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Allelopathy and Potential Impact of Invasive *Acacia saligna* (Labill.) Wendl. on Plant Diversity in the Nile Delta Coast of Egypt

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ABSTRACT: The introduction of *Acacia saligna* in the north Nile Delta of Egypt is causing harmful impacts on the plant diversity. Thirty stands were established in both invaded and non-invaded areas. The species abundance and diversity were determined. Soil samples were collected and analyzed. The correlation between vegetation and soil variables was investigated. The allelopathic potential of water and methanolic extracts from *A. saligna* leaves and flowers were examined. Approximately 19 and 50 plant species were recorded in the invaded and non-invaded areas, respectively. *Aegilopus bicornis* was the dominant species in the invaded areas, while *Senecio glaucus* dominated the non-invaded areas. The non-invaded areas attained high values of species richness and lower values of evenness than invaded one. Soil analysis revealed that the non-invaded areas attained significantly high content of sulphate, bicarbonate, Na, K and Ca than invaded areas. The methanolic and aqueous extracts of the flowers attained IC_{50} values of 2.89 g/L and 33.89 g/L, respectively on the germination of *Hordeum murinum*. However, IC_{50} values for leaves were 6.08 g/L and 55.04 g/L, respectively. The methanolic extracts of *A. saligna* expressed more effect on seedling length than the aqueous extracts. The aqueous extract showed stimulatory effect at low concentrations. The invasive successes of *A. saligna* seem to be related to its ability to release allelopathic compounds together with its competition for resources such as nutrient, water and sunlight. These findings may also have useful implications for coastal ecosystem management and conservation in Egypt.

Keywords: Invasion; *Acacia saligna*; Allelopathy; Biodiversity; Coastal land

INTRODUCTION

Invasive plant species are able to modify ecosystems (Ortega and Pearson 2005), resulting in losses of biodiversity, altering ecosystem functioning and changing in capacity to provide services (Vilà *et al.* 2011; Strydom *et al.* 2012; Del Vecchio *et al.* 2013; Simberloff *et al.* 2013). Coastal ecosystems are sensitive to the introduction of exotic species than other ecosystems (Stanisci *et al.* 2010; Padrón *et al.* 2011). Coastal plant species are characterized by special tolerance to the environment. As a consequence of this specialization, plant species are not able to establish in different environments, and this makes coastal ecosystems particularly vulnerable to the displacement of native species and to biodiversity loss (Carboni *et al.* 2011).

Acacia saligna (Labill.) Wendl. (syn. *Acacia cyanophylla* Lindl.) is considered to be an invasive species in several countries, while it is recognized as a multipurpose plant, in North Africa and Egypt benefiting communities through soil stabilization, wind break, nitrogen fixation, a source of fuel wood, livestock fodder, making paper pulp and natural timber (Midgley and Turnbull 2003; Ee and Yates 2013). Along the Mediterranean coast in Egypt, about one million *Acacia* seedlings were transplanted for range of rehabilitation. Nowadays, intensive extension packages on utilization of *A. saligna* have been implemented in different locations along the Mediterranean coast (El Shaer 2000). The invasion of *A. saligna* is now well studied (Thompson *et al.* 2011; Birnbaum *et al.* 2012; Del Vecchio *et al.* 2013), while the impact of its invasion is still poorly explored (Del Vecchio *et al.* 2013).

Allelospoly (competition) is the depletion of one or more resources required for growth. *A. saligna* is the most successful *Acacia* due to its tolerance of drought, salinity, ability to grow in poor soil, high biomass and high production of humus (Akkari *et al.*

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2008). In contrast, allelopathy is defined as any process involving secondary metabolites produced by plants, micro-organisms, viruses, and fungi that influence the growth and development of agricultural and biological systems (excluding animals), including positive and negative effects (Rice 1984). *Acacia* species have negative impacts on crop growth by competing for various environmental resources as their litter interferes with the establishment and growth of the adjoining crop plants (Kohli *et al.* 2006) by releasing numerous chemical substances, including phenolic compounds (Seigler 2003). Some of these substances acted as novel allelochemicals to native species enhancing its invasive success as well as reducing the plant diversity (Reigosa *et al.* 1999; Callaway and Ridenour 2004) and influenced germination and seedling growth.

