tournefortii* in reclaimed areas of the Nile Delta in Egypt, as well as to determine the soil factors controlling its distribution. In addition, the present investigation aimed to evaluate the allelopathic effects of some associated weeds on it as biological, ecofriendly control method.

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2. Materials and methods

2.1. Study area

The Nile Delta starts 20 km north of Cairo and it is embraced by the Rosetta and Damietta branches; the area of the Nile Delta is about 22,000 km^2, while that of the Nile Valley (the cultivated lands) is about 12,000 km^2. Thus, the Nile Delta accounts for about 63% of the fertile Egyptian lands (Abu Al-Izz, 1971). The sampled stands are distributed in many localities (east, west, and north of the Nile Delta), representing 6 governorates of the newly reclaimed Nile Delta region of Egypt, namely Damietta, El-Dakahlia, Kafr El-Sheikh, El-Behira, El-Ismailia, and El-Sharkia (Figure 1). The climatic conditions of the Nile Delta are similar to those of the northern part of Egypt. Summer is warm with an average temperature range of 20–30 °C, while winter is mild with an average temperature range of 10–20 °C. Most of the rain occurs during the winter, ranging between 100 mm/year in the north and 23 mm/year in the south. Accordingly, the studied provinces as part of the Nile Delta belong to the arid and/or semiarid climatic belts of the northern coastal region of Egypt (Zahran and Willis, 2009).

2.2. Estimation of species abundance

After regular visits to the different sites of the study area during 2010–2012, 60 stands (5 × 10 m each) were selected according to the variation in the structure of the vegetation, floristic composition, and/or change in the habitat of the study area. The density was measured according to Shukla and Chandel (1989), while the plant cover of each species was estimated in each selected stand. The plant cover was measured using the line-intercept method (Canfield, 1941). Relative values of density and cover were calculated for each species and summed to give an estimate of its importance value in each stand, based out of 200. Nomenclature of the species followed Tackholm (1974) and Boulos (1999–2005).

2.3. Soil analysis

Soil samples were collected from each stand (triplicates), representing a profile at a depth of 0–50 cm. Soil texture, water holding capacity, soil porosity, organic carbon, and sulfate were determined according to Piper (1947). Calcium carbonate was determined by titration against 1 N NaOH and expressed as percentage (Jackson, 1962). A soil solution (1:5) was prepared for each soil sample. The electrical conductivity (EC), pH, and chloride were determined according to Jackson (1962). Carbonate and bicarbonate were determined by titration method using 0.1 N HCl (Pierce et al., 1958). The extractable cations Na^+ and K^+ were determined using a flame photometer (Model PHF 80 Biologie Spectrophotometer), while Ca^{++} and Mg^{++} were estimated according to Allen et al. (1974) using an atomic absorption spectrometer (PerkinElmer Model 2380). The sodium adsorption ratio (SAR) and potassium adsorption ratio (PAR) were calculated to express the combined effects of different ions in the soil.

2.4. Multivariate analyses and statistical testing

Two-way indicator species analysis (TWINSPAN) was applied according to Hill and Smilauer (2005) and canonical correspondence analysis (CCA) according to Ter Braak (1988). Data of soil analyses were subjected to analysis of variance (ANOVA) and the mean values were separated based on the least significant difference (LSD) at the 0.05 probability level using the COSTAT 6.3 program.

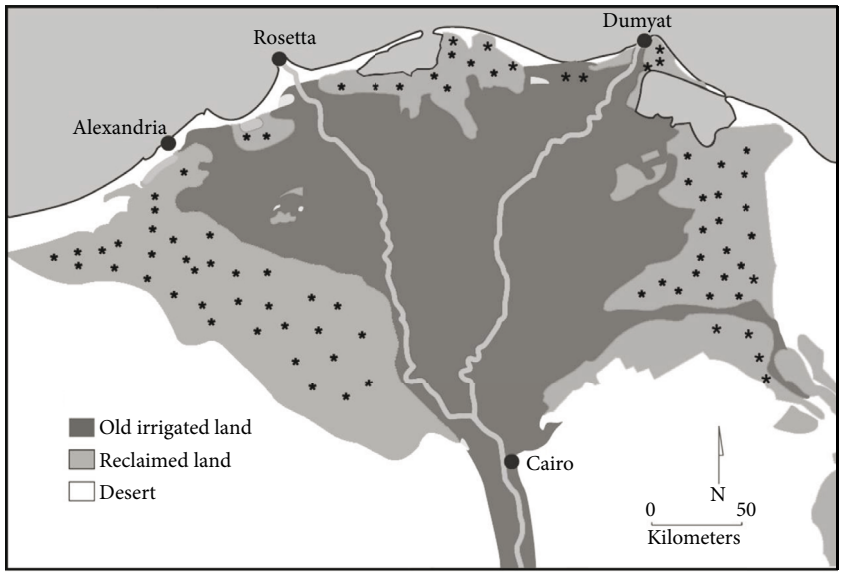

Figure 1. Map of the Nile Delta, Egypt, showing the location of the sampling sites as indicated by stars. Source: Danish Institute for International Studies.

2.5. Allelopathic studies

2.5.1. Weed seed source

The seeds of *Brassica tournefortii* were collected from different localities in the studied area. Seeds were sterilized with 0.3% calcium hypochlorite, rinsed in distilled water, and dried on filter paper in the laboratory at room temperature for 7 days (Uremis et al., 2005).