The allelopathic potential of *A. saligna* was studied by few authors among them El Ayeb *et al.* (2013). The poor vegetation under its canopy indicates that it has some allelopathic potential possibly caused by fallen leaves and flowers, plant leachates, or root exudates. Consequently, the release of allelochemicals into the soil inhibited seed germination and the establishment of agricultural crops and natural vegetation (Rice 1984). The allelopathic potential of *A. saligna* is not well studied yet as a mechanism of invasion.

The aim of the present investigation was to assess the potential impact of *A. saligna* on the plant diversity along the Nile Delta coast of Egypt. In addition, explaining the allelopathic potential of *A. saligna* extract on the germination and growth of the native associated species which may be responsible for its invasion.

MATERIALS & METHODS

Field work was carried out from March 2012 to June 2013 along the Nile Delta coastal region, Egypt, representing by three Governorates namely: El-Dakahlia, Damietta and Kafr El-Sheikh (Fig. 1). This area is characterized by coarse and fine sand, silt and clay, deposited by the River Nile (Abu Al-Izz 1971). The climate is arid, with a mean winter temperature above 10 °C and the rainy season during the winter. The annual rainfall ranges from 91.6 to 175.2 mm. Mean relative humidity is lower in summer than in winter (65% and 81%) and evaporation is higher in summer than in winter (7.8 and 2.8 mm Piche / day) (Anonymous 1977).

Vegetation analysis of 30 stands of *A. saligna* trees was carried out in several localities in the northern part of Egypt. The experimental design of comparing plots in invaded and non-invaded areas followed Jäger *et al.* (2007) with minor modification. Briefly, three replicates of one square meter quadrates were visually placed under and near the tree i.e., along the distance from the tree trunk to approximately one meter from the edge of the tree crown (hereafter called inner segment). Additionally, three more quadrates were placed outside the tree crown (called outer segment).

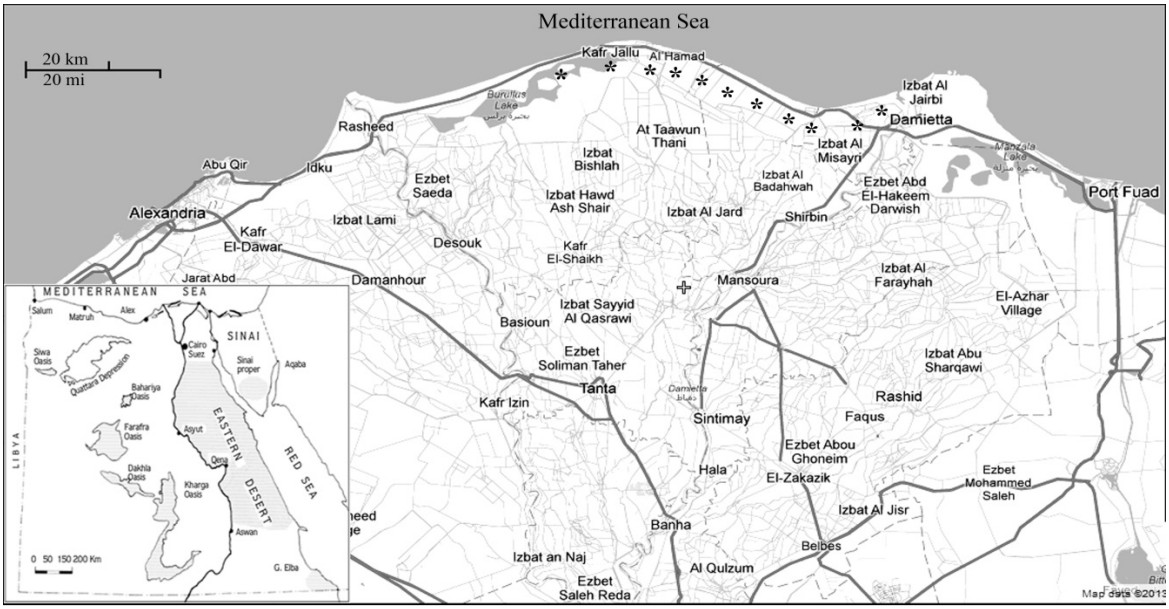

Fig. 1. Map of the studied locations of *Acacia slaigna* along the Deltaic Mediterranean coast of Egypt, the locations showed by asterisks (*)

Average plant density was measured according to Shukla and Chandel (1989). Relative values of density were calculated for each species as importance value. Nomenclature of the species follows Boulos (2009). Voucher specimens of plant material were collected, and deposited at the herbarium of Faculty of Science, Mansoura University, Egypt.

Diversity measures require an estimate of species importance (or evenness) within the community as well as their presence. Shannon-Wiener diversity index (H) was then calculated using the following equation:

$$H = \sum_{i=1}^{s} P_i \ln (P_i) \quad (1)$$

Where Pi = ni / N = proportional abundance of species i in a habitat made up of s species, ni = the number of stands containing species i and N = S ni.

The Shannon-evenness index (E) was applied to quantify the evenness component of diversity and was calculated according to the following equation:

$$E = \frac{H'}{\ln s} \quad (2)$$

While, the Simpson diversity index, D, was then calculated using the following equation:

$$D = \frac{\sum_i [n_i \times (n_i - 1)]}{[N \times (N - 1)]} \quad (3)$$

Where, ni is the total number of a particular species and N is the total number of all species.

Soil samples were collected from each stand (triplicates) representing a profile at a depth of 0-50 cm. Soil texture, water holding capacity (WHC), soil porosity, organic carbon and sulphate were determined according to Piper (1947). Calcium carbonate content was determined by titration against 1N NaOH and expressed as a percentage (Jackson 1962). The soil solution (1:5) was prepared for each soil sample. The electrical conductivity, pH and chloride were determined by the method adopted by Jackson (1962). Carbonate and bicarbonate were determined by titration using 0.1N HCl (Pierce *et al.* 1958). The extractable cations Na^+ and K^+ contents were determined using Flame Photometer (Model PHF 80 Biologie Spectrophotometer), while Ca^{2+} and Mg^{2+} were estimated using atomic absorption spectrometer (A Perkin-Elmer, Model 2380.USA) (Allen *et al.* 1974).

In order to study the allelopathy, seeds of *Hordeum murinum* L. were collected from the study area, 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). *H. murinum* was selected according to the vegetation analysis, where it attained high abundance in the non-invaded locations and low abundance in the invaded one.

The leaves and flowers of *A. saligna* were harvested at a flowering stage. The plant tissues were washed with distilled water and left to dry at room temperature (25 ºC) in a shaded place for several days till complete dryness. The dried samples were ground well to pass a 1 mm screen, packed in polyethylene bag and then stored in a refrigerator at 4 ºC. For bioassay tests, aqueous and methanol extracts were prepared at various concentrations (2, 4, 6, 8 and 10% w/v). The solutions were filtered through double layers of muslin cloth followed by a Whatman No. 1 filter paper. The pH of the mixtures was adjusted to 7 with 1M HCl, and then mixtures were stored in a refrigerator at 4ºC until further use (Rice 1972).

To study the effect on germination, two layers of Whatman No. 1 filter papers were placed in 90 mm diameter glass Petri dishes. In each Petri dish, 25 seeds were placed followed by 10 ml of methanolic plant extract. A control sample was assigned with distilled water and left at room temperature (25ºC). Starting from the first day after experiment set on, germinated seeds were counted and removed daily. A seed with radical of 0.5 cm was considered germinated seed. The experimental design was carried out as a RCB (randomized complete block) with three 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 Least Significant Difference (LSD) at 0.05 probability level using COSTAT 6.3 program.