2.5.2. Collection and preparation of plant material

Conyza bonariensis (L.) Cronquist, *Trianthema portulacastrum* L., and *Pulicaria undulata* (L.) C.A.Mey. were harvested at a vegetative stage. The plant tissues were clipped by hand 1 cm above the soil level, washed with distilled water, and left to dry at room temperature (25 °C) in a shaded place for several days until complete dryness (7 days). The dried samples were ground to pass a 1-mm screen, packed in a polyethylene bag, and stored in a refrigerator at 4 °C.

2.5.3. Preparation of water extracts

For bioassay tests, extracts were prepared from the plants *Conyza bonariensis*, *Trianthema portulacastrum*, and *Pulicaria undulata* as various concentrations (2%, 4%, 6%, 8%, and 10% w/v). Mixtures of *C. bonariensis* + *T. portulacastrum*, *C. bonariensis* + *P. undulata*, and *T. portulacastrum* + *P. undulata* were prepared (1:1 v/v). The solutions were filtered through double layers of muslin cloth followed by Whatman No. 1 filter paper. The pH of the mixtures was adjusted to 7 with 1 M HCl, and then mixtures were stored in a refrigerator at 4 °C until further use (Rice, 1972).

2.5.4. Germination bioassays

Two layers of Whatman No. 1 filter papers were placed in 90-mm-diameter glass petri dishes. Twenty-five seeds were placed in each petri dish, followed by 10 mL of plant extract. A control sample was assigned with distilled water and left at room temperature (25 °C). Starting from the first day after the experiment began, germinated seeds were counted and removed daily. A seed with a radical of 0.5 cm was considered to be germinated. The experimental design was carried out as a randomized complete block (RCB) with 3 replications. The experiment was repeated twice and the percentage of germination was calculated. The data were subjected to ANOVA and the mean values were separated on the basis of LSD at the 0.05 probability level using the COSTAT 6.3 program.

2.5.5. Growth bioassays

The seeds of *Brassica tournefortii* were germinated on filter paper in the dark at room temperature (25 °C) for 2 days. Fifteen germinated seeds were transferred to petri dishes, which were filled with 25 g of sterilized quartz sand, and 10 mL of tested extract (2%, 4%, 6%, 8%, and 10% w/v) was added. In addition, a control sample was added to the experiment without any treatment. The experiment was designed as a RCB with 3 replications and it was repeated twice. Shoot and root lengths of seedlings were measured 15 days after treatment (DAT). Data were subjected to ANOVA and the mean values were separated based on LSD at the 0.05 probability level using the COSTAT 6.3 program.

2.6. Phytochemical analysis

Conyza bonariensis, *Trianthema portulacastrum*, and *Pulicaria undulata* were collected and prepared as previously mentioned. The amount of phenol was determined spectrophotometrically (Sadasivam and Manickam, 2008), while the amount of tannins was determined using the method of Van Burden and Robinson (1969). Saponin content was estimated according to Obdoni and Ochuko (2001). Flavonoid content was determination according to Bohm and Kocipai-Abyazan, (1994), while alkaloid was determined according to Harborne (1973).

3. Results

3.1. Vegetation analysis

3.1.1. Classification of stands

The application of TWINSPAN classification based on the important value of 140 plant species recorded in 60 sampled stands representing different habitats (sand dune, sand flats, salt marsh, orchard, fallow land, cultivated land, and roadside) led to the recognition of 4 vegetation clusters (Figure 2). The vegetation clusters are presented in Table 1. Cluster A comprises 14 stands (sandy and fallow land habitats) dominated by *Brassica tournefortii*, which has the highest importance value of this group

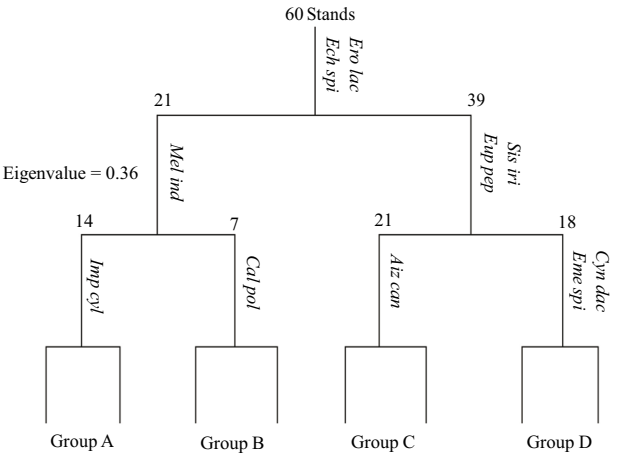

Figure 2. TWINSPAN dendrogram of 60 stands based on the importance value of the species. Indicator species names are abbreviated to the first 3 letters of both genus and species. *Aiz acan*: *Aizoon canariense*, *Cal pol*: *Calligonum polygonoides*, *Cyn dac*: *Cynodon dactylon*, *Ech spi*: *Echinops spinosus*, *Eme spi*: *Emex spinosa*, *Ero lac*: *Erodium laciniatum*, *Eup pep*: *Euphorbia peplis*, *Imp cyl*: *Imperata cylindrica*, *Mel ind*: *Melilotus indicus*, *Sis iri*: *Sisymbrium irio*.

Table 1. Characteristics of the different vegetation clusters resulting from TWINSPAN classification of the study area.

Cluster	No. of stands	Total species	Habitats	Dominant species	Other important species
A	14	50	SF - FL	*Brassica tournefortii* (24.38 [0.57])*	*Erodium laciniatum* (17.9 [0.67]) *Pancratium maritimum* (10.39 [1.23]) *Imperata cylindrica* (9.63 [1.09]) *Mesembryanthemum crystallinum* (9.37 [1.55]) *Daucus litoralis* (9.09 [1.99]) *Echinops spinosus* (8.31 [1.14]) *Rumex pictus* (7.65 [1.27])
B	7	51	RS	*Brassica tournefortii* (19.02 [0.72])	*Senecio glaucus* (13.79 [0.65]) *Hordeum murinum* subsp. *leporinum* (12.17 [0.72]) *Mesembryanthemum crystallinum* L. (11.52 [1.48]) *Anchusa humilis* (8.73 [0.63]) *Launaea mucronata* (8.19 [1.25]) *Sporobolus pungens* (8.05 [2.65) *Melilotus indicus* (7.85 [0.89]) *Rumex pictus* (7.82 [0.89]).
C	21	91	Or	*Senecio glaucus* (13.25 [1.21]) ——————— *Malva parviflora* (13.27 [0.91])	*Chenopodium murale* (12.57 [0.98]) *Brassica tournefortii* (11.43 [1.03]) *Mesembryanthemum crystallinum* (9.51 [1.31]) *Cynodon dactylon* (8.71 [2.21]) *Hordeum murinum* subsp. *leporinum* (7.44 [2.21]) *Melilotus indicus* (6.84 [1.60]) *Sonchus oleraceus* (6.79 [1.23])
D	18	68	NR - Or	*Brassica tournefortii* (23.96 [0.81])	*Cynodon dactylon* (15.85 [1.12]) *Euphorbia peplus* (13.13 [1.50]) *Chenopodium murale* (11.99 [1.59]) *Senecio glaucus* (9.45 [1.94]) *Sisymbrium irio* (9.,26 [1.10]) *Emex spinosa* (7.65 [1.11])

*: (Importance value [coefficient of variation]), SF: sand flat, FL: fallow land, RS: roadside, Or: orchard, NR: newly reclaimed areas.

(IV = 24.38). The other important and indicator species that attain relatively high importance values in this group are *Erodium laciniatum* (Cav.) Willd. (IV = 17.90), *Pancratium maritimum* L. (IV = 10.39), and *Imperata cylindrica* (L.) Raeusch (IV = 9.63). Cluster B includes 7 stands (roadside habitat) dominated by *B. tournefortii* (IV = 19.02). The other important and indicator species that attain relatively high importance values in this group are *Senecio glaucus* L. (IV = 13.79), *Hordeum murinum* L. (IV = 12.17), and *Mesembryanthemum crystallinum* L. (IV = 11.52). Cluster C comprises 21 stands (mainly orchard habitat) codominated by *Malva parviflora* (IV = 13.25) and *S. glaucus* (IV = 13.27). *Chenopodium murale* L. (IV = 12.57) is the subdominant species of this cluster. In this group, the other important and indicator species are *B. tournefortii* (IV = 11.43) and *M. crystallinum* (IV = 9.51). Cluster D comprises 18 stands (newly reclaimed areas in combination with orchard habitat) and is dominated by *B. tournefortii* (IV = 23.96). The other important species are *Cynodon dactylon* (L.) Pers. (IV = 15.85), *Euphorbia peplis* L. (IV = 13.13), and *C. murale* (IV = 11.99).

3.1.2. Vegetation–soil relationships

The soil variables of the 4 groups of stands derived from TWINSPAN classification indicate considerable variation in the edaphic factors among the stands of the different groups (Table 2). The water holding capacity, pH, calcium carbonate, carbonate, sodium, and SAR show significant variations ($P \leq 0.05$) among the 4 groups. However, soil texture, EC, chloride, sulfate, bicarbonate, potassium, calcium, magnesium, and PAR do not show significant variations. Group A attained the highest values of silt (7.66%), clay (1.68%), pH (8.23), chloride (0.24%), sulfate (0.25%), carbonate (0.01%), bicarbonate (0.10%), sodium (159.39 mg/100 g dry soil), calcium (27.87 mg/100 g

Table 2. Mean value and standard error of the different soil variables at depths of 0–50 cm in the sampled stands representing the different vegetation clusters obtained by TWINSPAN classification.