For Growth bioassays, seeds of *H. murinum* were germinated on filter paper in the dark at room temperature (25ºC) 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) were added. In addition, a control sample was added to the experiment without any treatment. The experiment was designed as a RCB with three replications and it was repeated twice. Shoot and root length of seedlings were measured 15 days after treatment (DAT). Data were subjected to ANOVA and the mean values were separated based on Least Significant Difference (LSD) at 0.05 probability level using COSTAT 6.3 program. 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 Least Significant Difference (LSD) at 0.05 probability level using COSTAT 6.3 program.

RESULTS & DISCUSSION

Analysis of the vegetation in the studied area led to recognition of 19 plant species in the invaded patches and 50 in the non-invaded areas, (Table 1). *Aegilopus bicornis* (Forssk.) Jaub. & Spach (IV=16.0) was the dominant species in the invaded areas (inner segment), while *Rumex pictus* Forssk. (IV=14.2), *H. murinum* (IV=12.9), *Cutandia memphitica* (Spreng.) K. Richt. (IV=11.1), *Carduus pycnocephalus* L. (IV=7.7), *Bromus diandrus* Roth (IV=7.1), *Erodium laciniatum* (Cav.) Willd. (IV=5.9) and *Mesembryanthemum crystalinum* L. (IV=4.8) were the important plant species.

Senecio glaucus L. (IV=10.8) dominates the non-invaded areas (outer segment), while, the important species were *Halocnemum strobilaceum* (Pall.) M. Bieb. (IV=10.4), *M. crystalinum* L. (IV=10.1), *R. pictus* Forssk. (IV=8.5), *A. bicornis* (Forssk.) (IV=7.9), *Plantago squarrosa* Marray (IV=6.6), *Ifloga spicata* (Forssk.) Sch. Bip. (IV=4.4), *B. diandrus* Roth (IV=4.4) and *E. laciniatum* (Cav.) Willd. (IV=4.2).

It is clear that the invasion of *A. saligna* affected the plant species diversity in the studied area (Table 1). The non-invade patches attained higher values of Shannon-Wiener and Simpson diversity indices (3.10 and 0.94 respectively) than invaded patches (2.58 and 0.91 respectively). The evenness of species in the invaded areas (E=0.88) was higher than the non-invaded areas (E=0.79). These results indicated the reduction of plant diversity under the invasion of *A. saligna*, these results are in harmony with those of other studies (Musil 1993; Pyšek and Pyšek 1995; Holmes and Cowling 1997; Odat *et al*. 2011; González-Muñoz *et al*. 2012; Del Vecchio *et al*. 2013).

The reduction of plant diversity could be attributed to high competitive ability of *A. saligna* where it is a good nitrogen fixer (Hellmann *et al*. 2011), tolerance of drought, salinity, ability to grow in poor soil, high biomass, high production of humus (Holmes and Cowling 1997; Akkari *et al*. 2008), forming physical barrier through litter in addition to fruits accumulation (Le Maitre *et al*. 2011) and allelopathy (El Ayeb *et al*. 2013).

Soil analysis revealed that the non-invaded areas attained significantly high content (Pd"0.05) of sulphate, bicarbonate, Na^+, K^+ and Ca^{2+} than invaded areas (Table 2). This revealed that possibly *A. saligna* consumed the soil nutrients in the invaded areas due to its rapid growth rates and ability to out-compete native plants (Morris *et al*. 2011). Calcium carbonate, carbonate and WHC showed moderate significant difference between invaded and non-invaded areas,

Table 1. Effect of *Acacia saligna* on the total number of species, Shannon-Wiener diversity index (E), Shannon-evenness index (H), Simpson diversity index (D).