Parameters		Vegetation clusters				F-value	$LSD_{0.05}$
		A	B	C	D		
Sand (%)		$93.31^{a} \pm 1.66$	$93.00^{a} \pm 2.40$	$94.23^{a} \pm 1.14$	$96.27^{a} \pm 0.94$	1.49^{ns}	4.073
Silt (%)		$7.66^{a} \pm 2.87$	$5.72^{a} \pm 1.87$	$4.63^{a} \pm 0.93$	$3.10^{a} \pm 0.82$	1.32^{ns}	4.876
Clay (%)		$1.68^{a} \pm 0.45$	$1.28^{a} \pm 0.57$	$1.14^{a} \pm 0.26$	$0.63^{a} \pm 0.13$	1.81^{ns}	0.958
Porosity (%)		$32.58^{a} \pm 2.46$	$30.85^{a} \pm 2.70$	$33.65^{a} \pm 2.23$	$31.63^{a} \pm 1.61$	0.12^{ns}	5.703
WHC (%)		$33.16^{a} \pm 3.81$	$33.37^{ab} \pm 0.99$	$29.14^{ab} \pm 1.56$	$25.73^{b} \pm 3.10$	3.71^{*}	7.041
pH		$8.23^{a} \pm 0.20$	$7.87^{ab} \pm 0.05$	$7.79^{ab} \pm 0.10$	$7.59^{b} \pm 0.09$	5.43^{**}	0.352
OC (%)		$1.15^{a} \pm 0.67$	$0.72^{a} \pm 0.19$	$0.88^{a} \pm 0.19$	$1.78^{a} \pm 0.72$	1.46^{ns}	1.614
$CaCO_3$ (%)		$8.75^{b} \pm 2.84$	$9.94^{b} \pm 3.05$	$8.63^{b} \pm 2.13$	$15.27^{a} \pm 1.61$	3.48^{*}	6.116
EC (µmhos/cm)		$181.39^{a} \pm 102.80$	$157.60^{a} \pm 66.44$	$466.53^{a} \pm 206.37$	$394.44^{a} \pm 218.04$	1.18^{ns}	530.796
Cl^- (%)		$0.24^{a} \pm 0.14$	$0.01^{a} \pm 0.00$	$0.18^{a} \pm 0.12$	$0.04^{a} \pm 0.02$	1.68^{ns}	0.279
SO_4^{--} (%)		$0.25^{a} \pm 0.06$	$0.23^{a} \pm 0.08$	$0.22^{a} \pm 0.06$	$0.14^{a} \pm 0.02$	0.98^{ns}	0.147
CO_3^{--} (%)		$0.01^{a} \pm 0.00$	$0.00^{b} \pm 0.00$	$0.00^{b} \pm 0.00$	$0.00^{b} \pm 0.00$	5.78^{*}	0.005
HCO_3^- (%)		$0.10^{a} \pm 0.02$	$0.06^{a} \pm 0.01$	$0.07^{a} \pm 0.01$	$0.04^{a} \pm 0.01$	2.69^{ns}	0.035
Na^+	(mg/100g dry soil)	$159.39^{a} \pm 58.80$	$19.02^{b} \pm 6.62$	$47.48^{b} \pm 29.95$	$23.67^{b} \pm 6.39$	3.65^{*}	98.175
K^+		$24.06^{a} \pm 3.16$	$16.60^{a} \pm 7.84$	$34.34^{a} \pm 20.93$	$23.90^{a} \pm 1.95$	0.896^{ns}	37.133
Ca^{++}		$27.87^{a} \pm 12.05$	$13.47^{a} \pm 8.52$	$20.64^{a} \pm 11.94$	$12.30^{a} \pm 3.07$	0.75^{ns}	25.215
Mg^{++}		$18.32^{a} \pm 11.95$	$29.55^{a} \pm 25.50$	$16.40^{a} \pm 7.01$	$7.97^{a} \pm 2.72$	0.72^{ns}	32.346
SAR		$54.61^{a} \pm 19.26$	$6.63^{b} \pm 2.22$	$11.53^{b} \pm 6.56$	$8.89^{b} \pm 2.03$	4.60^{**}	29.907
PAR		$11.30^{a} \pm 2.55$	$6.26^{a} \pm 3.35$	$8.26^{a} \pm 2.95$	$11.45^{a} \pm 1.86$	1.23^{ns}	7.539

WHC = Water holding capacity, OC = organic carbon, SAR = sodium adsorption ratio, EC = electrical conductivity, PAR = potassium adsorption ratio, ns = not significant at $p \leq 0.05$. *: Values are significant at $P \leq 0.05$, **: values are significant at $P < 0.01$. Different superscript letters indicate a significant difference at $P \leq 0.05$.

dry soil), and SAR (54.61). Group B attained the highest values of water holding capacity (33.37%) and magnesium (29.55 mg/100 g dry soil), while group C expressed the highest values of porosity (33.65%), EC (466.53 µmhos/cm), and potassium (34.34 mg/100 g dry soil). Group D attained the highest values of sand (96.27%), calcium carbonate (15.27%), and PAR (11.45). The correlation between vegetation and soil characteristics is indicated on the ordination diagram produced by CCA of the biplot of species, as well as the environmental variables, in Figure 3. Soil texture (sand, silt, and clay), pH, SAR, carbonate, bicarbonate, and sodium are the most controlling variables. Chloride, calcium, water holding capacity, and calcium carbonate attained moderate correlations. The other variables (EC, PAR, potassium, sulfate, magnesium, organic carbon, and porosity) showed low correlation.

Brassica tournefortii (the dominant species of groups A, B, and D, as well as an important species in group C) showed high correlation with sand, calcium carbonate, water holding capacity, and magnesium (Figure 3). *Malva parviflora* and *Senecio glaucus* (codominant species of group C) mostly correlated with organic carbon, calcium carbonate, and bicarbonate. *Chenopodium murale* (a subdominant species of cluster C and important species of cluster D) and *Erodium laciniatum* (an important species of cluster A) showed a high correlation with sand, carbonate, PAR, and pH. *Cynodon dactylon* (an important species of cluster D) correlated with calcium, EC, and PAR.

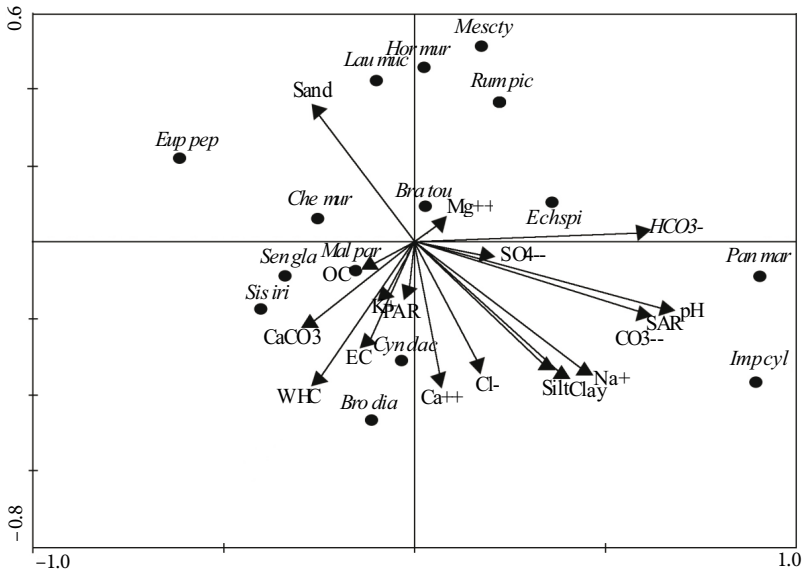

Figure 3. CCA species–soil variable biplot in different habitat types of the study area. EC: electrical conductivity, WHC: water holding capacity, OC: organic carbon, SAR: sodium adsorption ratio, PAR: potassium adsorption ratio, *Bra tou*: *Brassica tournefortii*, *Bro dia*: *Bromus diandrus*, *Che mur*: *Chenopodium murale*, *Cyn dac*: *Cynodon dactylon*, *Ech spi*: *Echinops spinosus*, *Eup pep*: *Euphorbia peplis*, *Hor mur*: *Hordeum murinum*, *Imp cyl*: *Imperata cylindrica*, *Lau muc*: *Launaea mucronata*, *Mal par*: *Malva parviflora*, *Mes cry*: *Mesembryanthemum crystalinum*, *Pan mar*: *Pancratium maritimum*, *Rum pic*: *Rumex pictus*, *Sen gla*: *Senecio glaucus*, *Sis iri*: *Sisymbrium irio*.

3.2. Allelopathic studies

3.2.1. Effect of different extracts on *Brassica tournefortii* germination

The allelopathic activities of water-soluble extracts from studied weeds on seed germination of *B. tournefortii* are shown in Table 3. After 5 days of treatment, all extracts significantly reduced the germination of *Brassica tournefortii* at high concentrations (4, 6, 8, and 10 g/L), while at a low concentration (2 g/L), *Trianthema portulacastrum* and *Pulicaria undulata* did not show significant inhibition ($P \leq 0.05$). The extract of *T. portulacastrum* was the most effective extract as it completely inhibited germination at a concentration of 10 g/L. The combination of extracts from *P. undulata* and *Conyza bonariensis* significantly increased the allelopathic activity of *C. bonariensis* on germination of *B. tournefortii* seeds, while the other mixtures decreased its allelopathic potential (Table 3).

3.2.2. Effect of different extracts on root growth of *Brassica tournefortii* seedlings

The allelopathic activities of water-soluble extracts from investigated weeds on root growth of *Brassica tournefortii* seedlings are shown in Table 4. Mixed extracts of *Pulicaria undulata*, of *Conyza bonariensis* + *P. undulata*, and of *Trianthema portulacastrum* + *P. undulata* showed significant stimulatory effects ($P \leq 0.05$) at low concentrations (2 and 4 g/L) on root growth. However, the higher concentrations (6, 8, and 10 g/L) expressed significant inhibitory effects. The aqueous extracts of *C. bonariensis*, *T. portulacastrum*, *P. undulata*, and *C. bonariensis* + *T. portulacastrum* showed significant inhibition at both low and high concentrations (Table 4). The extract of *T. portulacastrum* was the most effective as it inhibited root growth by about 93.17% at 8 g/L and 95.45% at 10 g/L. *Pulicaria undulata* extract inhibited root growth by about 75.72% at 8 g/L and 83.31% at 10 g/L. Generally, the combination of extracts did not enhance the allelopathic activity on the seedling root growth. The mixed extracts of *C. bonariensis* + *T. portulacastrum* and *T. portulacastrum* + *P. undulata* significantly decreased the allelopathic activity of *T. portulacastrum* on the seedling root growth of *B. tournefortii* ($P \leq 0.05$). On the other hand, mixed extracts of *C. bonariensis* + *P. undulata* significantly decreased the allelopathic potential of both *P. undulata* and *C. bonariensis*.

3.2.3. Effect of different extracts on shoot growth of *Brassica tournefortii* seedlings

The allelopathic activities of water-soluble extracts from investigated weeds on the shoot growth of *Brassica tournefortii* seedlings are shown in Table 5. The mixed extracts of *Conyza bonariensis* + *Trianthema portulacastrum* showed significant stimulatory effects ($P \leq 0.05$) at 2 g/L,

Table 3. The effect of different extracts on the germination percentage of *Brassica tournefortii* at 5 DAT.