Cluster	H	D	E	Total Spp.	Dominant Species	Important Plant Species (IV±SE)
Invaded areas	2.58	0.91	0.88	19	*Aegilopus bicornis* (Forssk.) Jaub. & Spach (16.0±7.6)	*Rumex pictus* Forssk. (14.2±5.7) *Hordeum murinum* L. subsp. *leporinum* (Link) Arcan (12.9±6.0) *Cutandia memphitica* (Spreng.) K. Richt. (11.1±4.2) *Carduus pycnocephalus* L. (7.7±4.5) *Bromus diandrus* Roth (7.1±3.7) *Erodium laciniatum* (Cav.) Willd. (5.9±3.8) *Mesembryanthemum crystalinum* L. (4.8±2.0)
Non-invaded areas	3.10	0.94	0.79	50	*Senecio glaucus* L. (10.8±3.5)	*Halocnemum strobilaceum* (Pallas) M. Bieb. (10.4±3.6) *Mesembryanthemum crystalinum* L. (10.1±2.7) *Rumex pictus* (Forssk.) Jaub. & Spach (8.5±2.7) *Aegilopus bicornis* (Forssk.) (7.9±3.4) *Plantago squarrosa* Marray (6.6±4.0) *Ifloga spicata (*Forssk.) Sch. Bip. (4.4±1.3) *Bromus diandrus* Roth (4.4±2.5) *Erodium laciniatum* (Cav.) Willd. (4.2±1.8)

where the trees can reduce the amount of sunlight reaching soil through shading and consequently increase the water content. On the other hand, soil texture, porosity, pH, EC and magnesium content did not show significant differences.

In the present study, the organic carbon in the invaded areas was higher than non-invaded one, which may be due to high amounts of litter fall (including leaves, twigs, flowers and fruits) of the invaded trees. The litter can modify the properties of the soil by enhancing the N pool and the organic matter content (Hellmann *et al*. 2011; Le Maitre *et al*. 2011; Montesinos *et al.* 2012).

The invasive plant can exert a pressure on the native soil community and thus express either a positive or negative plant-soil biota feedback (Inderjit and van der Putten 2010).

The correlation between vegetation and soil variables is seen in the Canonical Correspondence Analysis (CCA) ordination biplot (Fig. 2). The non-invade areas exhibit a close relationship with organic carbon, sulphate and Ca^{2+} content. However, the invaded areas showed close correlation with Na^{+}, K^{+}, Ca^{2+}, sulphate and carbonate content. The low nutrient levels in the invaded areas revealed that *Acacia* induced simultaneous changes in plant communities, microclimates and soil nutrient levels (Yelenik *et al.* 2004; Marchante *et al*. 2008; Werner *et al*. 2010; Gaertner *et al.* 2011).

The allelopathic effect of the flower and leaf extracts (aqueous and methanol) on the germination percentage of *H. murinum* at 4 DAT was shown in Table 3. It is observed from the table that the methanolic extract of *A. saligna* exhibited higher germination inhibition of *H. murinum* than the aqueous extract. This could be attributed to the methanol polarity that has ability to extract a wide variety of active components compared to water (Oskoueian *et al.* 2011).

The methanol and aqueous extracts of the flowers attained IC_{50} values of 2.89 g/L and 33.89 g/L, respectively. On the other hand, methanol and aqueous extracts of leaves attained IC_{50} values of 6.08 g/L and 55.04 g/L, respectively. The inhibition was a concentration-dependent (El Ayeb *et al.* 2013). The same results reported in *A. auriculiformis* which significantly inhibited the germination and growth of rice, cowpea (Kamal *et al.* 1997) and maize (Oyun 2006). Also *A. nilotica* inhibited the germination and growth of maize and kidney bean (El-Khawas and

Table 2. Mean values and standard error of the soil parameters of invaded and non-invaded areas of the studied locations