Treatment	Concentration of the extract (g/L)*				
	2	4	6	8	10
Control	$88.33^{a} \pm 0.47$	$88.33^{a} \pm 0.47$	$88.33^{a} \pm 0.47$	$88.33^{a} \pm 0.47$	$88.33^{a} \pm 0.47$
Con	$40.00^{d} \pm 0.58$	$30.00^{de} \pm 0.00$	$26.67^{d} \pm 0.33$	$16.67^{d} \pm 0.33$	$3.33^{d} \pm 0.33$
Tri	$86.67^{ab} \pm 0.88$	$63.33^{b} \pm 0.67$	$43.33^{c} \pm 0.33$	$6.67^{e} \pm 0.67$	$0.00^{d} \pm 0.00$
Pul	$73.33^{abc} \pm 0.33$	$36.67^{cd} \pm 0.33$	$26.67^{d} \pm 0.88$	$10.00^{de} \pm 0.00$	$3.33^{d} \pm 0.33$
Con + Tri	$70.00^{bc} \pm 0.00$	$53.33^{bc} \pm 1.20$	$30.00^{cd} \pm 0.58$	$26.67^{c} \pm 0.33$	$23.33^{c} \pm 0.67$
Con + Pul	$26.67^{d} \pm 0.33$	$13.33^{e} \pm 0.33$	$10.00^{e} \pm 0.00$	$6.67^{e} \pm 0.33$	$3.33^{d} \pm 0.33$
Tri + Pul	$66.67^{c} \pm 0.88$	$70.00^{ab} \pm 1.00$	$60.00^{b} \pm 0.58$	$50.00^{b} \pm 0.58$	$43.33^{b} \pm 0.33$
$LSD_{0.05}$	17.13	21.47	15.18	9.95	9.67

Con = *Conyza bonariensis*, Tri = *Trianthema portulacastrum*, Pul = *Pulicaria undulata*, *: mean value ± standard error. Different superscript letters indicate values significantly lower than the respective control ($P \leq 0.05$).

Table 4. The effect of different extracts on the seedling root length (mm) of *Brassica tournefortii* at 15 DAT.

Treatment	Concentration of the extract (g/L)*				
	2	4	6	8	10
Control	$43.64^{c} \pm 1.20$	$43.64^{ab} \pm 1.20$	$43.64^{a} \pm 1.20$	$43.64^{a} \pm 1.20$	$43.64^{a} \pm 1.20$
Con	$39.33^{d} \pm 0.67$	$22.67^{d} \pm 0.67$	$19.00^{d} \pm 0.58$	$16.00^{d} \pm 0.58$	$14.33^{c} \pm 0.67$
Tri	$28.33^{e} \pm 0.88$	$7.00^{e} \pm 0.58$	$4.67^{e} \pm 0.33$	$3.00^{f} \pm 0.00$	$2.00^{e} \pm 0.00$
Pul	$61.00^{a} \pm 0.58$	$44.67^{a} \pm 1.45$	$37.67^{b} \pm 1.33$	$10.67^{e} \pm 0.33$	$7.33^{d} \pm 0.33$
Con + Tri	$37.33^{d} \pm 1.45$	$36.00^{c} \pm 2.31$	$19.33^{d} \pm 0.67$	$16.33^{d} \pm 0.88$	$15.67^{c} \pm 0.33$
Con + Pul	$51.67^{b} \pm 0.88$	$41.00^{ab} \pm 0.58$	$39.00^{b} \pm 0.58$	$30.00^{b} \pm 0.58$	$24.33^{b} \pm 1.20$
Tri + Pul	$61.00^{a} \pm 2.65$	$40.67^{b} \pm 1.33$	$28.67^{c} \pm 0.88$	$19.33^{c} \pm 0.67$	$16.00^{c} \pm 0.58$
$LSD_{0.05}$	3.91	3.92	2.49	1.83	1.96

Con = *Conyza bonariensis*, Tri = *Trianthema portulacastrum*, Pul = *Pulicaria undulata*, *: mean value ± standard error. Different superscripted letters indicate values significantly lower than the respective control ($P \leq 0.05$).

while the mixture of *T. portulacastrum* + *Pulicaria undulata* expressed significant stimulatory effects ($P \leq 0.05$) at 4 g/L. At higher concentrations (6, 8, and 10 g/L), all extracts induced significant inhibitory effects (Table 5). The extract of *T. portulacastrum* was the most effective extract as it inhibited shoot growth of seedlings by about 90.15% at 8 g/L and 93.18% at 10 g/L. *Pulicaria undulata* extract was second as it inhibited seedling root growth by about 65.15% at 8 g/L and 75% at 10 g/L. Generally, the combination of extracts did not enhance the allelopathic activity on the seedling shoot growth. The extracts of all mixtures significantly decreased their allelopathic effects on the seedling shoot growth of *B. tournefortii* ($P \leq 0.05$).

3.3. Phytochemical analysis

The phytochemical analyses of *Conyza bonariensis*, *Trianthema portulacastrum*, and *Pulicaria undulata* are presented in Table (6). *T. portulacastrum* contained high contents of saponins (64.1 mg/g dry weight), phenolics (41.3 mg/g dry weight), and alkaloids (11.1 mg/g dry weight). *Conyza bonariensis* attained a high content of saponins (77.6 mg/g dry weight). On the other hand, *P. undulata* contained relatively low contents of phenolics (10.1 mg/g dry weight), alkaloids (5.3 mg/g dry weight), and flavonoids (6.4 mg/g dry weight) and did not contain tannins or saponins.