Parameters	Non-invaded areas	Invaded areas	p-value	LSD $_{0.05}$
Sand (%)	96.2±0.52	96.6±1.15	0.52^{ns}	1.122
Silt (%)	3.4±0.49	2.9±0.16	0.41^{ns}	1.041
Clay (%)	0.4±0.04	0.5±0.15	0.09^{ns}	0.082
Porosity (%)	32.2±1.42	31.3±0.01	0.59^{ns}	3.215
WHC (%)	23.1±0.62	25.0±0.68	0.02*	1.534
pH	7.8±0.01	7.8±0.42	0.47^{ns}	0.176
EC (mmhos/cm)	0.1±0.00	0.1±0.09	0.28^{ns}	0.025
$CaCO_3$ (%)	12.6±0.27	13.6±0.01	0.01*	0.787
OC (%)	0.1±0.28	1.6±0.26	0.00***	0.523
Cl^- (%)	0.0±0.00	0.0±0.01	0.01*	0.003
SO_4^{2-} (%)	0.2±0.01	0.0±0.00	0.00***	0.029
CO_3^{2-} (%)	0.0±0.01	0.0±0.00	0.01*	0.021
HCO_3^- (%)	0.1±0.00	0.0±0.00	0.00***	0.008
Na^+ (mg/100g dry soil)	12.3±0.20	14.4±0.00	0.00***	0.629
K^+ (mg/100g dry soil)	8.5±0.31	4.6±0.23	0.00***	0.685
Ca^{2+} (mg/100g dry soil)	5.7±0.46	7.5±0.13	0.00***	1.037
Mg^{2+} (mg/100g dry soil)	11.5±0.31	10.9±0.22	0.37^{ns}	1.192

WHC = water holding capacity, EC = electrical conductivity, OC = organic carbon, *: values are significant at Pd"0.05, **: values are significant at Pd"0.01, ***: values are significant at Pd"0.001, ns: non-significant at p>0.05.

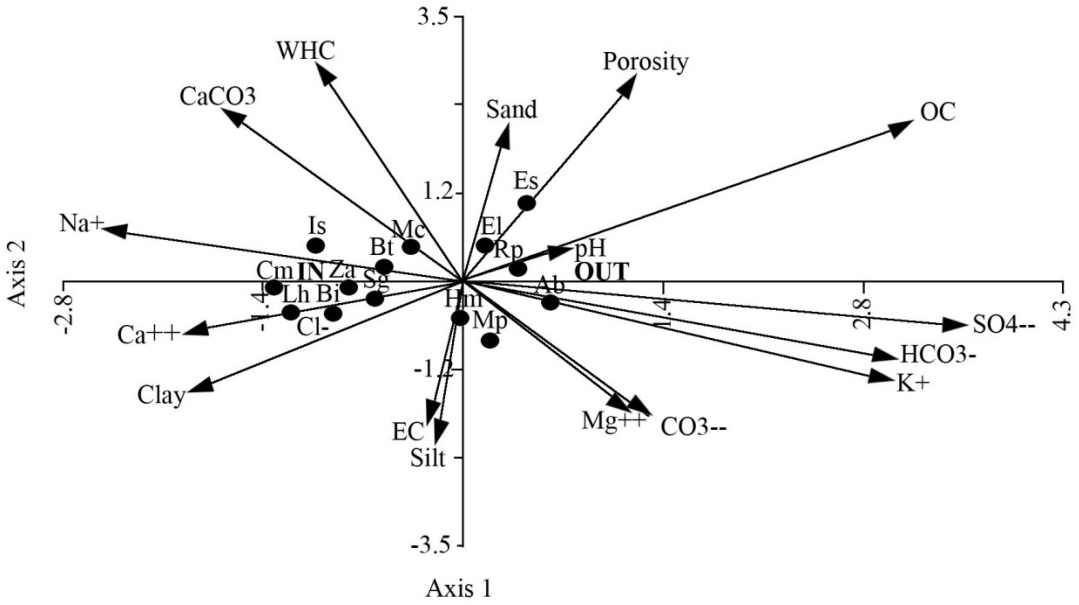

Fig. 2. CCA species-soil variable biplot in the invaded and non-invaded areas. EC: electrical conductivity, WHC: water hloding capacity, OC: organic carbon,Ab: Aegilopus bicornis, Bi: Bassia indica, Bt: Brassica tournefortii, Cm: Cutandia memphitica, El: Erodium laciniatum, Es: Echinops spinosus, Hm: Hordeum murinum, Is: Ifloga spicata, Lh: Lotus halophilus, Mc: Mesembryanthemum crystalinum, Mp: Malva parviflora, Rp: Rumex pictus, Sg: Senecio glaucus, Za: Zygophyllum album.

Table 3. The effect of Acacia saligna extracts on the germination inhibition percentage of Hordeum murinum at 4 DAT

Concentration (g/l)	Inhibition percentage respect to control*			
	Methanol extract		Aqueous extract	
	Flower	Leaf	Flower	Leaf
5	56.0^{d}±3.5	26.9^{e}±2.3	2.4^{e}±1.9	2.4^{e}±1.9
10	87.7^{b}±2.1	75.6^{c}±1.8	7.3^{de}±0.1	7.1^{de}±3.4
15	100.0^{a}±0.0	100.0^{a}±0.0	14.7^{bcd}±0.3	9.5^{cde}±3.9
20	100.0^{a}±0.0	100.0^{a}±0.0	19.6^{b}±2.2	17.0^{bc}±1.8
25	100.0^{a}±0.0	100.0^{a}±0.0	29.3^{a}±0.6	19.2^{b}±5.0
$LSD_{0.05}$	7.08		8.54	

*: mean value ± standard error, different letters indicate values significantly less than respective control (Pd≤0.05).

Shehata 2005), while *A. mearnsii* leaves extract (10 g/L) inhibited the germination of *Brassica oleracea* and *Eragrostis curvula* by about 46.7% and 70%, respectively (Fatunbi *et al.* 2009). On the other hand, El Ayeb *et al.* (2013) reported stimulatory effect of *A. saligna* aqueous extract on *Triticum aestivum*, *Lactuca sativa*, *Peganum harmala* and *Silybum marianum*; although they used higher extract concentration than the adopted concentrations compared to the present investigation.

The allelopathic effect of the flower and leaf extracts (aqueous and methanolic) on the seedling length of *H. murinum* at 8 DAT was shown in Table 4. The methanolic extracts showed more effect on seedling length than the aqueous extract. The aqueous extract showed enhanced effect at low concentrations, while the methanolic extract expressed the highest inhibitory effect at higher concentrations. These findings were supported by other studies where plant growth may be stimulated below the allelopathic threshold, while reduced above the threshold concentration depending upon the sensitivity of the receiver species (Tharayil 2009; Chon and Nelson 2010; Li *et al.* 2011). These observations were in agreement with El Ayeb *et al.* (2013). Stimulatory effects observed at lower concentration might be due to one or more chemical compounds acting as

Table 4. The effect of *Acacia saligna* extracts on the shoot and root lengths inhibition percentage of *Hordeum murinum* at 8 DAT