Table 5. The effect of different extracts on the seedling shoot length (mm) of *Brassica tournefortii* at 15 DAT.

Treatment	Concentration of the extract (g/L)*				
	2	4	6	8	10
Control	$44.00^{bc} \pm 1.28$	$44.00^{b} \pm 1.28$	$44.00^{b} \pm 1.28$	$44.00^{a} \pm 1.28$	$44.00^{a} \pm 1.28$
Con	$38.00^{c} \pm 3.06$	$31.67^{d} \pm 0.33$	$29.67^{f} \pm 0.33$	$25.67^{c} \pm 0.33$	$12.00^{c} \pm 0.58$
Tri	$48.33^{ab} \pm 1.86$	$15.33^{e} \pm 0.33$	$8.33^{g} \pm 0.33$	$4.33^{e} \pm 0.33$	$3.00^{d} \pm 1.00$
Pul	$48.00^{ab} \pm 3.06$	$40.33^{c} \pm 0.88$	$28.67^{a} \pm 1.33$	$15.33^{d} \pm 1.76$	$11.00^{c} \pm 0.58$
Con + Tri	$52.33^{a} \pm 0.33$	$43.67^{b} \pm 1.20$	$40.00^{c} \pm 0.58$	$33.00^{b} \pm 1.53$	$29.67^{b} \pm 1.20$
Con + Pul	$45.67^{ab} \pm 3.18$	$40.67^{c} \pm 0.67$	$37.33^{d} \pm 1.45$	$31.33^{b} \pm 1.86$	$30.00^{b} \pm 1.15$
Tri + Pul	$48.33^{ab} \pm 1.20$	$48.00^{a} \pm 1.00$	$33.67^{e} \pm 1.20$	$25.33^{c} \pm 1.45$	$12.67^{c} \pm 0.33$
$LSD_{0.05}$	7.22	2.38	2.60	4.01	2.48

Con = *Conyza bonariensis*, Tri = *Trianthema portulacastrum*, Pul = *Pulicaria undulata*, *: mean value ± standard error. Different superscripted letters indicate values significantly lower than the respective control ($P \leq 0.05$).

Table 6. Bioactive chemical constituents in the selected plant species.

Plant species	Phenolics	Tannins	Alkaloids	Flavonoids	Saponins
	Concentration (mg/g dry weight)				
Conyza bonariensis	11.50 ± 0.30	11.57 ± 2.41	4.30 ± 0.12	3.51 ± 0.07	77.60 ± 0.25
Pulicaria undulata	10.06 ± 0.01	0.00	5.30 ± 0.14	6.39 ± 0.13	0.00
Trianthema portulacastrum	41.32 ± 0.98	0.00	11.06 ± 0.30	0.52 ± 0.01	64.10 ± 0.20

4. Discussion

Weeds compete with crop plants for different growth factors and add significantly to the cost of farm operations (Qasem, 2003). Optimum crop production depends on successful weed control. The multivariate analysis of the sampled stands representing the different habitats led to the recognition of 2 main communities: the largest was the *Brassica tournefortii* community, which was characterized by sandy, roadside, cultivated land, and fallow land habitats. The other smaller one was the *Malva parviflora* and *Senecio glaucus* community, which was characterized by orchard and cultivated land habitats. This reflects that *B. tournefortii* dominates in sandy and roadside habitats (Brooks et al., 2006). The *Brassica tournefortii* community was associated with many important weeds, such as *Erodium laciniatum*, *Pancratium maritimum*, *Imperata cylindrica*, *Mesembryanthemum crystallinum*, *Senecio glaucus*, and *Cynodon dactylon*. Success of the plant community and individual native species was correlated with *B. tournefortii* dominance. This revealed high ecological amplitude, high competition, quick reproduction, and a strategy of early and quick growth (Minnich and Sanders, 2000); it is also drought-tolerant (West and Nabhan, 2002) and possesses allelopathic activity (Patterson, 1983).

Plant populations may be caused directly or through differences in growth rates due to age differences, genetic variation, heterogeneity of resources, herbivores, and competition (Zegeye et al., 2006). The community of *Brassica tournefortii* expressed high significant correlation with sand, calcium carbonate, water holding capacity, and magnesium. These results are in agreement with other studies (Mashaly et al. 2009; Salama et al., 2013). On the other hand, the *Malva parviflora* and *Senecio glaucus* community was correlated with organic carbon, calcium carbonate, and bicarbonate. This was reported in other studies (Hegazy et al., 2004, 2008; Abd El-Ghani et al., 2013). In the present study, *Brassica tournefortii* survived in sandy soil, and it appears to be highly susceptible to salinity; this is in harmony with the findings of other investigators (Thanos et al., 1991; Minnich and Sanders, 2000).

All extracts of the tested weeds significantly reduced the germination of *Brassica tournefortii* at high concentrations (4, 6, 8, and 10 g/L), while at 2 g/L,

Trianthema portulacastrum and *Pulicaria undulata* did not show significant inhibition ($P \leq 0.05$). The degree of inhibition was dependent on the concentration of extracts (Kayode and Ayeni, 2009).