Conc. (g/L)	Inhibition percentage respect to control*			
	Methanol extract		Aqueous extract	
	Flower	Leaf	Flower	Leaf
Shoot length				
5	13.2^{c}±2.7	-11.9^{d}±4.0	-50.2^{e}±4.7	-36.9^{d}±4.0
10	100.0^{a}±0.0	75.5^{b}±1.3	-86.4^{g}±3.9	-104.0^{h}±5.0
15	100.0^{a}±0.0	100.0^{a}±0.0	-45.4^{de}±2.9	-71.6^{f}±5.2
20	100.0^{a}±0.0	100.0^{a}±0.0	30.8^{b}±2.7	-22.5^{c}±2.4
25	100.0^{a}±0.0	100.0^{a}±0.0	55.8^{a}±0.5	40.3^{b}±8.8
$LSD_{0.05}$	5.46		12.55	
Root length				
5	40.7^{c}±3.1	-23.4^{d}±4.3	-7.9^{e}±3.9	-10.7^{e}±4.4
10	100.0^{a}±0.0	89.7^{b}±1.1	-22.6^{f}±5.2	-6.5^{e}±3.5
15	100.0^{a}±0.0	100.0^{a}±0.0	20.5^{d}±5.1	22.0^{d}±1.1
20	100.0^{a}±0.0	100.0^{a}±0.0	60.3^{b}±2.2	35.7^{c}±2.0
25	100.0^{a}±0.0	100.0^{a}±0.0	69.2^{a}±0.9	40.8^{c}±2.0
$LSD_{0.05}$	5.81		8.01	

*: mean value ± standard error, different letters indicate values significantly less than respective control (Pd" 0.05).

hormone analogues which positively increased the plant metabolism (Ghayal 2012). The methanolic extract, exhibited complete inhibition for seedling growth at concentrations 10 g/L and 15 g/L of flowers and leaves extracts, respectively. The shoot length of *H. murinum* seedling was stimulated by 104.0% under the effect of the *A. saligna* leaves aqueous extract, while the *A. saligna* leaves methanolic extract stimulated the root length of *H. murinum* seedling by 23.4%. The seedling root growth of *H. murinum* was sensitive than shoot under treatment of *A. saligna* (Netsere and Mendesil 2012). Generally, germination of *H. murinum* is less sensitive than seedling growth especially root growth (Chon and Nelson 2010).

Various bioactive secondary components were reported in *Acacia* species including amines, alkaloids, cyanogenic glycosides, terpenes (essential oils, diterpenes, phytosterol, triterpene and saponins), hydrolyzable tannins, condensed tannins, flavonoids, quinones, cyanogenin and complex phenolic substances (Glasby 2002; Seigler 2003; Gedara and Galala 2013). Some of these bioactive substances act as allelochemicals (Putnam and Tang 1986; Cheema *et al.* 2013).

Therefore, the observed allelopathic effects could be due to the presence of these allelochemical(s). The phytotoxicity might be ascribed to synergetic effect rather than single one (Oyun 2006). On the other hand, *Acacia* allelochemicals indirectly affect the associated species by affecting the soil micro flora of the ecosystem (Lorenzo *et al.* 2013).

The mode of action of allelochemicals can broadly be divided into direct and indirect actions (Rizvi *et al.* 1992). They interfere with various biochemical and/or physiological processes like mineral uptake, phytohormones, membrane permeability, photosynthesis, respiration, protein synthesis, enzyme activities, water relations, cytology and ultrastructure (Rice 1984; El-Shora and Abd El-Gawad 2014).

CONCLUSIONS

The present study revealed that *A. saligna* invasion reduced remarkably the plant diversity in the invaded areas of the Nile Delta coast of Egypt and its allelopathy may be considered as a weapon of invasion together with its competition for resources as nutrient, water and sunlight. Similar findings were reported for other invasive species such as *A. dealbata* (Lorenzo *et al.* 2011; Lorenzo *et al.* 2013), *A. mearnsii* (Fatunbi *et al.* 2009), *Ailanthus altissima* (Motard *et al.* 2011), *Ambrosia trifida* (Wang and Zhu 1996), *Chromolaena odoratum* (He and Zhang 2002), *Typha angustifolia* (Jarchow and Cook 2009). These results may have useful implications for coastal ecosystem management and conservation in Egypt.

Thus, it is recommended to isolate identify and investigate the mode of action of the various allelochemicals from various parts of *A. saligna* including leaves and/or flowers. Therefore, this plant could be a possible candidate to be used as bio-herbicide in agriculture purpose below the allelopathic threshold which may reduce the use of synthetic pesticides and lessen environmental deterioration.

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