The aqueous extracts of *Pulicaria undulata*, *Conyza bonariensis* + *P. undulata*, and *Trianthema portulacastrum* + *P. undulata* showed significant stimulatory effects ($P \leq 0.05$) on the seedling root growth of *B. tournefortii* at low concentrations (2 and 4 g/L), while *C. bonariensis* + *T. portulacastrum* and *T. portulacastrum* + *P. undulata* extracts stimulated the shoot growth. These results could be attributed to the presence of many allelochemicals, which enhance the defense system in the plant at low concentrations through stimulation of protein synthesis due to the increasing incorporation of amino acid into protein in seedlings (Liu et al., 2011).

In the present study, the extract of *Trianthema portulacastrum* (10 g/L) was the most potent inhibitor of seed germination of *Brassica tournefortii* (100% inhibition), root growth (95.45% inhibition), and shoot growth (93.18% inhibition). The probable reason for its potent allelopathic activity may be due to the presence of many bioactive secondary compounds in this plant, particularly phenolics (41.32 mg/g dry weight) and saponins (64.10 mg/g dry weight), as shown from the present results. In addition, this could be attributed to the presence of alkaloid trianthemine and ecdysterone (Shastri, 1952); phenolics, dimethoxycinnamic, caffeic, chlorogenic, and benzoic acids; and flavonoid, dimethylflavone, leptorumol (Nawaz et al., 2001), saponin, and punarnavine (Chopra et al., 1956) reported in this weed. These bioactive compounds were responsible for many biological activities of this weed (Nawaz et al., 2001; Hussain et al., 2011). The compounds, including phenolics, alkaloids, saponins, and flavonoids, have been described as allelochemicals (Blum, 2011; Cheema et al., 2013). The allelopathic potential of *T. portulacastrum* was investigated on other weeds such as *Cenchrus biflorus* (Al Sherif and Gharieb, 2011; Mashaly et al., 2013) and *Eichhornia crassipes* (Kannan, 2002).

Pulicaria undulata extract (10 g/L) followed *Trianthema portulacastrum* in its allelopathic potential as it inhibited the seed germination of *Brassica tournefortii* (96.67% inhibition), root growth (83.31% inhibition), and shoot growth (75% inhibition). This result could be attributed to the presence of phenolics (10.06 mg/g dry weight), flavonoids (6.39 mg/g dry weight), and alkaloids (5.30 mg/g dry weight), as it appeared from the present investigation. Furthermore, it could be attributed to the presence of terpenes (carvotanacetone, linalool, nerol, eugenol, menthone, and limonene) (Azizi et al., 2009; El-Kamali et al., 2009), pulicaroside, and undulatoside (Ahmad et al., 2006). The exact mechanism by which seed germination and seedling growth is affected by essential oils of medicinal plants is not completely known. However, it could be due to the inhibition of mitosis in the growing cells (Azizi et al., 2009).

Conyza bonariensis extract inhibited seed germination of *Brassica tournefortii* by about 96.67%, while it inhibited the shoot and root growth by about 72.73% and 67.16%, respectively. This inhibition could possibly be attributed to the presence of high contents of saponins (77.60 mg/g dry weight), tannins (11.57 mg/g dry weight), and phenolics (11.50 mg/g dry weight). Other studies also reported the presence of monoterpenes, acetylenes, sesquiterpenes, diterpenes, limonene, manool (Barbosa et al., 2005), xanthine, glycosides, amyrin, β-sitosterol, daucosterol, syringic acid, benzoic acid, eugenol, luteolin, apigenin, and takakin (Kong et al., 2001). Other *Brassica* species (*Brassica campestris*, *B. oleracea*, and *B. rapa*) were affected by the allelochemicals, and particularly phenolics, released from *Parthenium hysterophorus* (Singh et al., 2005). *Brassica campestris* was also inhibited by allelochemicals of *Cassia tora* (Sarkar et al., 2012).

It is widely accepted that the production of secondary metabolites, particularly phenolic compounds, can play a direct role in self-defense and plant protection to cope with the stress created by external conditions. The inhibitory effect of the selected weeds in the present study could be due to interference of allelochemicals with the key enzymes of metabolism (Batlang and Shushu, 2007) and cell division and elongation (Levizou et al., 2002). The results of the present study are in harmony with those of Mardani et al. (2012), who found that root length is more affected than shoot growth.

The combination of different extracts decreased the allelopathic activity on seed germination and seedling growth of *Brassica tournefortii* and these results agree with those of Hasegawa et al. (1992). Most allelopathic activities are due to the presence of several compounds in the mixture, where the concentration of each compound in a mixture might be significantly less than the concentration of individual compounds needed to cause growth inhibition. This is related to the inactivation of the enzymatic and nonenzymatic systems in the plant by different allelochemicals (Einhellig, 1996).

In conclusion, *Brassica tournefortii* dominated the community in newly reclaimed lands of the Nile Delta of Egypt, where it survived in sandy habitats. It is characterized by high competition with both cultivated plants and associated weeds. Although *Trianthema portulacastrum*, *Pulicaria undulata*, and *Conyza bonariensis* are considered as weeds, the present results suggest that their water extracts could be used at 10 g/L for management of *B. tournefortii* as an alternative control method. The characterization of the causative allelochemical(s) of these weeds needs further investigation.

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